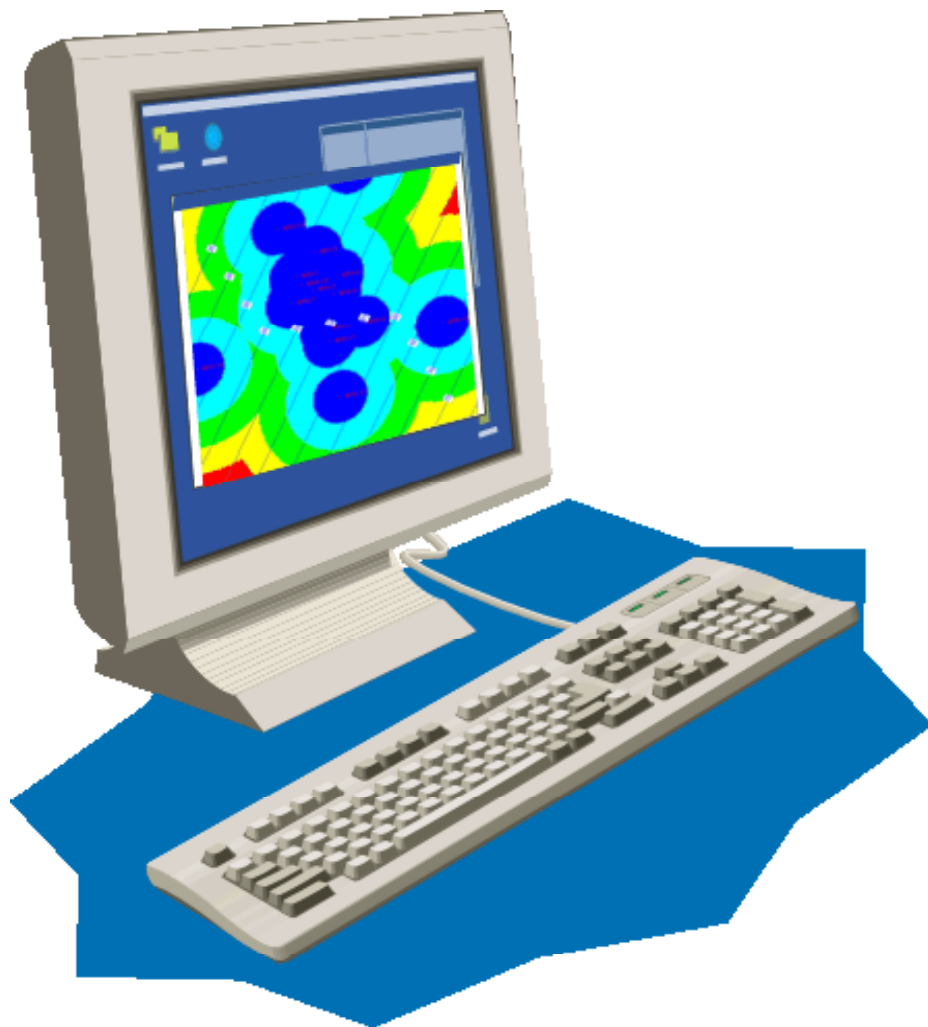


Optimal Well Locator (OWL)

A Screening Tool for Evaluating Locations of Monitoring Wells

User's Guide Version 1.2



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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet these mandates, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure effective implementation of environmental regulations and strategies at the national, state, and community levels.

The Optimal Well Locator (OWL) program is a simple screening tool to evaluate and optimize the placement of wells in long term monitoring networks at relatively simple sites. OWL uses typically available site data such as routine water level measurements and well locations in a simple algorithm to estimate the change in the direction/magnitude of the ground-water flow field over time. By viewing the potential variation in the ground-water flow field direction and magnitude over time, users will develop a greater understanding of the dynamic nature of ground-water flow at their site instead of assuming a static ground-water flow field, which is seldom the case. In addition, OWL uses minimal contaminant plume characterization data in a simple contaminant migration algorithm to estimate the potential plume migration paths at a site as a function of the change in ground-water flow field direction/magnitude over time. OWL combines the possible plume migration paths into a composite plume to allow users to clearly visualize the possible locations where the plume can be present. In addition, OWL can produce a map which combines plume migration with monitoring well coverage to pinpoint locations where the plume concentration is to predicted to be high and the well density to be low. This information will allow users to assess the location of existing wells in their networks and better position future wells to intercept the plume. OWL is specifically designed for users who have minimal ground-water and contaminant modeling experience. Site managers can use OWL as a screening tool to evaluate their site monitoring well networks and potentially reduce monitoring costs by optimizing well performance.



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The OWL presented in this guide is an integrated Windows-based program based on the concepts and methodology authored by Dr. John Wilson and Dr. Elise Striz of EPA. The OWL program was integrated into the Windows environment using a Graphical User Interface (GUI) developed by Ponniah Srinivasan of CertainTech, Inc.

1.0 Introduction

The Optimal Well Locator (OWL) program was developed and designed to be a screening tool to evaluate and optimize the placement of wells in long term monitoring networks at relatively simple sites. The OWL program enables users to approximate the change in ground-water flow field over time at their site and then use this variation to forecast the potential location of the plume. In addition, the program combines this predicted plume location with existing monitoring well coverage to allow the user to assess if their existing wells are in the optimal location and determine where to place new wells to intercept the plume. This information will allow site managers and others to make informed decisions on monitoring well locations using site specific data.

The OWL program is designed for users who have limited modeling experience and require a simple transparent tool to evaluate their monitoring well placement. It is not intended to replace more advanced models used to evaluate and optimize monitoring well locations. OWL is also not a comprehensive ground-water flow and contaminant transport model. It should not be used to try to reproduce the existing plume at a site. Instead, OWL is a screening program to evaluate well placement using typically available site data and simple algorithms to predict the possible plume locations at a site as a function of the variation in ground-water flow direction and magnitude over time. It is therefore subject to many limitations, which are provided in this manual to ensure its appropriate application.

1.1 Program Objectives

The first objective of the OWL program is to allow the user to visualize the change in ground-water flow direction and magnitude at a site over time. To accomplish this, OWL uses typically available site data including routine water level measurements and well locations in a regression algorithm to produce a linear plane approximation of the ground-water flow field. OWL provides an individual map of the ground-water potential for each measurement event. By viewing the variation in the ground-water flow direction and magnitude over time in these potential maps, users will be able to see and develop a greater understanding of the dynamic nature of ground-water flow at their site.

The second objective of the program is to allow the user to visualize the influence of the changes in ground-water flow over time on plume migration at the site. OWL uses minimal contaminant plume characterization data in a simple contaminant migration algorithm to forecast the potential plume migration path for each approximate ground-water flow field. OWL provides a separate plume concentration map for each ground-water flow field to demonstrate to users how variations in ground-water flow magnitude and direction can impact the movement of contaminants over the site. In addition, OWL combines all of the predicted plume migration paths into a composite plume concentration map. This map will show users the forecasted locations where the plume is likely to be present at their site, giving them a full picture of the sweeping coverage of the plume.

The third and final objective of OWL is to allow the user to assess the location of existing wells and to better position future wells. OWL performs this task by producing a map which combines the composite plume concentrations with a simple measure of monitoring well coverage into a Well Optimal Location Factor (WOLF). The WOLF map has two purposes. First, it will enable users to identify locations where the plume concentration is predicted to be high and the well density to be low. Such a spot would be an optimal location for a new well. Second, if plume concentration is forecast to be low and well density is high in an area, it will alert users that it may be possible to eliminate redundant existing wells.

1.2 Program Features

The OWL program provides a user-friendly graphical user interface (GUI) program environment for easy data entry, program execution and graphical presentation of results. The OWL program allows the user to:

1. Display a user-provided site map (basemap). OWL is capable of importing an electronic site map and displaying overlays of data such as well locations, ground-water head contours, and contaminant plumes on this basemap.
2. Approximate the ground-water flow direction and magnitude at the site (the ground-water “flow field”), using user-supplied ground-water elevation data from the site and display on the basemap. For each sampling event, OWL will fit a linear plane surface through the ground-water levels using a least squares regression and display the water level contour lines on the basemap. OWL supplies a coefficient of determination (R^2) for each approximation, to give the user an indication of how well the linear plane model approximation fits the observed water level data for each measurement date. If the linear plane provides a satisfactory fit, the user can compare the displays on the basemap to visually assess the changes in ground-water flow direction and magnitude at the various sampling events.
3. Calculate and display on the basemap the contaminant plume migration paths using a constant source concentration for each approximated ground-water flow field over a user-chosen time. The user can then compare the predicted plume migration paths to see how variation in the ground-water flow direction and magnitude can cause the predicted location and spread of the plume to vary for the same time of travel and source concentration.
4. Calculate and display on the basemap a composite plume which displays the average concentration contours of all plume migration paths combined. This provides users with a visual demonstration of the possible areas which may be swept by the plume as a consequence of the variation in the ground-water flow.
5. Calculate and display contours of the minimum distance to the nearest monitoring well on the basemap to interpret the well coverage at the site. This map shows users the areas of the site where there is minimal monitoring well coverage.
6. Calculate and display contours on the basemap of a Well Optimal Location Factor (WOLF) which combines the monitoring well coverage and the predicted location of the composite plume. Large values of the WOLF indicate locations where the monitoring well density is relatively low and contaminant concentrations are forecast to be high, i.e., good locations for new wells. Small values alert the user to regions where monitoring wells may be redundant, i.e., high monitoring well density and low predicted plume concentrations.
7. Display and print tables of the calculated data used to make the graphical displays in items 2-6 above. These tables can be used to export the calculated data to other programs for further modeling, graphical display, or for checking results. OWL provides the tables in text format, which enables them to be used by many word processing, database, spreadsheet, and modeling programs.

-
8. Display and print the site basemap with all of the described graphical displays with legends.

1.3 Program Data Requirements

The OWL program requires data which are typically available at most ground-water monitoring sites including:

1. A Scaled Basemap : The OWL program requires the user to have a scaled basemap of the site in electronic form. The basemap should be oriented with the y-axis parallel to north. This basemap is imported into the program and used as the basis for all graphics. It is also used to define the well locations (x,y) in consistent distance units on a rectangular grid. Most sites have a basemap in electronic or hard copy form. If the basemap is already in electronic form it may be directly imported if it has the correct format. OWL will import basemaps in electronic formats including raster (bitmap) images and vector format files. Raster maps (such as an aerial photo or scanned image) should be in Windows or OS/2 Bitmap (.bmp) format. Vector maps (CAD files) should be in AutoCAD Version 12 or 14 DWG format. OWL can accept other formats; see Appendix C Site Basemap Formats and Scaling. If the map is only in hard copy form, it may be scanned into electronic form using a scanner. When scanning, the user should select a *.bmp format. The lowest resolution for the scanned bitmap which still maintains image clarity should be used. By using a lower bitmap resolution, the OWL program will be able to display its many graphics more efficiently. An example of how to prepare and import a basemap is given in Appendix A.
2. Well Locations: OWL requires that all of the well locations be in consistent (x,y) coordinates from a rectangular grid based on the map dimensions. The map distance units must be in feet or meters or converted to these units. If the basemap is already in electronic form, a file will exist which provides the (x,y) values of the well locations. If one was fortunate enough to have or to obtain a survey, the well locations will be in standard mapping coordinates, such as UTM or State Plane, which can be used in the program. Sometimes well coordinates have been measured in terms of an artificial grid (i.e., distances from some reference origin to each well at the site) which is also satisfactory. For most sites, however, the basemap is only available in hard copy and shows well locations but no (x,y) coordinates. In this case, the user must define the well locations themselves by creating their own rectangular grid of the site dimensions based on the map scale bar. This may be accomplished by simply overlaying a grid on the map by hand, measuring the well locations with a ruler and employing the scale bar dimension to convert to distance units. The method by which the rectangular grid is defined is not important, as long as a consistent set of (x,y) coordinates is obtained for all of the wells which matches the basemap dimensions. An example of how to assign well locations using the grid method is given in Appendix A.
3. Ground-Water Elevations: The OWL program requires routine measurements of ground-water levels (preferably monthly or quarterly) from a monitoring well network demonstrating good spatial coverage of the site. All monitoring wells must be sampled at approximately the same time at each sampling event; e.g., a quarterly sampling event that takes a month will not represent the ground-water flow field at a specific point in time. Sampling events should be regularly spaced; e.g., quarterly or semiannually to produce the best record of ground-water flow field variation over time. The program requires that all the ground-water levels be corrected to elevations from a fixed datum such a mean sea level. They must also be corrected for any free product. The measurement units for the elevations must be in the same

units (feet, meters) as the well locations (x,y). An example of how to convert from ground-water levels to elevations and correct for free product is given in Appendix A.

4. Subsurface Geology: The monitoring wells used to provide water level data for OWL must be screened in the same aquifer at the site. The aquifer should be homogeneous, isotropic and of constant thickness to meet the assumptions inherent to the contaminant migration algorithm used by the program. Site data on the subsurface geology from cores and well completions can help the user select wells and aquifers that meet these restrictions. Although this data is not explicitly entered into the program, it is essential to review the subsurface geology at the site to ensure it does not violate the program assumptions. An example of how to determine if the aquifer at a site meets these requirements is given Appendix A.
5. Site Characterization: The contamination and hydrologic characteristics of the aquifer at the site must entered into the OWL program. This information includes:
 - contaminant source width
 - contaminant source concentration
 - contaminant retardation factor
 - contaminant half-life
 - aquifer hydraulic conductivity
 - effective porosity
 - longitudinal dispersivity
 - transverse dispersivity

The contaminant width and contaminant source concentration should be measured at the site. The contaminant retardation factor may be estimated from site data, or estimated using values from literature references for the contaminant and the site aquifer matrix. Contaminant half-life should be estimated from site data. Hydraulic conductivity should be determined from site data. Effective porosity may be estimated using literature reference values or simple relationships; e.g. longitudinal dispersivity = 10% of plume length, and transverse dispersivity = 10% of longitudinal dispersivity. Appendix A provides specific information on how to obtain the site characterization data.

1.4 Program Theory

OWL is intended for users who have limited modeling and programming experience and require a simple tool to assess monitoring well placement. It, therefore, employs an elementary step-wise approach to meet these objectives as described in the following sections. The user is referred to Appendix B for a detailed description of the algorithms used to perform these tasks.

1.4.1 Ground-Water Flow Field Variation

The OWL program can be used to approximate the ground-water flow field for each round of ground-water elevation measurements. Ground-water elevations should be recorded as hydraulic head values, z , for every well location, (x, y) , defined as a point on a rectangular grid overlain on the site basemap or in standard mapping coordinates (e.g., UTM, State Plane). For each round of ground-water elevation measurements entered into the program, OWL performs a least squares regression analysis of the water level values, (x,y,z) and produces the equation of the linear surface which best fits the observations. OWL

uses the equation to calculate the magnitude of the hydraulic gradient and the direction of flow given as an azimuth angle from North for each set of observations.

In addition, the OWL program provides an estimate of the goodness of fit of the linear surface to the water level observations through the coefficient of determination, R^2 . The coefficient of determination is the square of the Pearson correlation coefficient. An R^2 value close to one indicates that a linear model is a good approximation to the data, whereas a value less than one indicates that some variability in the data is not explained by the linear model. For example, an R^2 value of 0.8 indicates that the linear surface model explains 80% of the variation in the water level data, whereas a value of 0.5 indicates the model would only explain 50% of the variability. Values of R^2 more than 0.5 are preferred; values less than 0.5 are considered to be poor, indicating that the calculated linear surface does not fit the actual ground-water surface well. The user should examine the data to determine if particular data points contribute disproportionately to low R^2 values. Such data points may relate to recharge, discharge or other locations that adversely affect the linearity of the ground-water elevation surface.

A comparison of the simplified ground-water flow fields derived from each round of ground-water level measurements provides the user with a visual assessment of the variation of ground-water flow at the site. These fluctuations may be an outcome of seasonal variability, such as changes over the years in response to wet or dry years, and recharge and discharge. This variation in the ground-water flow field over time will directly impact the migration path of any contaminant plume.

1.4.2 Plume Migration Path Variation

The OWL program allows the user to examine the possible migration paths of a contaminant plume arising from a single continuous source as a function of each ground-water flow field. In particular, OWL uses the linear hydraulic head surface from the regression (to define the flow field), user-entered contaminant source data, and a user-chosen simulation time in the Domenico 1D analytical transport solution (Domenico, 1987). This solution of the one-dimensional advection-dispersion equation produces a two-dimensional estimate of contaminant plume shape for each ground-water flow field. The program also reports contaminant concentrations for each node on a grid of user-chosen spacing. The estimates can be plotted on a map of the site for display, and can be exported in a space-delimited text file for use by other programs.

1.4.3 Composite Plume

The OWL program creates a separate plume shape estimate for each set of ground-water elevation data (i.e., each round of water sampling). In addition to allowing viewing of the plume migration paths separately, the OWL program also averages the estimated contaminant concentrations from each plume shape to generate a composite plume shape based on several sets of sampling data (i.e., several sampling rounds). The composite average plume shape can be compared with the actual plume shape as revealed by sampling in order to assess the validity of the site conceptual model (e.g., source size and location, ground-water flow directions and rates, and attenuation). This composite plume can be used as a measure of the potential variation in the plume location at the site over time caused by the changing ground-water flow field.

1.4.4 Well Locations and Monitoring Well Coverage

OWL provides spatial measure of monitoring well coverage at the site based on contours of “the distance to the nearest monitoring well.” The program calculates the distance from each node of the user defined

grid to the nearest monitoring well, and plots the results as contours on the site basemap. By examining these “distance to nearest monitoring well” contours, the users can visually identify regions of high and low monitoring well coverage.

1.4.5 Well Optimal Location Factor

OWL uses the “distance to nearest monitoring well” contours, along with the composite plume which represents the potential variation in all the plume migration paths, to calculate a “Well Optimal Location Factor” (WOLF). WOLF is defined as the product of the composite plume concentration at a grid node and the square of the “distance to the nearest monitoring well” at the grid node. Contours of the WOLF values are plotted on the site basemap for display. High WOLF values indicate areas where the contaminant concentrations are expected to be high and the monitoring well coverage is low. Such locations may be considered optimal positions for new wells. In contrast, low WOLF values indicate areas where concentration is expected to be low and monitoring well coverage high. These areas would be good locations to assess if existing monitoring wells are redundant.

1.5 Program Application and Limitations

The OWL modeling algorithms are intentionally very simple, which means the program is subject to many assumptions and limitations. OWL first assumes that the ground-water surface in a single homogeneous, isotropic aquifer at a site can be represented as a linear plane. The program uses a linear regression technique to create a planar ground-water surface for each set of water level measurements. The presence of substantial surface relief, recharge or discharge zones, surface water features, pumping wells or ground-water divides on or near the site may cause deviation of the ground-water surface from a plane and violate this modeling assumption. Therefore, the user will find that OWL is mainly restricted to application at relatively small plume sites, where the user is already aware that the ground-water flow field can be approximated by a linear plane. The larger the site, the less likely this restriction will be met.

The Domenico contaminant migration algorithm used by OWL is also very simple, and is only applicable to sites with well defined uncomplicated contaminant sources. An example of an appropriate site would be an underground storage tank (UST) site with a single contaminant source and uniform hydrogeology. The contaminant source should exhibit minimal variability in its distribution throughout the vadose zone and saturated zone. Given these restrictions, OWL will generally be limited to LNAPL sites where most of the LNAPL is held in a small volume of vadose zone, with no more than a small pool of LNAPL on the water table. Long plumes of LNAPL on the water table, and large smear zones would be problematic. DNAPL sites might be considered if there is no evidence for movement of the DNAPL very far down into the aquifer. Sites where DNAPL has pooled on retarding layers should be excluded. It will be noted that, in general, these restrictions mean that the program is best used for UST sites, where fuels are the contaminants, the fuel has not moved far from the tank as a NAPL, most of the source has been removed, and the hydrogeology is very simple (homogeneous, isotropic, with no recharge, divides, etc. on the site—this practically means water table aquifers in a sand matrix underlain by thick continuous clay layers).

The OWL program assumes that the contaminant source is linear and constant along a vertical plane below the line. Sites with multiple or complexly-shaped sources, significant water table variations where smear zones or contaminated vadose zones are present, or other conditions where the source may vary significantly from the model assumptions should be assessed with more complex models. OWL is also not applicable where ground-water flow is very slow, such as in clay media, because the model does not consider molecular diffusion. When using OWL, the source characteristics (source width and concentration) can be changed by the user to test sensitivity of the predictions to variations in the source.

The OWL model assumes linear equilibrium adsorption and first-order decay. These assumptions are mainly applicable to certain organics, especially BTEX and chlorinated solvents, under the limited organic matter content typical of the subsurface. Inorganics, or reactive contaminants, may deviate markedly from these assumptions.

OWL allows the user to input values for several site parameters (e.g., conductivity, dispersivity, as listed above). The user should determine a range of these values that convey the variability in the site parameters, and input several values of each parameter into OWL to determine how the results are affected by variations in the site parameters. Hydraulic conductivity, solute (contaminant) half-life, source width and source concentration are examples of factors likely to significantly affect model results. In particular, the user should input a range of values of conductivity (k) to determine the sensitivity to k . This would show variability in the longitudinal aspect (how long the plume gets). This would be important if the program were used to locate guard wells because the length of plume would be expected to vary significantly due to differing k values in the subsurface.

The plume concentration and WOLF functions in OWL are based on a two-dimensional analytical model (the Domenico analytical solution of the one-dimensional advection-dispersion equation (Domenico, 1987) which assumes a constant source and constant hydrogeological properties throughout the modeled area. The aquifer and flow field are assumed to be homogeneous and isotropic; a uniform conductivity (k) is assumed throughout the modeled volume. OWL is not suitable where vertical flow gradients significantly affect contaminant transport, or where hydrogeologic conditions change significantly over the modeled part of the site. OWL does not and cannot replace professional judgement for siting wells and assessing plume behavior, but assumes that the user is able to adequately assess the applicability of the program results to particular site conditions.

In summary, the application of the OWL program will be subject to the following limitations:

1. The ground-water hydraulic head must be reasonably represented by a linear plane surface. There should be no ground-water divides, significant surface water bodies, pumping/injection wells, or anything else which could cause the ground-water heads across the site to deviate significantly from a flat surface.
2. The contaminant plume must be derived from a single continuous constant contaminant source in a well defined location. A continuous source provides a constant stream of dissolved contaminant to maintain the contaminant plume.
3. The monitoring wells used to provide data for OWL must be screened in a single aquifer. The screens should be of similar length and placement in the aquifer. The aquifer must be homogeneous and isotropic, and of constant thickness. Homogeneous and isotropic means that the structure or composition of the aquifer matrix is uniform throughout and has the same characteristics in all directions. For instance, a uniform sand aquifer which had the same hydraulic conductivity, whether measured in the horizontal or vertical direction, could be considered homogeneous and isotropic.
4. The monitoring wells used to provide data for OWL must provide good spatial coverage of the plume and surrounding aquifer. Too few wells, in scattered locations, will not provide enough uniformly-distributed ground-water elevation data to allow accurate estimation of the ground-water flow field and contaminant plume shape.

-
5. The locations of the monitoring wells must be known using a fixed two-dimensional coordinate system so that the OWL basemap of the site can be calibrated. At most sites, the well locations have been determined by survey, so the coordinates are available in UTM, State Plane, or a local coordinate system. If not, the user must create a rectangular grid derived from the basemap scale bar dimensions and assign well locations using this grid by hand.
 6. The OWL model assumes linear sorption and first-order decay. These assumptions of linear sorption and first-order decay are mainly applicable to certain organics, especially BTEX and chlorinated solvents, under the limited organic matter content typical of the subsurface. Inorganics, or reactive contaminants, may deviate markedly from these assumptions.

2.0 Installing OWL

The steps described in this section are required for successful installation of OWL. Because the OWL installation program creates files and subdirectories on your hard disk, you must have write-privileges to use the installation program. Most users should have no problems with installation, but if installation ends before it is complete, or if there are any error messages during installation, consult the system administrator in your organization for help.

2.1 Hardware Requirements

The OWL software requires the following hardware for reasonable performance:

- A PC capable of using Microsoft Windows 95, 98, NT, ME, 2000 or XP as the operating system
- At least 32 MB of RAM
- 40 MB of free hard disk space for the user directory
- A CD ROM drive for installation, if you receive OWL on a CD. A CD drive with at least 4X speed is recommended for reading the OWL Setup CD.

2.2 Software Requirements

The following software should be installed or made available through a network on the computer running OWL:

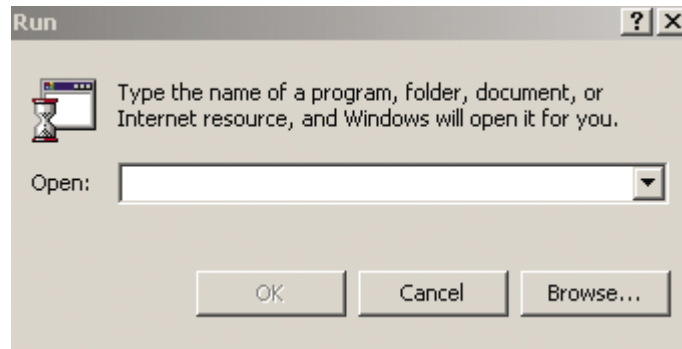
- Microsoft Windows 95, 98, NT, ME, 2000 or XP
- Spreadsheet software (Excel or Lotus) for creating water level and well locations data worksheets.

2.3 Installation Steps

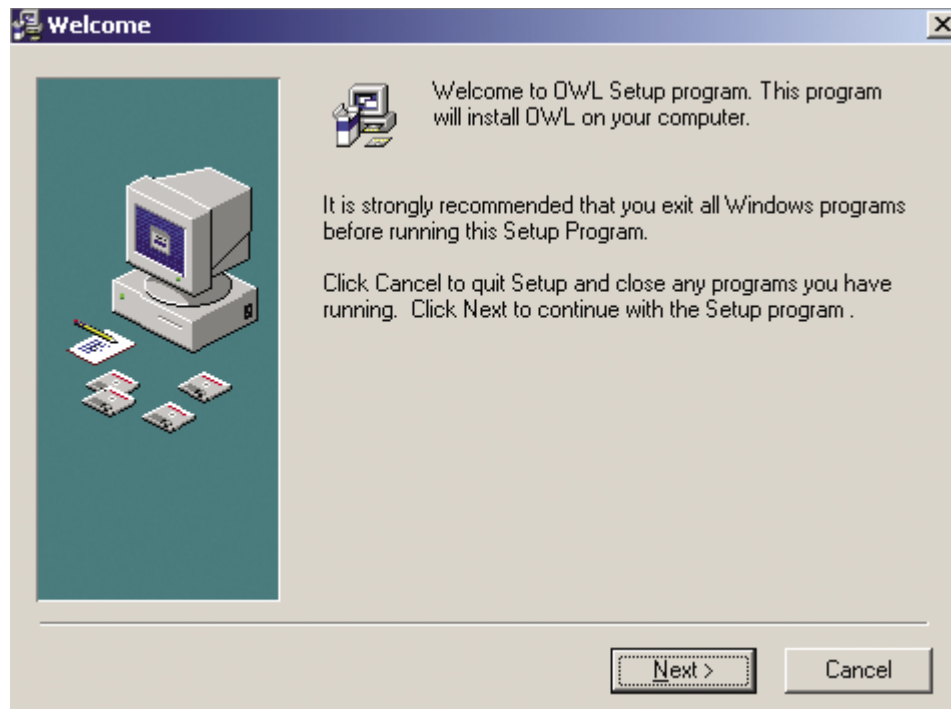
Run Windows 95, 98, NT, ME, 2000 or XP.

Insert the OWL CD ROM in the CD-ROM drive, and close the drive tray.

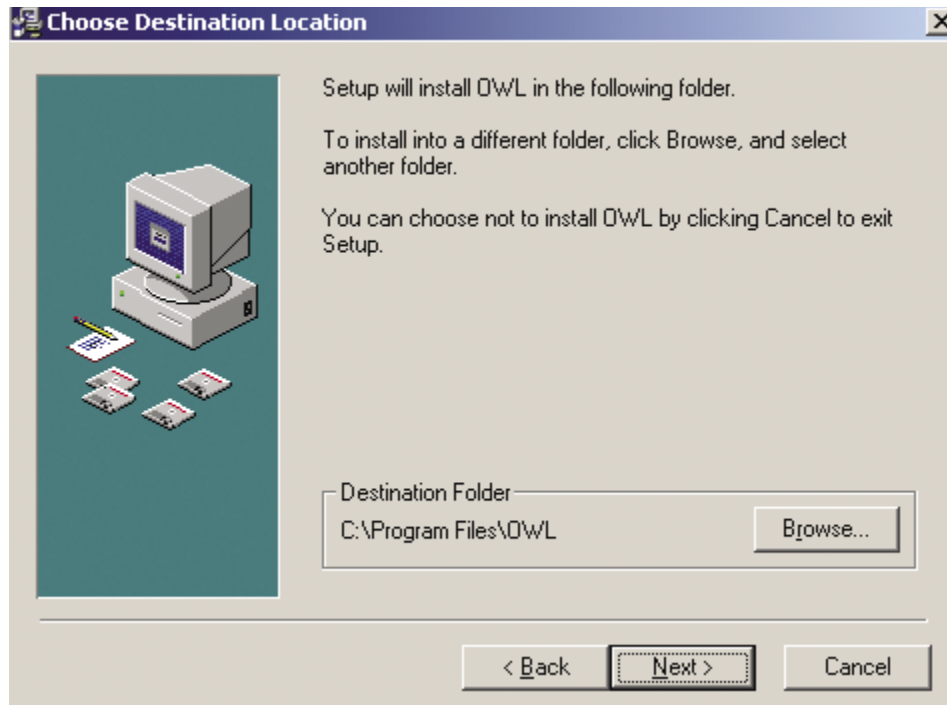
Click on the “<Start>” button at the lower left-hand corner of the screen, then click on the “<Run>” menu item. The Run dialogue will appear.



