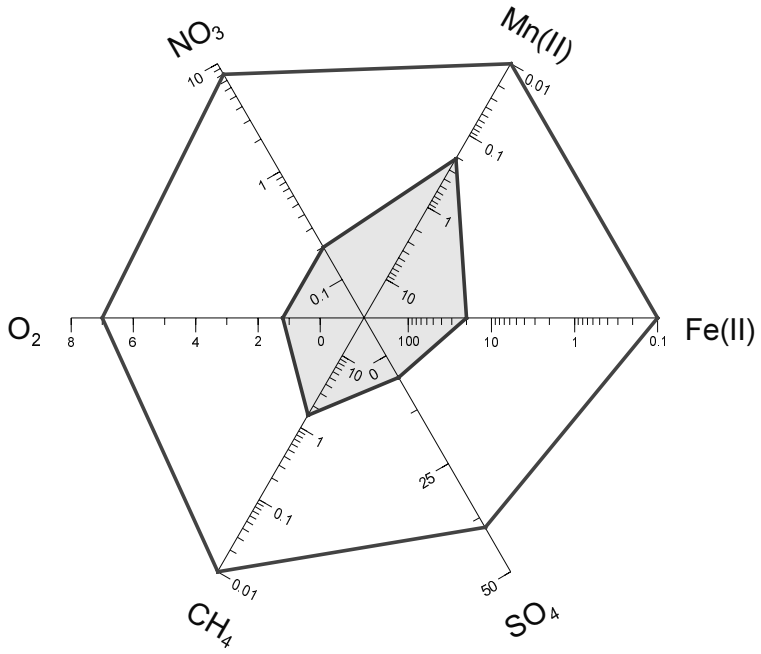
MoNA ToolKit V 1.1 Lab Exercise

Visualizing Natural Attenuation Trends

Bootstrap Site, Wyoming

Sunrise Fuel Supplies Co.



Featuring: SEQUENCE V 2.2
Biotrends V 1.1

Developed By

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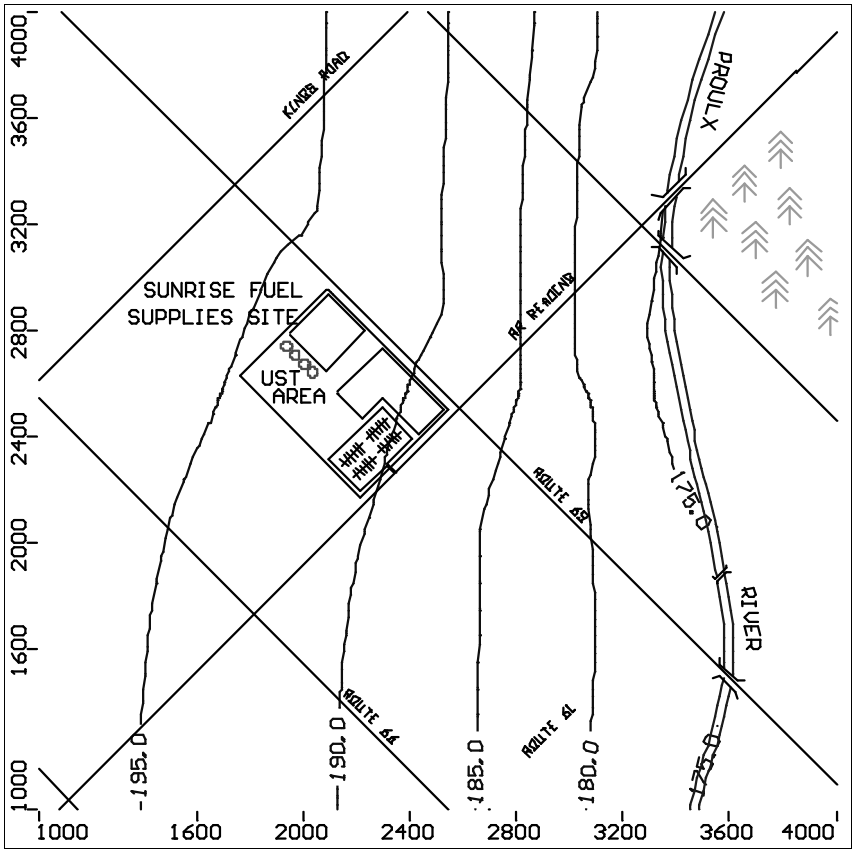
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1.0 Description of the Problem

1.1 Site History

Sunrise Fuel Supplies Co. is a fuel distribution company located in the rural municipality of Bootstrap, Wyoming. The site is located approximately 1000 ft west of the Proulx River. The regional groundwater flow direction in the shallow, unconfined aquifer underlying the site is from west to east, towards the river as shown below.



Site Location Map

The company has been in operation at this location since 1981. The site contains four 50,000 gallon above-ground storage tanks which have been well maintained. The company has no record of any leaks from these tanks during the entire period of operations. However, a Phase I investigation in 1994 identified the following:

(1) Badly stained pavement in the tanker truck filling area likely due to fuel spillage

(2) Small piles of fuel-stained sawdust scatted through a sparsely vegetated field adjacent to the tanker truck filling area

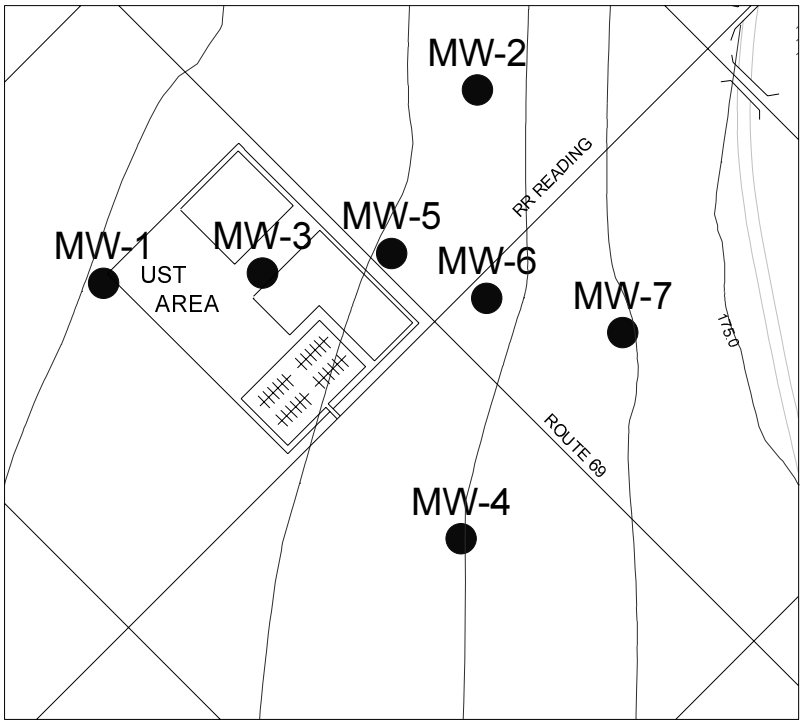
(3) Signs of severely stressed vegetative growth in the field adjacent to the tanker truck filling area

Subsequent interviews with plant personnel revealed that large fuel spills (>1000 gallons) at the site were rare. However, small fuel spills did occur quite frequently, and the spilled fuel would be contained and absorbed with sawdust. The fuel-soaked sawdust would then be discarded in the field adjacent to the filling area. In addition, the filling area would often be sprayed afterwards with a degreasing solution (consisting of TCE) in an attempt to clean the fuel from the concrete pads. The surface of the filling area drained into the field adjacent to the filling area.

Based on this information, a subsurface investigation was launched to determine the extent of the soil and groundwater contamination. During the subsequent investigations, the soil in field was found to have elevated concentrations of fuel hydrocarbons (BTEX) and chlorinated solvents (TCE and DCE). In addition, a groundwater sampling program determined the groundwater at the site had also been contaminated with both petroleum hydrocarbons and chlorinated solvents, and the contaminated groundwater was migrating off-site.

The contaminated soil at the site was immediately removed and disposed of at a licensed hazardous waste landfill. An on-going groundwater monitoring program is being conducted to assess whether Monitored Natural Attenuation (MNA) is a viable remedy for the site.

The figure below illustrates the locations of the seven groundwater monitoring wells that have been installed in the shallow aquifer at the site.



Monitoring Well Locations

Table 1 below illustrates the monitoring data collected during the past three monitoring events at the site.

Table 1 – Groundwater Monitoring Data

Spring 1995 Sampling Round

Station	X (m)	Y (m)	TCE (ug/L)	DCE (ug/L)	VC (ug/L)	BTEX (ug/L)	Cl- (mg/L)	O2 (mg/L)	NO3 (mg/L)	SO4 (mg/L)	Fe(II) (mg/L)	CH4 (mg/L)
MW-1	1750	2600	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-2	2691	3087	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-3	2150	2625	5000	3000	200	1500	8	<1	<0.1	<1	5	0.1
MW-4	2650	1955	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-5	2475	2675	100	500	2000	15	7	<1	<0.1	15	2	0.01
MW-6	2715	2562	10	100	1500	2	6	<1	<0.1	20	0.05	0.001
MW-7	3057	2475	<1	10	<1	<1	4	5	7	25	<0.01	<0.001

Spring 1997 Sampling Round

Station	X (m)	Y (m)	TCE (ug/L)	DCE (ug/L)	VC (ug/L)	BTEX (ug/L)	Cl- (mg/L)	O2 (mg/L)	NO3 (mg/L)	SO4 (mg/L)	Fe(II) (mg/L)	CH4 (mg/L)
MW-1	1750	2600	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-2	2691	3087	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-3	2150	2625	200	300	25	1500	5	<1	<0.1	<1	8	0.5
MW-4	2650	1955	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-5	2475	2675	25	75	100	20	3	<1	<0.1	10	5	0.1
MW-6	2715	2562	3	20	15	2	4	<1	<0.1	15	1	0.002
MW-7	3057	2475	<1	2	<1	<1	2	3.5	6	20	<0.01	<0.001

Spring 1999 Sampling Round

Station	X (m)	Y (m)	TCE (ug/L)	DCE (ug/L)	VC (ug/L)	BTEX (ug/L)	Cl- (mg/L)	O2 (mg/L)	NO3 (mg/L)	SO4 (mg/L)	Fe(II) (mg/L)	CH4 (mg/L)
MW-1	1750	2600	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-2	2691	3087	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-3	2150	2625	50	75	5	100	3	<1	<0.1	<1	10	1
MW-4	2650	1955	<1	<1	<1	<1	2	7	10	25	<0.01	<0.001
MW-5	2475	2675	10	15	2	5	2.2	<1	<0.1	2	5	0.2
MW-6	2715	2562	<1	5	<1	<1	2	<1	<0.1	5	2.5	0.1
MW-7	3057	2475	<1	<1	<1	<1	2	2	1	15	<0.01	0.05

1.2 BTEX-CAH Biodegradability

1.2.1 BTEX Biodegradation

Petroleum hydrocarbons such as benzene, toluene, ethylbenzene, and xylene (BTEX) are generally utilized as primary substrates during the biodegradation process. The biodegradation, or *oxidation* of BTEX results in an electron transfer from the BTEX compounds (also referred to as the electron donors) to available electron acceptors. This electron transfer results in the release of energy which is utilized for microbial metabolism.

Typical electron acceptors available in groundwater, in the order of those that release the greatest energy to those that release the least energy, are as follows: dissolved oxygen, nitrate, manganese (IV) oxide and iron (III) hydroxide coatings on soil sediments, dissolved sulfate, and carbon dioxide (Baedecker and Back, 1979; Lyngkilde and Christensen, 1992). Long-term oxidation of the primary substrate depletes the supply of available electron acceptors in a step-wise, or sequential manner, such that the redox potential in groundwater becomes more reducing during the biodegradation process.

Lines of Evidence for BTEX Biodegradation

The intrinsic biodegradation of BTEX will result in a reduction in pollutant concentrations over time. Such a reduction in pollutant mass is considered to be a direct, or primary line of evidence for supporting natural attenuation as a groundwater remedy.

BTEX degradation can also be supported indirectly by trends in specific geochemical indicators. This secondary line of evidence correlates the decrease in BTEX concentrations with a decrease in electron acceptor concentrations (e.g. oxygen, nitrate and sulfate), and an increase in metabolic by-products (e.g. iron(II), manganese and methane).

1.2.2 Chlorinated Ethene Biodegradation

Aerobic Processes

Vinyl chloride and (to a lesser extent) DCE are used as primary substrates in the aerobic zone, and thus undergo oxidation as electron donors. TCE will only undergo biodegradation under aerobic conditions through a process referred to as co-metabolism, where the degradation of another substrate (e.g. methane or toluene) results in favorable conditions for TCE degradation. Vinyl chloride and DCE are also degraded more rapidly under aerobic conditions in the presence of other substrates such as methane or toluene.

Anaerobic Processes

The anaerobic biodegradation processes for chlorinated solvents are strongly dependent on the redox conditions in groundwater, and on the make-up of the chemicals themselves.

The principal mechanism involved in the anaerobic biodegradation of chlorinated ethenes is reductive dechlorination, which involves the breakdown of a parent species (e.g. TCE) to a daughter product (e.g. DCE) and a chloride ion. The anaerobic reduction of PCE and TCE to ethene (through sequential intermediate products of DCE and vinyl chloride) has been observed at many sites, although the transformations may be incomplete. Reductive dechlorination will *only* occur if there is a primary substrate such as BTEX that is also biodegrading in groundwater.

In general, strongly anaerobic (i.e. reducing) conditions provide a more favorable environment for the reductive dechlorination of chlorinated ethenes than a mildly reducing environment. Also, the lesser chlorinated species (DCE and vinyl chloride) are more resistant to reductive dechlorination than the higher chlorinated species (PCE and TCE).

Recent evidence has shown that vinyl chloride will degrade rapidly through an oxidation process in iron-reducing environments, and some evidence indicates that DCE may also behave in a similar manner.

Lines of Evidence for Chlorinated Ethene Biodegradation

Similar to petroleum hydrocarbons, the primary line of evidence for the intrinsic biodegradation of chlorinated ethenes is evidence of mass loss over time, such as a significant reduction in chlorinated ethene concentrations along the primary flow path downgradient from the source.

Note: If reductive dechlorination is the dominant biodegradation mechanism for chlorinated ethenes in groundwater, then it is essential that the MNA documentation demonstrate the presence of a sufficient carbon source (e.g. BTEX) to support the biodegradation of these chlorinated solvents downgradient from the source area.]

A secondary line of evidence for the intrinsic biodegradation of chlorinated ethenes is a direct correlation between decreasing concentrations of a parent species and increasing concentrations of one or more daughter products (based on a spatial trend analysis).

If reductive dechlorination is considered to be a principal mechanism occurring at a site, it is also important to evaluate monitoring data for trends that indicate the concurrent oxidation of an organic carbon source (such as BTEX). As well, monitoring data trends can indicate whether groundwater redox conditions are favorable for the reductive dechlorination of each chlorinated ethene species (secondary line of evidence).

2.0 Using SEQUENCE

2.1 Learning Objective

Use SEQUENCE to clearly document primary and secondary lines of evidence that support the efficacy of Monitored Natural Attenuation for the site.