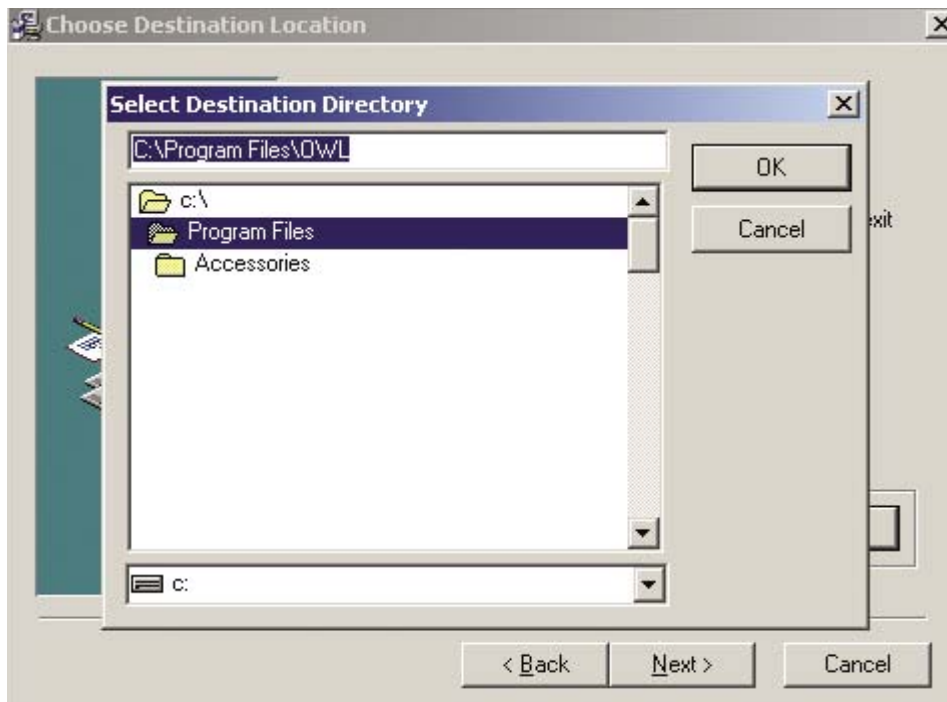
From the dialog command line, type `D:\setup.exe` (D is assumed to be your CD ROM drive letter. If your CD is a different drive letter, use the appropriate letter). Alternatively, you may click the “<Browse>” button and browse to the drive containing the OWL CD, and click on the `setup.exe` file on the CD. Click “<OK>” to start the setup process. The following setup screen will appear.



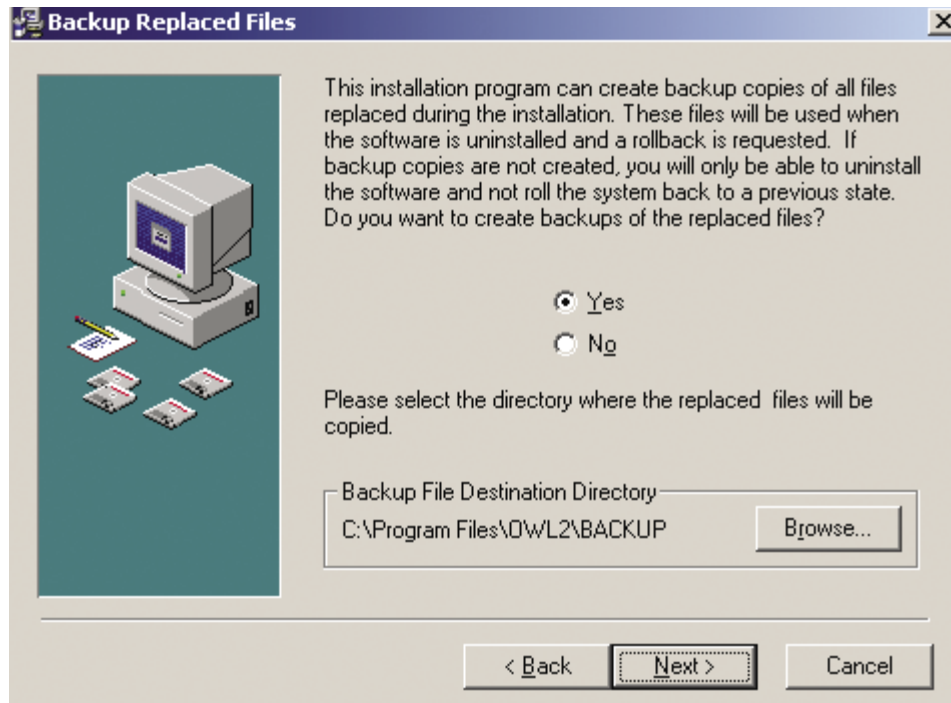
Click “<Next>” to continue to the next dialog as shown below.



The default folder shown in the dialog may be left as is, or if desired, click “<Browse>” to browse to another folder.



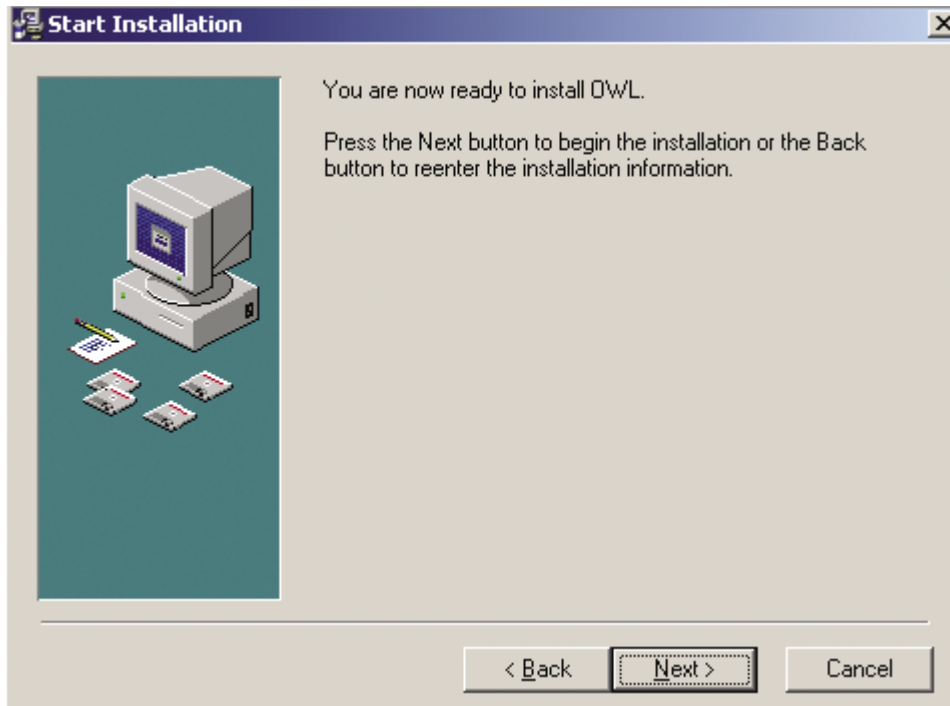
When the desired folder is chosen, click “<Next>” to continue. The dialog box as shown below will appear.



It is strongly recommended that you choose “<Yes>” to backup any files replaced by the OWL setup routine. By default the backup is created in a subfolder *BACKUP* under the OWL folder (or the user may choose a different folder). Click “<Next>” and a dialog will appear prompting for a default menu group in which to place the OWL start icon.

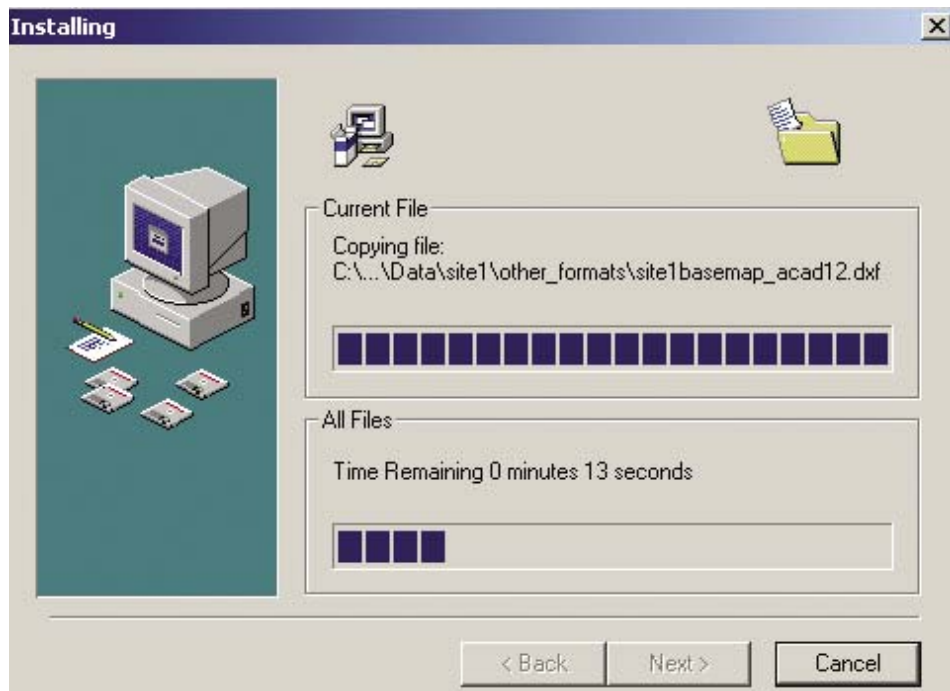


It is not necessary to choose a menu group, but the user may choose a preexisting group or type in a name for a new group. Click “<Next>” to continue.

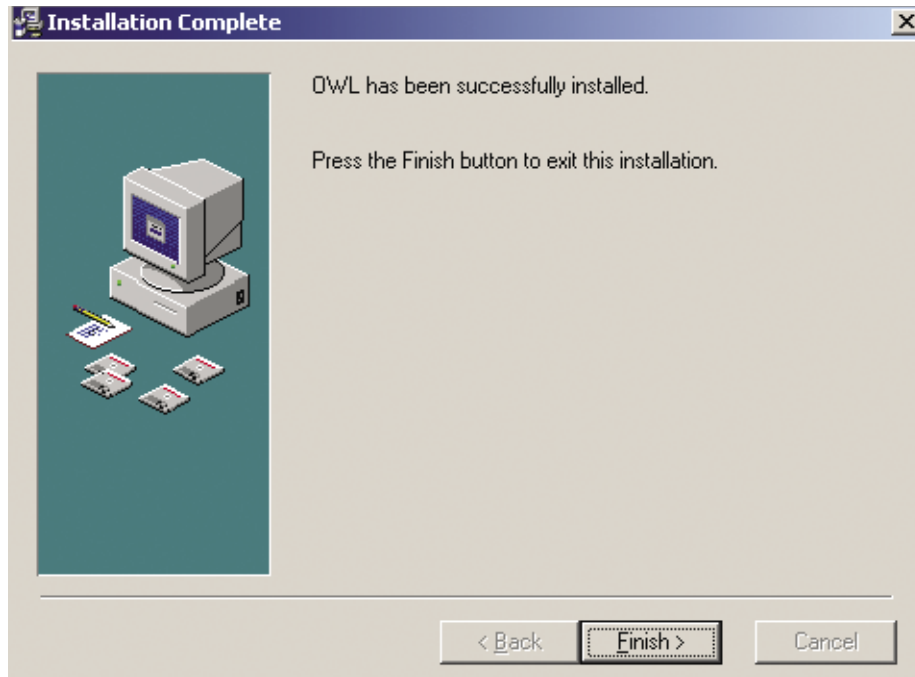


Click “<Next>” for the dialog Start Installation to continue. Follow the instructions of the setup program as they appear on the screen.

The setup program may take several seconds to install and verify the location of necessary Windows system files. You will see a progress bar dialog indicating progress of installation.

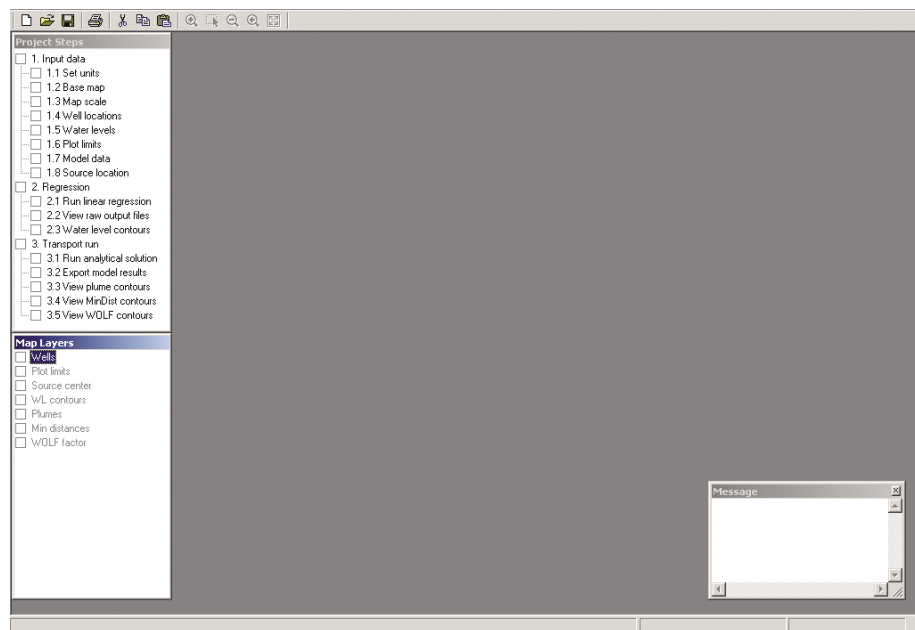


The installation program will then update the system configuration. After installation is complete, you will see the dialog box Installation Complete. Click “<Finish>” to close the dialog box.



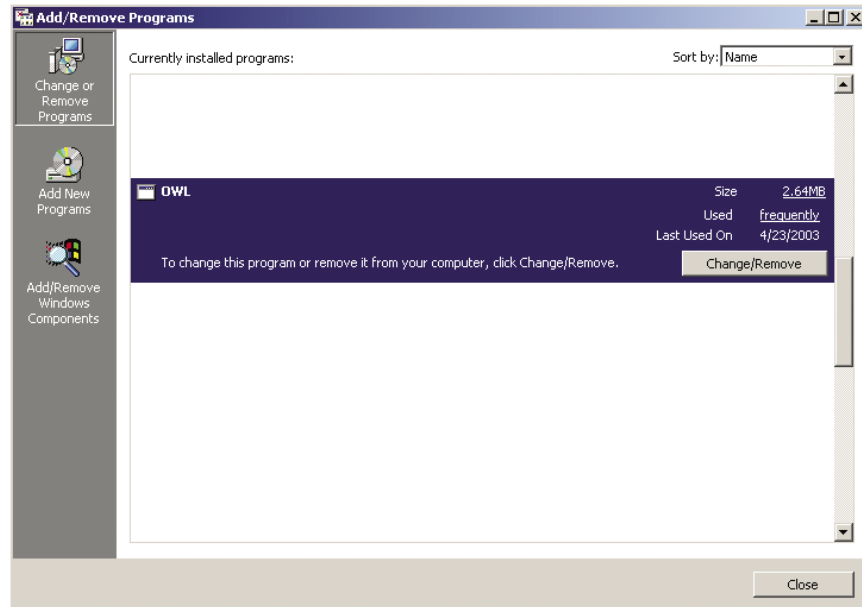
It may be necessary to restart the computer after installation is complete. If a dialog box appears prompting a restart of the computer, press “<Yes>” to proceed.

To run OWL, click on the “<Start>” button, select the Programs folder, then choose the OWL folder. Select the program item OWL to run the program. The initial screen as shown below will appear. The program is now ready to operate.

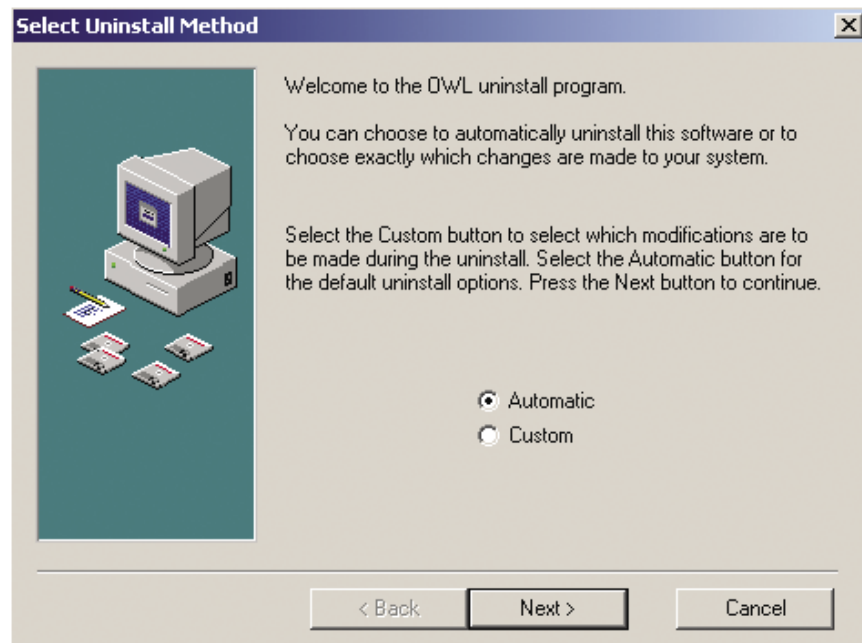


2.4 Uninstalling OWL

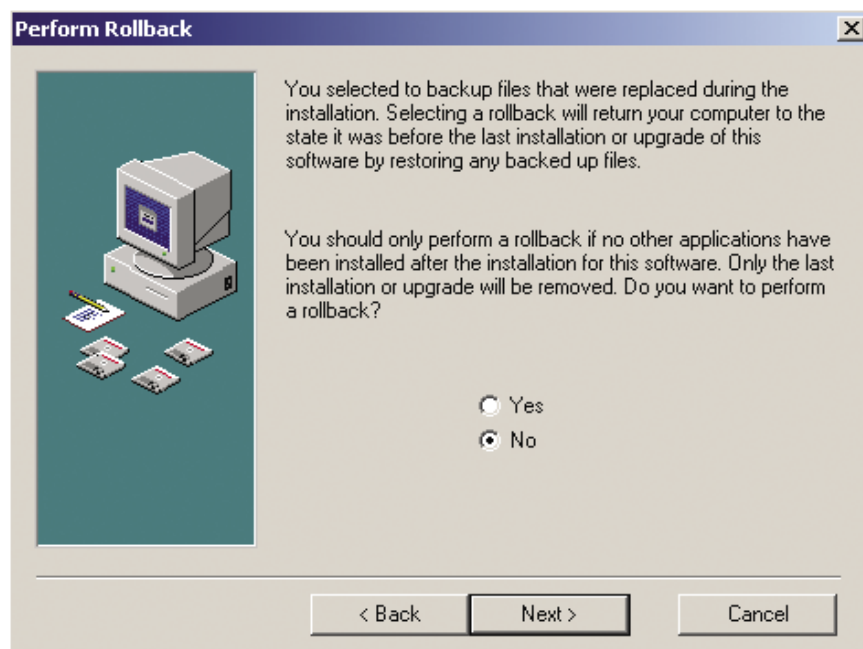
To uninstall the OWL program, select “<Start>” from the menu on the task bar, choose “<Settings>,” then choose “<Control Panel>.” Double click on the icon “<Add/Remove Programs>.” A dialog box titled “Add/Remove Program Properties” will appear, similar to that shown below.



Scroll through the list of software and select OWL as shown above, then click “<Add/Remove>.” Next the dialog box Select Uninstall Method will appear. Choose “<Automatic>” method (this is probably already chosen as the default selection), then press “<Next>.”

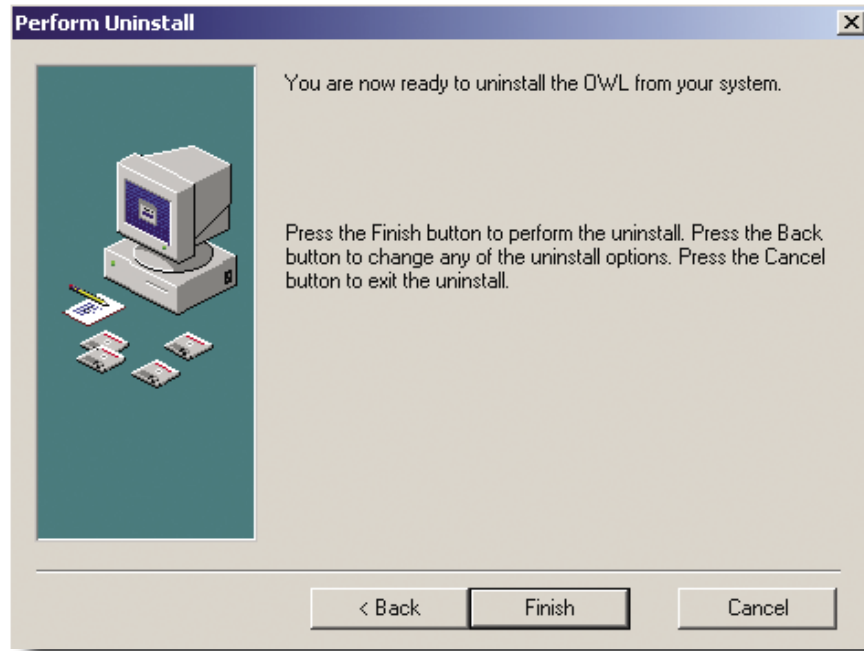


On the next dialog box, the uninstall routine gives the user a choice of including a “rollback” in the uninstall process. A rollback will use the system files stored during the initial installation of OWL (if that option was chosen during installation). A rollback reinstalls the stored system files that were originally on your computer, while removing the system files that the OWL installation added. If other programs have been installed after OWL was installed, a rollback could cause the removal of system files added to your computer during the installation of the other programs, possibly causing problems. If other software has been installed since originally installing OWL, it may be necessary to consult your PC support person before uninstalling OWL.



If no other program has been installed after OWL was installed, the user may click “<Yes>,” then press “<Next>” to perform an uninstall with rollback.

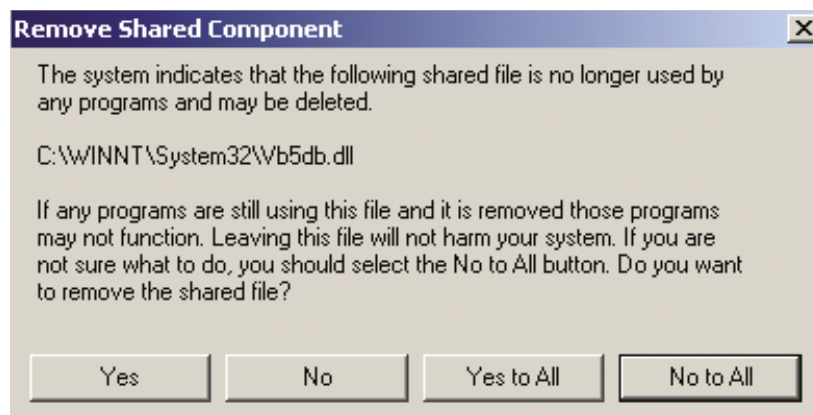
If other programs have been installed after OWL was installed, click “<No>” and then “<Next>” to proceed with uninstallation without rollback.



The Perform Uninstall dialog box will appear: click “<Next>” to proceed with the uninstall.

In a moment the setup program will uninstall all the OWL files, and restore the Windows system files (DLL, OCX, and so on) that may have been replaced during OWL installation.

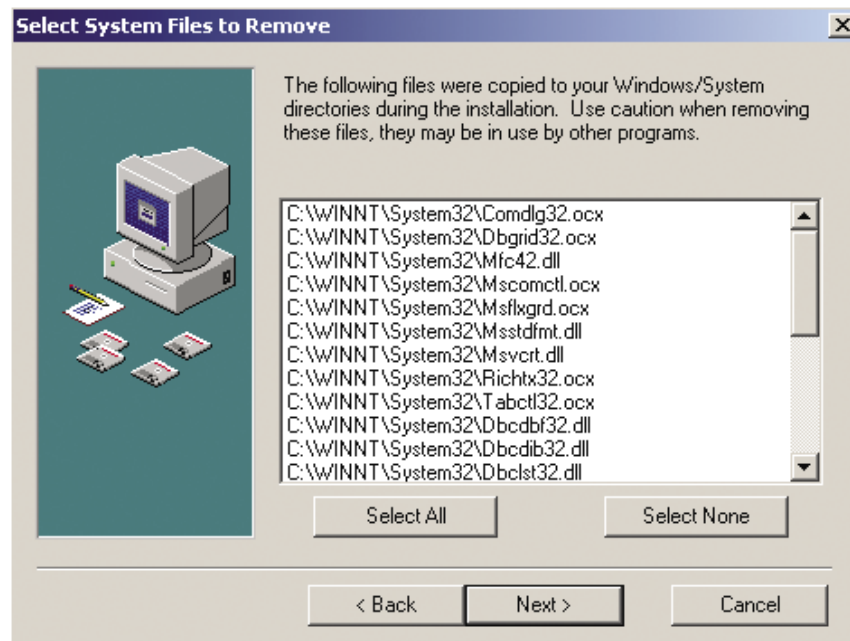
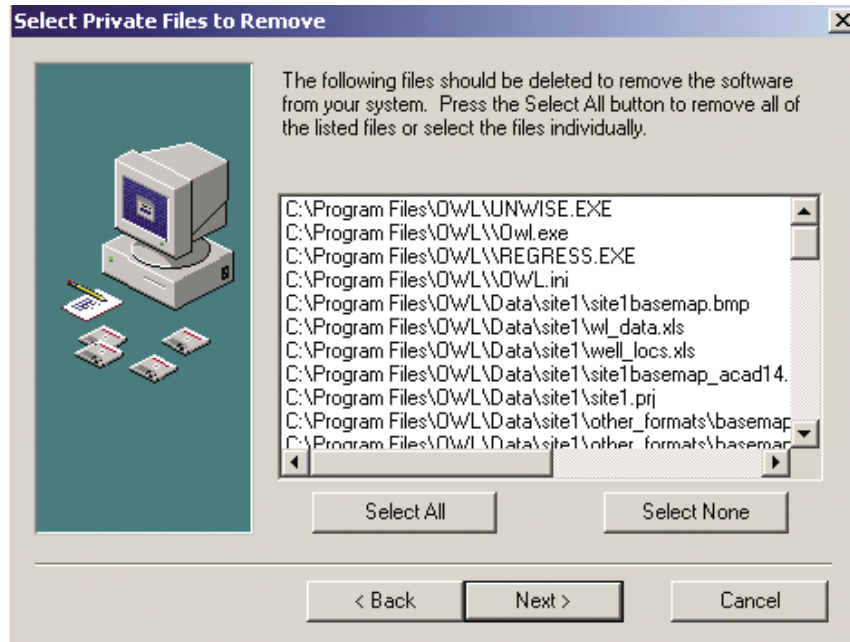
The uninstall program may prompt the user to choose whether to remove specific system files. Removing these files saves space on your computer, but may cause problems if the files are needed for another program. It is usually safe to select “<No to All>” to this dialog box.

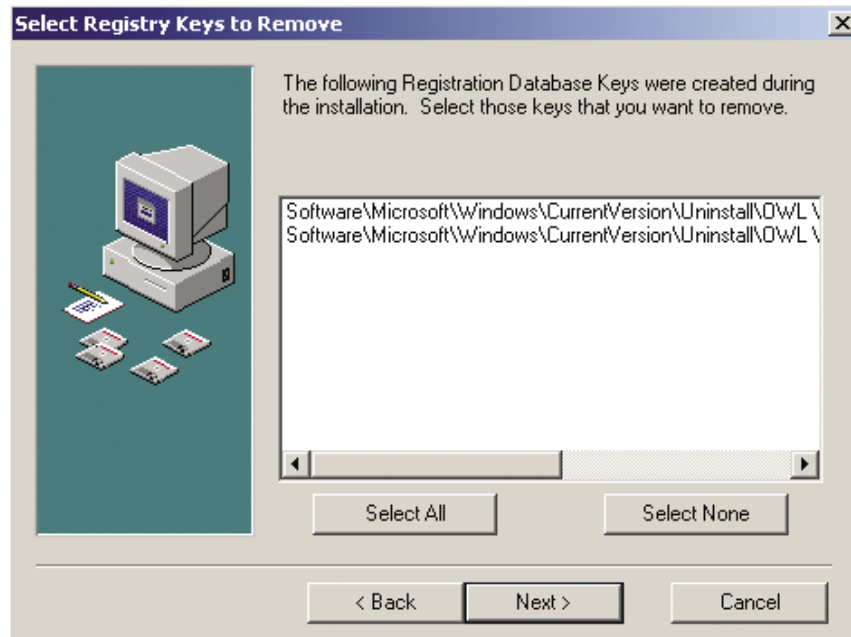
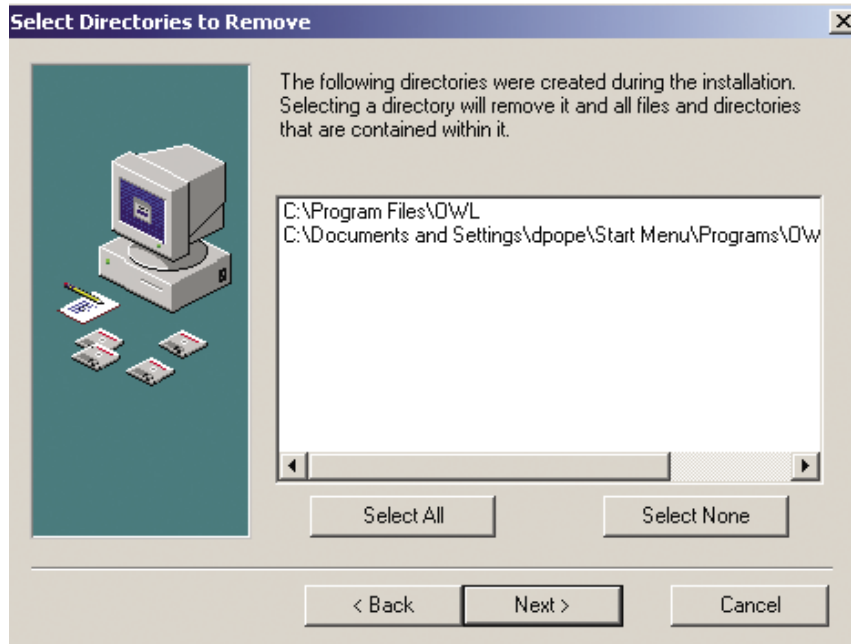


Once “<No to All>” is chosen, a message box showing the progress of uninstallation appears briefly, and then the uninstall process will finish.