2.2 Terms and Notations

For the purposes of this tutorial, the following terms and notations will be used:

Type - to type in the given word or value
select - to click the left mouse button where indicated
☞ - to click the left mouse button where indicated
☞☞ - to double-click the left mouse button where indicated

2.3 Starting a SEQUENCE Project

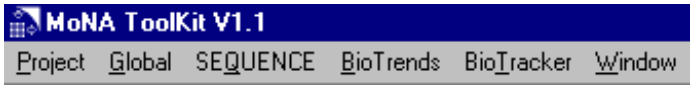
To start SEQUENCE, double click on the MoNA ToolKit icon on your computer's desktop:



The opening screens for the MoNA ToolKit will be displayed, which includes the following software packages:

SEQUENCE Version 2.2 – for Visualizing Natural Attenuation
Biotrends Version 1.1 – for Quantifying Natural Attenuation
Biotracker Version 1.1 – for Modeling Natural Attenuation

After the software has opened, the MoNA ToolKit work window is displayed with the following options in the top menu bar:



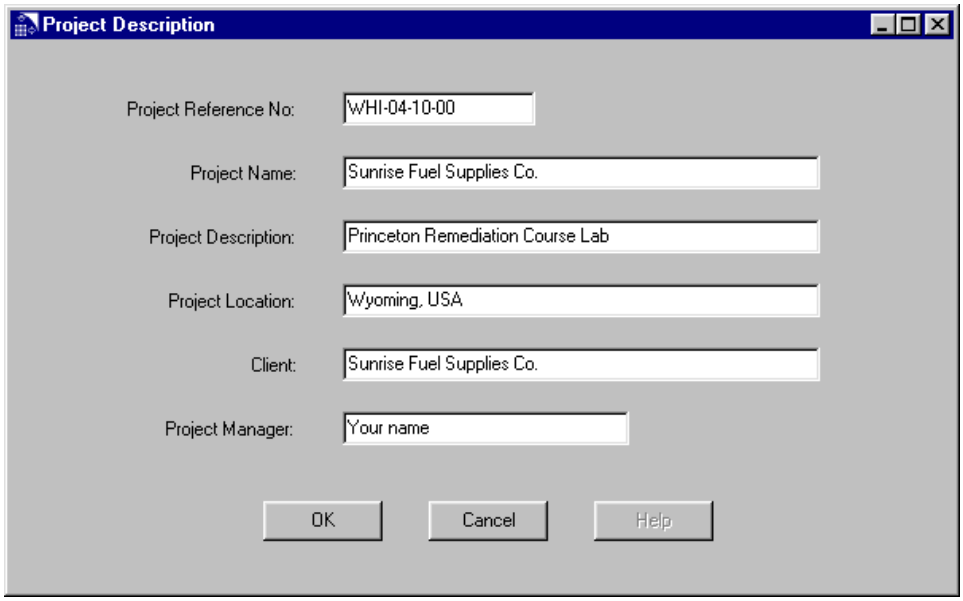
To start a new SEQUENCE project,

☞ **Project** (from the top menu bar)
☞ **New** (from the pull-down menu)

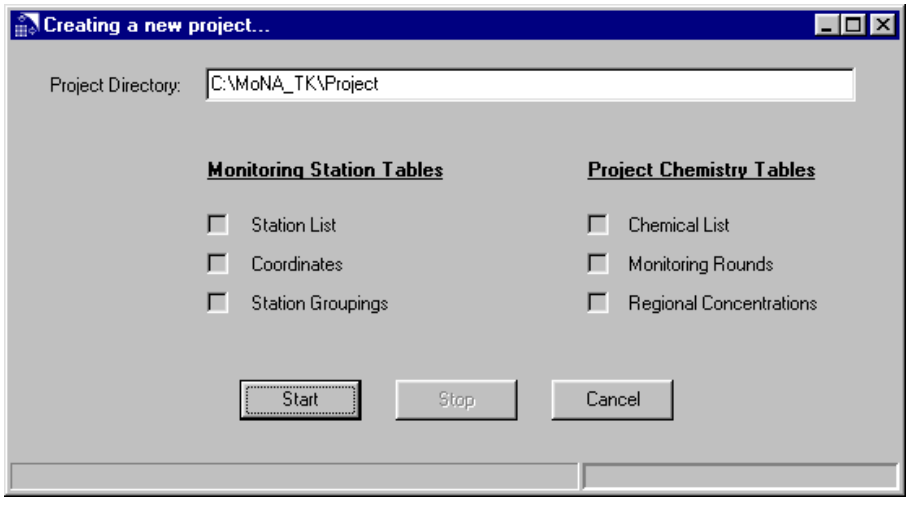
In the **Select Directory and Enter New Project Name** window that appears, navigate to the **C:\MoNA_TK\Project** folder.

Type **Sunrise** (in the **File name** field)
☞ **Open** (to open the new project)

A **Project Description** dialogue box will appear prompting you to enter descriptive information about the project. Please enter the information shown in the following figure:

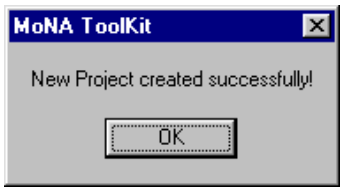


A dialogue box will appear for **Creating a new project…**, as seen below:



☞ **Start** (to create the required files for the project)

When the required files have been successfully created you will be notified with the following message:



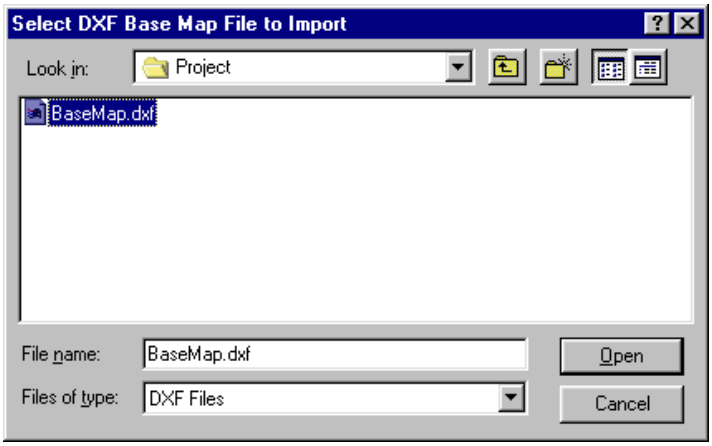
☞ **OK**

SEQUENCE will then load the project. The next task is to select a site base map for your project.

☞  (file folder icon beside the **Base Map** field)

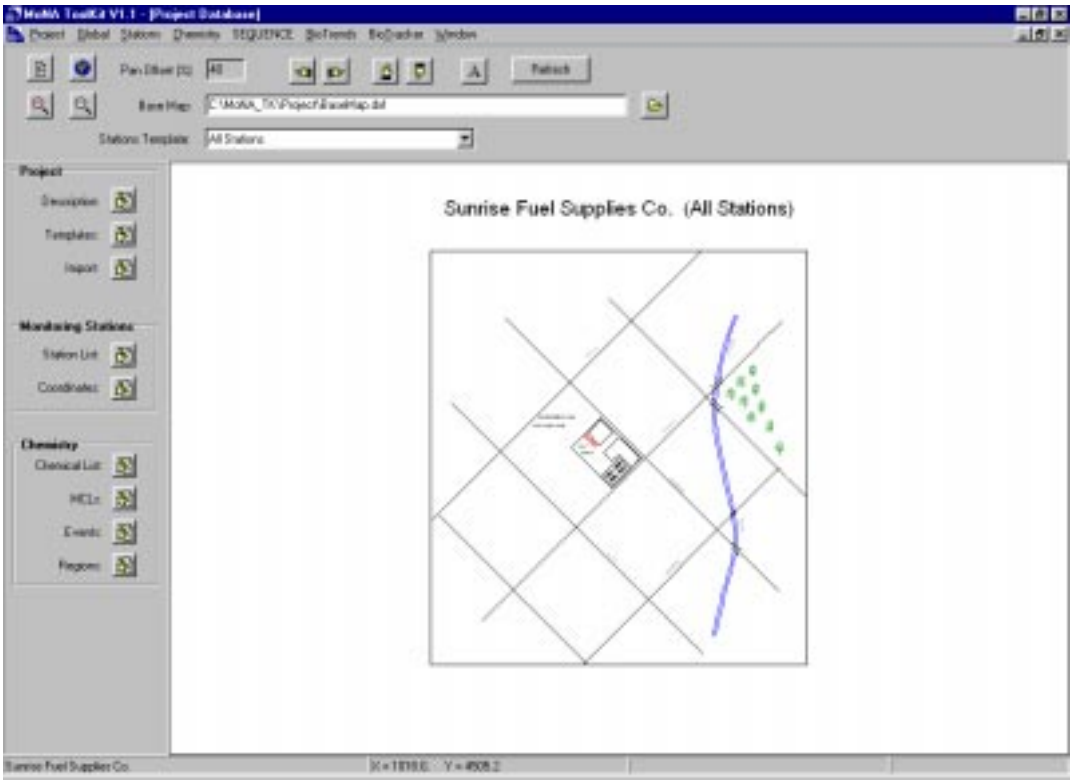
In the window that appears,

☞ **BaseMap.dxf**



☞ **Open**

The Sunrise Fuel Supplies site map should appear on your screen as shown in the figure on the following page.



2.3.1 Defining the Monitoring Stations

Once you have loaded your site map, the next step is to enter the monitoring stations and location coordinates of these stations.

☞ **Stations** (from the top menu bar)
☞ **Project List** (from the pull-down menu)

A **Project Stations List** dialogue box will appear.

At the Sunrise site, there are seven (7) groundwater monitoring wells being sampled (MW-1 to MW-7). To enter the stations, simply begin typing the information below. After each well name, ☞ **Append**:

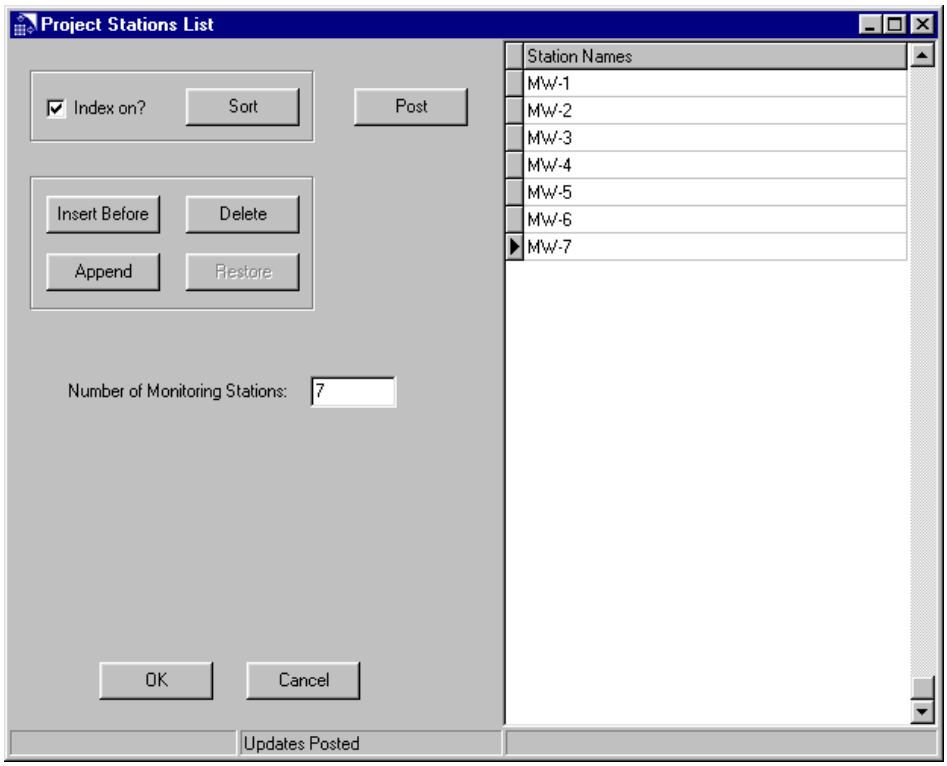
MW-1
MW-2
MW-3
MW-4
MW-5
MW-6
MW-7

If you have many monitoring stations, this information can also be easily imported.

Once you have enter the 7 well names,

☞ **Post** (to post the well names)

Your dialogue window should now appear as seen below,



☞ **OK** (to accept the Station List)

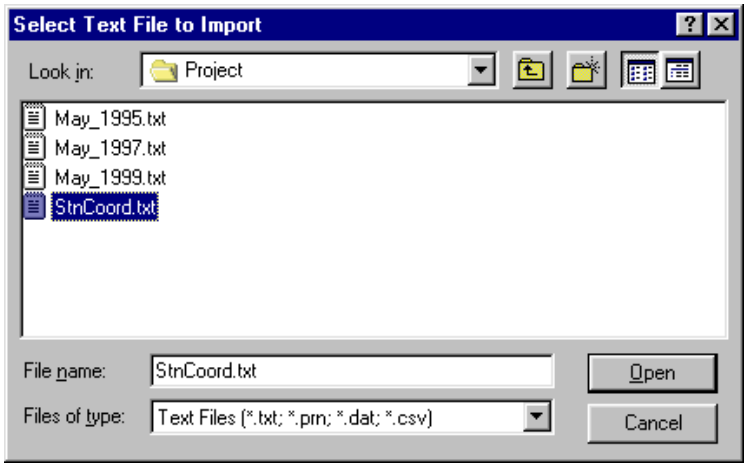
Next you will enter the location coordinates of the monitoring stations. For such a small number of monitoring stations, you would normally type the coordinates in manually. However, for larger projects with many monitoring stations, this would be a time-consuming and tedious task. Therefore, for this exercise, you will see how easy it is to import the station coordinates from an ASCII text file.

To import the station co-ordinates,

☞ **Project** (from the top menu bar)
☞ **Import** (from the pull-down menu)

From the window that appears,

☞ **StnCoord.txt** (text file containing the station coordinates)



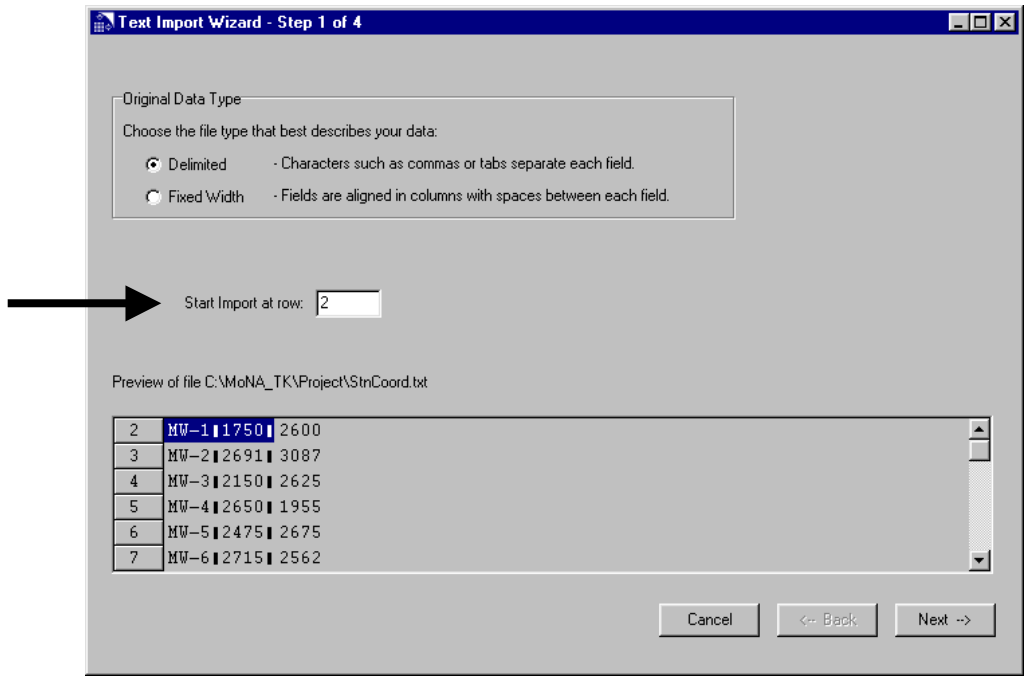
☞ **Open**

A Text Import Wizard will appear to help you import the ASCII data to the appropriate fields in your SEQUENCE database files. A preview of the ASCII data is shown in the lower half of the **Text Import Wizard** dialogue box.

Text Import – Step 1 of 4

The ASCII data file is a delimited data file, and the first row of the ASCII data file contains column headers. Therefore, you need to instruct SEQUENCE to import data starting from the **second row**.

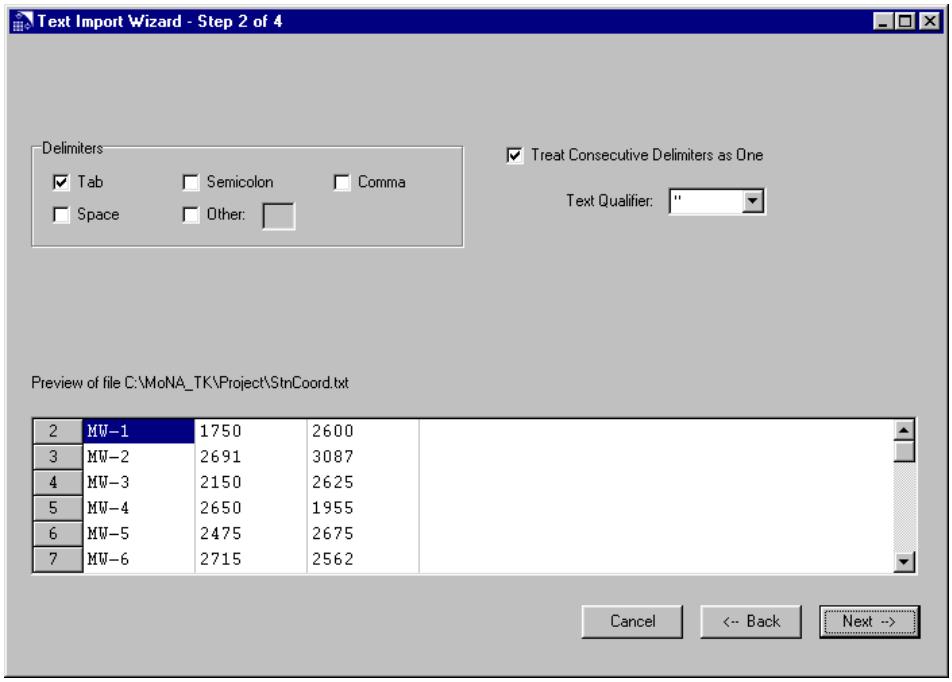
Ensure your **Step 1 of 4** dialogue window is identical to the following figure:



☞ **Next -->**

Text Import - Step 2 of 4

The ASCII text file containing the station coordinates is tab delimited, so the three columns of data should be separated as shown in the following figure. If the columns are not separated appropriately, try selecting a different Text Delimiter (e.g. Comma).



☞ **Next -->**

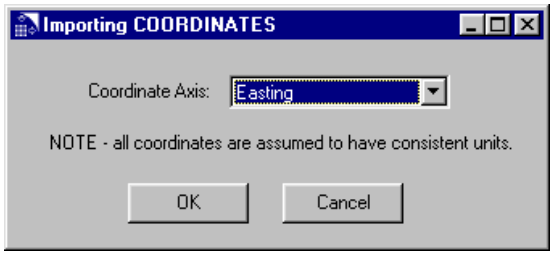
Text Import – Step 3 of 4

In Step 3, you must match the data column from the ASCII text file to the appropriate information required by SEQUENCE.

Click the mouse inside the first column (it should now be highlighted) and then select **Monitoring stations** from the **Column Options** frame. The Select Import Column field should indicate that Column 1 contains the Monitoring Station names (**STNS**).

Next, click the mouse in the second column (it should now be highlighted) and then select **Coordinates**. A pop-up window will prompt you to select the coordinate direction (Easting or Northing).

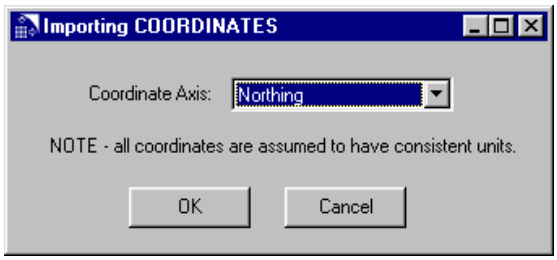
☞ **Easting**



☞ **OK**

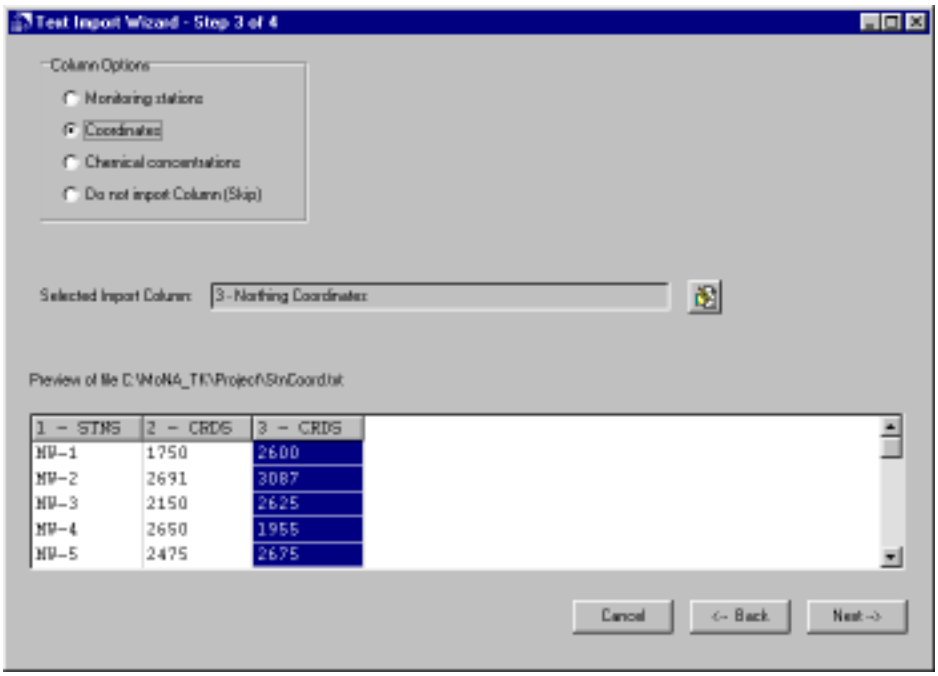
Finally, click the mouse in the third column (it should now be highlighted) and then select **Coordinates**. From the pop-up window that appears,

☞ **Northing**



☞ **OK**

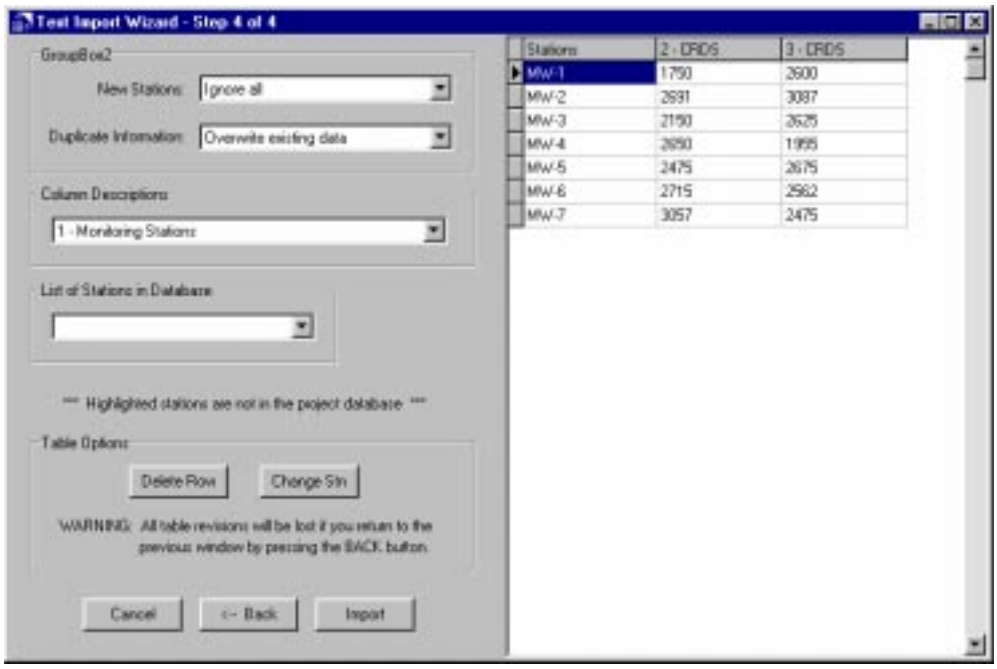
Your dialogue window should now appear as seen below:



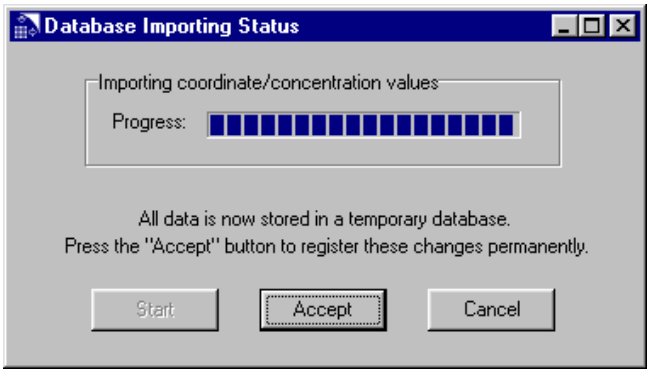
☞ **Next -->**

Text Import – Step 4 of 4

You will be shown a preview of the data to be imported, and you will have several options for treating duplicate data points or other unwanted information.



☞ **Import** (to accept the default settings)
☞ **Start** (to initiate the import process)

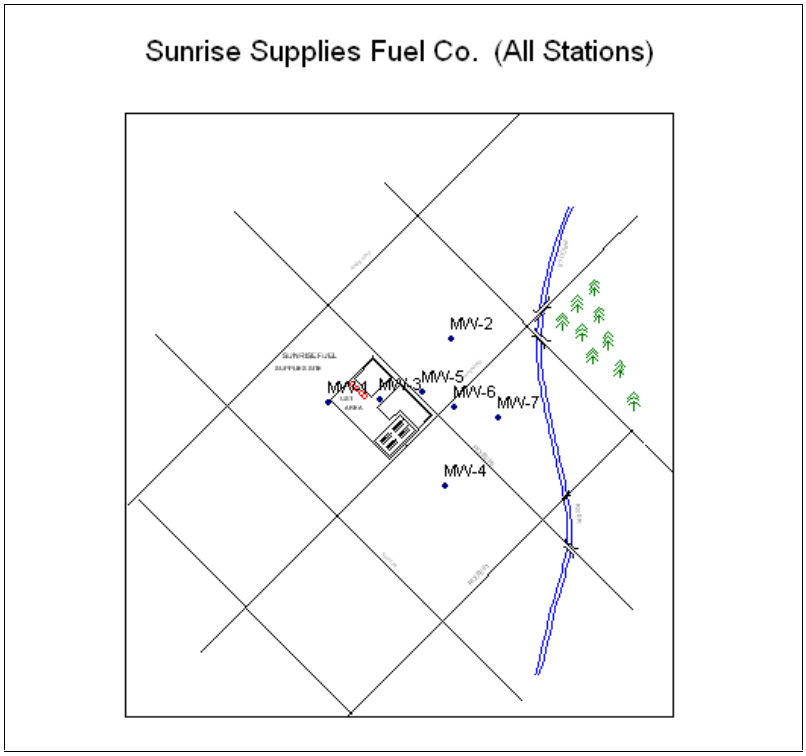


☞ **Accept** (to accept the imported data)

A message should appear indicating the data was successfully imported

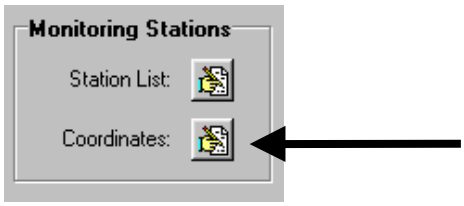
☞ **OK** (to proceed)

Your display should now appear as seen in the figure below:



To check on the station coordinates,

☞ **Edit Coordinates** (from the side menu bar)



A **Monitoring Station Coordinates** window will appear listing the Station Names and Coordinate Locations.

☞ **OK** (to close the dialogue box)

2.3.2 Defining The Project Chemical List

The next step in creating a new project is to identify the chemicals to be plotted on the radial diagram maps. The list of chemicals can include both chemicals of concern (usually organic chemicals for a site like this) as well as inorganic chemicals that can be used to indicate the presence of biological reactions.

☞ **Chemistry** (from the top menu bar)
☞ **Project List** (from the pull-down menu)

A **Project Chemical List** dialogue box will appear.

You must enter the chemical **Short Name** in your dialogue box, then link the chemical **Short Name** to the **CHEMbase Long Name**.

Let's start by entering the organic chemicals. To enter a chemical **Short Name**,

☞ **Append** (from the dialogue window)
Type TCE (press **Tab** to move to the next field)
Type ug/L (or use the pull-down menu in the **Default Units** field)

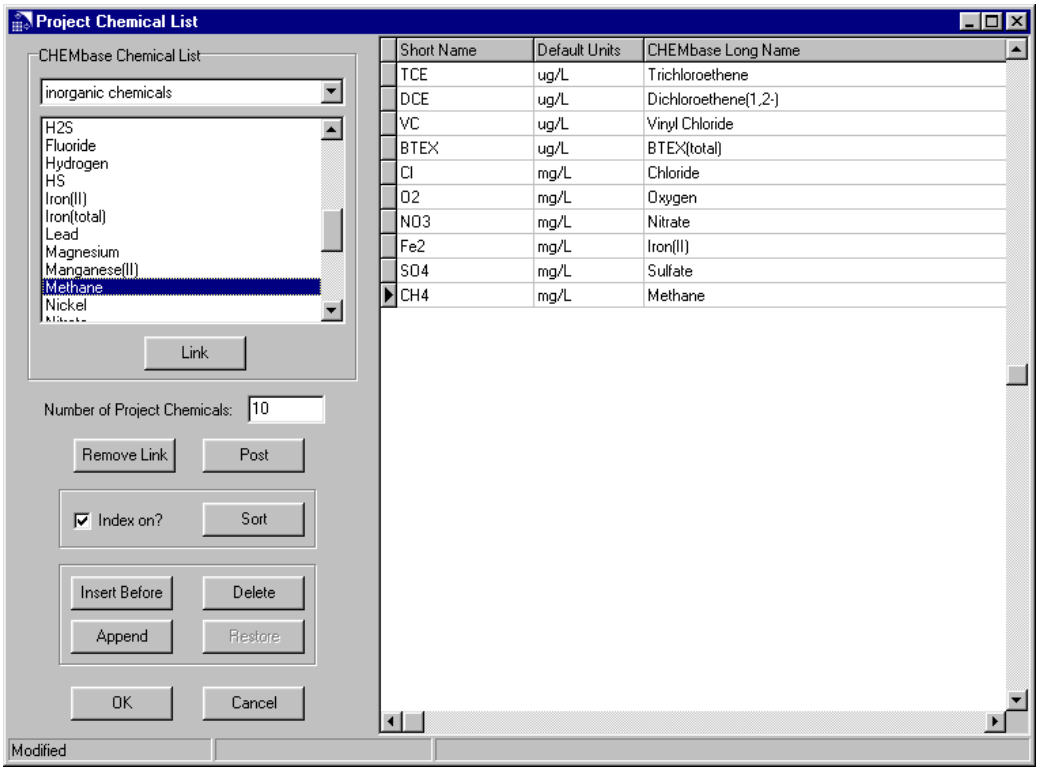
Then, using the scroll bars for the **CHEMbase Chemical List**,

☞ **TCE** (from the **CHEMbase Chemical List**)
☞ **Link** (create a link between project database and CHEMbase properties)

The **CHEMbase Long Name** should now display **Trichloroethene**.