For Custom Uninstall

If the “<Custom Uninstall>” process is chosen (when the “<Automatic>” method or “<Custom Uninstall>” choice is presented), a series of dialogue boxes appear, allowing the user to choose specific files to be uninstalled. The “<Custom Uninstall>” process is unlikely to be useful to the average computer user, but may be helpful to computer system administrators.





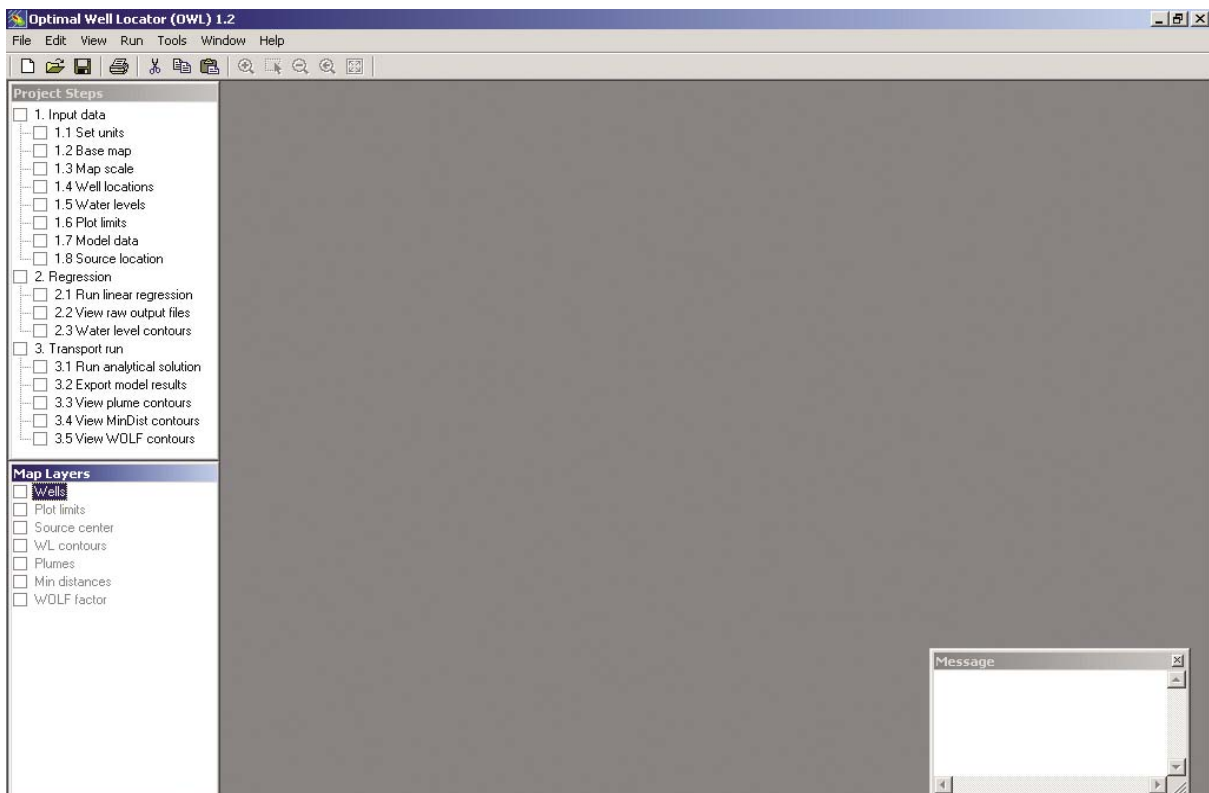


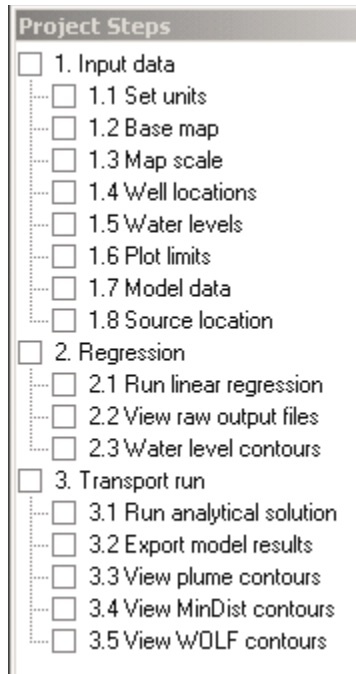
3.0 Program Layout and Screen Appearance

3.1 OWL Layout in the Windows Environment

The general layout of OWL and the menu options on the top of the screen (File, Edit, View, Run, Tools, Window and Help) are similar to that found in most Windows software. A button bar below the menu bar contains the editing and file operation buttons, which are similar to the ones typically found on most popular software.

A large section of the center of the OWL window is empty when the program is first opened. Later this section will have a Map View window showing a map of the project site (the basemap). The other elements of the user interface are designed not to interfere with the Map View window throughout the session.

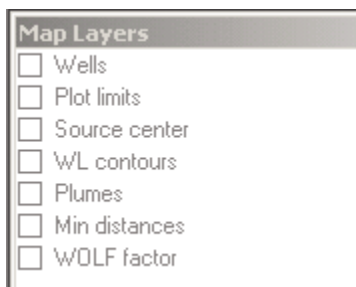




3.2 Project Steps and Map Layers Windows

Upon startup, there should be two windows (Project Steps and Map Layers) on the left side of the main “OWL” window. The window at the top left (Project Steps) displays the steps which should be followed in a session for a smooth interaction with OWL. As each step is completed, the corresponding box at left will be checked. Use this window as a reminder or guidance as progress through the OWL session is completed.

The window at the bottom left of the OWL window (Map Layers) lists the possible layers that can be seen in the Map View window. Layers are additions to the basemap, such as ground-water elevation contours, plume shapes, etc., whose display can be turned on or off without affecting the basemap. A layer is displayed on the screen over the basemap so that the layer appears to be part of the basemap; i.e., a ground-water elevation contour layer shows the contours on the basemap. If a layer is not yet available for display, its name will be shown using dimmed letters. The check box next to the layer name may be used to display or hide a layer selectively.



3.3 Map View Window

Clicking on the “<Basemap>” checkbox in the Work Outline window causes an Open Basemap File dialogue box to appear for opening a basemap file. The user can browse to and open a basemap file. The basemap can be made to appear in the Map View window by clicking the “<Open>” button at the right-hand bottom of the dialogue box. The Map View window will fill most of the OWL window.

On the tool bar, there are several buttons for manipulating the view of the basemap shown in the MapView window.



The function of each button is described below:

The first button allows the user to zoom the basemap view in order to enlarge the view.



The second button allows the user to zoom to a selected window of the map. Just select this button and a crosshair cursor will appear. Move the crosshair to the top corner of your window selection using the mouse. Click and hold left mouse button. Drag the mouse across the map to select the window you wish to zoom in on. Click the left mouse button again to zoom in on the window.



The third button allows the user to zoom out on the basemap view in order to reduce the view.



The fourth button allows the user to return to the previous view.



The fifth button allows the user to return back to the entire basemap.



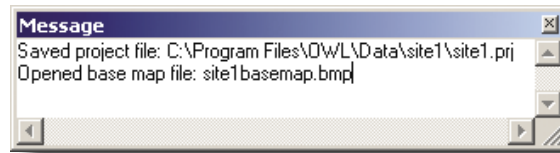
At the bottom right of the Map View window, the coordinate display is provided. The numbers displayed here represent the X and Y coordinates of the cursor position on the basemap. The coordinates are used for calibrating the basemap, locating wells, and other operations where specific positions on the basemap must be located in reference to positions at the site.

When a bitmap format basemap is first opened, the XY coordinates shown in the coordinate display are in pixel units, and the top left corner of the bitmap image is considered the origin (0,0 point). If the user calibrates the bitmap basemap to real coordinates (in the Set Map Scale dialogue box), the XY coordinates shown in the coordinate display are based on the real coordinates system, and are in the units of the real coordinates system. For example, if during the calibration to real coordinates dialogue, the user set the lower left corner of the bitmap to (0, 0) and the upper right corner to (1000, 1000) , moving the cursor over the bitmap would cause the XY coordinates shown in the coordinate display to vary between (0, 0) and (1000, 1000), depending on where the cursor was located on the screen display of the bitmap.

X:+500.000000 Y:+320.000000

3.4 Message Window

A message window appears on the lower-right corner of the OWL application window. Messages regarding file open, file save, and any error conditions are displayed in this window.



4.0 Guided Tour and Field Case Study Tutorial

The Guided Tour and Field Case Study Tutorial (Case Study/Tutorial) provides a step-by-step tutorial to introduce the user to OWL. A description of the site used in the Case Study/Tutorial is found in Appendix A of this document. Notes on site characterization and basemap preparation are also found in Appendix A. The user should read Appendix A before using this Case Study/Tutorial, and refer to Appendix A for more site information while using the Case Study/Tutorial.

This Case Study/Tutorial will guide the user to:

- produce a project file,
- input site data, including a basemap of the site,
- carry out regression and Domenico solution calculations on the site data,
- apply the results (ground-water elevation and contaminant concentrations contours) for viewing on the site basemap, and
- calculate and view Minimum Distances and WOLF contours on the basemap.

For comparison of your results with an analysis prepared by professional modelers, the OWL installation program provides a folder containing a completed Case Study project file (with all data input and calculations completed). This completed Case Study project file is found in the folder C:\Program Files\OWL\Data\site1, named '*casestud.prj*' (assuming that you used the default installation locations for OWL).

Using OWL - Basic Workflow

Using OWL involves four basic steps:

Provide Site Data, Set Units, and Choose Map Presentation Settings

The user inputs site data, including an electronic map of the site (site basemap), well locations, ground-water elevations, contaminant source location, and model data (site parameters: e.g., hydraulic conductivity, effective porosity). The user chooses the area of the basemap to include in calculations and presentation of program output ("Plot Limits").

Calculate Ground-Water Flow Field

OWL uses the well locations and ground-water elevation data to run a linear regression in order to calculate the ground-water flow field for each sampling event. The ground-water elevation contours can be plotted on the site basemap.

Predict Contaminant Plume Shape and Size

OWL uses the input data to run the Domenico solution to predict contaminant transport/plume development. The plume contours can be plotted on the site basemap.

Calculate Well Location Factors

OWL calculates and plots the Minimum Distance function and the WOLF values. The Minimum Distance function shows the variation in well density across the site. The WOLF combines monitoring well coverage and predicted contaminant concentration into a single term which can be mapped. The WOLF can be used to decide where additional monitoring wells could be placed, and which existing monitoring wells might be providing redundant data.

4.1 Site Selection and Characterization

The first step in using OWL requires gathering and analyzing site data to ensure that the site characteristics meet OWL requirements. As explained in the *Introduction*, the OWL program is a site screening program for use in helping to determine possible locations for new monitoring wells, and assessing the usefulness of existing monitoring wells. OWL provides only a cursory assessment, and is meant to replace neither professional judgment nor more advanced mathematical models for use in assessing monitoring well locations. It should only be applied to sites which possess the characteristics outlined in the *Introduction Sections 1.3 and 1.5*, and in *Appendix A: Field Case Study Site Characterization Data Collection and Evaluation for Application of OWL*.

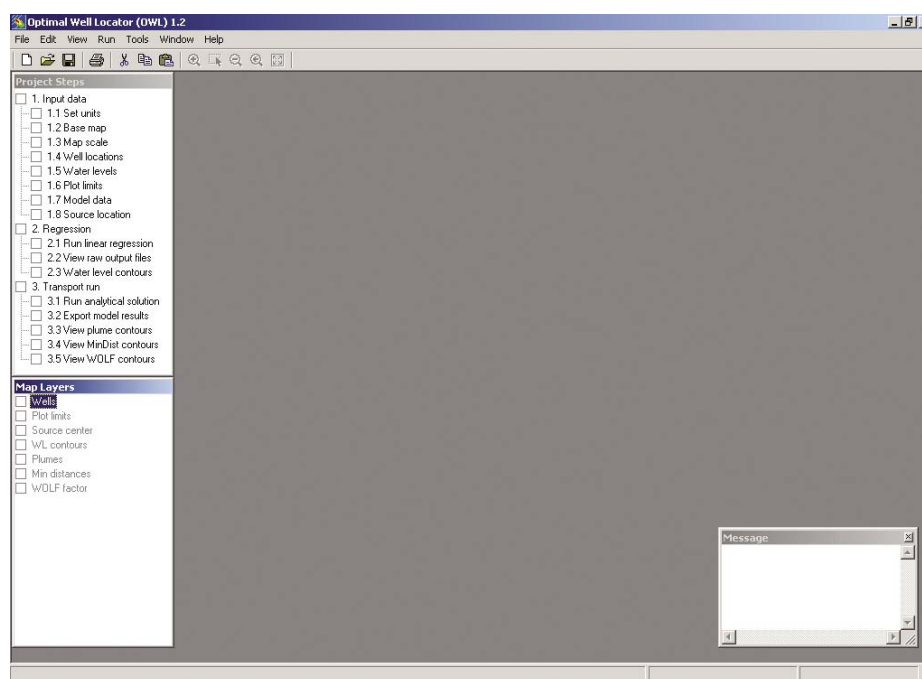
The data needed for using OWL include:

- an electronic map (“basemap”) of the site (See Appendix C for basemap specifications)
- well locations based on a rectangular grid system (x,y) in an acceptable spreadsheet (see Appendix D for spreadsheet formats). These may be easting, northing, UTM, State Plane or from a user-defined grid system based on basemap scale bar dimensions (see Appendices A and C for more details)
- ground-water elevation data for each well at each sampling date in an acceptable spreadsheet (see Appendix D for spreadsheet formats)
- contaminant source width transverse to ground-water flow (if free product is present, may be estimated as diameter of circle circumscribing free product area, otherwise can be estimated based on soil or ground-water concentrations)
- contaminant source concentration (dissolved concentration near the source)
- contaminant retardation factor
- contaminant half-life
- hydraulic conductivity
- effective porosity
- longitudinal dispersivity
- transverse dispersivity

The contaminant source width and contaminant source concentration should be measured at the site. The contaminant retardation factor may be estimated from site data, or estimated using values from literature references for the contaminant and the site aquifer matrix. Contaminant half-life should be estimated from site data. Hydraulic conductivity should be determined from site data. Effective porosity may be estimated using literature reference values for the site aquifer matrix (e.g., gravel, sand, silt, clay). Longitudinal dispersivity and transverse dispersivity are usually estimated using literature reference values or simple relationships; e.g. longitudinal dispersivity = 10% of plume length, and transverse dispersivity = 10% of longitudinal dispersivity.

4.2 Opening OWL

OWL can be started by choosing OWL in the Program menu section of the Start menu.



OWL opens displaying a “Project Steps” window, a “Map Layers” window, and a “Message” window (see Section 3.0 *Program Layout And Screen Appearance*).

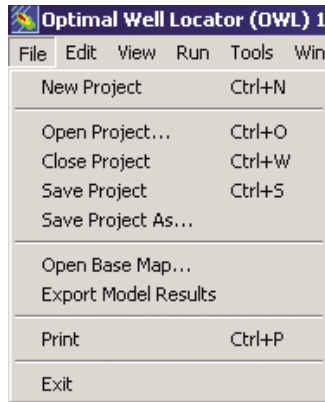
The Project Steps window assists the user to proceed in an orderly fashion; each consecutive step in using the program is presented in order in the Project Steps window, with convenient checkboxes to allow the user to initiate each step, and keep up with which steps have been finished.

The Map Layers window shows the user which “layers” (overlays; additions to the site basemap) have been activated. For instance, when monitoring well locations are plotted on the basemap, the locations are part of an overlay which can be turned on and off (made visible on the map, or invisible) by checking or unchecking the “<Wells>” checkbox in the Map Layers window. The site basemap is an electronic copy of a site map which can be displayed in the OWL program. An example site map (*site1basemap.bmp* or *site1basemap_acad14.dwg*) comes with the program for use in the tutorial; the user can import maps for their sites from many GIS programs, or they can scan a paper map and save it as a bitmap or TIF file for importing into OWL.

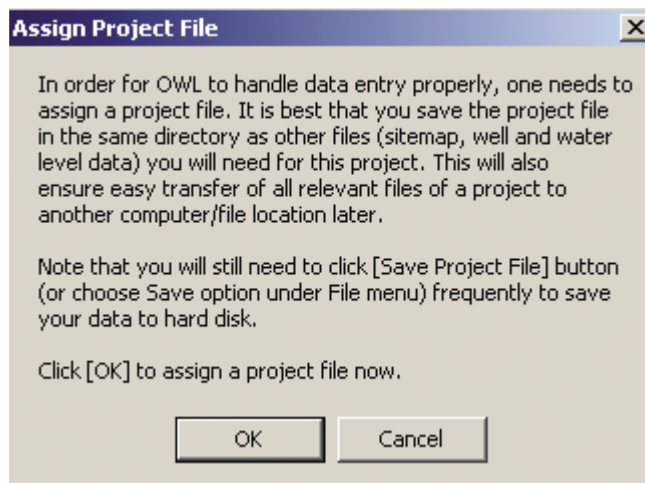
The Message window shows the user messages about what the OWL program is doing. For example, when the user opens the Case Study/Tutorial example project file, the Message window shows the message “Opened project file:site1.prj.”

4.3 Opening a New Project File

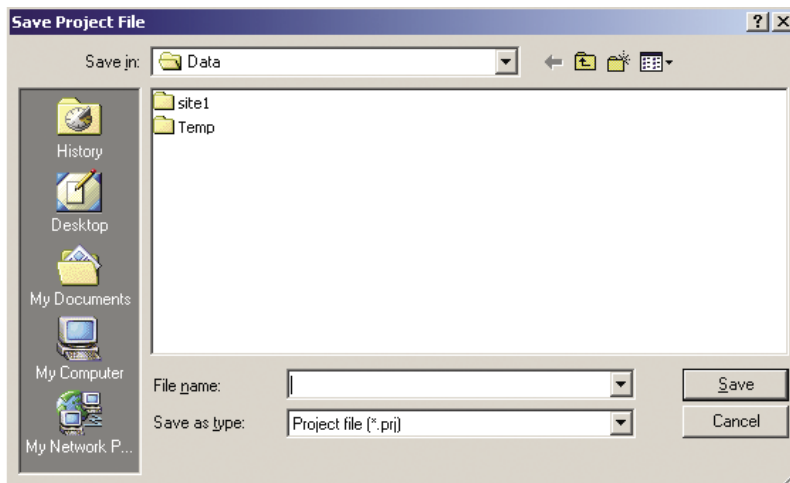
After OWL is started, click on the “<File>” item in the Menu Bar.



A drop-down menu will appear. Click on “<New Project>.” A message box will appear.



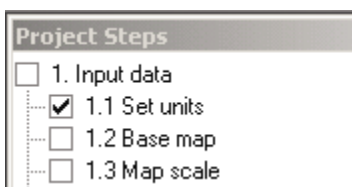
After reading the message, click on “<OK>.” A Save Project File dialogue will appear.



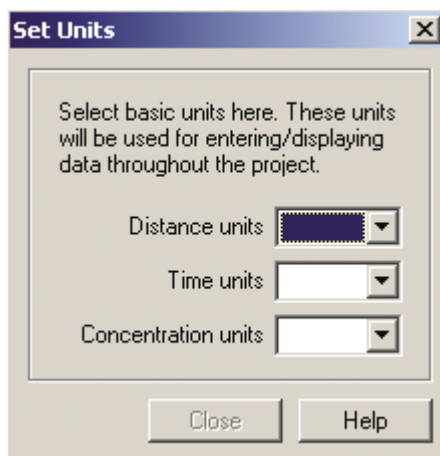
Double-click on the “Site1” folder to open that folder, type in the desired file name (*site1.prj* is suggested) and click “<Save>.”

4.4 Setting the Measurement Units

Click on the checkbox beside “<Set Units>” in the Project Steps window.



A dialogue box will appear.



Click on the drop-down menu for each item (“<Distance>, <Time>, and <Concentration>”) and choose the units for each. The Case Study/Tutorial uses ft, yr, and mg/L (feet, years and milligrams per liter) units, so choose those units for this tutorial.

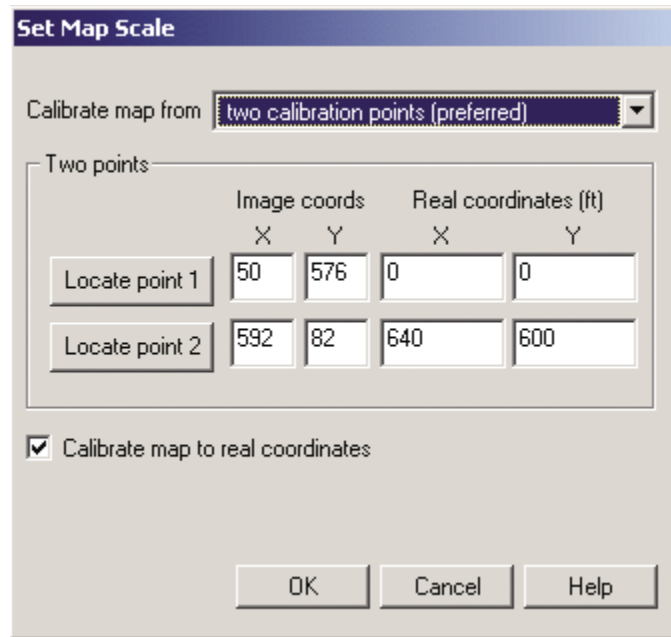
Note that all measurements entered into OWL must be in units consistent with those chosen in the Set Units dialog box, and all calculations and displays in OWL will be based on these same units.

4.5 Import the Site Basemap

Click on the checkbox beside “<Basemap>” in the Project Steps window. A dialogue box will appear, allowing the user to navigate to and choose a basemap for the site. The basemap for the Case Study/Tutorial is in the OWL\Data\site1 folder. Click on the “<site1basemap.bmp>” filename, and click “<Open>.” The basemap will appear in the Map Layers window.

4.6 Set Basemap Scale

Click on the checkbox beside “<Map scale>” in the Project Steps window. The “Set Map Scale” dialogue box will appear which allows the user to set the scale of the map in its field units (ft, m). There are two methods to set the map scale. The first is using two calibration points and the second is using the map scale bar if available.



Two Calibration Points

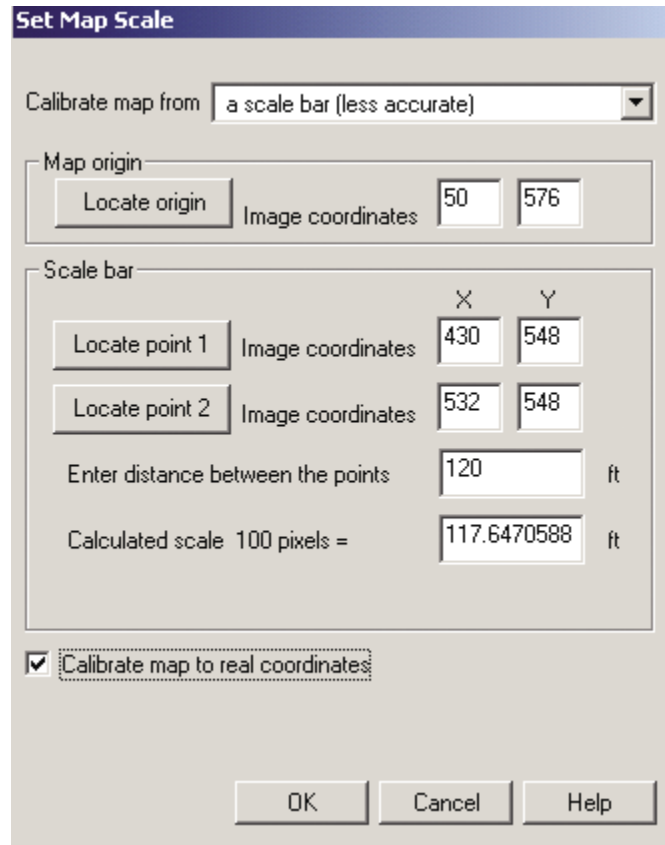
For the tutorial, choose the default choice “<two calibration points>.” Click “<Locate point 1>.” A crosshair cursor will appear and the “Set Map Scale” dialogue box will be temporarily hidden behind the Map Window. Move the crosshair cursor down to the origin at the bottom left corner of the basemap. Click on the origin. The “Set Map Scale” dialogue box should reappear with the image coordinates X: +50.0000 and Y:+576.000. Please note that there may be some slight variability in these numbers depending on how you placed the crosshair, and it is not critical to reproduce them exactly. Next, enter the real site coordinates X=0 and Y=0 into the Real Coordinates X and Y locations in the dialogue box.

Click “<Locate Point 2>.” The crosshair cursor will appear again and the dialogue box will be temporarily hidden behind the Map Window. Move the crosshair cursor up the top right corner of the basemap and click on the tickmark just below the top right corner of the map. The “Set Map Scale” dialogue box should reappear with the image coordinates X: +592.0000 and Y:+82.000. Please note that there may be some slight variability in these numbers depending on how you placed the crosshair, and it is not critical to reproduce them exactly. Next, enter the real site coordinates “X = 640” and “Y = 600” into the Real Coordinates X and Y locations in the dialogue box.

Click “<Calibrate Map to Real Coordinates>” and “<OK>.” The X-Y coordinate numbers shown at the bottom right of the Map Window are now calibrated to the actual site coordinates on the map instead of the image coordinates.

A Scale Bar

If desired, the user may also register the map to its field units using the scale bar on the map if available. This method is not recommended because it is less accurate than the two point calibration. There are several pop-up boxes which warn the user about the lack of accuracy.



To use this method, first click on the checkbox beside “<Map scale>” in the Project Steps window. The “Set Map Scale” dialogue box will appear. Select “<a scale bar>” in the first dialog box. Next click on the “<Locate origin>” button. A crosshair cursor will appear. Move the crosshair to the origin of the map and click. The “Set Map Scale” dialogue box should reappear with the image coordinates X:50 and Y:576. Please note that there may be some slight variability in these numbers depending on how you placed the crosshair, and it is not critical to reproduce them exactly.

Click “<Locate point 1>.” A crosshair cursor will appear and the “Set Map Scale” dialogue box will be temporarily hidden behind the Map Window. Move the crosshair cursor down to the left end of the map scale bar and click. The “Set Map Scale” dialogue box should reappear with the image coordinates X: 430 and Y:548. Please note that there may be some slight variability in these numbers depending on how you placed the crosshair, and it is not critical to reproduce them exactly.

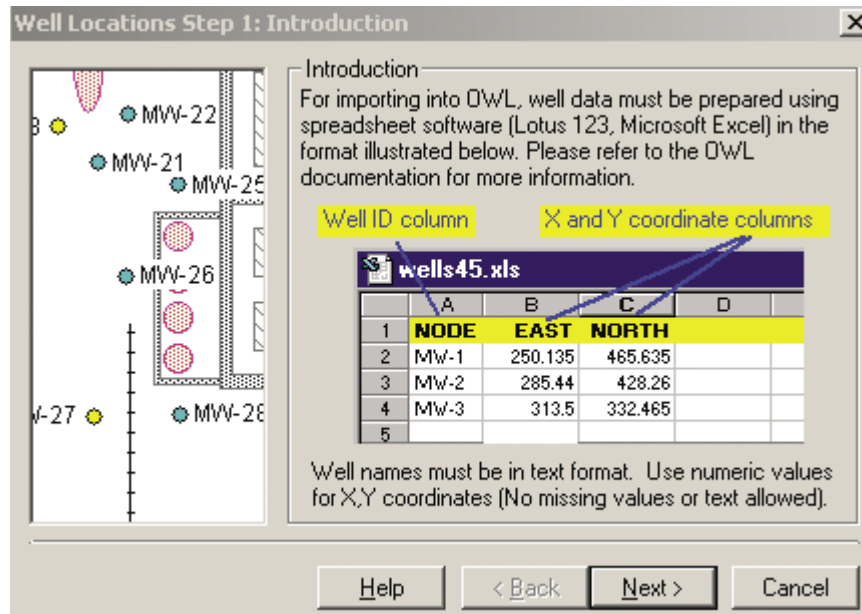
Click “<Locate point 2>.” A crosshair cursor will appear and the “Set Map Scale” dialogue box will be temporarily hidden behind the Map Window. Move the crosshair cursor down to the right end of the map scale bar and click. The “Set Map Scale” dialogue box should reappear with the image coordinates X:532 and Y:548. Please note that there may be some slight variability in these numbers depending on how you placed the crosshair, and it is not critical to reproduce them exactly.