☞ **Append** (to add another chemical)

Following the same procedure, fill out the **Project Chemical List** to match the figure on the following page.



When linking the organic chemical **DCE**, select **Dichloroethene (1,2)** from the **CHEMbase Chemical List**.

Note: You have to change the **CHEMbase Chemical List** to **inorganic chemicals** using the pull-down menu option to link Cl, O2, NO3, Fe2, SO4, and CH4.

When all of the project chemicals have been entered and linked,

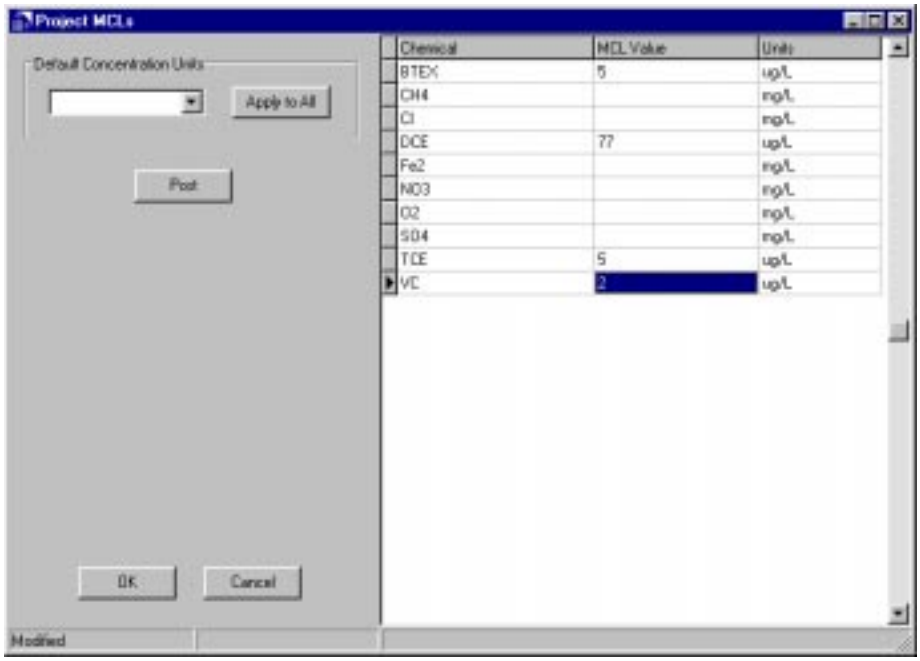
☞ **OK** (to accept the **Project Chemical List**)

Now, you must enter the maximum concentration limits (**MCLs**) for the selected chemicals at the site.

☞ **Chemistry** (from the top menu bar)
☞ **Project MCLs** (from the pull-down menu)

A **Project MCLs** dialogue box will appear listing the project chemicals. Enter the following MCL values:

BTEX	**5**	(ug/L)
DCE	**77**	(ug/L)
TCE	**5**	(ug/L)
VC	**2**	(ug/L)



☞ **OK** (to accept the **Project MCLs**)

2.3.3 Defining the Monitoring Events

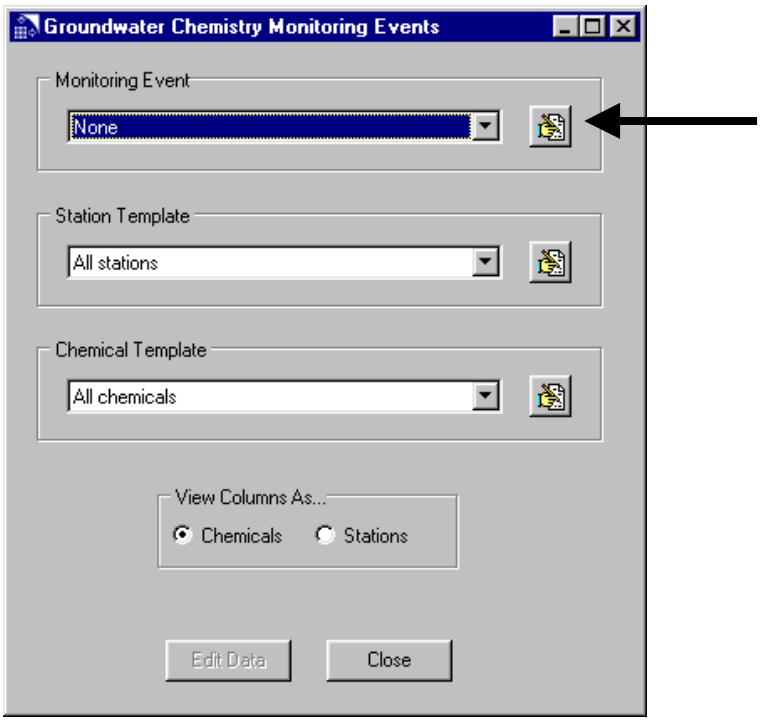
The monitoring events generally describe the time when the groundwater sampling rounds took place. For this particular site, quarterly monitoring events have been conducted at each of the seven monitoring stations since the spring of 1995. However, for the purposes of this lab, you will be examining only the spring sampling events from 1995, 1997 and 1999.

☞ **Chemistry** (from the top menu bar)
☞ **Monitoring Data** (from the pull-down menu)

A dialogue window will appear that allows you to define and describe monitoring events, select the monitoring stations sampled during each event, and define the chemicals sampled during each event.

To create a new Monitoring Event, click the **Edit** button  beside the **Monitoring Event** field.

☞  (**Edit Monitoring Round Descriptions**)



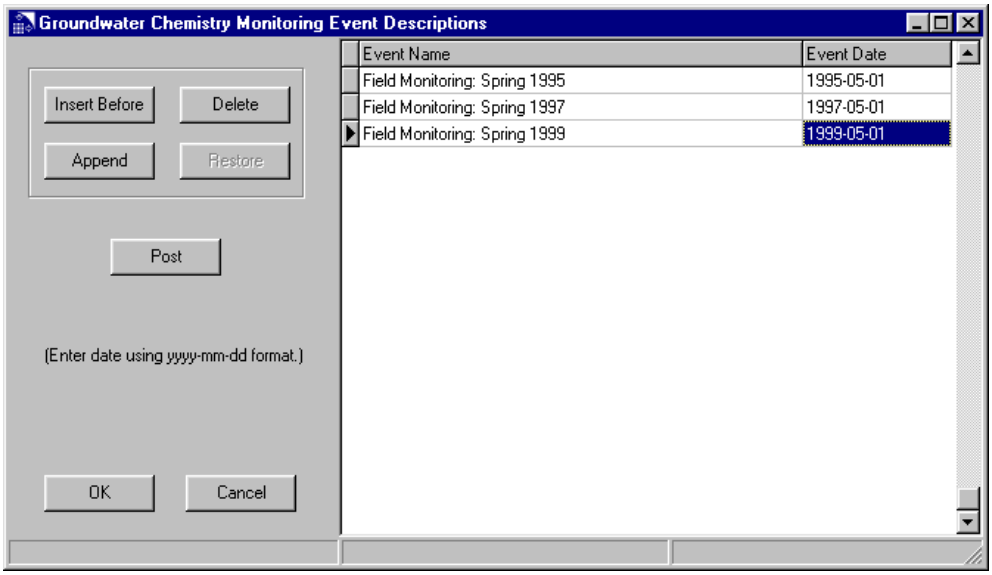
A **Groundwater Chemistry Monitoring Event Descriptions** dialogue window will appear (as shown in the following figure). You must enter the **Event Name** and **Event Date** for each field monitoring event.

Type **Field Monitoring: Spring 1995** (press **Tab**)
Type **1995-05-01**
☞ **Append** (to add another monitoring event)

Using the same steps, enter the remaining 2 monitoring events:

Field Monitoring: Spring 1997 **1997-05-01**
Field Monitoring: Spring 1999 **1999-05-01**

Your dialogue window should now appear as seen on the following page.



☞ **OK** (to accept these Monitoring Events)

2.3.4 Entering the Monitoring Data

Once you have defined the monitoring events, you can begin to enter the monitoring data. To begin,

☞ **Field Monitoring: Spring 1995** (from the list of **Monitoring Events**)
☞ **Edit Data** (from the bottom of the window)

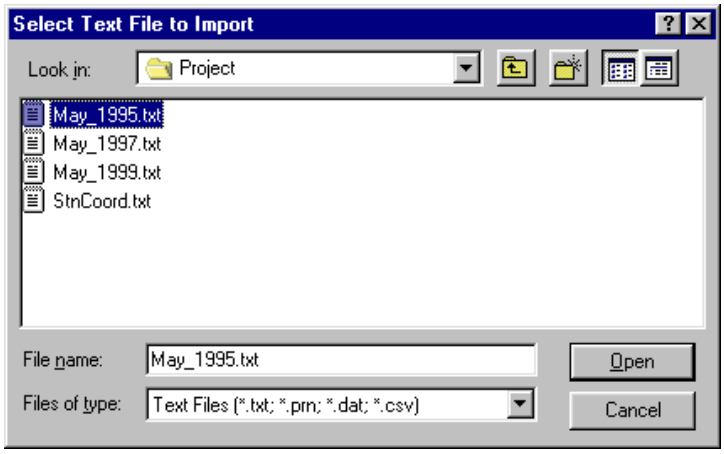
A **Field Monitoring: Spring 1995** window will appear allowing you to enter the chemical concentration for a selected chemical (**BTEX**) for each **Station** sampled during the monitoring event.

To begin, you can either manually type the monitoring results for each station, or you can import the data from an ASCII text file. For this exercise you will import the data from an ASCII text file.

☞ **Cancel** (to close the **Spring 1995** window)
☞ **Close** (to close the **Monitoring Events** window)

☞ **Project** (from the top menu bar)
☞ **Import** (from the pull-down menu)

☞ **May_1995.txt**



☞ **Open**

Use the **Text Import Wizard** to import the chemical concentrations for each Monitoring Event, for each of the Project Chemicals as follows.

Text Import - Step 1 of 4

Type 4 (**Start Import at row**)
☞ **Next -->**

Text Import - Step 2 of 4

☞ **Next -->**

Text Import - Step 3 of 4

Click the mouse inside the first column (it should now be highlighted) and then select **Monitoring Stations** from the Column Options frame. The Select Import Column field should indicate that Column 1 contains the Monitoring Station names.

Next, click the mouse in the second column (it should now be highlighted) and then select **Coordinates**. A pop-up window will prompt you to select the coordinate direction (Easting or Northing).

☞ **Easting**

Next, click the mouse in the third column (it should now be highlighted) and then select **Coordinates**.

☞ **Northing**

Next, click the mouse in the fourth column (it should now be highlighted) and then select **Chemical concentrations.** An Import Concentrations dialogue box will prompt you to select the associated Project Chemical, Monitoring Event, and Concentration Units. Select the following:

Chemical	**TCE**
Monitoring Round	**Field Monitoring: Spring 1995**
Concentration Units	**ug/L**

☞ **OK**

Repeat this for the remaining columns, changing the chemical name and units as listed below:

Column 5	**- DCE**	**(ug/L)**
Column 6	**- VC**	**(ug/L)**
Column 7	**- BTEX**	**(ug/L)**
Column 8	**- Cl**	**(mg/L)**
Column 9	**- O2**	**(mg/L)**
Column 10	**- NO3**	**(mg/L)**
Column 11	**- Fe2**	**(mg/L)**
Column 12	**- SO4**	**(mg/L)**
Column 13	**- CH4**	**(mg/L)**

☞ **Next -->**

Text Import - Step 4 of 4

☞ **Import** (to import the ASCII text data)
☞ **Start**
☞ **Accept**
☞ **OK**

Now go back to **Section 2.3.4**, and **REPEAT THESE STEPS** to import sampling data for the 2 remaining monitoring events (May_1997.txt, May_1999.txt).

2.3.5 Defining the Regional Data

The final step for setting up the SEQUENCE project is to define the Regional Data. The Regional Data is typically used to identify either background concentrations of each chemical, or to characterize the chemical concentrations at the source.

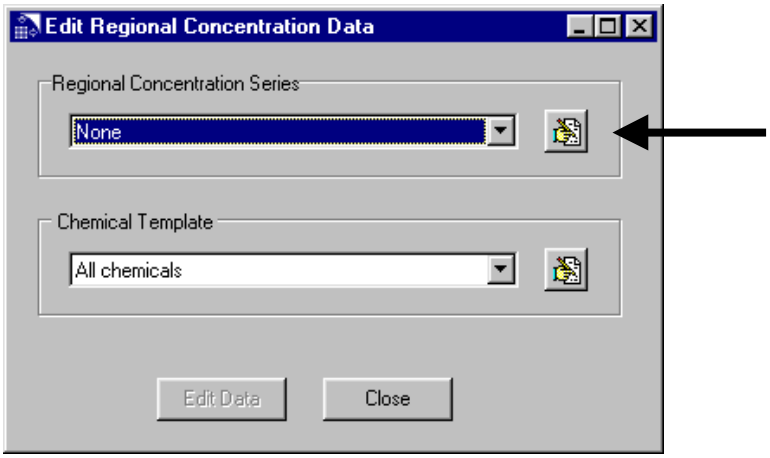
The background concentrations are used as reference values to determine whether the activities at the site have impacted the groundwater. If a chemical is detected in a groundwater sample from an on-site monitoring station with higher concentrations than the background values, it is a good indication that the elevated concentration is due to on-site activities.

The Source Area concentrations are also used as reference values to identify trends in the groundwater samples collected down-gradient of the source area.

To define the background concentrations for this project,

☞ **Chemistry** (from the top menu bar)
☞ **Regional Data** (from the pull-down menu)

An **Edit Regional Concentration Data** window will appear. This window contains a list of the Regional Concentration Series descriptions. Click the **Edit** button beside the **Regional Concentration Series** field,

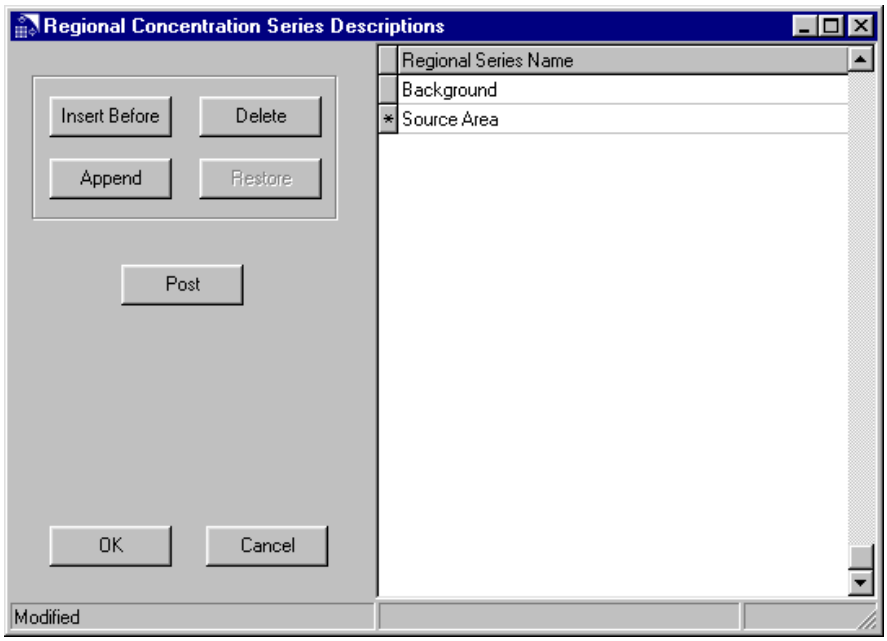


A **Regional Concentration Series Descriptions** window will appear.