Next enter the field distance from the map shown on the length of the scale bar in the dialog box next to “<Enter the distance between the points>.” For this basemap the scale bar length is 120 ft, so the user should enter “120” in the box. The distance in pixels in the next dialog box will be calculated automatically.

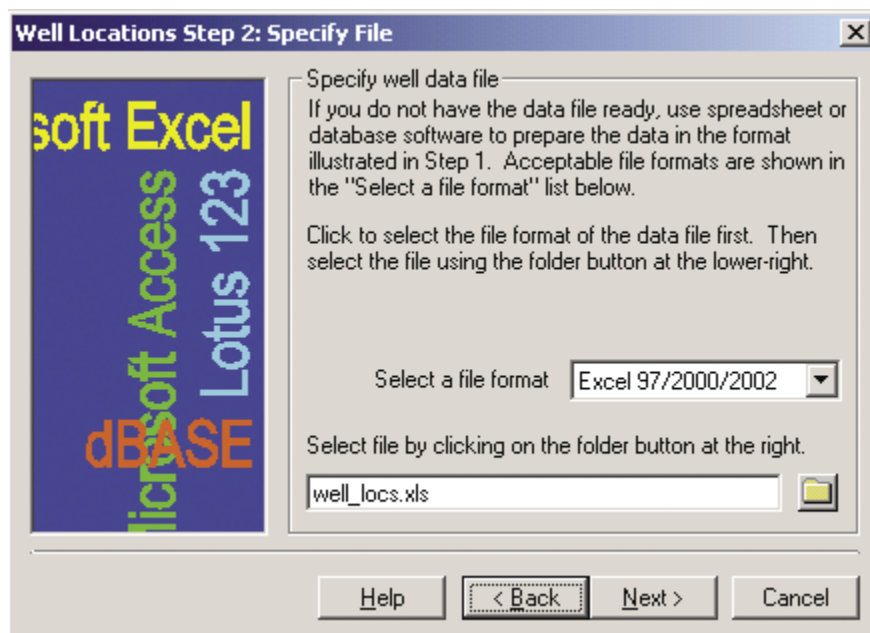
Click “<Calibrate Map to Real Coordinates>” and “<OK>.” The X-Y coordinate numbers shown at the bottom right of the Map Window are now calibrated to the actual site coordinates on the map instead of the image coordinates.

4.7 Import Well Location Data

Click on the checkbox beside “<Well locations>” in the Project Steps window. The first of a series of dialogue boxes will appear; the first box describes the data format for the Well Location data.

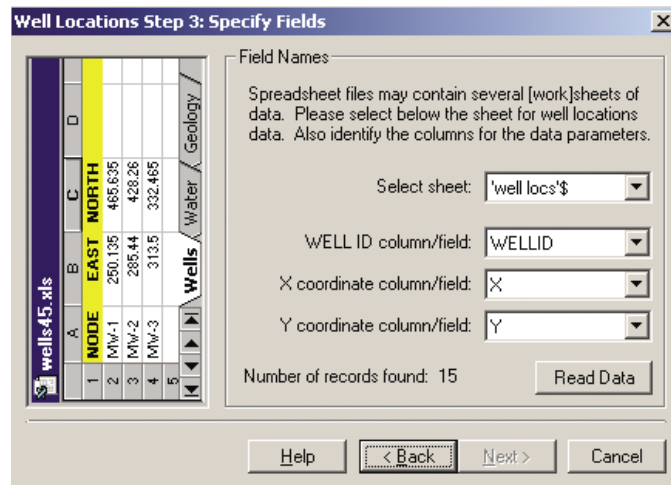


The sample Well Location file for the Case Study/Tutorial is in the correct format, so click “<Next>” to go to the Well Locations Step 2 dialogue box, where the user can select the file format and select the data file.



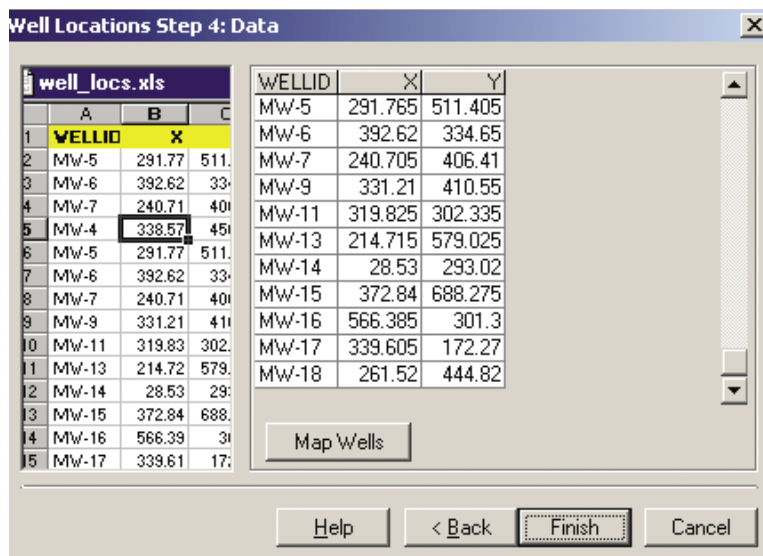
The Case Study/Tutorial sample well location data file is in Excel 97 format, the default choice, so leave that selection unchanged in the first drop-down menu. Click on the “<folder>” button in the dialogue box to bring up a dialogue box for finding the well location data file. Browse to the correct folder if necessary (the Case Study/Tutorial sample data file should be in the site1 folder), select the *well_locs.xls* file, and click “<Open>.” Click “<Next>” in the Well Locations Step 2 dialogue box.

The next dialogue box in the series allows the user to specify the fields in the spreadsheet or database which contain the well location data.



The spreadsheet “sheet” (worksheet) that contains the Case Study/Tutorial data is ‘*well_locs*’\$, so leave the first drop-down menu unchanged. Likewise, the Well ID column/field is WELLID, the X coordinate column/field is X, and the Y coordinate column/field is Y, so leave those drop-down menus unchanged. Click “<Read Data>” so that OWL will read the spreadsheet and bring the data into the program for use. A message should appear at the bottom left of the dialogue box indicating, “File is successfully read.” The number of records found should be 15. Click “<Next>.”

The final dialogue box in the Well Locations data series should appear, allowing the user to view the imported data.



The user cannot edit the well location (or ground-water elevation) data in OWL. If data changes, corrections or additions are needed, the user should edit the data in the original program used for the data (e.g., Excel). The user should make changes to the data file using the original program, save the changes to a file, and then read the file using OWL to incorporate the changes.

If, while editing the data file, problems such as “file access-violation” errors are encountered, the user should:

- (1) close the OWL session (after saving the project),
- (2) modify the data file using another software program (e.g., Excel), and save the data file,
- (3) close the other program (e.g., the program used to modify the data), and
- (4) start an OWL session, and read the modified versions of the data files.

The widths of the data columns shown in the dialogue box may be adjusted by clicking and dragging the column borders to make editing and viewing easier.

Note that in the Well Locations Step 4 Data dialogue box, the user can:

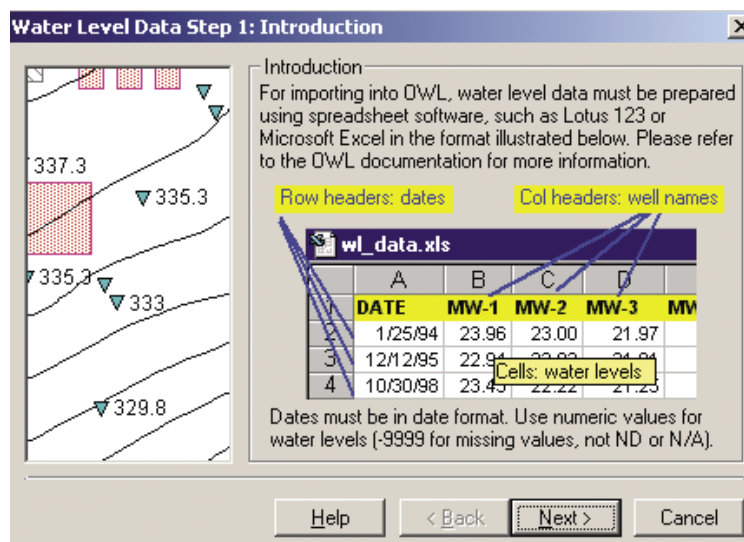
- Scroll horizontally if the spreadsheet exceeds the window width
- Scroll vertically if the spreadsheet exceeds the window height
- Change column width by clicking and dragging on the line between columns
- Change row height by clicking and dragging on the line between rows

Click “<Map Wells>” to cause the well locations to be shown on the basemap. Click “<Finish>” to continue. The wells should overlay their basemap counterparts. If they do not, the user can return to the map scale dialog box and choose a different method to calibrate the map or improve the calibration by choosing new points.

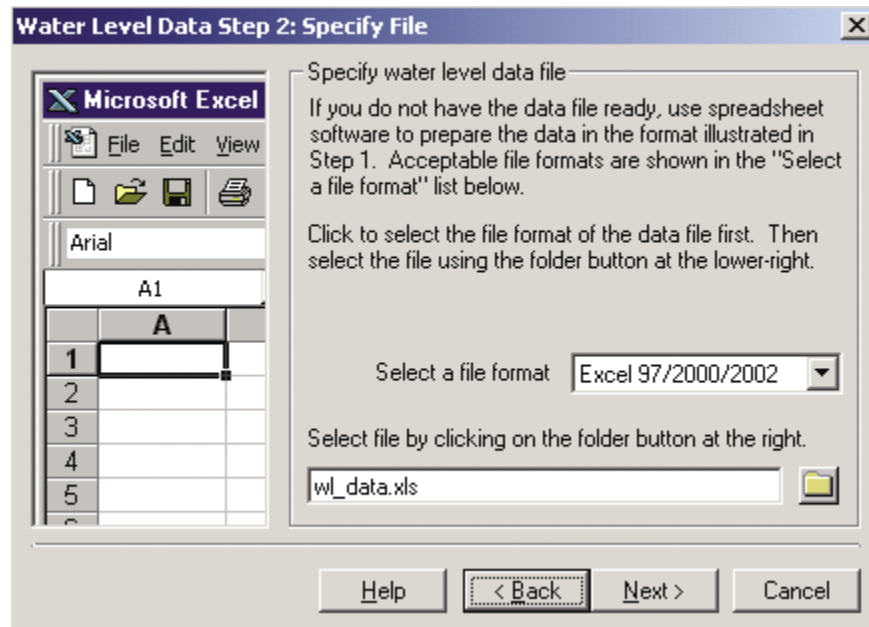
Click on the “<Wells>” checkbox in the Map Layers window to display or hide the well locations symbols and well names.

4.8 Import Ground-Water Elevation Data

Click on the checkbox beside “<Water levels>” in the Project Steps window. The first of a series of dialogue boxes will appear; the first box describes the data format for the water level data.

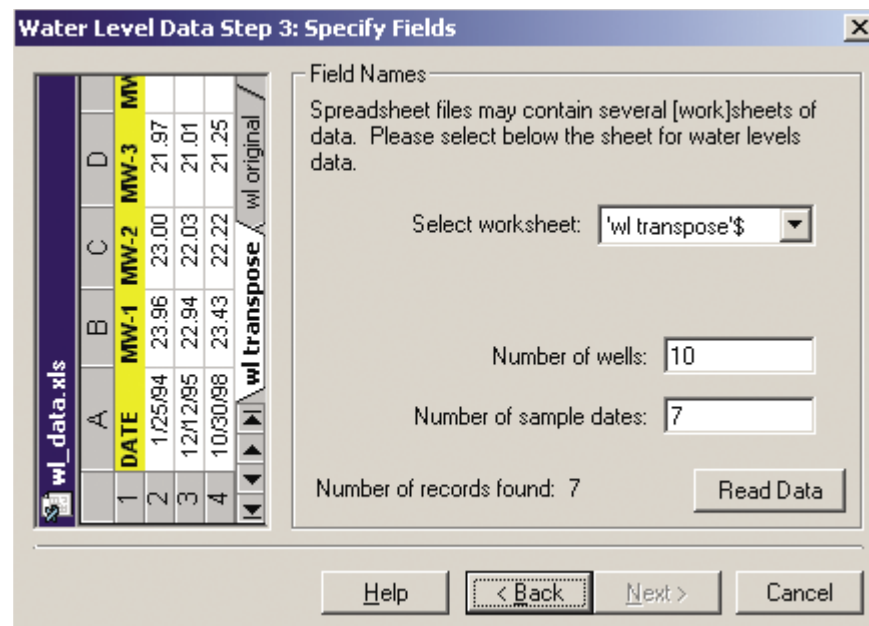


Click “<Next>.” The second dialogue box in the series allows the user to select a file format and a file for the ground-water elevation data to be used.



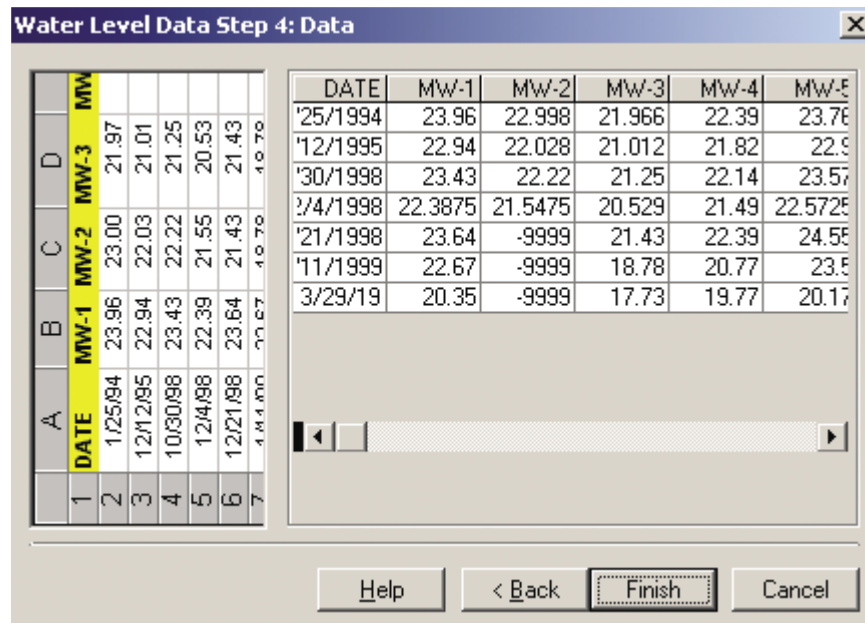
The sample water level data file in Excel 97 format, the default choice, so leave that selection unchanged in the first drop-down menu. Click on the folder button in the dialogue box to bring up a dialogue box for finding the well level data file. Browse to the correct folder if necessary (the sample data file should be in the site1 folder), select the *wl_data.xls* file, and click Open.

Click “<Next>” in the Water Level Step 2 dialogue box. The third dialogue box in the series allows the user to select the worksheet in the spreadsheet which contains the ground-water elevation data to be used.



The worksheet should be 'wl transpose \$' in this Case Study/Tutorial. Click Read Data so that OWL will read the spreadsheet and bring the water level data into the program for use. A message should appear at the bottom left of the dialogue box indicating "File is successfully read." The number of wells should be 10, and the number of sample dates should be 7.

Click "<Next>." The final dialogue box in the series will appear, showing the imported water level data.



Note that the convention in OWL for denoting missing water level data is -9999. The user cannot edit the ground-water elevation (or well location) data in OWL. If data changes, corrections or additions are needed, the user should edit the data in the original program used for creating the data (e.g., Excel). The user should make changes to the data file using the original program, save the changes to a file, and then read the file using OWL to incorporate the changes.

If, while editing the data file, problems such as "file access-violation" errors are encountered, the user should:

- (1) close the OWL session (after saving the project),
- (2) modify the data file using another software program (e.g., Excel), and save the data file,
- (3) close the other program (e.g., the program used to modify the data), and
- (4) start an OWL session, and read the modified versions of the data files.

Note that in the Water Level Data Step 4 dialogue box, the user can:

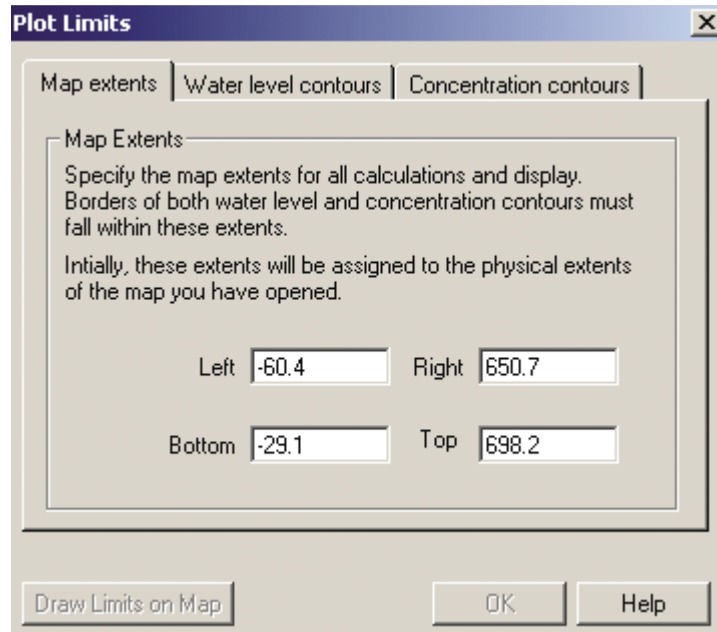
- Scroll horizontally if the spreadsheet exceeds the window width
- Scroll vertically if the spreadsheet exceeds the window height
- Change column width by clicking and dragging on the line between columns
- Change row height by clicking and dragging on the line between rows

Note also that the water levels data must be in a specific format, without any other data on the same worksheet. No other columns of data can be present on the same sheet. The data must be in the format as shown in Appendix D.

Click "<Finish>."

4.9 Set Plot Limits

Click on the checkbox beside “<Plot limits>” in the Project Steps window. The Plot Limits dialogue box will appear.



The Plot limits dialogue box has three tabs: Map Extents, Water Level Contours, and Concentration Contours. The Plot Limits dialogue box allows the user to set the area of the basemap where results of OWL calculations are displayed.

Note that OWL uses all the available well data for regression calculations, regardless of any plot limits that are chosen from any of the three tabs in the Plot Limits dialogue box. That is, all the data that have been read into OWL from the Well Location and Water Level Data dialogue boxes are used in OWL calculations. The various plot limits options affect only the display of results on the basemap.

The user should be certain that the chosen plot limits include all the wells for which sampling data is imported into OWL. If the Plot Limits area does not include all wells for which data is used in the calculations, errors could occur. Also, for display purposes, if the well falls outside the raster map, it may cause an error.

Map Extents

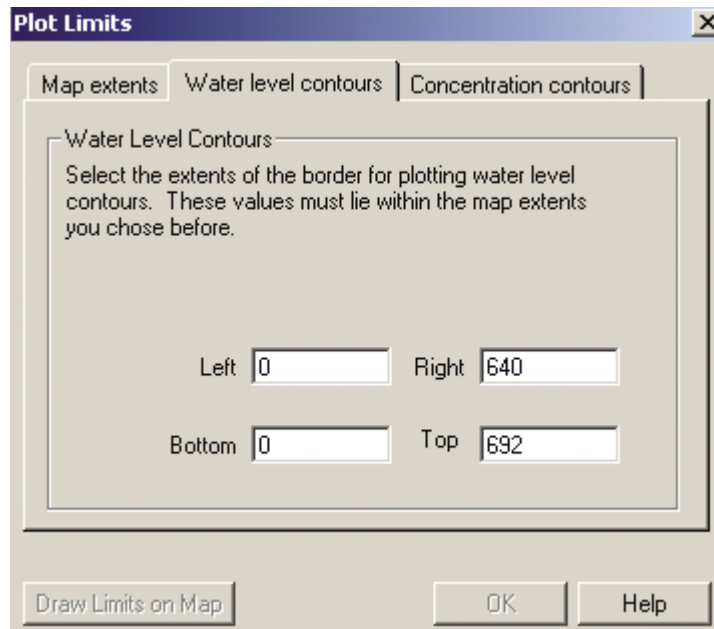
The Map Extents tab in the Plot Limits dialogue box allows the user to “Specify the map extents for all calculations and display.” By typing in the XY coordinates of Left, Right, Top and Bottom locations of a rectangular area on the basemap, all calculations and display of water level contours, plume contours, Minimum Distance contours and WOLF contours are constrained to that chosen area on the basemap. The XY coordinates of the desired locations can be determined by placing the cursor on the desired location on the basemap, and noting the XY coordinates displayed at the lower right of the Map View window.

For this Case Study/Tutorial, type in:

Left: 0	Right: 640
Bottom: 0	Top: 692

Water Level Contours

The Water Level Contours tab in the Plot Limits dialogue box allows the user to select a rectangular area of the basemap where water level contours will be plotted. (The data for these contour lines come from the water levels worksheet imported in the Water Levels window.) The area selected must be within the area previously selected under the “Map Extents” tab of the Plot Limits window.



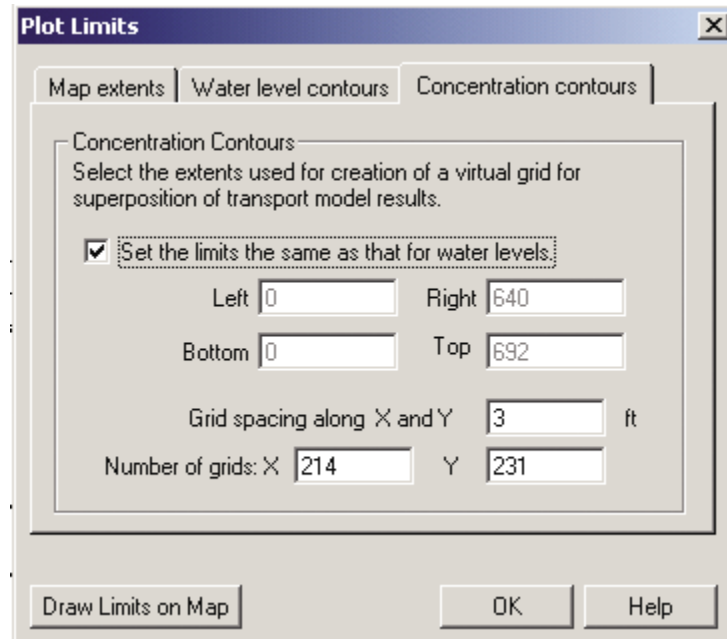
For this Case Study/Tutorial, type in:

Left: 0	Right: 640
Bottom: 0	Top: 692

Concentration Contours

The Concentration Contours tab in the Plot Limits dialogue box allows the user to “Select the extents used for creation of a virtual grid for superposition of transport model results.” The user can select a rectangular area of the basemap where a grid of points will be located, so that results of calculations in the transport model (the Domenico model used in this program to calculate contaminant fate and transport) can be plotted on the basemap. The transport model calculation results are the contaminant concentrations and locations; these results are used to draw the estimated contaminant plume on the basemap.

In general, a smaller grid (i.e., a smaller rectangular area specified under the Concentration Contours tab) would calculate faster.



There is a checkbox so that the rectangle extents can be automatically set the same as that for the water levels contours, as set under the “Water level contours” tab. For this Case Study/Tutorial, click the checkbox.

The Concentration Contours tab in the Plot Limits dialogue box also allows setting the grid spacing along the X and Y axis. The grid space is the length and width of one square in the grid, in whichever distance units were selected from the Set Units dialogue box. The grid spacing is used by OWL to calculate the number of grid nodes (points) along the X and Y axis on the basemap. Smaller grid spacings mean more grid nodes. More grid nodes provide more detailed plume maps, and involve longer calculation times. When the grid spacing is entered (and the user tabs away), the “number of grids” (the number of nodes or points in the grid) on the X and Y axes is automatically listed below in the boxes. The user cannot type data into the boxes where the “number of grids” is shown.

The grid spacing also determines the spacing of the lines that OWL uses to render the calculated contaminant plume on the basemap (“Plume contours” checkbox in the Project Steps window). Grid spacing should be chosen to provide about 200-300 grid lines along each direction in the virtual grid. If the user changes the grid spacing after running the analytical solution (“Run analytical solution” checkbox in the Project Steps window), the analytical solution must be rerun to use the new grid spacing.

For this Case Study/Tutorial, set the grid spacing to 3 ft. Tab down or click on the “Number of Grids: X” data box, and the grid numbers will be automatically set at X = 214 and Y = 231.

Click on the “<Draw Limits on Map>” button to show the chosen area on the basemap.

Click the “<OK>” button to close the dialogue box.

Click on the “<Plot Limits>” checkbox in the Map Layers window to display or hide the plot limit rectangles.

4.10 Inputting Model Data

Click on the “<Model data>” checkbox in the Project Steps window. The Transport Model Input Data dialogue box will appear.

The screenshot shows a dialog box titled "Transport Model Input Data". It contains the following fields and values:

Parameter	Value	Unit
Hydraulic conductivity	514	ft/yr
Effective porosity	0.45	
Longitudinal dispersivity	30	ft
Transverse dispersivity	3	ft
Retardation factor	1	
Simulate first-order decay	<input type="checkbox"/>	
Solute half-life		yr
Simulation time	6	yr
Source width	30	ft
Source concentration	125	mg/L

Buttons: Close, Help

The following site data are needed for calculation of the Domenico solution to contaminant transport (i.e., plume development). Note that the units used are based on the units chosen in the Set Units dialogue box.

- Hydraulic conductivity
- Effective porosity
- Longitudinal dispersivity
- Transverse dispersivity
- Contaminant retardation factor
- Simulation time (time allowed in the modeling calculation for the contaminant to move from the source to form the plume)
- Source width (width of source area transverse to ground-water flow)
- Source concentration (dissolved concentration near the source)

For this Case Study/Tutorial use the following values:

- Hydraulic conductivity (K) = 514 ft/yr
- Effective porosity = 0.45
- Longitudinal dispersivity = 30 ft
- Transverse dispersivity = 3 ft
- Contaminant retardation factor = 1
- Simulation time = 6
- Source width = 30
- Source concentration = 125

Note that the contaminant source width and contaminant source concentration should be measured at the site. The contaminant retardation factor may be estimated from site data, or estimated using values from literature references for the contaminant and the site aquifer matrix. Contaminant half-life should be estimated from site data. For this Case Study/Tutorial we assume that no degradation is taking place at the site. Hydraulic conductivity should be determined from site data. Effective porosity may be estimated using literature reference values for the particular site aquifer matrix. Longitudinal dispersivity and transverse dispersivity are usually estimated using literature reference values or simple relationships; *e.g.* longitudinal dispersivity = 10% of plume length, and transverse dispersivity = 10% of longitudinal dispersivity.

OWL allows the user to input values for several site parameters (e.g., conductivity, dispersivity, as listed above). The user should determine a range of these values that convey the variability in the site parameters, and make model runs with several values of each parameter to determine how the model results are affected by variations in the site parameters. Hydraulic conductivity, solute (contaminant) half-life, source width and source concentration are examples of factors likely to significantly affect model results. In particular, the user should input a range of values of conductivity (*k*) to determine the sensitivity to *k*, because site values of *k* are likely to vary more than any of the other site parameters used in the model. Using a range of values for *k* will cause the model to calculate different plume lengths. Knowledge of potential variability of plume lengths should help the user assess the impact of program results on site decisions. For example, this would be important if the program were used to locate guard wells because the length of the plume would be expected to vary significantly due to differing *k* values in the subsurface.

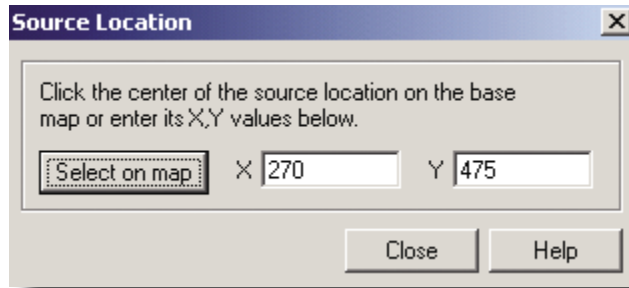
Simulation time is the time that will be simulated for contaminant plume travel from the source. The simulation time starts at the date of the sampling data used (the sampling round), continues for the selected time, assumes that there is no plume existing before the sampling date used, and assumes that the ground-water conditions prevailing at the time of the sampling data continue for the full simulation time. The estimated plume shape at the end of the simulation time is displayed on the basemap.

The Solute Half-Life is the attenuation half-life of the soluble contaminant that makes up the plume. The half-life is the time that it takes for contaminant concentration to decrease by one half.

The Source Width specifies the width of the source transverse to ground-water flow. The source line is always arranged perpendicular to the calculated ground-water flow direction for each sampling date. As ground-water flow varies over the various sampling periods, the source line varies in its orientation to the map coordinates.

4.11 Choosing the Source Location

Click on the “<Source Location>” checkbox in the Project Steps window. The Source Location dialogue box will appear.



The Source Location dialogue box allows the user to set the location of the contaminant source on the basemap. The user can click the “<Select on Map>” button to allow scrolling over the basemap and setting the center of the source location on the basemap by clicking on the desired point on the basemap. Alternatively, the user can set the location of the contaminant source on the basemap by entering the X and Y coordinates of the source center in the input boxes. For the Case Study/Tutorial, enter 270 and 475 (X = 270, and Y = 475).

A red circle with an interior cross is displayed on the map view to represent the chosen source location. The diameter of the red circle is drawn to scale to represent the source width. Click the “<Close>” button to close the dialogue box.

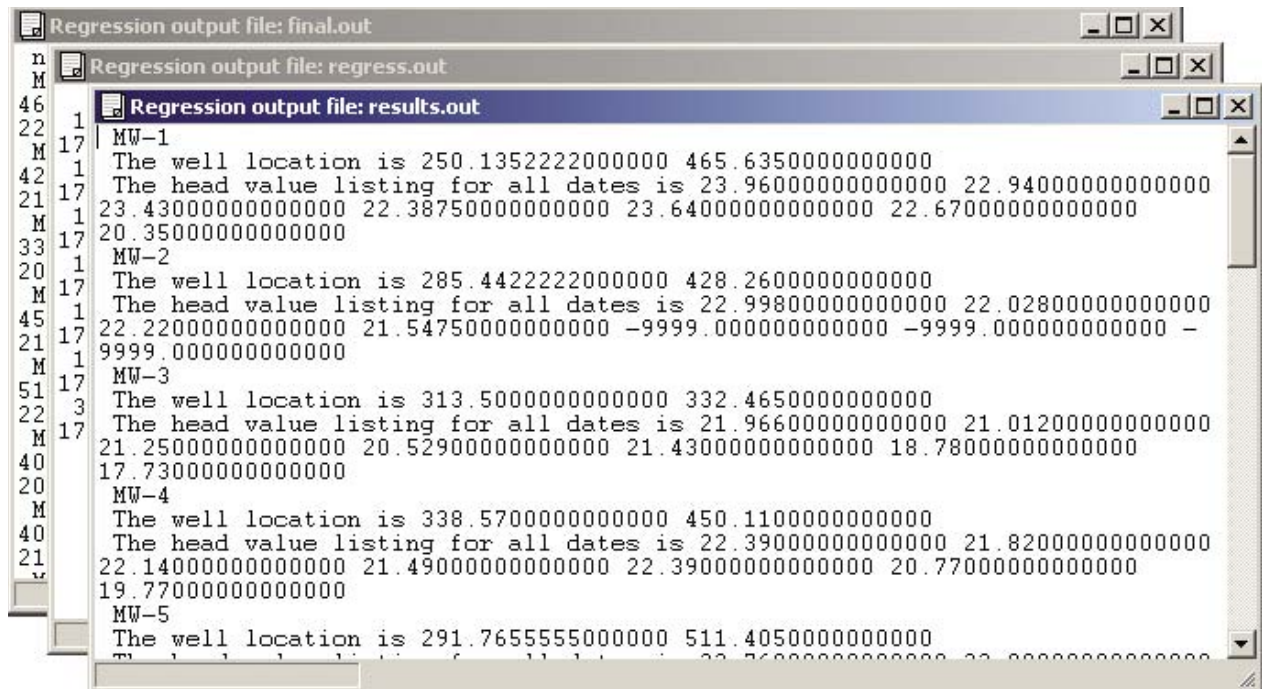
Click on the “<Source Center>” checkbox in the Map Layers window to display or hide the source location.

4.12 Run Linear Regression

Click on the “<Run linear regression>” checkbox in the “Project Steps” window to cause the program to run a linear regression calculation to determine a ground-water plane surface for each sampling event (each sampling date listed in the Water Levels spreadsheet where ground-water head measurements were determined). When the regression analysis is finished, a message will show in the status bar panel at the lower left of the OWL program window (“Regression analysis finished.”). Appendix B gives details on the implementation of the regression used in OWL.

4.13 View Raw Output Files

Click on the “<View raw output files>” checkbox in the “Project Steps” window to cause OWL to open three windows showing the linear regression output files *results.out*, *regress.out*, and *final.out*. This option on the Project Steps checklist provides a means to export the linear regression results to other programs for study, verification, or printing. The regression results are output in a space-delimited ASCII text file, which is suitable for opening in a spreadsheet, database, or word processor. For instance, the files can be opened in Excel, and parsed to put each value in the output file in a single cell of the worksheet in the spreadsheet. The OWL program uses double precision format in its calculations for the linear regression. When the *regress.out* file is opened in Excel, the numbers will be written as xxxD.xx. They can be changed to a scientific format recognized by Excel by using the “find and replace” command and changing the “D” to “E”.



For each well, *results.out* gives:

- 1) The well location coordinates (“The well location is...”) and
- 2) The ground-water elevations data for each date when the well was sampled (“The head value listing for all dates is...”)

For each sampling date, *results.out* gives:

- 1) The sampling date (“The date for this regression is...”),
- 2) The regression equation with coefficients (“The regression equation is...”)
- 3) The correlation coefficient to show how well the regression fits the data; i.e., the R-square value (“the regression coefficient for the equation fit is...”)
- 4) The value for the calculated ground-water gradient (“The magnitude of the ground-water gradient is...”) and
- 5) The difference in degrees of ground-water flow direction from the north (“The direction of the ground-water flow from north is...”).

Regress.out gives a summary table of the regression results:

- 1) The sampling date for the data used in each regression equation (“date”),
- 2) the x coefficient of each regression equation (“xcoeff”)
- 3) the y coefficient of each regression equation (“y coeff”)
- 4) the constant of each regression equation (“constant”)
- 5) the correlation coefficient of each regression equation (“R²”)
- 6) the value for the calculated ground-water gradient (“mag”) and
- 7) the difference in degrees of ground-water flow direction from the North (“dir”).

Final.out gives:

Number of wells (n1), Number of dates (k)

The following information is given for each well:

Well name, X, Y coordinates of location
Water elevations for all the sample dates

The following results are shown for each date of measurement:

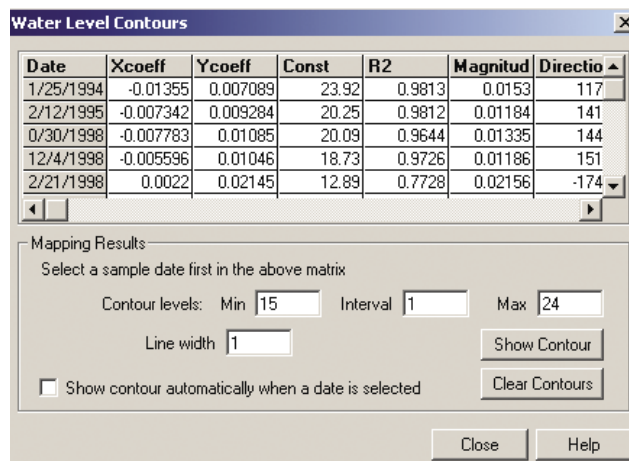
Sample date
Regression matrix details
Matrix dimension (mm, same as number of wells)
Final adjusted matrix
Coefficient matrix
Right-hand-side matrix (rhs)
Rank of matrix
Parameters
Residuals
Variance of residuals
Regression coefficient
Hydraulic gradient
Flow direction (degrees from the north)

Click the “<X>” in the upper right corner of each output file window to close each window.

The output files are opened in the user-specified text editor during OWL installation (for example, Notepad for small text files, and Wordpad for large text files). The user can check which programs are specified (and change the specified programs) by clicking on “<Tools -> Options>” on the OWL menu bar.

4.14 View Water Level Contours

Click on the “<Water Level Contours>” checkbox in the “Project Steps” window to bring up a dialogue box allowing the user to see a spreadsheet view of the linear regression results, and to set and view the water level contours on the basemap.



The first frame at the top of the dialogue box shows a spreadsheet-like view of the X coefficient (Xcoeff), Y coefficient (Ycoeff), constant (Const), correlation coefficient (R²), magnitude, and direction for each sampling date.

The regression equation is:

$$\{\text{GW head}\} = [\text{Xcoeff}] \{\text{X coordinate}\} + [\text{Ycoeff}] \{\text{Y coordinate}\} + \text{Const}$$

The term “R²” gives an indication of how closely the regressed plane fits the ground-water elevation data. Values of R² closer to 1.0 show a better fit of the regression to the sampling data. “Magnitude” gives the calculated average change in ground-water elevation along the flow direction; i.e., the ground-water gradient. “Direction” gives the angle of ground-water flow in degrees clockwise from the north (north is 0 degrees; OWL assumes that north is at the top of the screen on the basemap).

The R² term is the square of the Pearson Product Moment Correlation Coefficient. It can be thought of as the portion of the total variation in the data that can be explained by the regression. The values of R² in the case study vary from 0.7728 to 0.9813. These are particularly good fits. The regression explains from 77% to 98% of the variation in the data. These data fit the assumption in OWL that the water table is a plane; at other sites, the fit to the assumption may not be as good. Appendix E provides recommendations for editing the data set when R² is low.

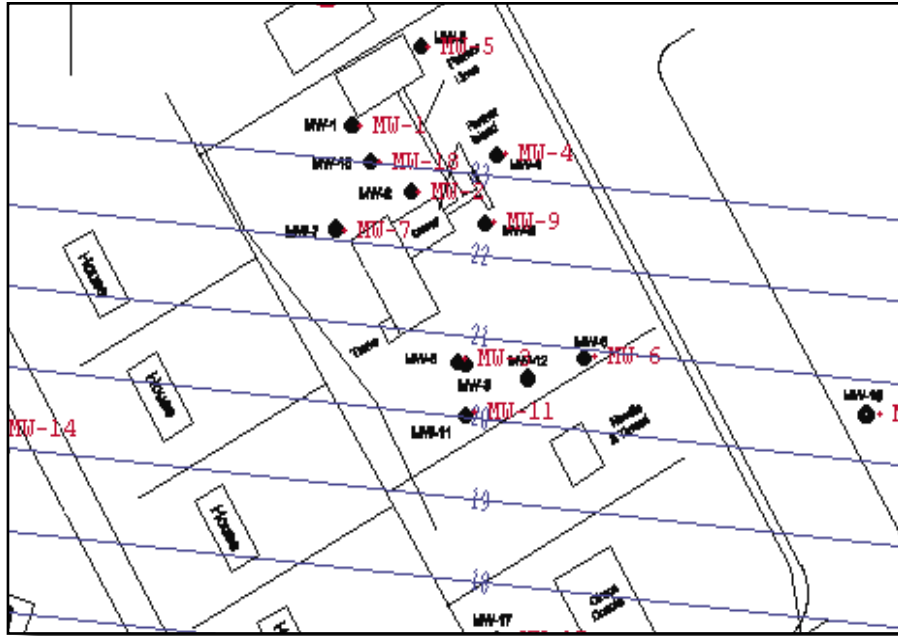
If necessary, horizontal and vertical scrollbars are present so that all the results can be viewed by scrolling. Column width and row height of the spreadsheet view can be changed by clicking and dragging on the line between the columns or rows, in order to fully view the contents of each cell.

Just below the frame containing the spreadsheet view in the “Water Level Contours” dialogue box is a frame showing the “Mapping Results.” This part of the dialogue allows the user to show the calculated ground-water level contours on the basemap, for a chosen sampling date. The user can select a sampling date in the spreadsheet view by clicking on a cell in the desired row, or by moving up and down among the sampling dates using the up and down arrow keys on the keyboard.

The range of ground-water levels to be plotted as contour lines on the basemap can be entered (“Contour levels”); the minimum value of ground-water head to be plotted as a contour line on the basemap (Min) and the maximum value of ground-water head to be plotted (Max) can be typed into the entry boxes. The contour interval can also be entered; this is the difference in ground-water elevations between successive contour lines. The width of the contour lines to be plotted can be entered; wider lines are more easily visible on the basemap. The width is entered in screen units (pixels). That is, when the width is 2, lines that are two pixels wide are displayed on the map.

The default contour interval is 1 foot or 1 meter, depending on whichever distance unit was selected from the Set Units dialogue box. If the hydraulic gradient across the site is very flat, a contour line may not be displayed at a contour interval of 1. In this case set the contour interval to 0.1 foot or 0.03 meter. Although depth to water data are often read and recorded with a precision of 0.01 foot with respect to the top of the well casing, the survey of the elevation of the well casings is usually accurate to 0.1 foot.

A checkbox is provided to show the contour lines on the basemap automatically when a sampling date is chosen by clicking on the spreadsheet view.



Two buttons are provided in the “Water Level Contours” dialogue box; one displays the contours for the chosen sampling date and contour parameters on the basemap (“Show Contour”), and the other button removes the display of contours from the basemap (“Clear Contours”).

Note that the contours are plotted as though the ground-water surface was a plane; ground-water flow at specific locations on the actual site may differ significantly from the flow directions indicated by the contour lines shown in this program. These differences in flow could be caused by ground-water recharge or discharge, or other processes or structures that could cause deviations from a planar ground-water surface.

Click on the “<basemap>” to bring it to the front for viewing the contours without the dialogue box covering the map. The dialogue box can be brought back to the front by clicking on “<Window>” (on the Menu Bar), and clicking on “<Water Level Contours.>”

The differences in ground-water flow direction and gradient at the different sampling dates may be examined by choosing sampling dates and plotting the contours.

Click the “<Close>” button to close the dialogue box.

The basemap with contour lines may be printed when the basemap window is active. Click “<File>” (on the Menu Bar), “<Print>,” enter a map title if desired in the dialogue box that appears, and click “<OK>” to print. If Print is selected when the basemap window is not active, an error box appears. Click “<OK>” on the error box, click the basemap to make it active, and choose “<Print>” from the Menu Bar again.

4.15 Transport Run

Click on the “<Run analytical solution>” checkbox in the Project Steps window to run the Domenico model calculations for solute transport in ground water. The model calculations are based on the well

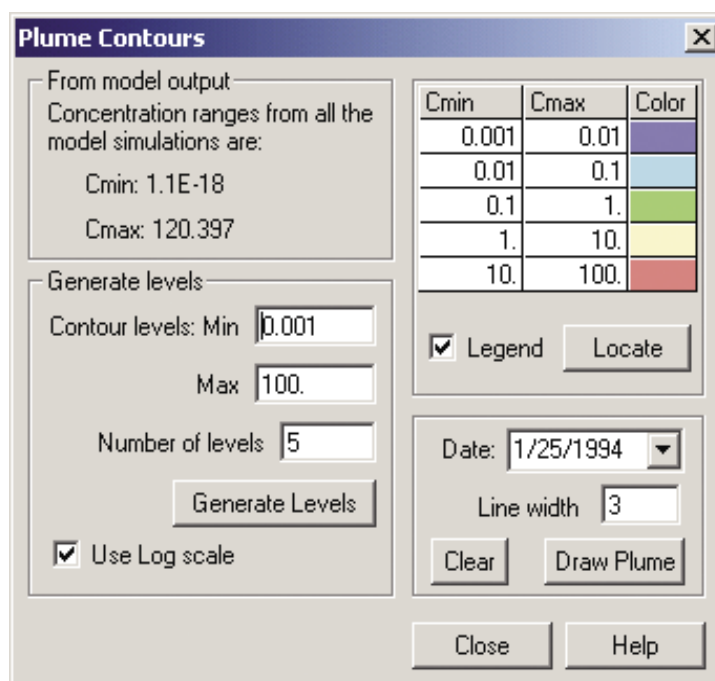
location data, water level data, and source location data entered earlier, and the Transport Model input data entered after clicking on the Model Data checkbox in the Project Steps window. A message will be shown in the status bar at the bottom right of the OWL window indicating the model was successfully run (“Analytical simulation finished”). Appendix B gives details on the implementation of the Domenico solution used in OWL.

4.16 Export Model Results

Click on the “<Export model results>” checkbox in the Project Steps window to save the model results in a text file suitable for exporting to other programs. A Select File for Model Results dialogue box appears, allowing the user to save the model results in a text file to the desired directory. The default filename is *OWLResults.out*, but the user can type in a new name if desired. If a file by that name is already in the directory, a warning message is displayed. The file may be quite large, depending on the amount of sampling data input to OWL as well locations and ground-water elevations.

4.17 View Plume Contours

Click on the “<View plume contours>” checkbox in the Project Steps window to make the View Plume Contours dialogue box appear.



The first frame in the “Plume Contours” dialogue box (on the top left hand side of the box) “From model output” shows the minimum and maximum calculated contaminant concentration ranges from all the model simulations. These values are automatically placed in the “Generate levels” part of the dialogue box discussed below.

On the bottom left hand side of the “Analytical Model Results” dialogue box (“Generate levels”) the user may enter minimum and maximum values for the solute (contaminant) contour levels to be contoured on the basemap, and the number of contour levels desired to present. The “Number of levels” is the number

of contours that the contaminant concentration range is to be divided into to be displayed as contours on the basemap. The maximum number of levels is five.

An option is provided to use a log scale for the plume contours. Clicking the “<Use Log scale>” checkbox causes the contour levels to be divided based on a logarithmic scale rather than the usual linear scale. This option is helpful when contaminant concentrations vary over several orders of magnitude. For this Case Study/Tutorial, enter Min = .001, Max = 100, and Number of Levels = 5. Click the “<Use Log Scale>” check box and click the “<Generate Levels>” button.

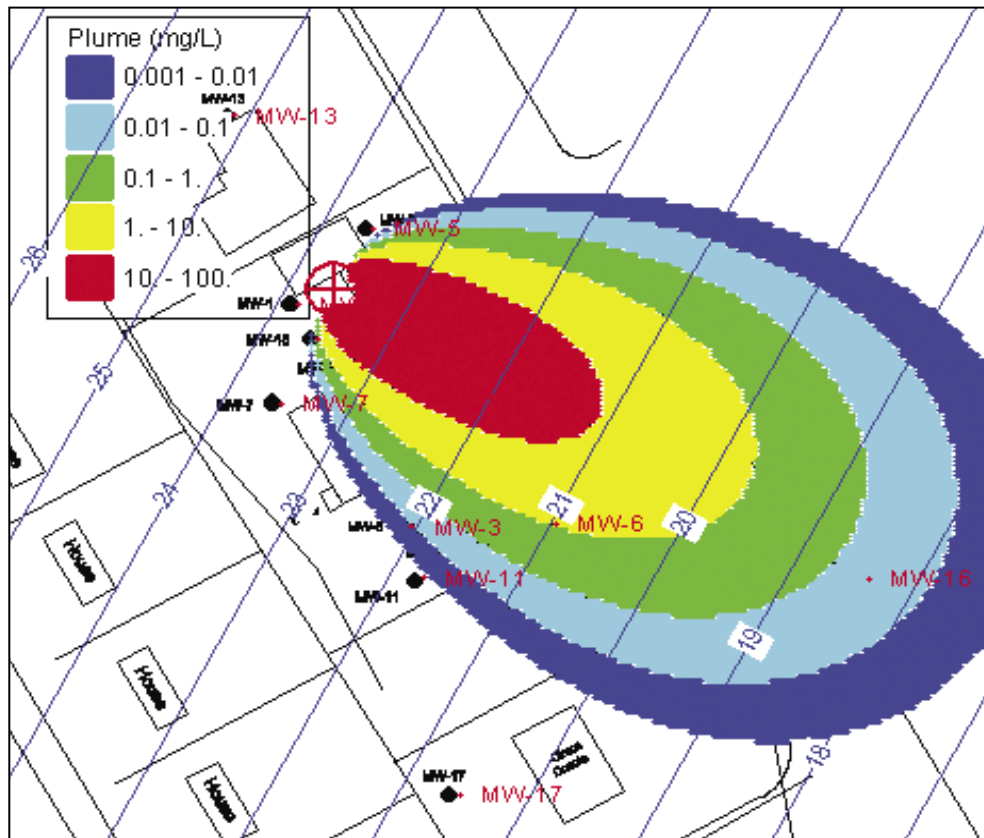
The colors used for contours can be changed by the user, if desired. The user may click the “<Color>” column in the spreadsheet view to show the “Select a color” palette. Click the appropriate cell under the Color column in the spreadsheet view, then click the desired color in the “<Select a color>” palette. The selected color will appear in the spreadsheet cell. Continue clicking a spreadsheet cell and a color until colors are selected for all the levels shown in the “View Plume Contours” dialogue box.



OWL provides an option to place a legend showing the concentration ranges associated with colors. Check the box labeled “<Legend>” and click the “<Locate>” button to place the legend on the map. When the cursor is moved over the basemap, the shape of the cursor changes to a crosshair. Click on the map where the upper left corner of the legend is to be placed. When the “<Draw Plume>” button is clicked, the plume and legend will be drawn on the map. If the user is not satisfied with the location of the legend, go back to the “<Plume Contours>” dialog box, and repeat the process. Select the new legend location with the cursor. Click on the “<Draw Plume>” button, and the legend will be placed in the new location. The legend may also be removed by unchecking the “<Legend>” box and redrawing the plume.

In the “Plume Contours” dialogue box on the bottom right hand side of the window, the user can choose the sampling date (Date) from a drop-down menu to get the contaminant concentration data to be plotted as contours on the basemap. The sampling date of the data used to draw the currently-shown plume contours is shown in the drop-down menu. The user can also choose “<Average>” from the drop-down menu, to show a composite plume that is an average of the calculated plumes based on data from all the sampling dates.

Click on the “<Draw Plume>” button to display the plume contours (and legend, if chosen) on the basemap. Click on the “<clear>” button to clear the currently-drawn plume (and legend, if chosen).



The basemap with plume contours (and legend, if chosen) may be printed by choosing “<File, Print>” from the Menu Bar. The basemap window must be active, or an error message will appear. When Print is selected, a dialogue box will appear allowing the user to enter a map title to be printed on the bottom of the page.

Click the “<Close button>” to close the dialogue box.

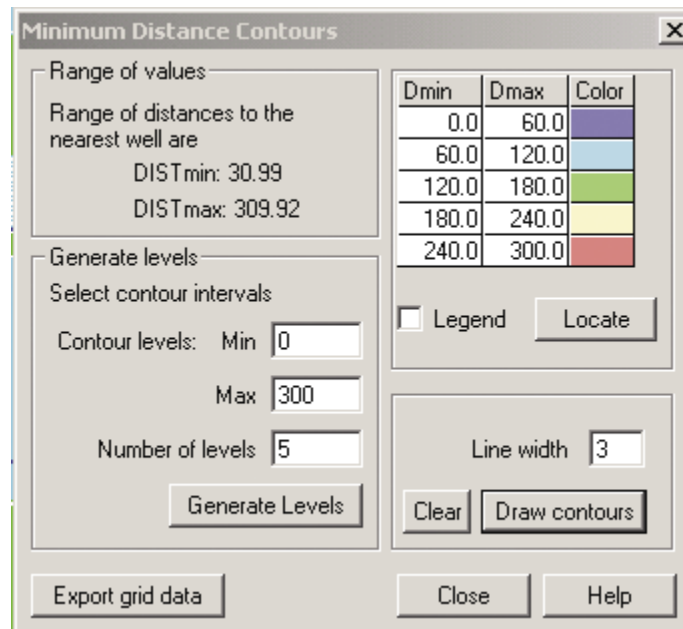
The user can step through the plots of each plume to view the impact of the change in ground-water flow direction and magnitude. If there is a large variation in the ground-water flow field over time, the difference in the plumes created for the same source concentration and time of travel can be striking, as it is in this case study. In addition, the user can view the “<Average>” plume, which is a composite of all the possible plume migration paths. This composite plume provides the user with all the possible locations where contamination may exist at the site, given the historical ground-water flow variation. For this case study, the composite plume is predicted to be present over a large region and the existing monitoring wells clearly cover only a small portion of that region.

4.18 View Minimum Distances

OWL provides the capability to calculate distances from each grid point to the nearest well and present these distances as contours on the basemap. These contours give the user a visual indication of the

monitoring well coverage across the site. The minimum distance data will be used in the next section to calculate a Well Optimal Location Factor (WOLF), to indicate locations where new monitoring wells might be needed and where existing wells may be redundant.

Click on the “<View **MinDist** contours>” checkbox in the Project Steps window. The “Minimum Distance Contours” dialogue box appears.



The first frame (on the top left hand side of the dialogue box) in the “Minimum Distance Contours” dialogue box is “Range of Values.” This frame reports the range of distances from the node points on the superimposed grid to the nearest well; the minimum distance (DISTMin) and maximum distance (DISTMax). This range is for locations within the map limits (as set before in the Plot Limits dialogue box). Zero and the DISTmax values are automatically entered into the “Generate levels” Min and Max part of the dialogue box discussed below.

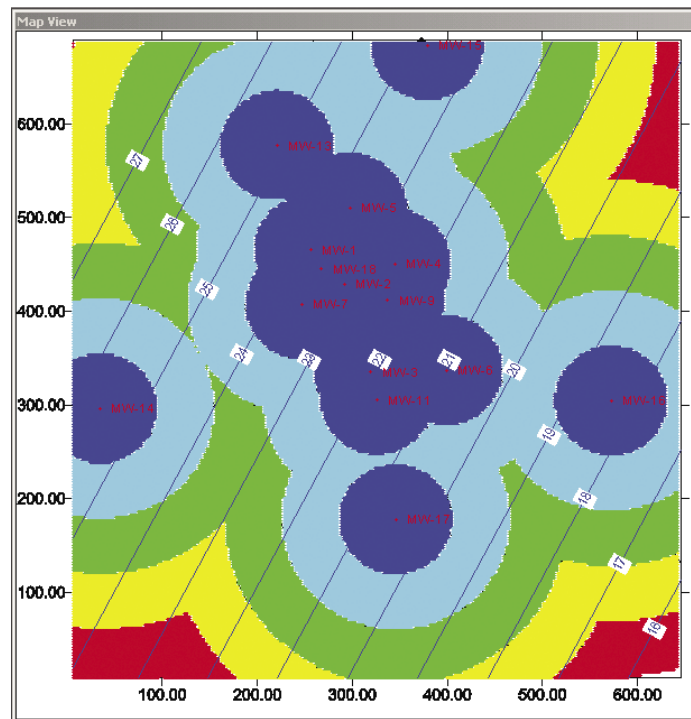
On the bottom left hand side of the “Minimum Distance Contours” dialogue box (“Generate levels”) the user may enter minimum and maximum values for the distance contour levels to be contoured on the basemap, and the number of contour levels desired to present. The “Number of levels” is the number of contours that the minimum/maximum distance range is to be divided into to be displayed as contours on the basemap. For this Case Study/Tutorial, enter Min = 0.0, Max = 300, and Number of levels = 5. Click the “<Generate levels>” button to use the chosen contour min, max and levels.

The colors used for contours can be changed by the user, if desired. The user may click the “<Color>” column in the spreadsheet view on the top right hand side of the “Minimum Distance Contours” dialogue box to show the “Select a color” palette. Click the appropriate cell under the Color column in the spreadsheet view, then click the desired color in the “Select a color” palette. The selected color will appear in the spreadsheet cell. Continue clicking a spreadsheet cell and a color until colors are selected for all the levels shown in the “Minimum Distance Contours” dialogue box. Click on the “<Close>” button to shut the “Select a color” dialogue box.

OWL provides an option to place a legend showing the minimum distances associated with colors of the contours. Check the box labeled “<Legend>” and click the “<Locate>” button to place the legend on the map. When the cursor is placed over the basemap, the cursor changes to a crosshair. Click on the map where the upper left corner of the legend is to be placed. When the “<Draw Contours>” button is clicked, the contours and legend will be drawn on the map. If the user is not satisfied with the location of the legend, go back to the “Plume Contours” dialog box, and repeat the process. Select the new legend location with the cursor. Click on the “<Draw Plume>” button, and the legend will be placed in the new location. The legend may also be removed by unchecking the “<Legend>” box and redrawing the plume.

In the lower right corner of the “Minimum Distance Contours” dialog box, the user can choose the line width to be used for drawing the distance contours on the basemap.

Click on the “<Draw contours>” button to display the distance contours (and legend, if chosen) on the basemap. Click on the “<clear>” button to clear the currently-drawn distance contours (and legend, if chosen).



The distance data may be exported in a text file by clicking on the “export grid data” button in the lower left of the dialog box. (There is no warning for overwriting a previously existing file of the same name.) This file contains the grid data showing the distance to the nearest well at each grid node. The grid nodes are the same as those chosen in the “Plot Limits” dialog box, “Concentration Contours” tab (click on “<Plot limits>” in the “Project Steps” window to show this dialog box).

The basemap with distance contours (and legend, if chosen) may be printed by choosing File, Print from the Menu Bar. The basemap window must be active, or an error message will appear. When Print is selected, a dialog box will appear allowing the user to enter a map title to be printed on the bottom of the page. The file should be printed to a color printer.

Click the “<Close>” button to close the Minimum Distance Contours dialogue box.

The user can look at the color contours of “Minimum Distance” and develop an understanding of the existing well coverage at the site. For this case study, the dark blue circles highlight the region where a monitoring well is close, within 60 ft. As you move away from the wells, the contour colors indicate that there is less and less coverage by existing monitoring wells. At some point, it is clear that there are regions where the nearest monitoring well is so far away that it represents essentially no coverage. This “Minimum Distance” is useful by itself, because the user can begin to have a meaningful measure of “void space” where the site lacks monitoring well coverage.