Enter the following **Regional Series Names:**

Type Background (under Regional Series Name)
☞ **Append** (to enter another data series)

Type Source Area (under Regional Series Name)



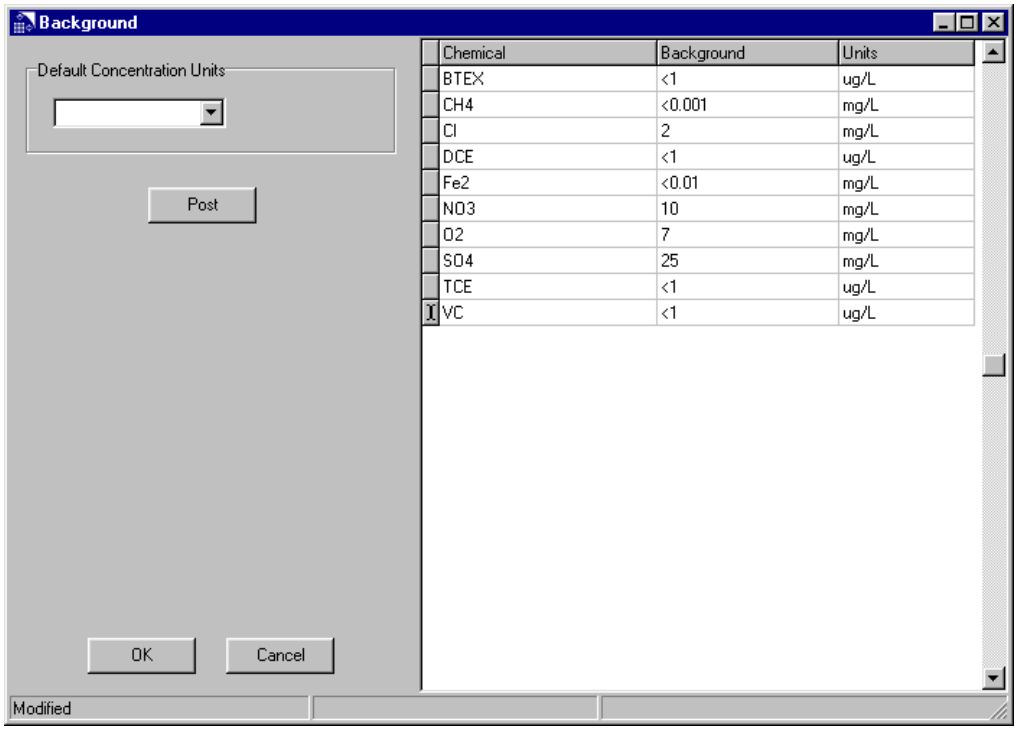
☞ **OK**

Next you will enter the Regional Concentration Data for the Background Series.

☞ **Edit Data**

A **Background** Regional Concentration Series window will appear as shown in the figure at the top of the following page. The Background concentrations are usually obtained by averaging the values from non-impacted monitoring stations located up-gradient of the contaminant source area.

Enter the Background concentration data as shown below.



☞ **OK**

Next, you will enter the Source Area Concentration values.

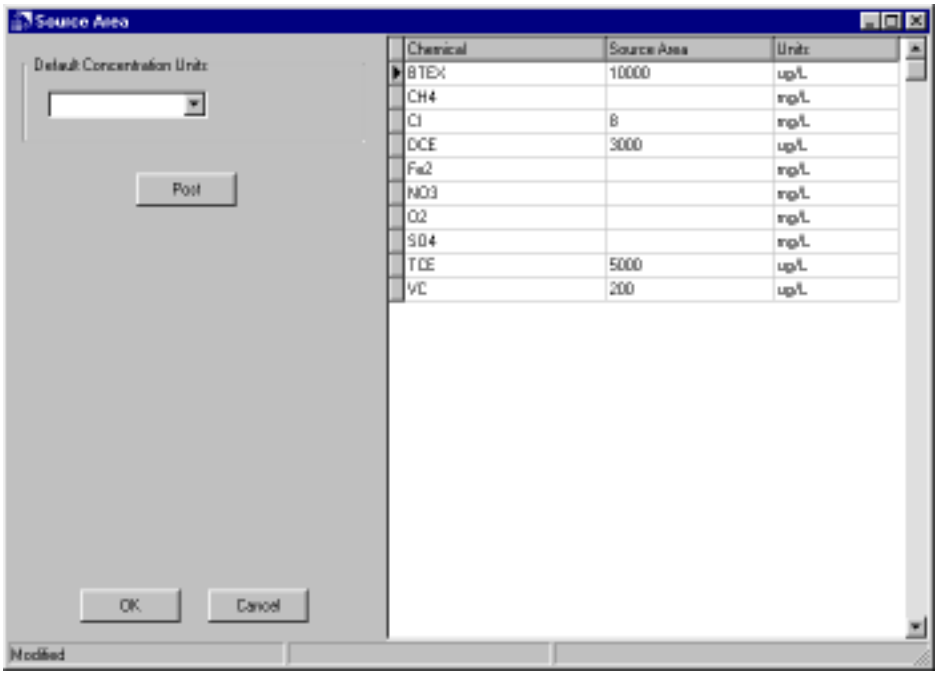
☞ **Source Area** (from the Regional Concentration Series pull-down menu)
☞ **Edit Data**

A **Source Area** Regional Concentration Series window will appear. The Source Area concentrations are usually obtained by averaging the values from impacted monitoring stations located within the contaminant source area.

Enter the following Source Area concentration data:

TCE	**5000**
DCE	**3000**
VC	**200**
Cl	**8**
BTEX	**10000**

Once you have enter the Background concentration values and your display appears as seen below,



☞ **OK**

☞ **Close** (to return to the SEQUENCE main menu)

Now you have completed the SEQUENCE project data files and you are ready to begin visualizing and evaluating the trends in the data using SEQUENCE CAH-BTEX maps and SEQUENCE Redox maps.

2.4 Creating SEQUENCE CAH-BTEX Maps

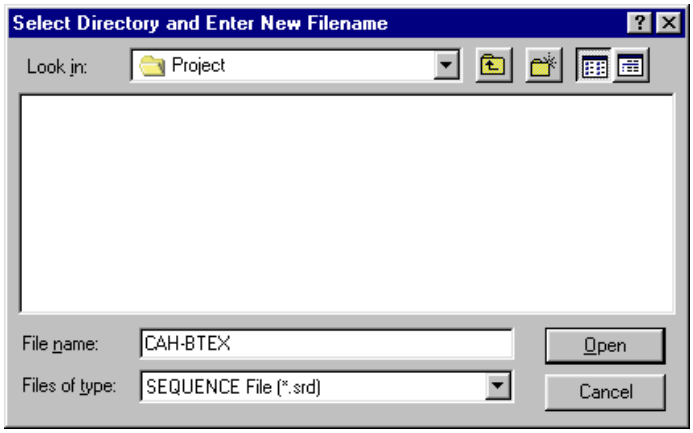
SEQUENCE CAH-BTEX maps are used to plot the spatial and temporal trends in the concentration of Chlorinated Aliphatic Hydrocarbons (CAHs) and BTEX compounds in groundwater. These trends serve as primary lines of evidence for evaluating the effectiveness of natural attenuation processes as a remedial alternative for contaminated groundwater.

To create a SEQUENCE CAH-BTEX map,

☞ **SEQUENCE** (from the top menu bar)
☞ **New** (from the pull-down menu)

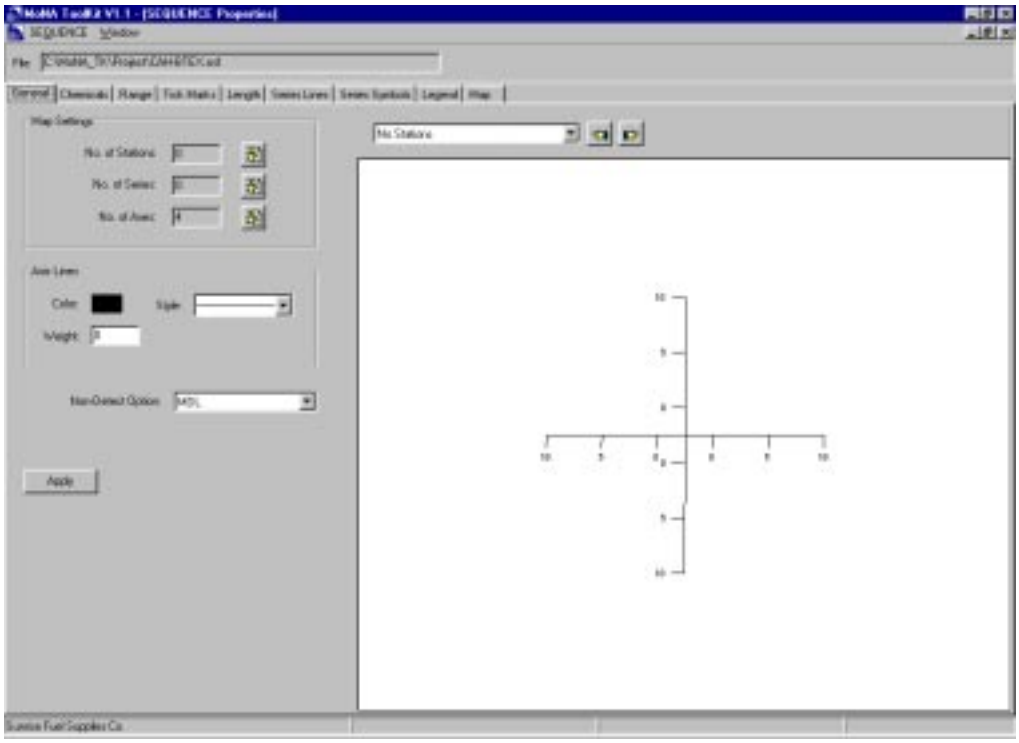
In the dialogue window that appears,

Type CAH-BTEX (in the **File name** field)



☞ **Open**

The SEQUENCE Radial Diagram Design window will appear as shown in the figure on the following page.



The various tabs across the top of the window allow you to design and customize the radial diagrams that will appear on the map. The default radial diagram starts with four axes, each scaled from a value of 0 near the origin to 10 at the end of each axes. There are no parameters associated any of the axes (yet).

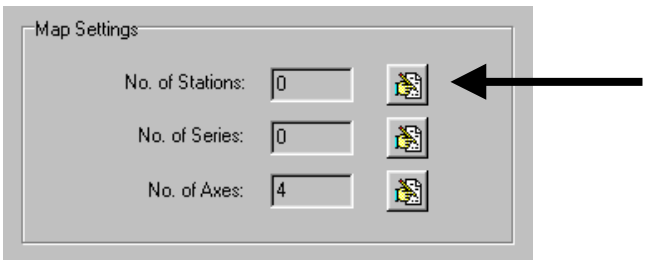
To begin designing the radial diagrams, you must:

(a) Identify the Monitoring Stations where the radial diagrams will be plotted
(b) Define the number of data series (Monitoring Events) to plot
(c) Specify the number of axes for the radial diagrams

2.4.1 Identifying the Monitoring Stations

To identify which monitoring stations to include in the radial diagram,

☞  (**Edit Monitoring Stations List** icon)

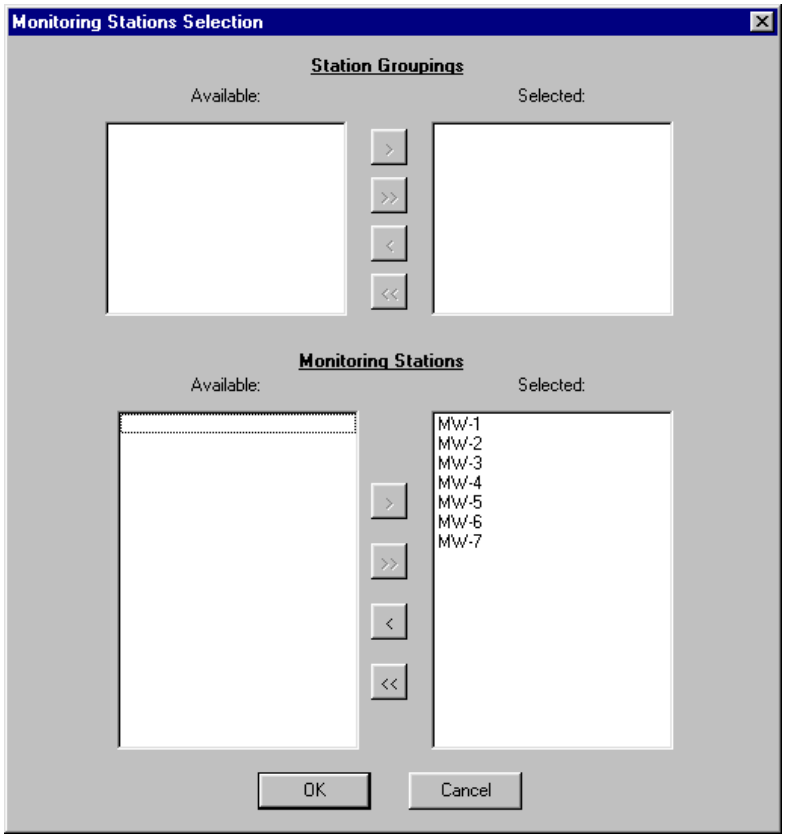


A **Monitoring Stations Selection** window will appear, which lists all of the available Monitoring Stations for each Station Template. Since there are no Station Templates for this project, all of the Monitoring Stations are listed by default.

For this exercise you will plot radial diagrams for all Monitoring Stations. To move all of the **Monitoring Stations** from the **Available** list to the **Selected** list,

☞ 

Your dialogue window should now appear as seen below:

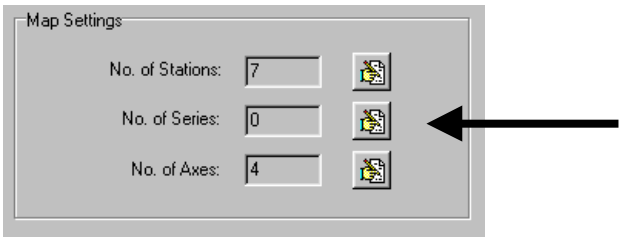


☞ **OK**

2.4.2 Defining the Number of Data Series (Monitoring Events)

To define the number of data series to plot in the radial diagram,

☞  (**Edit Series List** icon)



A **Data Series Selection** window will appear with 2 lists to choose from:

1. **Regional Concentration Series** list
2. **Station Monitoring Events** list.