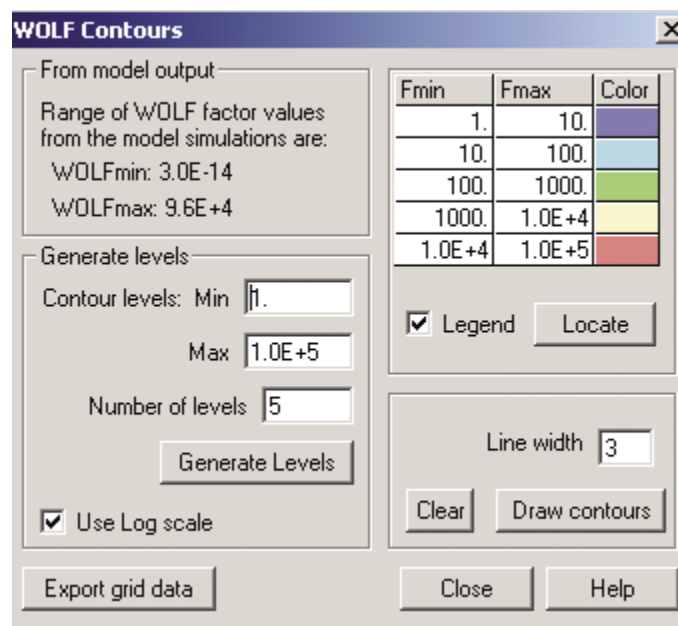
4.19 Well Optimal Location Factor (WOLF)

OWL provides the capability to calculate a number that combines the distance from each grid point to the nearest well (minimum distance) and the average concentration from the composite plume, and present these numbers as contours on the basemap. This number, known as the Well Optimal Location Factor (WOLF), is based on the following calculation:

$$\text{WOLF} = (\text{average concentration at each grid node}) * (\text{square of the minimum distance to the nearest well})$$

WOLF contours give the user a visual indication of how the predicted contaminant concentration at a location as a function of the change in ground-water flow over time can be combined with monitoring well coverage to highlight areas of concern in a monitoring well network. Such areas would be locations where monitoring well coverage is high, but contamination concentration is forecast to be low. Or vice-versa, contaminant concentration is predicted to be high, but monitoring well coverage is low. Thus the WOLF becomes the yardstick, by which the user can evaluate the location of existing monitoring wells and select locations for new monitoring wells.

Click on the “<View WOLF Contours>” in the Project Steps window and the WOLF Contours dialogue box appears.



The first frame (on the top left hand side of the dialogue box) in the WOLF Contours dialogue box is “From model output.” This reports the range of calculated WOLF values from the model simulations, the minimum WOLF (WOLFMin) and maximum WOLF (WOLFMax). This range is for locations within the map limits (as set previously in the Plot Limits window). The WOLF for a grid node is the average predicted contaminant concentration at that grid node multiplied by the square of the minimum distance from the node to the nearest well. The WOLFmin and WOLFmax values are automatically entered into the Min and Max part of the “Generate levels” frame discussed below.

On the lower left of the “WOLF Contours” dialogue box (“Generate levels”) the user may enter minimum and maximum values for the WOLF contour levels to be contoured on the basemap, and the number of contour levels desired to present. The “Number of levels” is the number of contours that the WOLFmin/WOLFmax range is to be divided into to be displayed as contours on the basemap. An option is provided to use a log scale for the WOLF contours. Clicking the “Use Log scale” checkbox causes the WOLF contours to be divided based on a logarithmic scale rather than the usual linear scale. This option is helpful when WOLF values vary over several orders of magnitude, as is usually the case. For this Case Study/Tutorial, check the “<Use Log scale>” box.

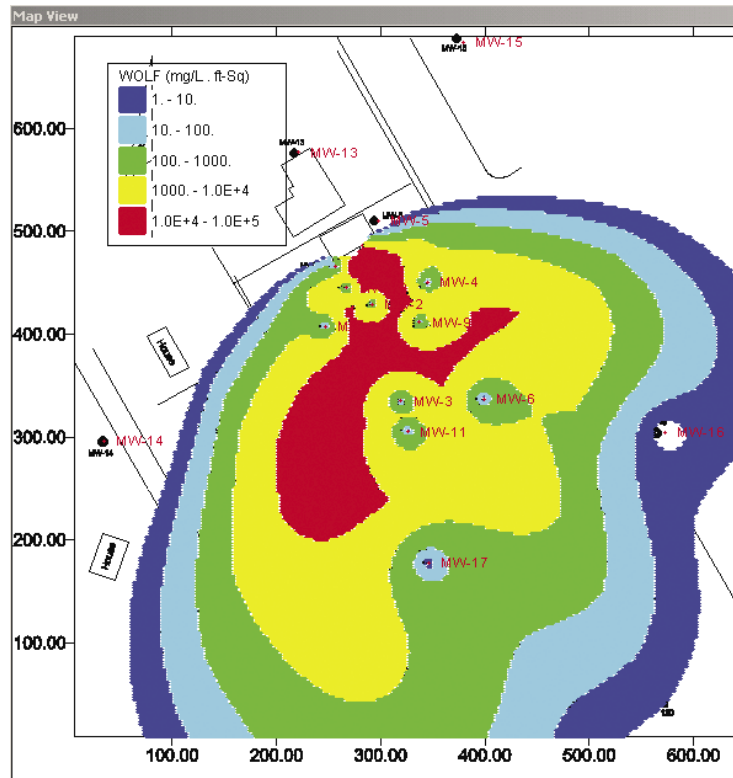
Typically, small WOLF values are not as important as large WOLF values. This is because large WOLF values indicate where concentrations are high and monitoring well coverage is low. When choosing levels to plot in WOLF, it is therefore important to capture the highest values. For this case study, enter Min = 1, Max = 1.0E+5, and the Number of levels = 5 in the boxes. Click the “<Generate Levels>” button to use the chosen contour min, max, and levels.

The colors used for contours can be changed by the user, if desired. The user may click the “<Color>” column in the spreadsheet view on the top right hand side of the “WOLF Contours” dialogue box to show the “Select a color” palette. Click the appropriate cell under the Color column in the spreadsheet view, then click the desired color in the “Select a color” palette. The selected color will appear in the spreadsheet cell. Continue clicking a spreadsheet cell and a color until colors are selected for all the levels shown in the “Wolf Contours” dialogue box. Click on the “<Close>” button to shut the “Select a color” dialogue box.

OWL provides an option to place a legend showing the WOLF factors associated with colors of the contours. Check the box labeled “<Legend>” and click the “<Locate>” button to place the legend on the map. When the cursor is placed over the basemap, the cursor changes to a crosshair. Click on the map where the upper left corner of the legend is to be placed. When the “<Draw contours>” button is clicked, the contours and legend will be drawn on the map. If the user is not satisfied with the location of the legend, go back to the “Plume Contours” dialog box, and repeat the process. Select the new legend location with the cursor. Click on the “<Draw Plume>” button, and the legend will be placed in the new location. The legend may also be removed by unchecking the “<Legend>” box and redrawing the plume.

In the lower right corner of the “WOLF Contours” dialogue box, the user can choose the line width to be used for drawing the WOLF contours on the basemap.

Click on the “<Draw contours>” button to display the WOLF contours (and legend, if chosen) on the basemap. Click on the “<clear>” button to clear the currently-drawn WOLF contours (and legend, if chosen).



The WOLF data may be exported in a text file by clicking on the “<export grid data>” button in the lower left of the dialogue box. (There is no warning for overwriting a previously existing file of the same name).

The basemap with WOLF contours (and legend, if chosen) may be printed by choosing File, Print from the Menu Bar. The basemap window must be active, or an error message will appear. When Print is selected, a dialogue box will appear allowing the user to enter a map title to be printed on the bottom of the page. The file should be printed to a color printer.

Click the “<Close>” button to close the dialogue box.

The user can now look at the contours of the WOLF on the site basemap and begin to pinpoint areas of concern for the performance of the monitoring well network. For this case study, using a time of travel of six years, the red region in the WOLF plot indicates that there are high concentrations predicted based on the variation in historical ground-water flow and low monitoring well coverage. This red region, especially west of most of the existing wells, may therefore be a good place to consider putting a new monitoring well. The WOLF values will change depending on the time of travel and continuous source concentrations used to create the plumes. So the user can vary these values, rerun the plume migration and see how the monitoring well network performs for different timelines. But the objective is still clear, to assess the monitoring network by combining the predicted concentrations produced from the historical variation in the ground-water flow field with the coverage of the existing monitoring wells.

4.20 Project Data Management and Printing

The project file containing all currently entered data can be saved by clicking on “<File, Save Project>” to bring up the Windows Save dialogue box. The project file can be saved under a new name by clicking on “<File, Save Project As..>” to bring up the Windows Save as dialogue box.

To delete a file, the user should go to the hard drive location where they created the project file and delete the project file name. For this case study, the user was asked to create the project files in C:\program files\owl\data\site1\ directory. The case study name suggested was site1.prj. If the user goes to this directory, they can select the site1.prj file and delete it from the hard drive.

Any of the basemap contour plots may be printed by choosing “<File, Print>” from the Menu Bar. The map window must be active to print, or an error message will appear. When “<Print>” is selected, a dialogue box will appear allowing the user to enter a map title to be printed on the bottom of the page. The maps are best to view when printed in color.



5.0 Glossary

adsorption process by which molecules collect on and adhere to the surface of an adsorbent solid because of chemical and/or physical forces

attenuation a lessening in concentration, degree, or mass

basemap an electronic map of a site, used in OWL for display of site data and results of OWL calculations

constant thickness aquifer aquifer thickness is assumed to be essentially uniform in the study area. For example, the aquifer should not be twenty feet thick at one point, and one foot thick at another point

coordinate system for use in OWL, a Cartesian coordinate system for describing the location of monitoring wells at the site. For example, the Universal Transverse Mercator (UTM) system, or the State Plane (state plane coordinate system (SPCS)) may be used by surveyors to describe locations. Alternatively, the OWL user may describe well locations in terms of an arbitrary Cartesian coordinate system based on a grid established on a site map

coefficient of determination (R^2) a statistic used in least squares regression to describe the goodness of fit of an assumed model to the observed data. The coefficient of determination is the square of the Pearson correlation coefficient. OWL calculates a coefficient of determination to describe the fit of a linear plane to ground-water elevation data. An R^2 close to one indicates that the linear surface model explains almost all of the variation in the ground-water level data. If the value of R^2 is 0.500, the assumption that the ground-water surface is a plane explains half the variation. As a general rule of thumb, elevation data sets that produce a value of R^2 that is less than 0.500 indicate that a linear plane is not an acceptable model for the ground-water elevation surface

diffusion process by which ionic and molecular species move from a region of higher concentration to a region of lower concentration

dispersion phenomenon by which a solute in flowing ground water mixes with uncontaminated water, becoming reduced in concentration. Dispersion is due both to differences in water velocity at the pore level and differences in the rate at which water moves through different strata. Also refers to statistical measures of how widely a set of data vary

dispersivity property that quantifies dispersion in a medium

Domenico solution a mathematical model used to simulate multidimensional transport of a decaying contaminant species. For use in OWL, the Domenico solution is modified to simulate two-dimensional transport. See Appendix A for a detailed description

first-order decay attenuation or degradation (i.e., of a dissolved contaminant) according to a first-order rate law; the rate of a first-order reaction depends on the concentration of the reactant. A chemical reaction in which an increase (or decrease) in reactant concentration results in a proportional increase (or decrease) in the rate of the reaction. The equation can be written as $dc/dt = -kc$, where c = contaminant concentration, and k is the rate constant

fully penetrating well well in which the screened length is equal to the saturated thickness of the aquifer

geological log a description of the underground features (depth, thickness, matrix, type of formations) found while drilling a well

ground-water divide site location, on either side of which ground water flows in opposing directions

half-life time required for a concentration or mass of contaminant to diminish by one-half

head (elevation head) elevation of the ground-water table above a specified point, usually a standard reference point such as mean sea level

homogeneous aquifer structure or composition of the aquifer matrix is uniform throughout the aquifer

hydraulic conductivity relative ability of soil, sediment, or rock to transmit water; a coefficient of proportionality describing the rate at which water can move through a permeable medium

hydraulic gradient the change in total hydraulic head divided by the change in distance in a given direction

hydraulic head sum of the elevation head, the pressure head, and the velocity head at a given point in an aquifer. Also referred to as the total head

hydrostratigraphic unit in which the geologic materials have similar hydrologic properties

isotropic aquifer the aquifer matrix has the same characteristics in all directions; e.g., the hydraulic conductivity is the same horizontally and vertically

ground-water head contours lines on a map representing equal ground-water elevations

ground-water flow field the direction of flow and elevation changes of ground-water across a site

line source a compact source of solute (i.e., contaminant) not elongated along the length of the ground-water plume

minimum distance function a calculation in OWL that determines the minimum distance from a grid point to the nearest monitoring well. Used to calculate the WOLF values

porosity the ratio of void volume to total volume of a rock or sediment

sorption movement of a substance from the dissolved phase to the solid phase, whether by adsorption, absorption, fixation or precipitation. Sorption may be reversible or irreversible

transmissive zones subsurface units where ground-water flow is constrained or bounded by lower hydraulic conductivity materials (i.e., geologic impediments to flow) or hydrologic barriers (e.g., hydraulic head boundaries). Transmissive zones may be bounded by components as obvious as the water table or units with low hydraulic conductivity, or by conditions as subtle as small differences in grain size, sorting, and packing of seemingly uniform sands

uncertainty reduction of confidence in a conclusion when more than one estimate is available for a variable

vadose zone zone between the ground surface and the water table

water-table aquifer an unconfined aquifer

Well Optimal Location Factor (WOLF) calculated factor used to help determine possible locations for new monitoring wells, and eliminate redundant wells. See Appendix A for a detailed description



6. References

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Appendix A. Field Case Study Site Characterization, Data Collection, and Evaluation for Application of OWL

The following material provides data for a Case Study/Tutorial to demonstrate application of OWL for analysis of site data. The material is designed to be used in conjunction with Section 4.0 Guided Tour and Field Case Study Tutorial of the main document, which explains how to input and analyze the Case Study/Tutorial data in OWL.

1. Appropriate Application of OWL Program

The OWL program is a simple screening program which is subject to numerous limitations on its use. It should only be applied to sites which possess the characteristics outlined below. The first step in using OWL requires gathering and analyzing site data to ensure that the site characteristics meet OWL requirements.

1.1. Required Site Characteristics

- a. The ground-water elevation data and site characteristics should indicate that the water table or piezometric surface of the aquifer of interest can be represented by a linear plane. The assumption of a linear hydraulic head surface means that flow in the aquifer is a consequence of a constant horizontal gradient and no vertical gradients are present.
- b. There should be good spatial coverage of monitoring wells screened in the aquifer of interest across the site. The locations of the source and wells should be known using a fixed coordinate system (see Appendix C for more details on the coordinate system). At least three widely-spaced wells (in a triangular configuration; i.e., not in a straight line) are required to define a linear plane reasonably well, but more wells improve the quality of OWL predictions.
- c. There should be several sets of measurements of ground-water elevations from the monitoring wells in the aquifer at different times. Routine ground-water elevation measurements on a monthly or quarterly basis are preferred. If free product such as LNAPL exists in the wells, its depth must be measured so that ground-water elevations may be corrected for its presence.
- d. The aquifer of interest should be homogeneous and isotropic, and be of constant thickness.
- e. There should be a single constant contaminant source which is well delineated, i.e., the three-dimensional extent of the source is known. All sampling points (e.g., monitoring wells) used in the OWL calculations should be outside the source area.

2. Data Collection and Evaluation Steps for a Field Case Study

The appropriateness of the application of the OWL program to a site is dependent on the site's ability to meet the criteria outlined in Section 1 above. The following is a step by step description of data collection using a field case study to teach the user to simultaneously evaluate the site and prepare the input data for the OWL program. This material is to be used in conjunction with Section 4.0 Guided Tour and Field Case Study Tutorial of the main document, which explains how to input and analyze the Case Study/Tutorial data in OWL.

2.1 Initial Data Collection for Site

- a. Collect all available site characterization data including:
 - 1) site history, well types and locations,
 - 2) well completion information, core or drilling logs,
 - 3) historical ground-water elevations,
 - 4) hydraulic conductivity measurements,
 - 5) well historical contaminant concentrations,
 - 6) historical source area contaminant concentrations,
 - 7) site basemaps, and
 - 8) site plume maps.

- b. At a minimum, the following information must be available to use the OWL program properly:
 - 1) well types/locations/completions,
 - 2) description of aquifer of interest based on core/drilling logs,
 - 3) aquifer hydraulic conductivity measurements,
 - 4) source area location, and
 - 5) routine measurements of ground-water elevations across the monitoring well network.

Field Case Study

The site of interest is an inactive gas station which previously dispensed regular leaded, unleaded plus and supreme grades of gasoline. The fuels were stored in four single-walled steel underground storage tanks which had been in place for 18 years. When the tanks were excavated, four soil samples at the excavation indicated total BTEX concentrations ranging from 8.37 to 266 mg/kg. Ground-water quality measurements in the source area of the excavation indicated total BTEX concentrations up to 81.4 mg/L. BTEX concentrations remain high. Measurements of total BTEX in the monitoring wells down gradient of the source area established the presence of a significant plume emanating from the tank field.

Based on these findings, further site characterization was undertaken, including installation of several monitoring wells in and around the plume area. Source area soil and ground-water contaminant concentrations were measured. Soil and sediment core samples were taken during construction of the monitoring wells to determine the subsurface geology and help delineate plume shape and position. The core data were used to construct fence diagrams to display the subsurface geology along the apparent centerline of the existing plume, and perpendicular to the centerline. Screened intervals of the wells were also shown on the fence diagrams. A hard copy basemap was drawn to show the contaminant source locations and the monitoring well locations. Contaminant concentration contour maps were prepared to depict plume location and shape. Slug tests were used to measure hydraulic conductivity of the contaminated aquifer in several locations to determine whether the aquifer was isotropic and to provide hydraulic conductivity measurements for use in OWL. Ground-water elevations were measured in the monitoring wells seven times over a five year period.

2.2. Prepare a Scaled Basemap of Site for OWL

- a. Prepare or obtain a scaled basemap of site with significant features, including location of source, monitoring wells, surface water, pumping wells, etc.
- b. The best way to prepare a basemap is to have a professional surveyor conduct a survey to determine well locations/elevations and other features such as buildings. A scaled basemap on which the surveyed coordinates of the well locations are known can then be prepared (see Appendix C for more details on the coordinate system).
- c. If a hard copy basemap exists, it can be scanned into electronic form and scaled by the OWL user based on the map scale bar, or on three points on the map whose location is known. OWL accepts basemaps in both raster (*.bmp) and vector format (*.dwg). Appendix C has information on basemap requirements.
- d. If possible, the mapping convention of north being coincident with the y-axis should be used for all basemaps.
- e. If the basemap indicates the presence of significant surface water bodies, pumping wells, or any other features which produce vertical gradients, the site may be inappropriate for OWL.

Field Case Study

For the field case study, a hard copy basemap with scale was available. This hard copy was scanned into electronic form (*.bmp). The basemap for the case study is shown in Figure 1 with distances defined in feet. As can be seen in the figure, there are no apparent features (surface water, pumping/injection wells) which would preclude one from using OWL on this site. There is also good spatial coverage of monitoring wells across the site.

2.3. Determine monitoring well locations based on map scale

- a. Use the scaled basemap to determine the (x, y) coordinates of each well location. Be sure to identify the units (ft, m) associated with the coordinate convention. The well coordinates may have been assigned using an origin and scale created by a mapping specialist, or they may have been assigned using a professional survey which may be in UTM, State Plane, or in other mapping convention coordinates. If a scaled basemap is only in hard copy form and no well locations are assigned, the user must use the scale bar on their map and determine the well locations by hand. It is only important that the same scale be used for all well locations (i.e., one cannot mix UTM with State Plane coordinate system).
- b. Enter the well locations into a spreadsheet program so they may be imported into the OWL program. The necessary data format is described in Appendix D.

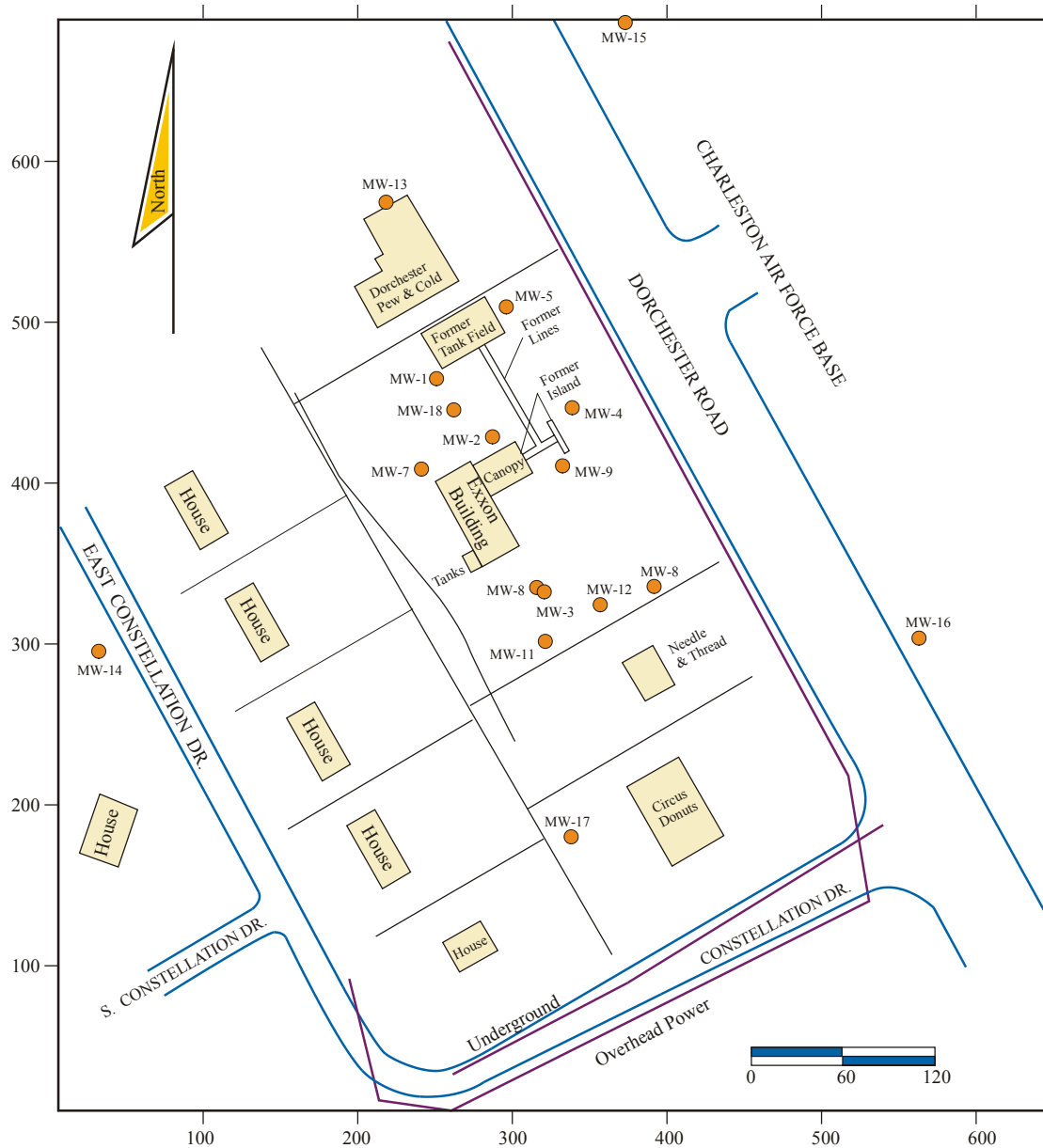


Figure 1. Site basemap.

Field Case Study

For the field case study site, the basemap shown in Figure 1 was only available in hard copy. It was possible to use the hard copy map scale and a ruler to determine the locations of the wells. For the case study, the well locations based on the assigned grid are shown in Table 1. The user then scanned the basemap into electronic *.bmp form, so it could be imported into OWL.

Table 1. Monitoring Well Locations in Feet Based on Site Basemap Grid

<i>Well</i>	<i>x (ft)</i>	<i>y (ft)</i>
MW-1	250.135	465.635
MW-2	285.44	428.26
MW-3	313.5	332.465
MW-4	338.57	450.11
MW-5	291.765	511.405
MW-6	392.62	334.65
MW-7	240.705	406.41
MW-8	321.21	331.80
MW-9	331.21	410.55
MW-11	319.825	302.335
MW-12	359.17	324.02
MW-18	261.52	444.82

2.4 Characterize the hydrogeology of the aquifer of interest

- a. Collect all core/drilling log information for the site. Also collect well completion information such as depths and screen locations.
- b. Prepare fence diagrams which show the subsurface geology defined at the monitoring wells and correlate the thickness of the formations between wells.
- c. Determine the thickness of the aquifer across the site from the fence diagrams.
- d. Identify the wells completed into the aquifer of interest. Do not use data from wells not completed into the aquifer of interest.
- e. Collect available hydraulic conductivity measurements on aquifer. Perform well testing and slug testing if no measurements are available.

Field Case Study

OWL assumes that the site aquifer can be represented as a single homogenous isotropic aquifer of constant thickness. In reality there are no such aquifers, but many aquifers come close to this definition. The best way to characterize an aquifer is to obtain drilling logs or cores which describe the subsurface geology. It is then possible to draw fence diagrams which represent this geology and assess the aquifer lithology and thickness. In addition, it is essential to have completion reports on every well to determine which monitoring wells are screened in the aquifer of interest.

For the field case study, Figures 2 and 3 display site fence diagrams which were used to determine the location and thickness of the aquifer at each available monitoring well. These figures clearly demonstrate the presence of a sandy confined aquifer which is overlain and underlain by clay confining units. Although fence diagrams indicate that the aquifer is not defined as purely homogeneous, it appears to be sufficiently similar to warrant that assumption.

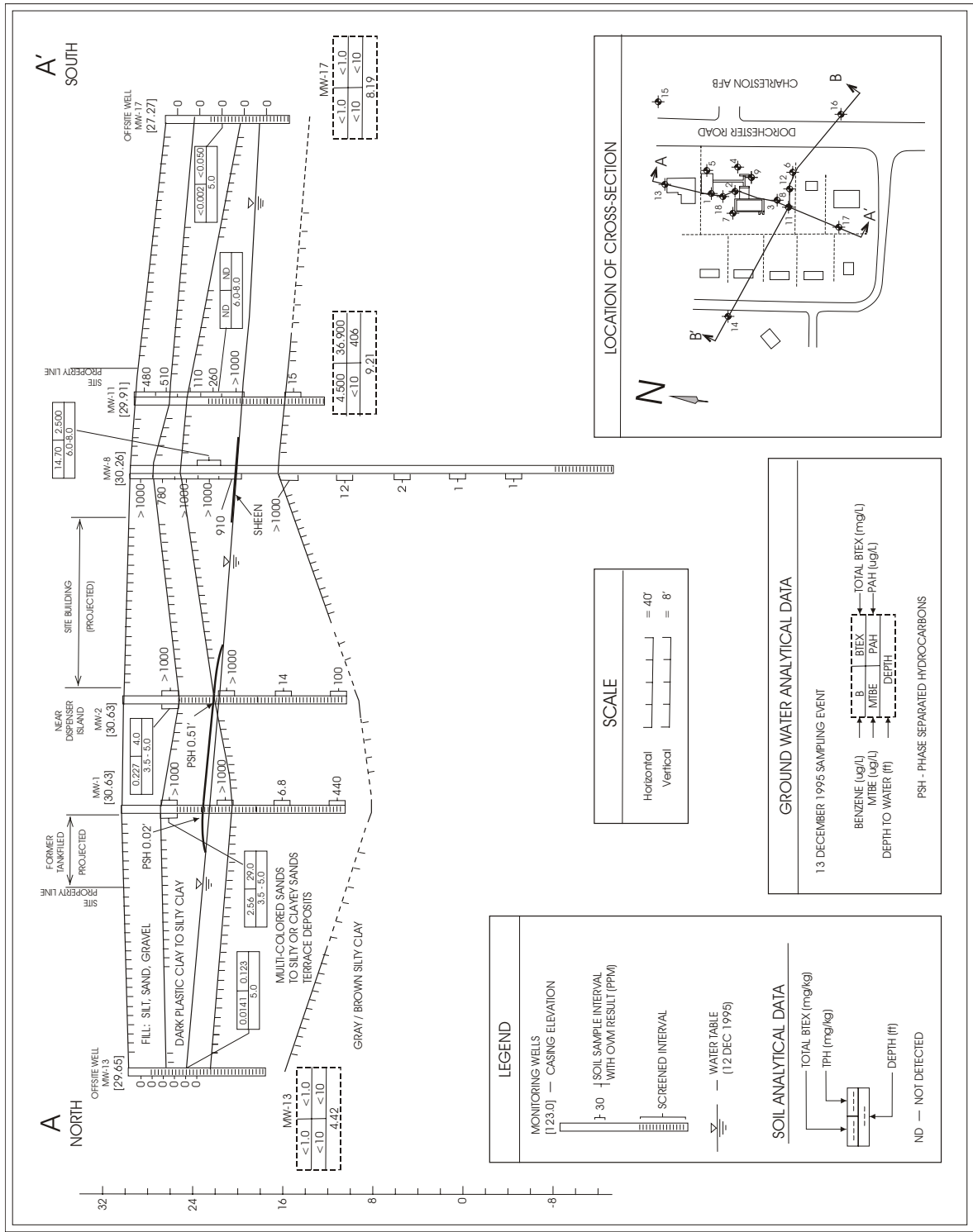


Figure 2. Cross Section A-A' for the field case study site demonstrating subsurface geology as defined by monitoring wells.

Figures 2 and 3 also display the thickness of the aquifer across the site. One can measure this thickness to determine if it remains essentially constant. Table 2 shows the thickness of the aquifer at each monitoring well. Although not constant, the thickness ranges between 6-11 feet which is a small variation for this problem.

Finally, the fence diagrams show that MW-8 and MW-12 are not completed in the aquifer of interest. These wells should therefore be dropped from the list of wells to be used to perform the regression to compute the linear hydraulic head surface for the aquifer since they do not measure the head in the aquifer of interest.

Table 2. Range of Aquifer Thickness at Field Case Study Site

<i>Well</i>	<i>Elevation of Bottom Dark Plastic Clay (msl)</i>	<i>Elevation of Gray Brown Silty Clay Bottom (msl)</i>	<i>Aquifer Thickness (ft)</i>
MW-1	20	9	11
MW-2	21	10	11
MW-6	23	16	7
MW-8	25	17	8
MW-11	23	16	7
MW-12	23	16	7
MW-13	22	16	6
MW-14	22	15	7
MW-16	23	14	9
MW-17	20	14	6

Several measurements of hydraulic conductivity were made for the field case study site. Rising head slug tests were performed on three monitoring wells (MW-6, MW-9, and MW-11) which were all completed into the aquifer of interest. The hydraulic conductivities measured at these wells were 2.21 ft/day, 0.77 ft/day, and 1.66 ft/day, respectively. The geometric mean of these conductivities is 1.41 ft/day (514 ft/yr) which can be used in the OWL program. An effective porosity of 0.45 was used based on literature values for the subsurface matrix present at the site.

2.5 Collect and correct all ground-water elevation measurements for the wells

- a. Collect all ground-water elevation measurement data for the monitoring wells. OWL requires that ground-water elevation data from the monitoring well network be collected over a sufficient time period to capture any variation in the ground-water flow field. The best data will be taken on a routine schedule, either monthly or quarterly.
- b. Adjust all ground-water elevation measurements to mean sea level (msl) and correct for free product. All data must be in converted to msl before it is used in the program to insure it is all referenced to the same constant datum. Site data may record ground-water elevations as feet below ground surface, or below the top of the well casing (TOC). Such data must be converted to msl as indicated in the equations below. The conversion of ground-water elevation data to msl depends on whether free product such as LNAPL is present in the well

(see below for method to correct for free product). See Figure 4 for a typical well diagram showing top of casing (TOC), ground surface, free product depth, ground water depth, and well screen location.

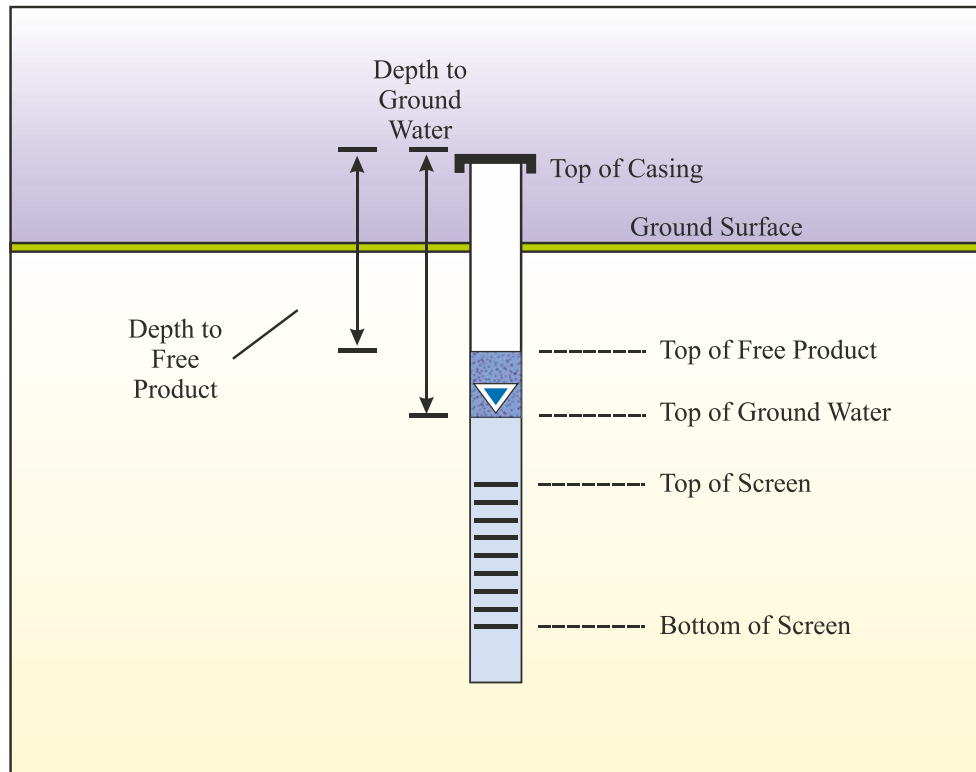


Figure 4. Well completion and fluid level definitions.

- c. Enter the ground-water elevation measurements into a spreadsheet for entry into the OWL program. The format shown in Appendix D must be used.
- d. If a ground-water elevation measurement is missing at a well for a particular date, enter a null value of -9999 for that data.

Field Case Study

For the field case study there were eight separate dates when ground-water elevation measurements were taken from 10 wells. Unfortunately, the measurement dates were not on a quarterly or monthly basis, but they did cover five years and two seasons. For this reason they were considered to be marginally representative of the seasonal variation in the ground-water flow field. Future measurements at the site should be taken at least quarterly, and the sampling dates placed at times representative of seasonal variation.

The ground-water elevation measurements were taken as feet below ground surface (bgs). Several of the wells also had free product present, and the thicknesses of the free product had been measured. It was therefore necessary to correct all the ground-water elevations to a consistent datum of msl and also for free product. The corrections may be made as follows:

Free product in the wells indicates that the wells are in the source area. In such cases the OWL assumption that the source is a line should be carefully examined to see if the OWL program is really a valid application for the site.

1. No Free Product Present

If no free product is present and the ground-water elevation is measured as below ground surface (bgs), it is necessary to have the top of the casing (TOC) in msl to determine the ground-water elevation as follows:

$$TOC (msl) - GW \text{ elevation (bgs)} = GW \text{ elevation (msl)}$$

For the example site, MW-1 with a TOC of 30.63 ft msl, displayed a ground-water elevation reading of 6.67 ft bgs on Jan 25, 1994. No free product was present in the well. Therefore the ground-water elevation in msl at MW-1 on that date was:

$$30.63 \text{ ft msl} - 6.67 \text{ ft bgs} = 23.96 \text{ ft msl}$$

2. Free Product Present

If free product such as LNAPL is present in the well, it is necessary to convert the thickness of the free product to an equivalent water thickness to determine the corrected ground-water elevation in msl. This is accomplished using the following equation:

$$\text{Corrected GW Elevation (msl)} = \text{GW Elevation (msl)} + (\text{LNAPL specific gravity}) * (\text{thickness of free product})$$

For the case study site, monitoring well MW-2 with a TOC of 30.63 ft displayed a depth to ground water of 9.01 feet and a depth to free product of 8.50 ft on Dec 12, 1995. The thickness of the free product is therefore:

$$\text{Free Product Thickness} = 9.01 \text{ ft} - 8.50 \text{ ft} = 0.51 \text{ ft}$$

The ground-water elevation in msl is :

$$30.63 \text{ ft (msl)} - 9.01 \text{ ft (bgs)} = 21.62 \text{ ft msl}$$

If the specific gravity of the free product (density of fluid/density of water)= 0.8, the corrected ground-water elevation is:

$$\text{Corrected GW Elevation (msl)} = 21.62 \text{ ft msl} + 0.8 (0.51 \text{ ft FP}) = 22.03 \text{ ft}$$

All wells which demonstrate free product thickness must have their ground-water elevations corrected in this manner before their data may be used in the OWL program.

Once all the ground-water elevations for the case study are corrected for any free product and converted to mean sea level, they should be entered in a spreadsheet like that shown in Table 3 for the example site data (see Appendix D for the specific format). A null value of -9999 should be substituted for any missing values. This null value is used as a flag in the program. The spreadsheet can then be imported into OWL or the data may be hand entered into the OWL program spreadsheet.

Table 3. Site Monitoring Well Locations and Corrected Ground-Water Level Measurements (msl)

<i>Well</i>	<i>x(ft)</i>	<i>y(ft)</i>	<i>1/25/94 Head (ft)</i>	<i>12/12/95 Head (ft)</i>	<i>10/30/98 Head (ft)</i>	<i>12/4/98 Head (ft)</i>	<i>12/21/98 Head (ft)</i>	<i>1/11/99 Head (ft)</i>	<i>3/29/99 Head (ft)</i>
MW-1	250.135	465.635	23.96	22.94	23.43	22.39	23.64	22.67	20.35
MW-2	285.44	428.26	23.00	22.03	22.22	21.55	-9999.00	-9999.00	-9999.00
MW-3	313.5	332.465	21.97	21.01	21.25	20.53	21.43	18.78	17.73
MW-4	338.57	450.11	22.39	21.82	22.14	21.49	22.39	20.77	19.77
MW-5	291.765	511.405	23.76	22.90	23.57	22.57	24.55	23.50	20.17
MW-6	392.62	334.65	21.14	20.64	20.86	20.14	21.98	19.24	17.23
MW-7	240.705	406.41	23.52	22.19	22.55	21.49	22.60	20.64	20.15
MW-9	331.21	410.55	22.13	21.49	21.81	20.88	22.26	19.92	18.36
MW-11	319.825	302.335	21.81	20.70	20.96	20.16	18.63	16.46	15.91
MW-18	261.52	444.82	23.51	22.48	22.94	21.93	-9999.00	-9999.00	-9999.00

The OWL program assumes that the hydraulic head in the aquifer can be represented by a linear surface. If pumping/injection wells, ground-water divides or significant surface water features are present, the ground-water surface probably will not meet the linear surface assumption. The user should examine the ground-water elevation data to determine if there are any obvious deviations from a plane surface. If there are wells where the ground-water elevations are significantly lower or higher than the surrounding wells it can indicate the surface is not linear. Such deviations can violate program assumption, making OWL inappropriate to use. However, it may not be possible to be certain whether the linear surface assumption is appropriate merely by examining ground-water elevation data. For instance, hidden features such as leaking water mains with ground-water mounds are not readily determined from ground-water elevation data. To be certain that the linear surface assumption is appropriate, the user should run the linear regression in the OWL program to determine how well the linear surface fits the data. An R^2 value of 0.90 or higher is considered good (see the *Introduction Section 1.2.1*). For the Case Study/Tutorial data, it was clear that the data did not display any unusual ground-water elevation highs or lows.

2.6 Collect data on contaminant source location and contaminant transport properties

- a. Delineate the contaminant source location using site characterization data to establish if it can be represented as a single source. Estimate source width and the maximum time the contaminant source was present.

-
- b. Estimate transport properties of aquifer using existing plume to establish dispersion. A rule of thumb for a screening model is

$$\begin{array}{lcl} \text{longitudinal dispersivity} & = & 10\% \text{ of plume length and} \\ \text{transverse dispersivity} & = & 10\% \text{ of longitudinal dispersivity.} \end{array}$$

- c. Estimate fate parameters for adsorption and decay rate information if desired.

Field Case Study

For the field case study there were numerous measurements of contaminant concentrations in the ground-water and soil/ground-water contamination in the source area. Figure 5 shows the benzene plume contours and delineated source area on the site basemap for December 1995. From the figure, it is clear that the source of contamination is limited to the area where the fuel tanks were located. If one looks at the ground-water concentrations in wells in the source area they are consistent over time which supports the OWL model assumption of a continuous source. The width of the source was estimated to be about 30 feet using a ruler on the scaled basemap. The tanks were installed in 1970. Although it is impossible to know when the tanks may have begun leaking, the most conservative estimate of leakage duration would be 31 years (installation date of the tanks). The length of the plume is about 300 ft so the estimated longitudinal dispersivity is 30 ft and the estimated transverse dispersivity is 3 ft. For the case study and most other studies, fate parameters such as adsorption and decay are unknown. Therefore a retardation factor of one (no adsorption) was chosen and the decay rate was set to zero (no decay); these choices provide conservative estimates of plume extent in OWL. The user should always check the effects of using different parameter values in OWL to determine the effect of changes in the parameters on the OWL model results. In particular, the user should input a range of values of hydraulic conductivity (k) to determine the sensitivity to k , because site values of k is likely to vary more than any of the other site parameters used in the model. Using a range of values for k will cause the model to calculate different plume lengths. In addition, the user may vary the simulation times in OWL to determine how they impact the plume length. The plume will achieve steady state depending on the different parameter and time values used. Knowledge of potential variability of plume lengths should help the user assess the impact of program results on site decisions.

3. Run the OWL Program

Once the data have been collected, corrected and checked to see if they meet the requirements of the program limitations, it is possible to run the OWL Program. Please proceed to 4.0 *Guided Tour and Field Case Study Tutorial* of the user's manual to see how to enter the data for the field case study, execute the program and view the results.



Appendix B. Program Algorithms

The algorithms used in OWL are best described using the schematic illustration in Figure 1. The input to the program includes ground-water level data for several sample dates. Linear regression is used to fit a planar ground-water surface for each sample set. Based on these surfaces, ground-water elevations are interpolated on the nodes of a virtual uniformly-spaced grid. Scalar data for contaminant transport simulation (for defining the flow field, dispersivity terms, decay terms, source location, etc.) are supplied by the user. The Domenico analytical solution is then used to perform contaminant transport simulation for each set of data (Domenico, 1987). Concentration values are calculated at each of the grid nodes based on the analytical solution. An average concentration matrix is then calculated for each grid node, from the concentration values of that node for all sample dates. For each grid node, distance to the nearest ground-water well is determined. By multiplying a square of this minimum distance with the average concentration for the node, a Well-Optimal Location Factor (WOLF) is calculated for each node. Each algorithm is described in the following.

1. Linear Regression Algorithm

OWL uses least squares linear regression to fit the following function describing a planar ground-water surface to each set of ground-water level data:

$$z = Ax + By + C \quad (1)$$

where	z	regressed ground-water level at the node location (x,y)
	x	x coordinate of the node (x,y)
	y	y coordinate of the node (x,y)
	A	Regression coefficient for x direction
	B	Regression coefficient for y direction
	C	Regression constant

Once the coefficients for the best fit plane for each set of observations on a particular date are determined, OWL uses equation 1 to predict the ground-water elevation, z , for any location (x, y) and plots linear contours of these elevations on the basemap for the given observation date. OWL calculates the magnitude of the ground-water gradient, dz/ds , from the slope of this plane:

$$\left(\frac{dz}{ds}\right)^2 = \left(\frac{dz}{dy}\right)^2 + \left(\frac{dz}{dx}\right)^2 \quad (2)$$

If the y coordinate axis is coincident with north as required by the program, OWL provides the ground-water flow direction, θ , in degrees from north as:

$$\theta = \arctan\left(\frac{dz}{dx} / \frac{dz}{dy}\right) \quad (3)$$

The least squares linear regression in OWL uses observations of ground-water levels from each available sampling date to determine the best-fitting plane representing the ground-water surface. For a particular date, the ground-water elevations are assumed to fit the following linear equations:

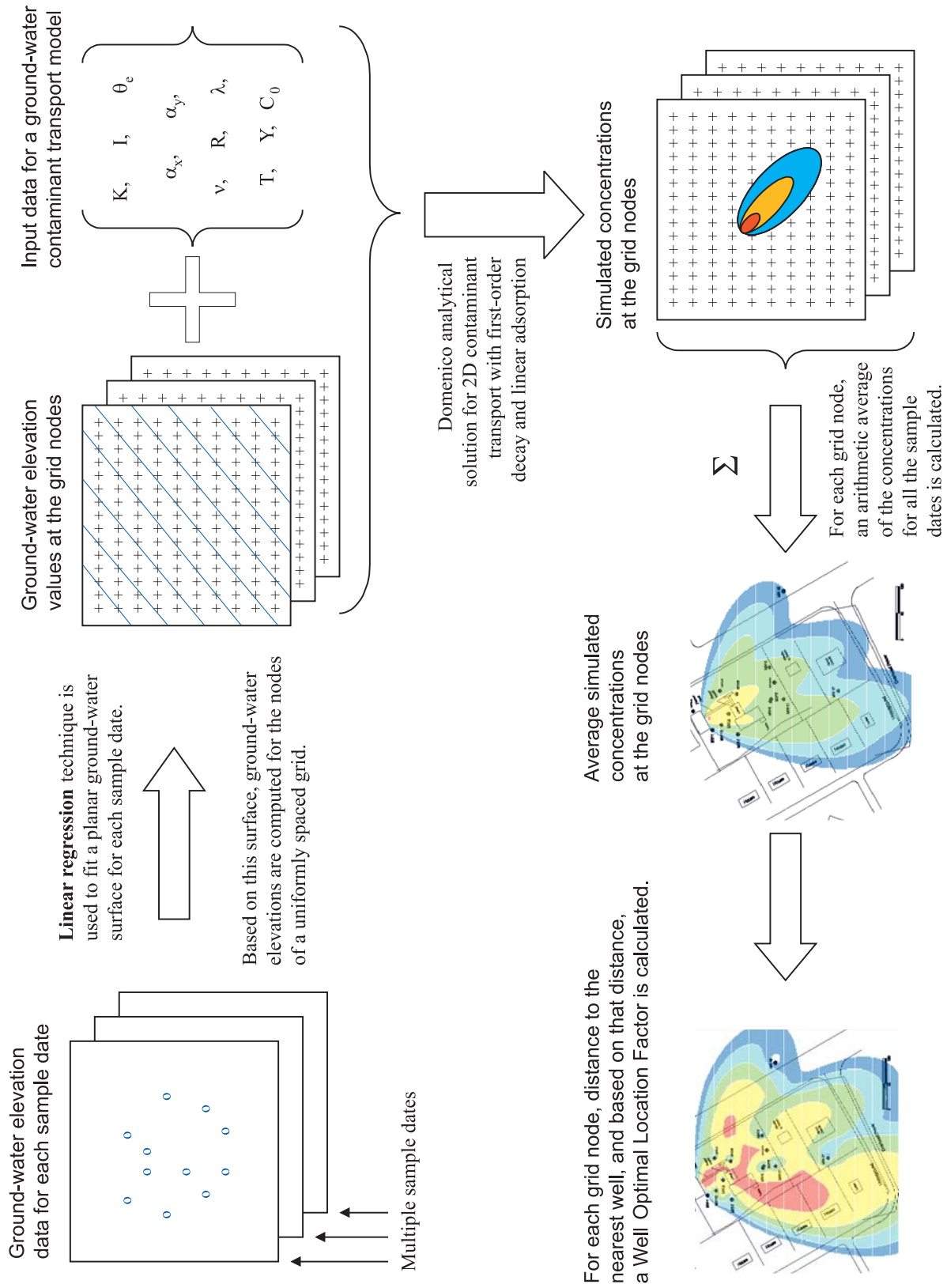


Figure 1. Schematic representation of OWL program logic.

$$\begin{aligned}
MW1: \quad z_1 &= C_1 + Ax_1 + By_1 + e_1 \\
MW2: \quad z_2 &= C_2 + Ax_2 + By_2 + e_2 \\
&\dots \\
MW_i: \quad z_i &= C_i + Ax_i + By_i + e_i \\
&\dots \\
MW_n: \quad z_n &= C_n + Ax_n + By_n + e_n
\end{aligned} \tag{4}$$

where the residual errors, $e_1, e_2, \dots, e_i, \dots, e_n$ are assumed to be independent and normally distributed with zero mean and constant variance. In least squares regression, the strategy is to solve for the coefficients, $A, B,$ and $C,$ by minimizing the sum of the square of the residual errors, $S_r,$ for all of the available data:

$$S_r = \sum_{i=1}^n e_i^2 = \sum_{i=1}^n (z_i - Ax_i - By_i - C)^2 \tag{5}$$

Because the approach is to minimize the sum of the squares, it is called least squares fitting. Minimizing S_r will produce the best-fit plane for the given set of observations $(x_i, y_i, z_i),$ by minimizing the distance from each ground-water level observation to the regressed plane.

There are many different solution algorithms which may be used to determine a set of coefficients, $A, B,$ and C which will minimize the sum of the squares, $S_r.$ Most solutions are based on a system known as the normal equations. First, the sum of the squares of the residuals is differentiated with respect to each of the unknown coefficients:

$$\begin{aligned}
\frac{\partial S_r}{\partial C} &= -2 \sum (z_i - C - Ax_i - By_i) \\
\frac{\partial S_r}{\partial A} &= -2 \sum x_i (z_i - C - Ax_i - By_i) \\
\frac{\partial S_r}{\partial B} &= -2 \sum y_i (z_i - C - Ax_i - By_i)
\end{aligned} \tag{6}$$

These partial derivatives are set to zero to give a system of simultaneous linear equations which when solved produce the coefficients that minimize the sum of the residuals, $S_r:$

$$\begin{aligned}
nC + \sum x_i A + \sum y_i B &= \sum z_i \\
\sum x_i C + \sum x_i^2 A + \sum x_i y_i B &= \sum x_i z_i \\
\sum y_i C + \sum x_i y_i A + \sum y_i^2 B &= \sum y_i z_i
\end{aligned} \tag{7}$$

These equations may be written in matrix form as:

$$\begin{bmatrix} C \\ A \\ B \end{bmatrix} = \begin{bmatrix} n & \sum x_i & \sum y_i \\ \sum x_i & \sum x_i^2 & \sum x_i y_i \\ \sum y_i & \sum x_i y_i & \sum y_i^2 \end{bmatrix}^{-1} \begin{bmatrix} \sum z_i \\ \sum x_i z_i \\ \sum y_i z_i \end{bmatrix} \quad (8)$$

where the $[\]^{-1}$ denotes the inverse of the matrix. When the inverse exists, the matrices may be solved and the solution is unique. If the inverse does not exist, an infinite number of solutions exist.

Unfortunately, the above normal equation approach may fail when it is applied to the least squares problem of fitting a plane to ground-water elevation data. This is because the well locations are often in UTM or State Plane coordinates which may be quite large (more than six digits) and only vary by the last two digits. In addition, water level elevations from well to well may only change by small fractions. This produces a set of observations which appear very similar numerically. As the least squares systems of equations are formulated for such ground-water elevation data, it is apparent that the modeling functions appear to be linearly dependent. Linearly dependent equations produce a singular coefficient matrix which leads to a solution to the system of equations that is not unique. Kahaner et al. (1989) noted that the normal equation solution to the general least squares problem is not the best approach since it performs poorly with overdetermined, underdetermined, and singular systems. Instead, they suggested a method of matrix factorizations known as orthogonal matrices to solve singular systems like those produced from attempting to fit a plane to ground-water elevation data. It is this least squares solution method which is used in OWL. A description of the orthogonal factorization solution to the least squares problem is beyond the scope of this document and the reader is referred to Kahaner et al. (1989) for a complete discussion.

The OWL program provides a coefficient of determination, R^2 , to judge the goodness of fit of a linear plane to fit ground-water elevation data. The equation for R^2 is:

$$R^2 = \frac{S_t - S_r}{S_t} \quad (9)$$

where S_t is given by:

$$S_t = (z_i - \bar{z})^2 \quad (10)$$

The value of R^2 from the regression results compares the amount of variation of ground-water elevation in wells one from another to the amount of variation of elevation in wells from the plane fit through all the elevation data by the regression equation. When there is perfect match between the measured elevations and the elevation of the plane, then the assumption that the ground-water surface is a plane explains all the variation between the individual wells and the value of R^2 is 1.000. If the value of R^2 is 0.5000, the assumption that the ground-water surface is a plane explains half the variation in elevation between wells. If the value of R^2 is less than 0.5000, the assumption that the ground-water surface is a plane explains less than half the variation. As a general rule of thumb, elevation data sets that produce a value of R^2 that is less than 0.5000 are not appropriate for use in OWL.

It should be noted by the user that the coefficient of determination, R^2 , provided by OWL is not an adjusted R^2 . It does not account for sample size (number of wells and observations) and should not be used to compare the fit of the data between different sampling dates. It can only be used as a measure of goodness of fit of the plane model to the observations for the sample set from which it was calculated.

The least squares linear regression program code for OWL was written in FORTRAN. It calls the SQRLS subroutine of Nash (1987). SQRLS solves an overdetermined, underdetermined, or singular system of linear equations in a least square sense using an orthogonal factorization solution. SQRLS contains the Linpack Subroutine SQRDC. This code was substantially modified by the authors to address the specific problem of fitting a plane to ground-water elevation data posed by OWL. The performance of this algorithm was verified using the linear regression package available in Mathematica.

2. Analytical Transport Solution

The Domenico analytical solution for 1D contaminant transport is used in OWL (Domenico, 1987). This solution is used to simulate the multidimensional transport of a decaying contaminant species. For the purpose of OWL, the Domenico solution is adapted to a two-dimensional transport. In this solution, the concentration at a distance x downstream of the source and distance y off centerline of plume at time t is specified as

$$C(x, y, t) = \frac{C_0}{4} \exp \left[\frac{x}{\alpha_x \cdot 2} \left(1 - \sqrt{1 + \frac{4\lambda\alpha_x}{v}} \right) \right] \operatorname{erfc} \left[\frac{\left(x - v \cdot t \sqrt{1 + \frac{4\lambda\alpha_x}{v}} \right)}{2\sqrt{\alpha_x vt}} \right] \left[\operatorname{erf} \left\{ \frac{y + \frac{Y}{2}}{2\sqrt{\alpha_y \cdot x}} \right\} - \operatorname{erf} \left\{ \frac{y - \frac{Y}{2}}{2\sqrt{\alpha_y \cdot x}} \right\} \right] \quad (11)$$

where
$$v = \frac{K \cdot i}{\theta_e \cdot R} \quad (12)$$

Definition of the terms:

$C(x, y, t)$	Concentration at a distance x downstream of the source and distance y off centerline of plume at time t (Concentration units)
C_0	Concentration in the source zone at time $t = 0$. (Concentration units)
Y	Line source width (L)
x	Distance downgradient of source (L)
y	Transverse distance from the plume centerline (L)
t	Simulation time (T)
α_x	Longitudinal ground-water dispersivity (L/T)
α_y	Transverse ground-water dispersivity (L/T)
λ	First-order degradation rate (1/T)

v	Ground-water [retarded] seepage velocity
K	Horizontal hydraulic conductivity (L/T)
i	Hydraulic gradient (L/L)
θ	Effective soil porosity
R	Constituent linear retardation factor

The equation is similar to the Domenico analytical model used in the Bioscreen (U.S. EPA, 1996) program, except the equation has been reduced to two dimensions. For further discussions of the applicability of the solution and assumptions, the reader is referred to the Bioscreen User's Manual (U.S. EPA, 1996). The Domenico analytical solution in OWL was programmed in Visual Basic. It was verified using MATHCAD.

In OWL, the user should note that the (x,y) values used in the Domenico solution represent the distance traveled down the centerline of the plume and transverse to this centerline, respectively. They are therefore along the direction of ground-water flow and transverse to it. This is standard notation for the Domenico solution which was maintained for consistency with the reference. As the ground-water flow field magnitude and direction changes for the regressed ground -water surface plane produced from each set of ground-water level observations, OWL automatically rotates the line source to be perpendicular to the direction of flow and maintains a constant source width Y. This ensures that the Domenico solution uses the same source but produces a plume which is unique to each ground-water flow field.

The following assumptions are inherent to the application of the Domenico analytical solution:

- The aquifer and flow field are assumed to be homogeneous and isotropic.
- Adsorption is assumed to be a reversible process simulated by linear equilibrium isotherm.
- The ground-water flow field is assumed to be uniform and one-dimensional.
- The ground-water velocity is fast enough that molecular diffusion in the dispersion terms can be ignored. This may not be appropriate for transport through clays.
- It is assumed that the degradation can be effectively simulated using first-order degradation (by specifying a half-life value).
- A line source of specified width extending perpendicular to the flow direction is assumed. The source is also fully mixed in the vertical direction.
- The orientation of the "line" in the line source is assumed to be based on the ground-water flow direction, and not any other physical extent or shape.

3. Average Concentration Plume Algorithm

For each grid node, an arithmetic average of the concentration values for all the sample dates is calculated as shown below.

$$C_{avg}(i,j) = \frac{1}{n} \sum_t C(i,j,t) \quad (13)$$

where:

$C(i,j,t)$	Concentration value for node (i,j) at time t
n	Number of sample dates
$C_{avg}(i,j)$	Average concentration value for node (i,j)

The average plume concentration algorithm for OWL was programmed in Visual Basic. Its performance was verified by spreadsheet.

The following assumptions are inherent to the application of the average plume concentration calculation:

- Ground-water flow field interpreted from each sample date is given equal weight to that from any other sample date. For example, if three sample dates fall within one year, followed by a sample date 2 years later, taking a simple arithmetic average may not be the best approach.
- Contaminant transport based on the flow field set by each sample set, is assumed to take place independently of the transport based on other sample sets. This is in contrast with a typical numerical transport model where the effects of varying ground-water field are sequentially applied.
- The arithmetic average technique works best when the concentrations from different sample sets do not vary significantly from each other. If the concentrations vary by orders of magnitude, a geometric average may be better.
- The average concentrations should not be used as predicted concentrations for design purposes.