For the SEQUENCE CAH-BTEX maps you only need to select the 3 Station Monitoring Events. To move all of the **Station Monitoring Events** from the **Available** list to the **Selected** list,

☞ 

Your dialogue should appear as seen below:

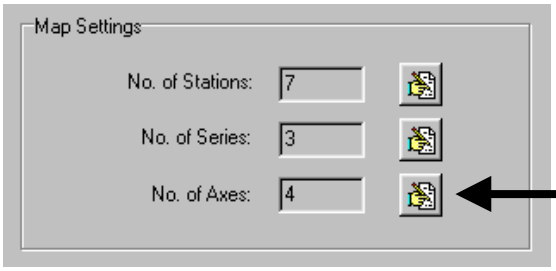


☞ **OK**

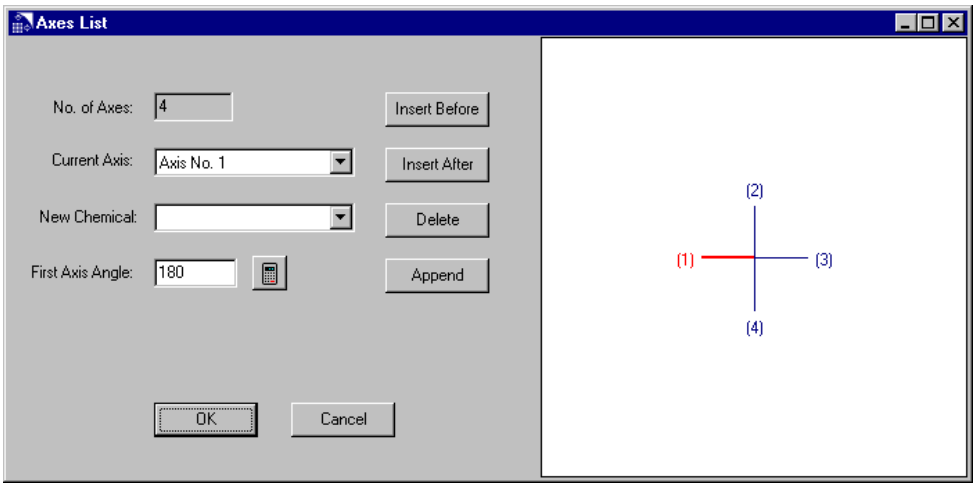
2.4.3 Specify the Number of Axes

To define the number of axes in the radial diagram,

☞  (**Edit Axes List** icon)



An **Axes List** window will appear. Click your mouse on the radial diagram axis labeled **(1)**. The red color of the axis indicates it is the active axis.



Next, choose a Project Chemical to plot on this axis from the **New Chemical** list.

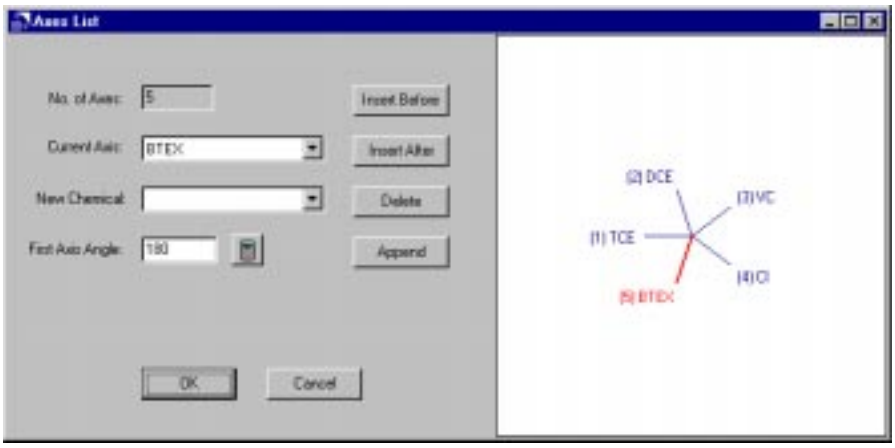
For **Axis No. 1,** choose **TCE**
For **Axis No. 2,** choose **DCE**
For **Axis No. 3,** choose **VC**
For **Axis No. 4,** choose **Cl**

Finally, to add BTEX to the radial diagram you must **INSERT** an additional axis. Click on the axis labeled **(Cl),**

☞ **Insert After**

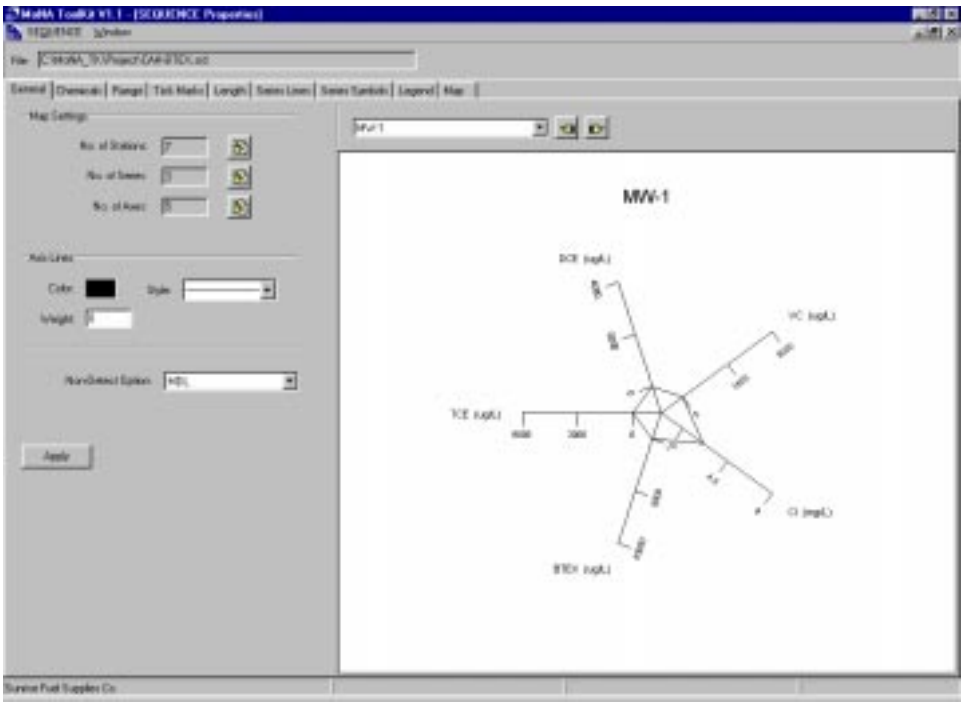
For **Axis No. 5,** choose **BTEX**

Your **Axes List** should appear identical to the figure below:



☞ **OK** (to return to the Radial Diagram Design window)

A radial diagram will appear in the Radial Diagram Design window as shown in the figure below. SEQUENCE will automatically search the project database to determine the default minimum and maximum values for each axis.



The default setting is to display the radial diagram for the first monitoring station in the list. To view the radial diagram for a different monitoring station, select any of the seven monitoring stations from the dropdown list above the radial diagram

Note: MW-3, MW-5 and MW-6 are the most interesting radial diagrams.

2.4.4 Customizing the Appearance of the Radial Diagrams

To customize the scale of the individual axes and the minimum and maximum values for each axis,

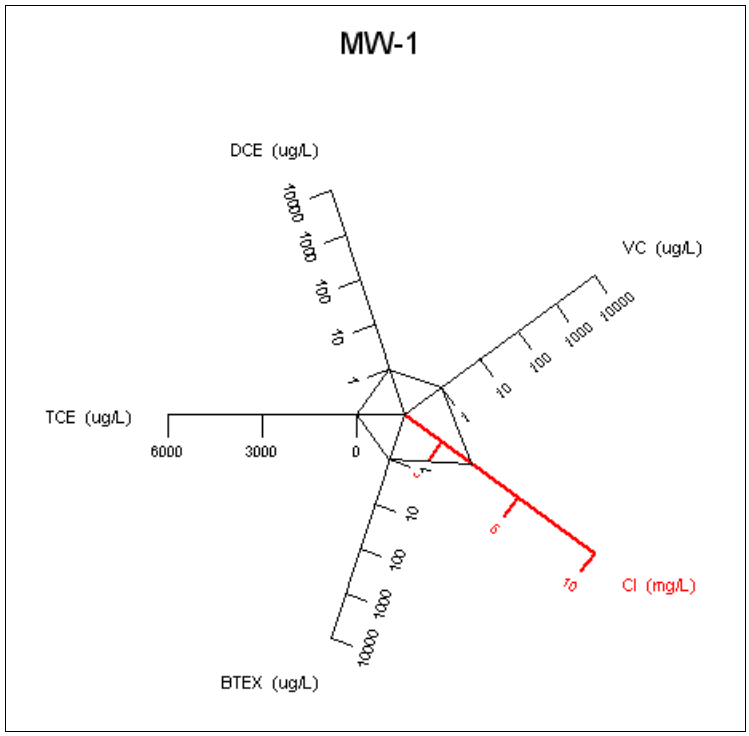
☞ **Range** tab (to switch from the **General** tab)

For the SEQUENCE CAH-BTEX maps, it is usually best to choose a log-scale for the organic chemicals due to the large contrast in values from one station to the next, and from one monitoring event to the next.

Set the axis scale to Log-Scale for each of the organic chemicals (**TCE**, **DCE**, **VC** and **BTEX**).

Use the default settings for the minimum and maximum values for each of these axes. However, change the **Maximum Value** for **Cl** to **10** (from the default value of **9**).

When you have finished making these changes, the radial diagram should appear as seen in the figure below:



Next, you will customize the appearance of the series lines in order to distinguish between each of the Monitoring Events at each Monitoring Station.

☞ **Series Lines** tab (to switch from the **Range** tab)

These options allow you to customize the line color, type and thickness for each data series. The default data series selection should be **Field Monitoring: Spring 1995**.

To change the color of the line representing the **Field Monitoring: Spring 1995** event,

☞ in the black box labeled **Color**

From the **Color** window that appears, select **blue** (any shade).

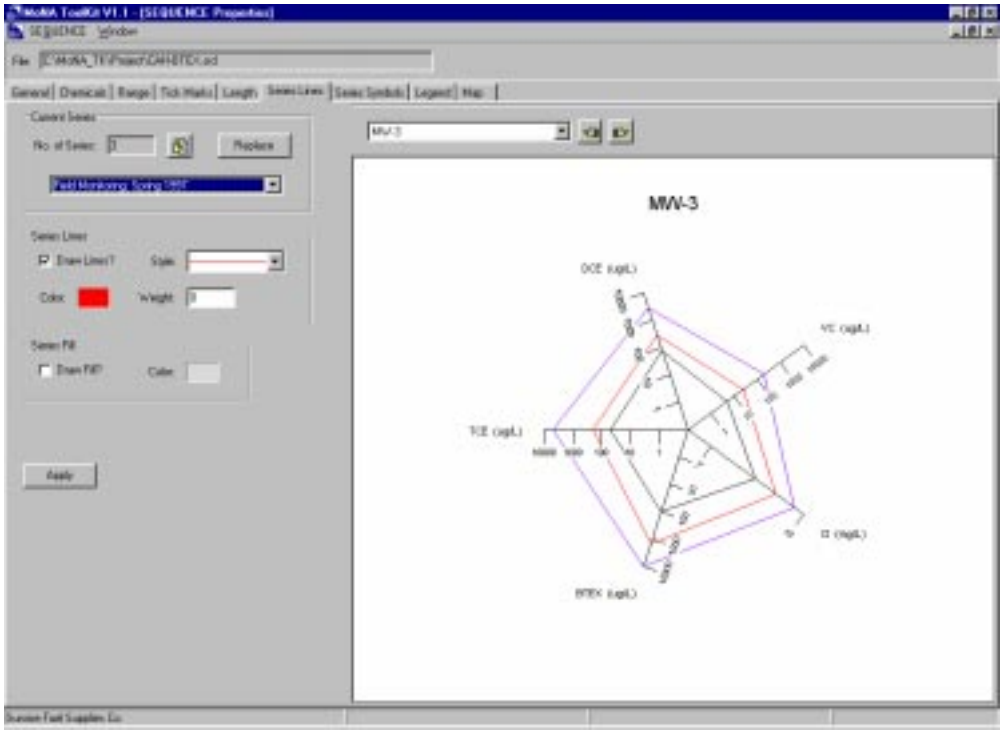
☞ **OK**

Now, you will change the color of the line representing the **Field Monitoring: Spring 1997** event.

☞ **Field Monitoring: Spring 1997** (from the list of data series)

Change the color of the line to **red**.

To see an example of how the radial diagram now looks, view the radial diagram for **MW-3**. It should look similar to the following figure.



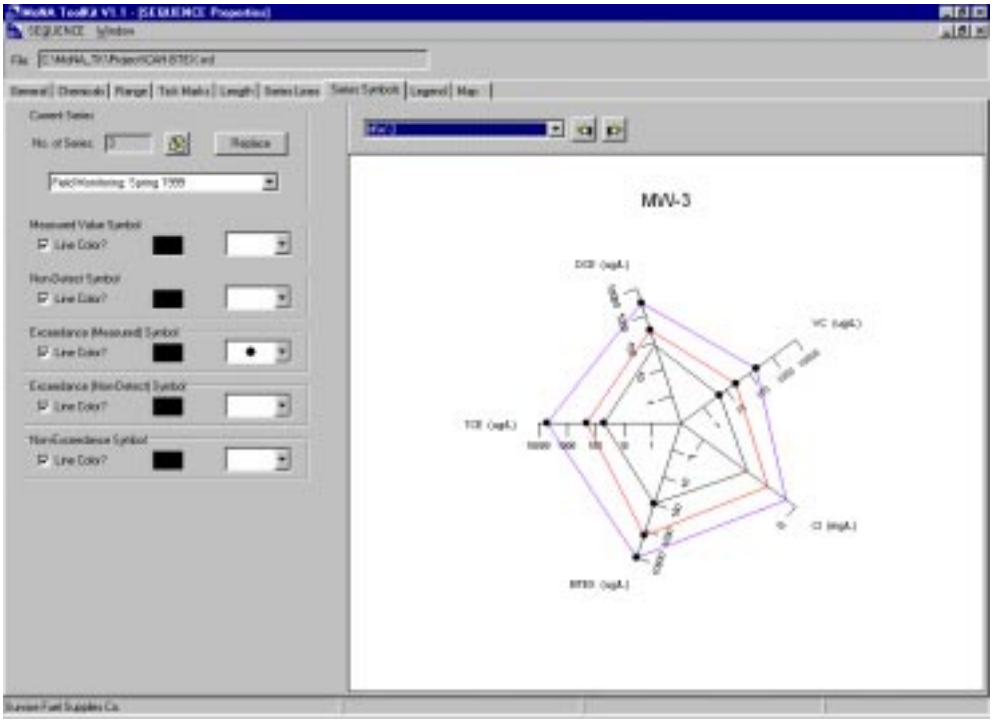
This single radial diagram clearly shows decreasing trends in the concentrations of five (5) different chemicals during three successive monitoring events.

Next, you will customize the appearance of the markers indicating where MCLs are exceeded.

☞ **Series Symbols** tab (to switch from the **Series Line** tab)

For each data series, select an **Exceedence (Measured) Symbol**. These symbols will be plotted on each radial diagram on the base map to indicate measured chemical concentrations exceeding the MCLs for that chemical.

For the figure below, the same symbol was selected for each monitoring event, as well as the same color (black, closed circle). You may select any symbol or color you wish.