4. Well Optimal Location Factor (WOLF) Algorithm

The Well Optimal Location Factor (WOLF) is calculated for each node of the grid using the function

$$WOLF(i, j) = D_{\min}(i, j)^2 \cdot C_{\text{avg}}(i, j) \quad (14)$$

where:

$D_{\min}(i, j)$	Distance from node (i,j) to the nearest monitoring well
$C_{\text{avg}}(i, j)$	Average concentration value for node (i,j)
$WOLF(i, j)$	WOLF factor value for node (i,j)

Nodes with a higher value of the WOLF value as compared to neighboring nodes, denote a likelihood of a significant plume concentration where there are no nearby monitoring wells. The relative WOLF values can therefore be used to select optimal locations to place new monitoring wells. Note that this approach is designed to be used as an initial screen tool for locating wells.

The following assumptions are inherent to the calculation of the Well Optimal Location Factor:

- The application of relative WOLF values to place new monitoring wells is based on numerous assumptions and is a simple initial tool for locating wells.
- Several other factors such as geology, uncertainty of the source extent, etc. should be evaluated to assess the usefulness of the WOLF.

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Appendix C. Site BaseMap Formats and Scaling

The Optimal Well Locator (OWL) can import a digitized site map (the “basemap”). OWL can import a scanned or electronically generated image of a site map and display the map in the background of the Map View window, for use in overlaying other data such as well locations and plume contours.

The following image types are recommended for use in OWL:

- 1) Raster maps (such as an aerial photo or scanned image): Use Windows or OS/2 Bitmap *.bmp format. OWL does not accept the *.jpg format.
- 2) Vector maps (CAD files): Use AutoCAD Version 12 or 14 DWG format.

OWL may also accept the following raster and vector formats. However, use these optional formats with caution, as there are strict limitations (compression type, monochrome, etc.) with each of the formats below:

Raster formats:

.RLE: Windows Bitmap Compressed (.RLE); (not CompuServe .RLE)

.RLC: Files RLC (.RLC) in two colors

.TIF: Files TIFF (.TIF) OWL may accept monochromatic non-compressed, PackBits compressed, or Group 3 Modified Huffman compressed, but not LZW compressed.

Vector formats:

.DXF files

ESRI ShapeFiles (.SHP)

.WMF files (Windows MetaFile)

AutoCAD DWG formats are recommended for vector-formatted OWL basemaps. Typically a vector-format basemap has several types of objects (text labels, lines, polygons, arcs, etc.), but an ESRI Shapefile can store only one type of graphic object. Because OWL can only import one Shape file, the Shape file format is not recommended for use as an OWL basemap. Instead, Shape files may be imported into AutoCAD and saved as a single DWG or DXF file.

The basemap should be to scale, and should show significant site features, including location of contaminant source, monitoring wells, surface water, pumping wells, etc. At most sites the well locations have been determined by survey, so the coordinates are available in UTM, State Plane, or similar coordinate system. If not, a professional surveyor should conduct a site survey to determine well locations/elevations and other features such as buildings. A scaled basemap on which the exact coordinates of the well locations are known can then be prepared. If possible, the mapping convention of north being coincident with the y-axis should be used for all basemaps.

Map Calibration

Many site maps already have Cartesian coordinate systems (XY coordinates such as northings and eastings) associated with the map, either printed on the sides of a paper map, or stored in the file with the electronic map. The XY location values for known points on the map can be used for the real coordinates in the Set Map Scale dialogue box in OWL. If the site map does not have a pre-existing XY coordinate system, the user can make up their own coordinate system assigning an origin (a 0, 0 point) to a location on the site (perhaps at the lower left-hand corner of the site paper map) and laying out an XY coordinate system along the sides of the map. Then the user can locate known points on the site map (e.g., monitoring wells, buildings, benchmarks) and determine the XY coordinates of these points in relation to the origin point for use as the real coordinates in OWL.

Calibration Using Two Known Points

When choosing two points on the basemap to calibrate the map in OWL, the user should choose two points as far from each other as possible, and located on a diagonal to the XY coordinate system. If the two points are close together, the error in calibrating distance can be very large. If the two points are along the same coordinate line (e.g., both points on a line parallel to the X axis), OWL will not be able to calibrate to distances along the other axis.

Click on the checkbox beside “<Map scale>” in the Project Steps window. A dialogue box will appear, allowing the user to set the map scale. There are two methods to set the map scale (two calibration points or a scale bar); the default choice is using two calibration points.

Click “<Locate point 1>.” The dialogue box will be hidden behind the Map Window (the user can make the dialogue box reappear if desired by clicking on Window on the Menu Bar, and choosing Set Map Scale in the dropdown menu). To fill in the X and Y Image Coordinates for Point 1 in the Set Map Scale dialogue box, click on a known point on the basemap (*i.e.*, a point with known real coordinates), preferably one near a corner of the basemap. (Alternatively, the user can enter the coordinates under the X and Y Image Coordinates in the Set Map Scale dialogue box.) The Set Map Scale dialogue will reappear. Enter the site coordinates corresponding to the image coordinates just chosen or entered, into the Real Coordinates X and Y locations in the dialogue box.

Click “<Locate point 2>.” The dialogue box will be hidden behind the Map Window (the user can make the dialogue box reappear if desired by clicking on Window on the Menu Bar, and choosing Set Map Scale in the dropdown menu). To fill in the X and Y Image Coordinates for Point 2 in the Set Map Scale dialogue box, click on a known point on the basemap (*i.e.*, a point with known real coordinates), preferably one near a corner of the basemap diagonally opposite to Point 1. (Alternatively, the user can enter the coordinates under the X and Y Image Coordinates in the Set Map Scale dialogue box.) The Set Map Scale dialogue will reappear. Enter the site coordinates corresponding to the image coordinates just chosen or entered, into the Real Coordinates X and Y locations in the dialogue box.

Click “<Calibrate Map to Real Coordinates>,” and click “<OK>” to continue. The X-Y coordinate numbers shown at the bottom left of the Map Window are now calibrated to the actual site coordinates, rather than the image coordinates.

Calibration using a scale bar

The basemap may also be calibrated by clicking on opposite ends of an object such as a scale bar on the basemap and specifying the distance between the points. This method of calibration may be much less accurate than using two calibration points as in the preceding method.

Identify a scale bar on the raster map and specify another point on the map as the origin of the X,Y coordinate system. Click on the “<Locate origin>” button to specify the map origin. Now zoom in to a section of the map where the map origin is to be placed, and click on the center of the origin.

Next, zoom in to a section of the map where the scale bar is displayed. Identify two scale markings and enter the distance between these two points. For example if the scale bar markings are at 0, 200, 400 ft, the marking for 0 ft and 400 ft may be selected.

On the dialog box, click on “<Locate point 1>,” and locate a marking point on the scale bar and click on it. Then click on “<Locate point 2>,” and locate the other marking point on the scale bar and click on it. The two points of a scale bar usually fall on a line parallel to the X axis; this is acceptable.

Enter the requested distance data as shown below:

Enter the distance between the points:

Type the distance between the points 1 and 2 in real map coordinates. Enter the values in the distance units requested on the dialog box.

Calculated scale 100 pixels =:

After entering the distance value, the calculated scale will be displayed in this field.

Once the map origin, the two scale bar points, and the distance between them are entered, check the “<Calibrate map to real coordinates>” check box. The map is now calibrated. The status bar of the user interface should now read “Raster map calibrated. Coordinates = ft.” Press “<OK>” to close the dialog.



Appendix D. Spreadsheet Formats for OWL Data Files

OWL supports import of well location and ground-water elevation data from common spreadsheet software file formats, including Excel 4.0, Excel 5.0, Excel 97, Excel 2000, Excel 2002, Lotus WK3, and Lotus WK4. The data must be in a specific layout format in the spreadsheet, as described below.

Spreadsheet Format for Well Location Data

The spreadsheet format for the well location data is shown below.

	A	B	C
1	WELLID	X	Y
2	MW-1	250.135	465.635
3	MW-2	285.44	428.26
4	MW-3	313.5	332.465
5	MW-4	338.57	450.11
6	MW-5	291.765	511.405
7	MW-6	392.62	334.65
8	MW-7	240.705	406.41
9	MW-9	331.21	410.55
10	MW-11	319.825	302.335
11	MW-13	214.715	579.025
12	MW-14	28.53	293.02
13	MW-15	372.84	688.275
14	MW-16	566.385	301.3
15	MW-17	339.605	172.27
16	MW-18	261.52	444.82

The well location data should be in the following format. There should be three columns:

- Column 1: contains the well identification
- Column 2: contains the X coordinate for the well locations
- Column 3: contains the Y coordinate for the well locations

Each column should have a title or label, such as “Well ID, X Coordinate, Y Coordinate.” The rows and columns should be contiguous; there should be no empty rows or columns between the data rows and columns. The well names should be in text format. Numeric values must be used for the X,Y coordinates. No missing values or text are allowed in the X,Y coordinate cells.

Survey data on the location of the monitoring wells may not be available to you. You can use OWL to help create the spreadsheet that is needed to Import Well Location Data from information in the basemap. Create a blank spreadsheet listing wells and locations, and print the spreadsheet. After you have calibrated the basemap to real coordinates, the x and y coordinates of the cursor are listed in left hand side of the gray bar below the basemap. Position the cursor over each monitoring well, and write the coordinates on the hardcopy of the spreadsheet. Then enter the data in the spreadsheet from the hardcopy.

Spreadsheet Format for Water Level Data

The spreadsheet format for the water level data is shown below.

	A	B	C	D	E	F	G	H	I	J	K
1	DATE	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-9	MW-11	MW-18
2	1/25/1994	23.96	23.00	21.97	22.39	23.76	21.14	23.52	22.13	21.81	23.51
3	12/12/1995	22.94	22.03	21.01	21.82	22.90	20.64	22.19	21.49	20.70	22.48
4	10/30/1998	23.43	22.22	21.25	22.14	23.57	20.86	22.55	21.81	20.96	22.94
5	12/4/1998	22.39	21.55	20.53	21.49	22.57	20.14	21.49	20.88	20.16	21.93
6	12/21/1998	23.64	-9999.00	21.43	22.39	24.55	21.98	22.60	22.26	18.63	-9999.00
7	1/11/1999	22.67	-9999.00	18.78	20.77	23.50	19.24	20.64	19.92	16.46	-9999.00
8	3/29/1999	20.35	-9999.00	17.73	19.77	20.17	17.23	20.15	18.36	15.91	-9999.00

The water level data must be in the specified format as shown in the above screenshot. No other data can be present on the same worksheet; i.e., only the column titles, a date for each row, and the water level data can be on the worksheet. The rows and columns should be contiguous; there should be no empty rows or columns between the data rows and columns.

Water level data from each well are in a column below the well name. Data from each sampling date are in a row right of the sampling date. Missing data are indicated by the value -9999.0.

If the available water level data is formatted as sampling dates across the columns and well IDs are down the rows, use the Transpose operation (in Excel) to convert the data to the above format. To do so, highlight and copy the data range first, then use Edit > Paste Special and select Transpose to paste the data on a different worksheet.

Appendix E. Guidance to Edit Ground-Water Elevation Data for OWL

OWL assumes that the ground-water surface at a site is a plane and uses linear regression of the available water elevation data to fit a plane through the data points. OWL provides the regression results in the Water Level Contours dialog box to alert the user to water level data sets which are not well fitted by a linear plane. The ground-water elevations in particular wells at a site will vary one from another. The ground-water elevations in particular wells may also vary from the hypothetical plane that was fit by the regression through all the elevations. The value of R^2 from the regression results compares the amount of variation of water elevation in wells one from another to the amount of variation of elevation in wells from the plane fit through all the elevation data by the regression equation. When there is a perfect match between the measured elevations and the elevation of the plane, then the assumption that the ground-water surface is a plane explains all the variation between the individual wells and the value of R^2 is 1.000. If the value of R^2 is 0.5000, the assumption that the ground-water surface is a plane explains half the variation in elevation between wells. If the value of R^2 is less than 0.5000, the assumption that the ground-water surface is a plane explains less than half the variation. As a general rule of thumb, elevation data sets that produce a value of R^2 that is less than 0.5000 are not appropriate for use in OWL. If the fit is poor, it is important that the user review the ground-water elevations within the questionable data sets and determine if they are truly not suitable for a plane fit or if there are anomalous points which cause the deviation.

When reviewing the points in a data set, the user should be aware there is an important difference between the data requirements for OWL and the data requirements for a transport and fate model. Statisticians recognize two types of error in drawing an inference from a data set. Type I error draws an inference from the data set when the inference is not true. Type II error fails to draw an inference from the data set even though the inference is true. In other words, type I error sees something that is really not there, while type II error fails to see something that really is there. Transport and fate models are used to shape the conceptual model of a plume, and make predictions about its behavior. Data to calibrate a transport and fate model should be selected to guard against type I error. The data that are available to calibrate the model should be screened, and data that are at all questionable should be excluded. OWL is intended to identify the best locations to look for a plume. Actual monitoring data from the wells that are installed at the best locations are used to shape the conceptual model of the plume, and make predictions about its behavior. Data for use in OWL should be selected to guard against type II error. As much as possible, the data available for OWL should be retained. This is particularly true if the available data are limited.

1. Sources of Error in Ground-Water Elevations

Several factors or events can influence the relative variation in the elevation of the ground-water in monitoring wells at a site. There may be a simple error in reading the tape or transcribing the measurement. There are several models of depth-to-water meters, and the tapes on some of them are difficult to read. Only fractions of a foot are marked, and the foot increments are only labeled every foot. It is easy for an inexperienced field technician to associate the mark for a fraction-of-a-foot with the wrong mark for a foot. For example, the technician may read 8.4 feet as 9.4 feet. Some meters will give a false reading if there is moisture condensing on the side of the riser or screen above the free water surface. Individual measurements of depth to water may have significant errors.

In areas where the ground freezes, frost heave can raise the elevation of the top of casing by several inches. If the elevation of the ground-water in a well is consistently a few inches higher than its neighbors, there may be an error in the elevation of the top of the casing.

If the well is not properly sealed, drainage from rain or snowmelt can infiltrate the aquifer in the area of the well and raise the ground-water level. Are anomalously high ground-water elevations associated with periods of precipitation? Water from leaking water mains and sewer lines can also raise the water levels. Compare the map of monitoring wells to an as-built map of utilities.

A particular well may be screened in a different hydrologic unit than the unit containing the plume of contamination, and there may be differences in head between the units. If there are marked differences in elevation between neighboring wells, consult the well logs. Use wells to calibrate OWL that have narrow screens in the contaminated depth interval, and exclude wells with wide screen intervals. If water in one well is clean and the water in a neighboring well is contaminated, keep the elevation data from the contaminated well and exclude the data from the clean well.

If the well with anomalous ground-water elevations is in or near a cluster of other wells with more representative water elevations, the anomalous well can be excluded with little damage to the conceptual model of water flow in the aquifer. When the regression statistics are calculated, the constant will change (the average water level elevation for that sampling date), and R^2 should have a larger value, but the direction (of flow) and magnitude (the hydraulic gradient) should change relatively little. If the anomalous well has no close neighbors or is at the margin of the well field, it will have a strong influence on the direction and magnitude of flow that is extracted by the regression. In this case it is best to have an external reason to exclude the well from the data set used in OWL. At a minimum, compare runs of OWL with and without the anomalous data, to see if its presence makes a practical difference.

2. Site Example

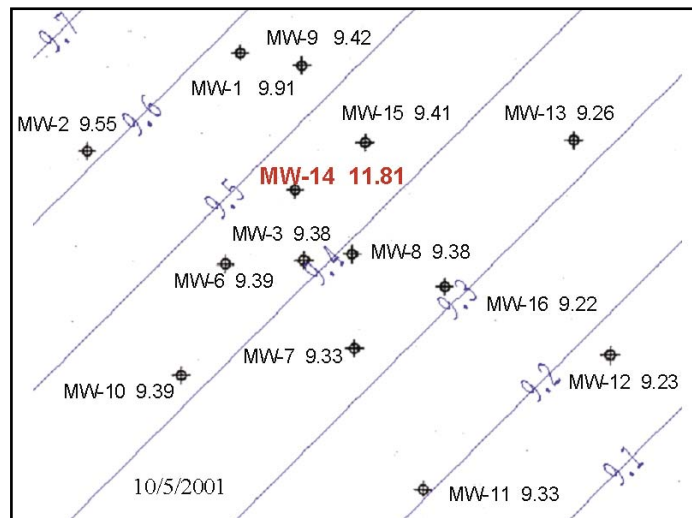
The data used in OWL should be evaluated systematically. This process will be illustrated with data from a site in Southern California. A spill of gasoline formed a plume of contamination in ground water in a shallow aquifer in silty fine sands and clean sands. The sand aquifer was confined above by 15 to 20 feet of clays and silts that extended to the land surface. The ground-water surface was near the contact between the sands and clays. Monitoring wells were screened across the first 10 to 15 feet of the sandy aquifer.

The site basemap was scanned, imported and calibrated to real map coordinates in OWL. Data was imported on elevations in 14 wells on each of 14 sampling dates. After OWL ran the regressions, the following information was provided in the Water Level Contours dialogue box.

Date	Xcoeff	Ycoeff	Const	R2	Magnitude	Direction
4/16/1999	-0.0003305	0.000158	8.052	0.003971	0.0003665	115.6
7/26/1999	-0.002093	0.003013	9.649	0.09294	0.003668	145.2
10/15/1999	-0.001118	0.001617	9.491	0.6465	0.001966	145.4
1/11/2000	-0.001646	0.001682	8.9	0.7303	0.002354	135.6
4/18/2000	-0.001298	-0.000609	9.205	0.1055	0.001433	64.87
7/28/2000	-0.001482	0.001704	9.478	0.6654	0.002258	139
10/25/2000	0.00008204	0.003496	8.646	0.1673	0.003497	181.3
1/17/2001	-0.001422	0.001168	9.148	0.6411	0.00184	129.4
4/3/2001	-0.001532	0.002036	8.951	0.6389	0.002547	143
7/9/2001	-0.001403	0.002069	9.39	0.6197	0.0025	145.9
10/5/2001	-0.001969	0.002483	9.531	0.0997	0.003169	141.6
1/25/2002	-0.001973	0.003078	9.366	0.1288	0.003656	147.3
4/17/2002	-0.001508	0.002351	8.635	0.6515	0.002793	147.3
7/15/2002	-0.001428	0.001996	9.072	0.6651	0.002455	144.4

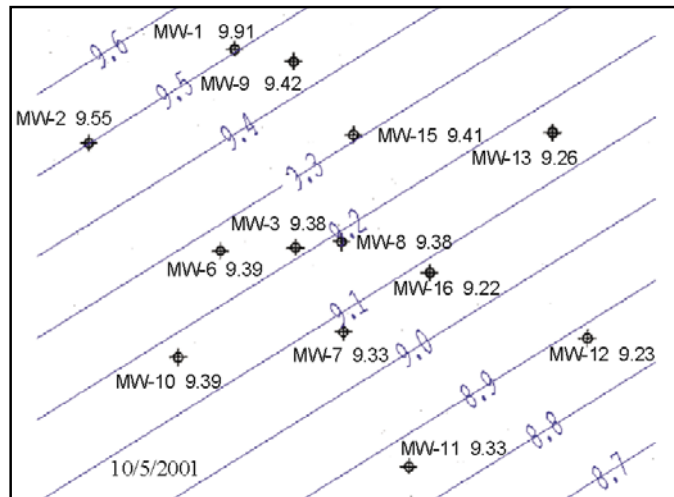
Sampling dates with R² less than 0.5000 are highlighted in red and are bolded. At first examination, the regression was not useable for 6 of the 14 sampling dates.

To determine the cause of the low values for R², the contoured elevations were compared to the actual elevations in the ground-water elevation data file. To facilitate the comparison, the basemaps with the contours were printed from OWL and the actual values of elevation were hand written on the printed maps next to the location of the monitoring wells. The example below compares the actual data and contours for data collected 10/5/2001. The value of R² for the regression to elevation data collected on that day was only 0.0997. In the contour map below, the wells are labeled by name followed by the ground-water elevation. There was reasonable agreement between the contours and the actual data except for one well. The other wells range in elevation from 9.23 to 9.91 feet. The anomalous well has an elevation of 11.81 feet (red on the contour map). The anomalous well is near the center of the site, and is surrounded on all sides by wells with much lower elevation.



When the elevation of MW-14 in the ground-water elevation data file was replaced with -9999.00 (null value), and the data were contoured again, the new value of R² was 0.5536. In the new contour map

below, notice that the average elevation was lower, and that the hydraulic gradient was steeper when the questionable datum was removed.



The original ground-water elevation data file is presented below. The process of comparing the elevation data to the contoured data revealed a highly suspect datum in five of the six dates with low values of R^2 in the regression equation. The dates and suspect data are colored red and bolded in the table below. The suspect data deviated by at least 1.0 foot from a more representative value.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	DATE	mw-1	mw-2	mw-3	mw-5	mw-7	mw-8	mw-9	mw-10	mw-11	mw-12	mw-13	mw-14	mw-15	mw-16	
2	4/16/1999	8.41	8.17	7.96	7.49	8.98	7.90	8.22	7.90	7.74	8.35	7.70	8.21	7.55	7.79	
3	7/26/1999	9.98	9.67	9.50	9.52	9.44	9.50	9.78	9.51	9.44	9.34	9.36	-9999.00	9.48	9.42	
4	10/15/1999	9.79	9.68	9.49	9.52	9.41	9.44	9.81	9.49	9.43	9.36	9.40	9.81	9.49	9.45	
5	1/11/2000	9.18	9.02	8.87	8.91	8.76	8.81	9.18	8.86	8.78	8.55	8.71	9.14	8.84	8.78	
6	4/18/2000	9.26	9.20	8.96	8.98	8.92	8.93	-9999.00	8.99	8.91	8.89	8.85	9.29	8.97	8.91	
7	7/28/2000	9.85	9.65	9.45	9.40	9.39	9.41	9.78	9.48	9.36	9.29	9.26	9.71	9.45	9.35	
8	10/25/2000	9.63	9.30	9.12	-9999.00	9.01	9.09	9.81	9.13	9.09	8.88	9.00	9.45	9.11	9.06	
9	1/17/2001	9.36	9.32	9.05	9.08	9.01	9.01	9.18	9.06	9.01	8.90	8.94	9.40	9.05	9.01	
10	4/3/2001	9.49	9.15	8.92	8.99	8.85	8.88	9.24	8.95	8.88	8.77	8.81	9.27	8.90	8.88	
11	7/9/2001	9.97	9.57	9.38	9.45	9.35	9.34	9.69	9.38	9.33	9.22	9.27	9.72	9.40	9.33	
12	10/5/2001	9.91	9.55	9.36	9.39	9.33	9.38	9.42	9.39	9.33	9.23	9.26	-9999.00	9.41	9.22	
13	1/25/2002	9.79	9.46	9.25	9.26	9.24	9.27	9.63	9.27	9.23	9.11	9.14	-9999.00	9.31	9.10	
14	4/17/2002	9.22	8.87	8.63	8.67	8.58	8.62	9.08	8.67	8.57	8.48	8.52	8.99	8.85	8.58	
15	7/15/2002	9.56	9.28	9.04	9.11	9.01	9.04	9.40	9.05	9.00	8.90	8.93	9.38	9.07	9.00	
16																

Three of the five suspect ground-water elevations were associated with the same monitoring well (MW-14). Although comparison of the elevation data to the contours made it easier to recognize the suspect data, they could also be easily distinguished by comparing the elevations in a well for a particular date to the elevations on the date before and the date after the particular date, and by comparing elevations in adjacent wells on the date before and date after. However, this process of comparison did not reveal any suspect data in the elevations collected on 4/16/1999. The suspect data were replaced with the code for missing data, and the file was imported into OWL, and the regression was run a second time. The edited ground-water elevation data file is presented below.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	DATE	mw-1	mw-2	mw-3	mw-5	mw-7	mw-8	mw-9	mw-10	mw-11	mw-12	mw-13	mw-14	mw-15	mw-16	
2	4/16/1999	8.41	8.17	7.96	7.49	8.98	7.90	8.22	7.90	7.74	8.35	7.70	8.21	7.55	7.79	
3	7/26/1999	9.98	9.67	9.50	9.52	9.44	9.50	9.78	9.51	9.44	9.34	9.36	-9999.00	9.48	9.42	
4	10/15/1999	9.79	9.68	9.49	9.52	9.41	9.44	9.81	9.49	9.43	9.36	9.40	9.81	9.49	9.45	
5	1/11/2000	9.18	9.02	8.87	8.91	8.76	8.81	9.18	8.86	8.78	8.55	8.71	9.14	8.84	8.78	
6	4/18/2000	9.26	9.20	8.96	8.96	8.92	8.93	-9999.00	8.99	8.91	8.89	8.85	9.29	8.97	8.91	
7	7/28/2000	9.85	9.65	9.45	9.40	9.39	9.41	9.78	9.48	9.38	9.29	9.26	9.71	9.45	9.35	
8	10/25/2000	9.63	9.30	9.12	-9999.00	9.01	9.09	9.81	9.13	9.09	8.88	9.00	9.45	9.11	9.06	
9	1/17/2001	9.36	9.32	9.05	9.08	9.01	9.01	9.18	9.06	9.01	8.90	8.94	9.40	9.05	9.01	
10	4/3/2001	9.49	9.15	8.92	8.99	8.85	8.88	9.24	8.95	8.86	8.77	8.81	9.27	8.90	8.86	
11	7/9/2001	9.97	9.57	9.38	9.45	9.35	9.34	9.69	9.38	9.33	9.22	9.27	9.72	9.40	9.33	
12	10/5/2001	9.91	9.55	9.38	9.39	9.33	9.38	9.42	9.39	9.33	9.23	9.26	-9999.00	9.41	9.22	
13	1/25/2002	9.79	9.46	9.25	9.26	9.24	9.27	9.63	9.27	9.23	9.11	9.14	-9999.00	9.31	9.10	
14	4/17/2002	9.22	8.87	8.63	8.87	8.58	8.82	9.08	8.67	8.57	8.48	8.52	8.99	8.85	8.58	
15	7/15/2002	9.56	9.28	9.04	9.11	9.01	9.04	9.40	9.05	9.00	8.90	8.93	9.39	9.07	9.00	
16																

Presented below are the statistics from the Water Level Contours dialogue box after the regression was run with the edited data set. The values of R^2 in the regressions for the dates where the suspect datum was deleted are now all greater than 0.5000, and are now acceptable to use in OWL.

Date	Xcoeff	Ycoeff	Const	R2	Magnitude	Direction
4/16/1999	-0.0003305	0.000158	8.052	0.003971	0.0003665	115.6
7/26/1999	-0.001327	0.001648	9.514	0.6599	0.002116	141.2
10/15/1999	-0.001118	0.001617	9.491	0.6465	0.001966	145.4
1/11/2000	-0.001646	0.001682	8.9	0.7303	0.002354	135.6
4/18/2000	-0.00129805	-0.001149	9.035	0.5901	0.001665	133.6
7/28/2000	-0.001482	0.001704	9.478	0.6654	0.002258	139
10/25/2000	-0.001612	0.002623	9.102	0.5931	0.003078	148.4
1/17/2001	-0.001422	0.001168	9.148	0.6411	0.00184	129.4
4/3/2001	-0.001532	0.002036	8.951	0.6389	0.002547	143
7/9/2001	-0.001403	0.002069	9.39	0.6197	0.0025	145.9
10/5/2001	-0.00133	0.001346	9.419	0.5536	0.001892	135.3
1/25/2002	-0.001347	0.001964	9.256	0.6375	0.002382	145.6
4/17/2002	-0.001508	0.002351	8.635	0.6515	0.002793	147.3
7/15/2002	-0.001428	0.001996	9.072	0.6651	0.002455	144.4

The magnitude (slope of the regression) for data collected on 4/16/1999 is low, about 10% of the magnitude on other dates. The magnitude of the regression is the hydraulic gradient. If the gradient is truly flat, then variations in elevations are dominated by errors of measurement and by minor variations caused by spatial heterogeneity. If there is no contribution to the variations caused by the hydraulic gradient, then a regression to fit a plane would not explain the variations in elevation and the value of R^2 should be low. If the ground-water surface is truly flat, the data collected on 4/16/1999 should be retained to use in OWL.

To determine if the gradient was truly flat, the range in ground-water elevations on 4/16/1999 was compared to the range in elevations on the other dates. If the ground-water surface is truly flat, and other sources of variation are the same, the range in variation in elevations on 4/16/1999 should be less than the

ranges in variation on other dates. This was not the case. The range in variation across all the wells on 4/16/1999 was 1.49 feet. After the suspect data were deleted, the range in variation across all the wells on each of the other dates extended from a high of 1.07 feet to a low of 0.30 feet, with an average of 0.65 feet. The data collected on 4/16/1999 was more variable than the other data, and the very flat gradient extracted by the regression was probably circumstantial. Data collected on 4/16/1999 was therefore excluded from the final OWL run.

The average direction of flow was 141 ± 6.1 degrees on the eight sampling dates when the value of R^2 was greater than 0.5000 without editing. The direction of flow predicted from the original data collected on 4/18/2000 was 64.9 degrees and the direction of flow predicted on 10/25/2000 was 181.3 degrees. When the regressions were calculated with the edited data sets, the direction of flow was much more representative of the other dates. The direction of flow on 4/18/2000 was 133.6 degrees and the direction of flow on 10/25/2000 was 148.4 degrees. The regression equations extracted from the edited data set were more internally consistent. The possible plume contours generated by OWL were confined to a smaller area when OWL was run with the edited data set.