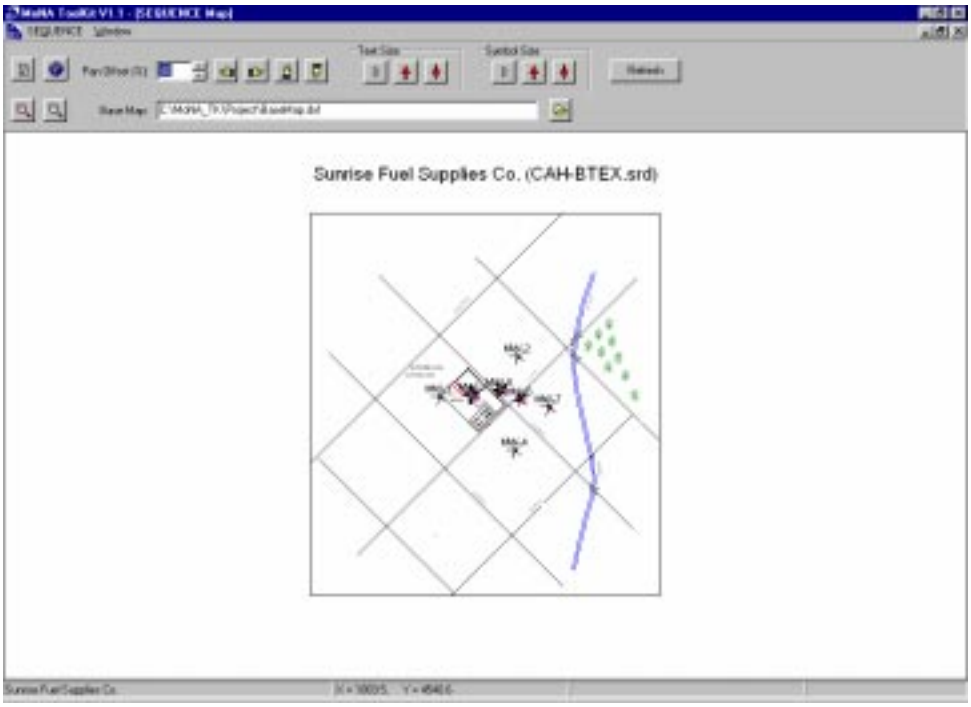


2.4.5 Plotting a SEQUENCE CAH-BTEX Map

Once the radial diagrams have been customized to your liking, you can plot a map view of the radial diagrams for each monitoring station.

☞ **SEQUENCE** (from the top menu bar)
☞ **Map** (from the pull-down menu)

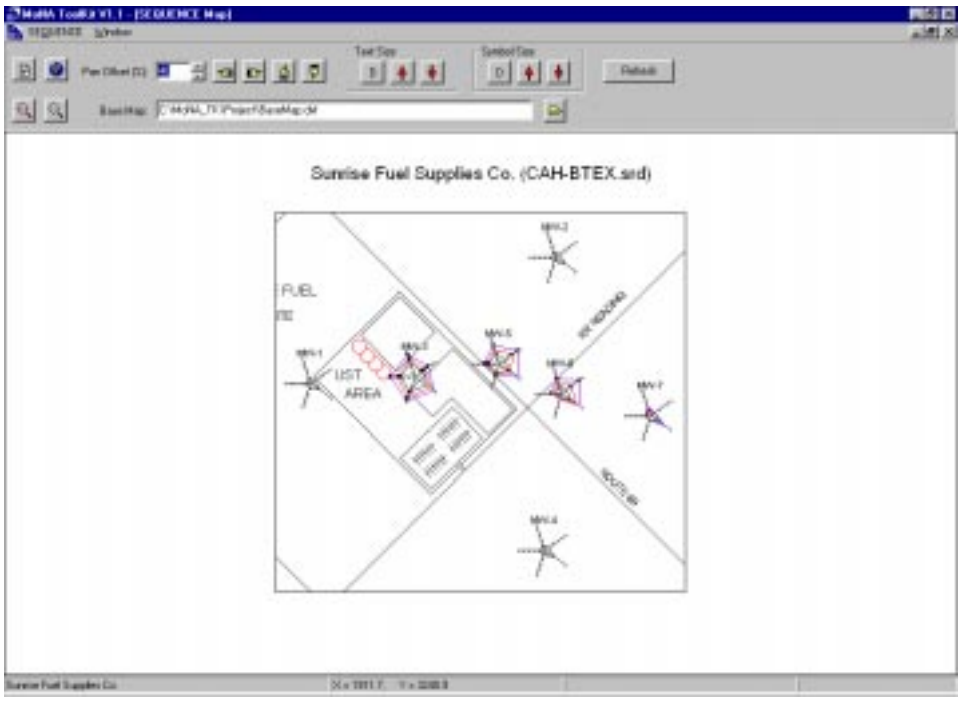
A map view of the site will be plotted with radial diagrams at each monitoring location as shown in the figure on the following page.



To zoom in on the area of interest,

☞  (**Zoom in** icon from the top menu bar)

Using the **left** mouse button, stretch a window that encompasses the radial diagrams and then **release** the mouse button. Your display should appear similar to the figure below:

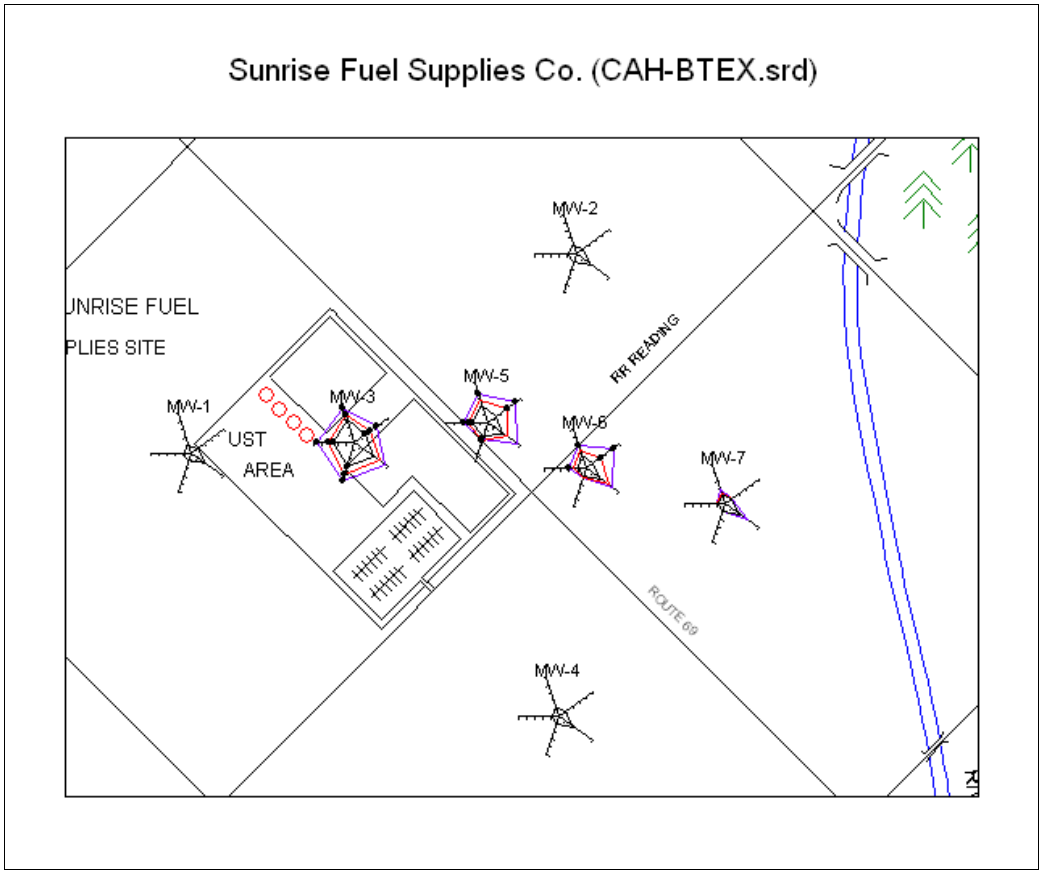


A closer look at the SEQUENCE CAH-BTEX map clearly shows;

(1) Decreasing concentration trends with time for the three monitoring events

(2) Decreasing concentration trends with distance from the source zone for the three down-gradient Monitoring Stations (MW-5, MW-6 and MW-7)

These two observations provide convincing evidence that natural attenuation processes are effective acting to remediate the contaminated groundwater from site.



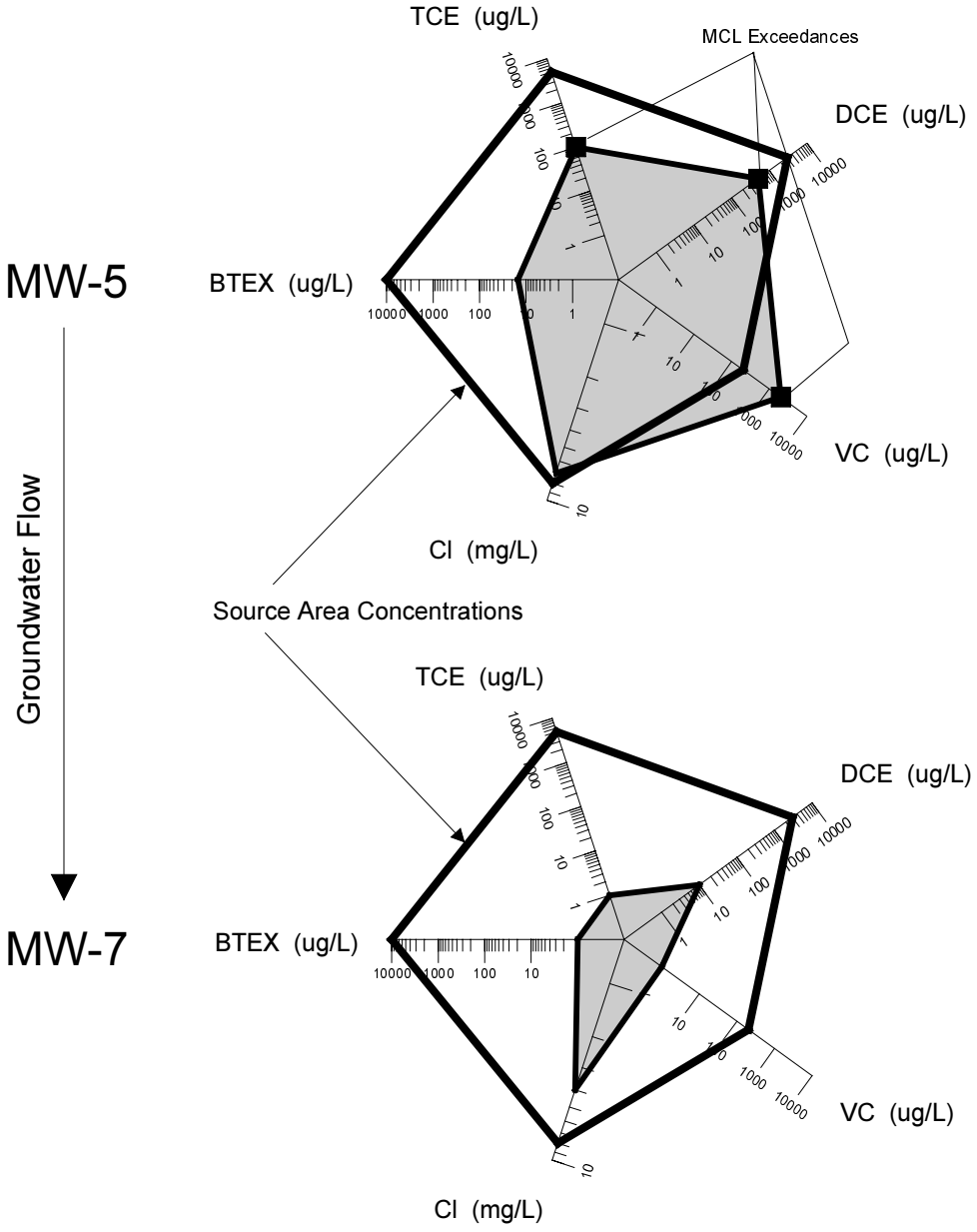
3.0 Discussion of Results

As discussed in Section 1.2, the following are potential lines of evidence that would support the efficacy of Monitored Natural Attenuation as a remedy for the site:

- a reduction in contaminant concentrations over time (i.e. BTEX, TCE, DCE, and vinyl chloride) provides primary lines of evidence for the natural attenuation of each contaminant → temporal trend analysis
- the presence of daughter products of TCE (e.g. DCE and vinyl chloride) provide secondary evidence for the biodegradation of TCE → spatial trend analysis
- evidence of BTEX biodegradation must exist to confirm that a sufficient supply of carbon is present to support the reductive dechlorination of the chlorinated ethene compounds → spatial and temporal trend analyses
- changes in redox indicator concentrations (i.e. decreasing electron acceptor concentrations, increasing metabolic by-product concentrations) provides secondary evidence that biodegradation of BTEX is occurring → spatial trend analysis

The figure on the previous page provides an example of SEQUENCE-BTEX/CAH radial diagrams that illustrate spatial trends for BTEX, and for the parent and daughter products of biodegradation for the chlorinated ethene compounds.

The radial diagrams shown in the following figure represent the 1995 BTEX, TCE, DCE, vinyl chloride, and chloride concentrations measured at MW-5 and MW-7 (both situated down-gradient from the source area).



Parent-Daughter Product Spatial Trends (1995)

A second data series has been added to both radial diagrams, to show the concentrations for each chemical that were measured in the source area monitoring well MW-3. By showing both sets of data series on the radial diagram, it is a simple matter to see how the parent and daughter product ratios are changing with distance down-gradient from the source area.

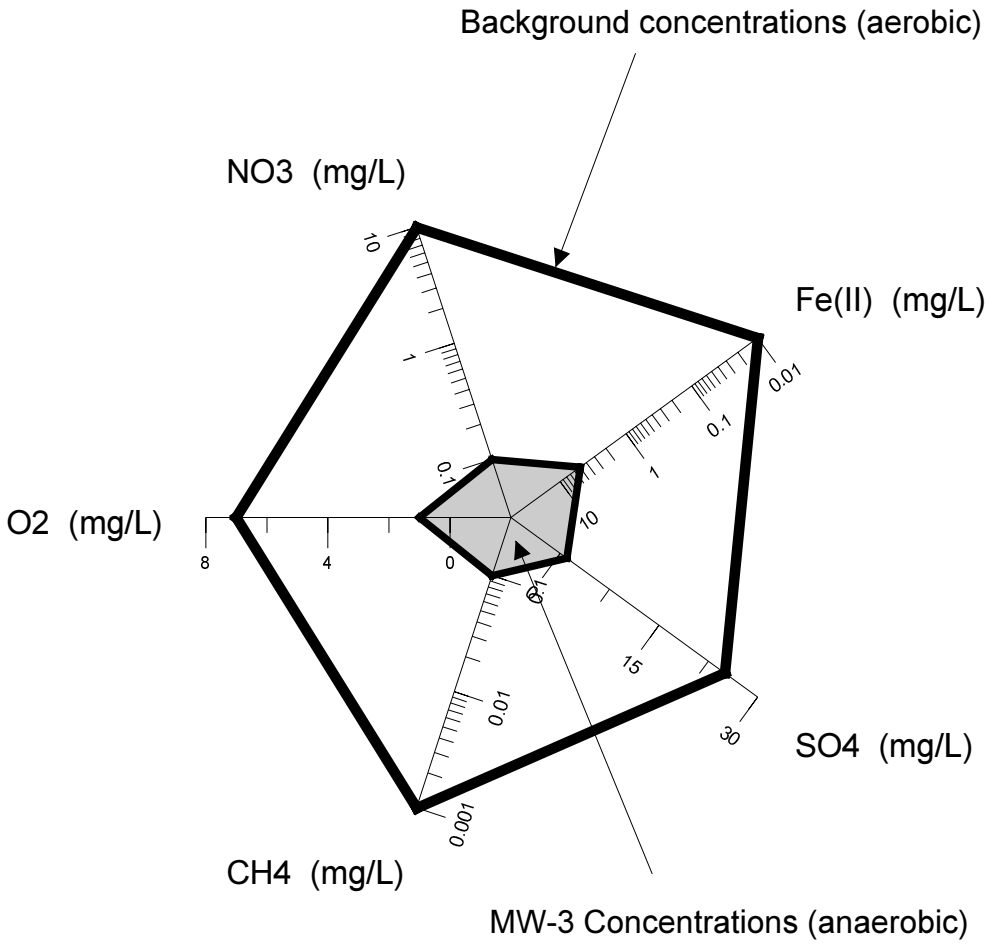
For example, the SEQUENCE-BTEX/CAH radial diagram for monitoring well MW-5 shows that TCE and DCE concentrations are both decreasing, and that vinyl chloride concentrations have increased downgradient from the source area. These trends confirm that both TCE and DCE are being attenuated (through dispersion, dilution, and/or biodegradation). The increasing concentrations of vinyl chloride provide evidence that at least the DCE is undergoing biodegradation between the source area and monitoring well MW-5. The fact that the initial source consisted of only TCE, and the presence of DCE in groundwater, indicates that TCE is also undergoing biodegradation reactions.

The obvious concern with the natural attenuation of chlorinated solvents is the production of potentially harmful daughter products such as DCE and vinyl chloride. In this case, we see by comparison of the radial diagrams for monitoring wells MW-5 and MW-7 that vinyl chloride concentrations decrease significantly between these two wells, indicating that this compound is also being effectively attenuated through dispersion, dilution, and/or biodegradation reactions.

We can also see from these radial diagrams that chloride concentrations are decreasing down-gradient from the source area, indicating that dispersion and/or dilution are contributing to the natural attenuation of the site chemicals.

Another benefit is that radial diagrams also allow us to evaluate the available supply of carbon source (i.e. BTEX) at the same time that we are evaluating the natural attenuation of the chlorinated solvents. Visualizing these trends with the radial diagrams allows facilitates the data evaluation, and provides an important advantage over other analysis methods such as the comparison of tabulated data.

The following figure presents the SEQUENCE-Redox diagram for monitoring well MW-3 (source area). The SEQUENCE-Redox diagram provides a simple approach for clearly demonstrating that BTEX biodegradation is occurring in the source area. The dramatic changes in redox indicator concentrations indicate that conditions are strongly anaerobic (i.e. reducing) in the source area, and that background concentrations are aerobic in nature. The strong reducing conditions are favorable for the biodegradation of the chlorinated ethene species also, as discussed in Section 1.2.2.



SEQUENCE-Redox Diagram for Source Area (MW-3, 1995)

4.0 Using BioTrends

4.1 Learning Objectives

The objectives of this exercise are to use BioTrends to:

- evaluate the change in chemical concentrations both spatially (concentration vs. distance) and temporally (concentration vs. time), and
- use the Buscheck and Alcantar method to determine chemical biodegradation rates.

4.2 Starting a BioTrends Analysis

If you are beginning a BioTrends analysis from a saved SEQUENCE project,

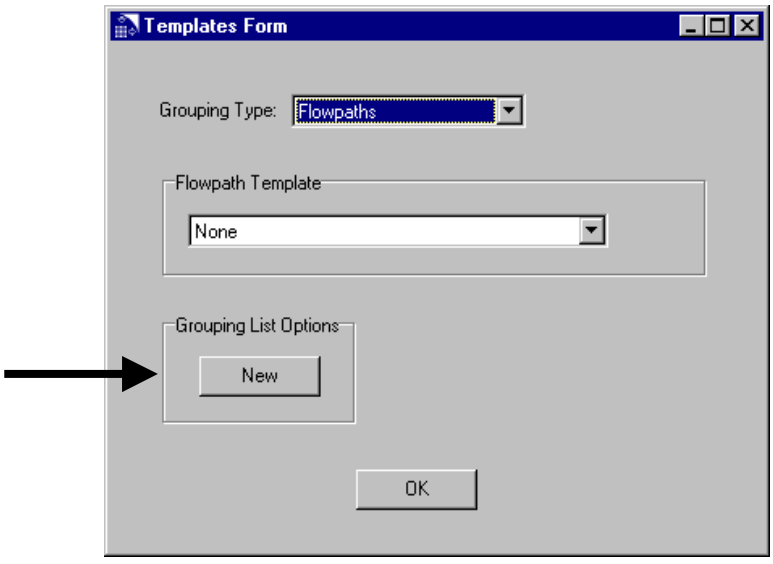
☞ **Project** (from the top menu bar)
☞ **Open** (from the pull-down menu)
☞ **sunrise.prj**
☞ **Open**

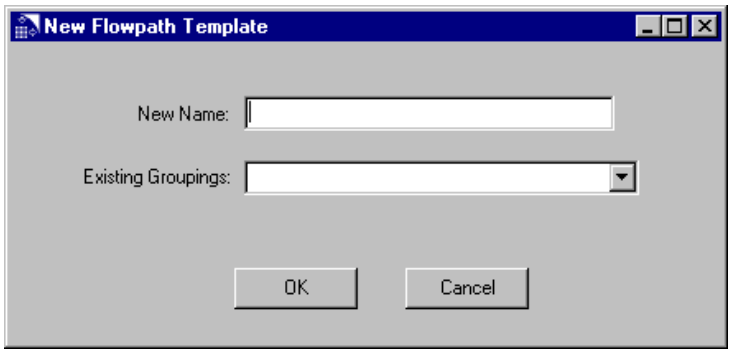
This will bring you into the Project Database screen.

4.3 Defining a Flowpath

To start a BioTrends analysis, the first thing that must be defined is a flowpath along which any calculations will be performed.

☞ **BioTrends** (from the top menu bar)
☞ **Flowpaths**
☞ **New**





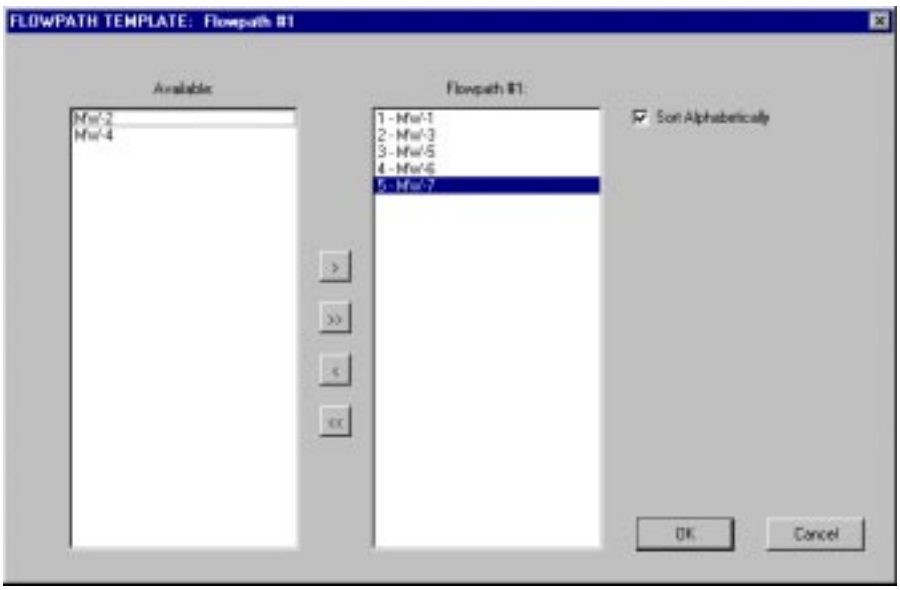
Type **Flowpath #1** (in the Name field)

☞ **OK**

From the list of available wells, select MW-1 followed by the icon. This will move the well from the **Available** list into the **Flowpath #1** list.

Repeat this procedure for wells: OW-3
OW-5
OW-6
OW-7

Once completed, your display should appear as seen below:



☞ **OK** (to close the **Flowpath #1** window)
☞ **OK** (to close the **Templates Form** window)

You have now defined a flowpath through the site that extends from MW-1 to MW-7.

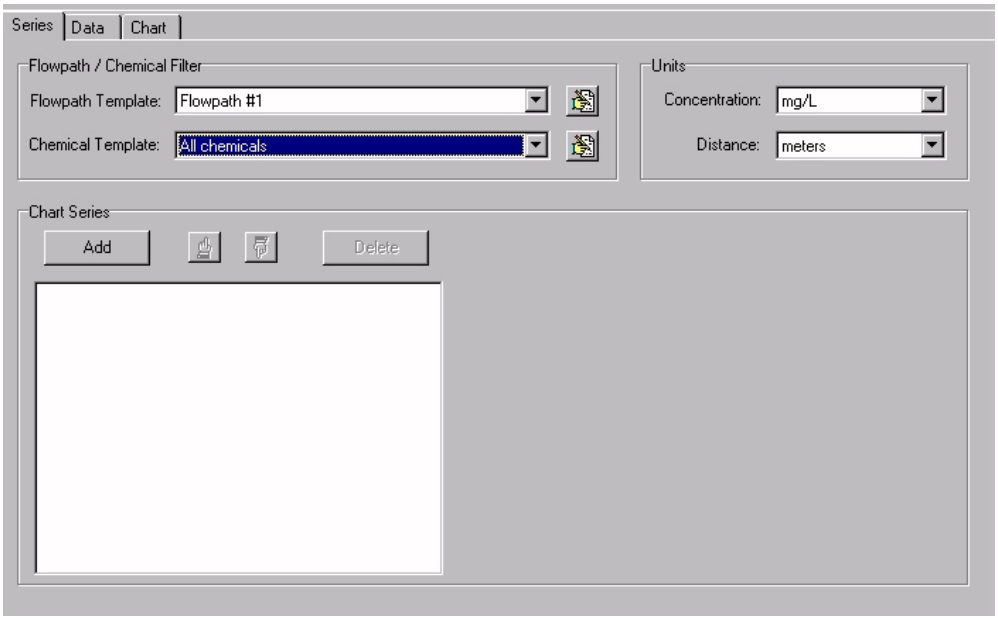
Next you are going to analyze spatial trends in chemical concentration.

4.4 Analyzing Spatial Trends in Concentration

☞ **BioTrends** (from the top menu bar)
☞ **C vs. X Trends** (from the pull-down menu)

This will take you into a **C vs. X** window where you can define the parameters of the concentration versus distance analysis.

The first thing to note is that there are 3 tabs at the top of the C vs. X window: **Series**, **Data** and **Chart** tabs. Under the **Series** tab, we will be defining the monitoring events to be analyzed.

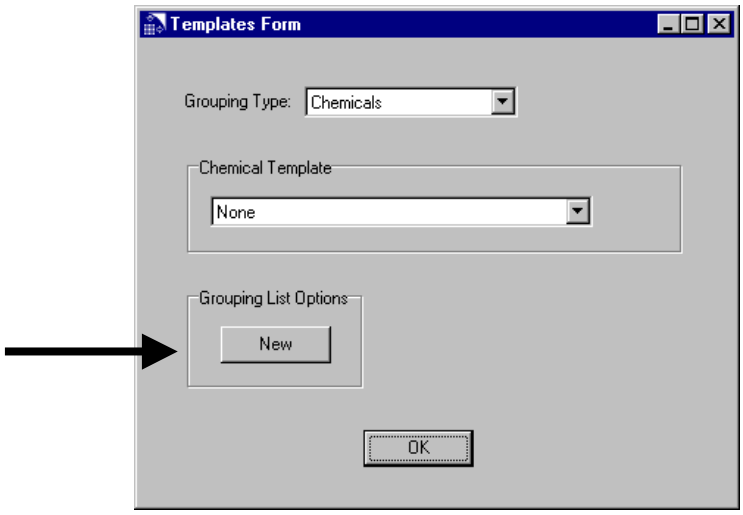


The existing flowpath (**Flowpath #1**) that we just defined is the default flowpath listed under the **Flowpath Template**. You may edit the current flowpath, or define new ones using the edit button for this template.

Let's choose to analyze the VOCs in the 1995 Field Monitoring event. In order to make it easier to pick from the complete chemical list, we will define a Chemical Template containing the necessary chemicals.

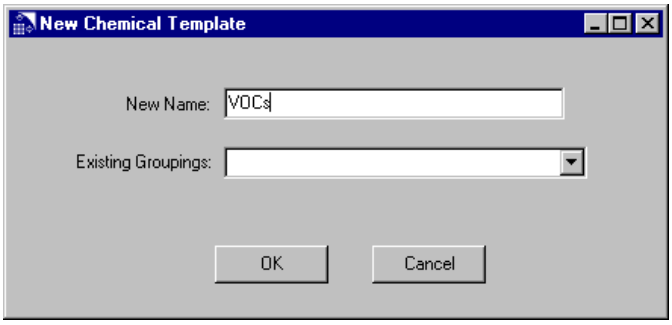
Click the edit button to the right of the **Chemical Template** field.

☞ **New**

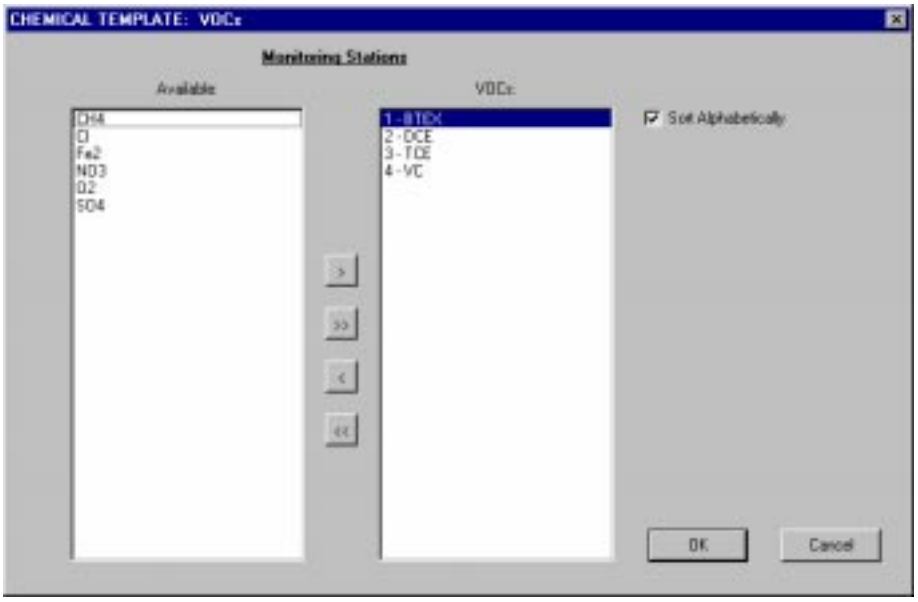


In the **New Chemical Template** window that appears,

Type **VOCs** (in the **New Name** field)



Choose TCE, DCE, VC and BTEX for this chemical grouping.

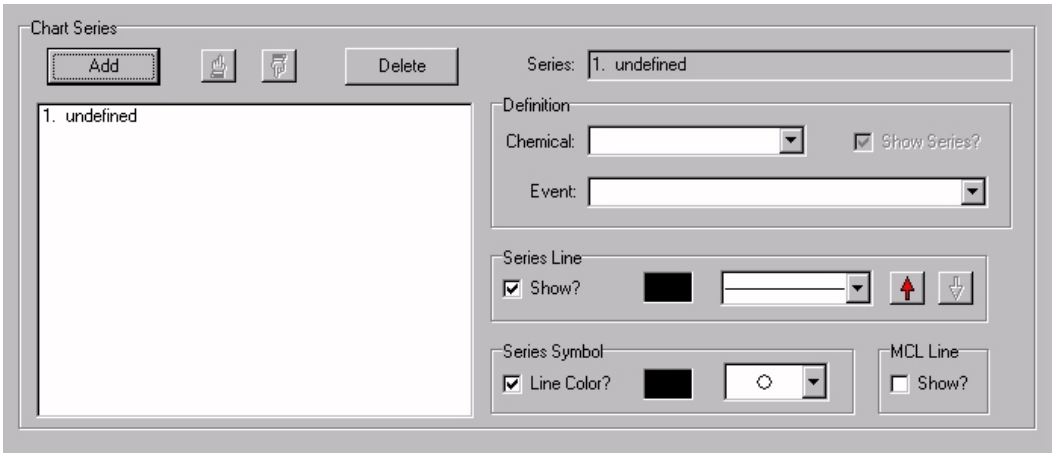


☞ **OK** (to close the **Chemical Template** window)
☞ **OK** (to close the **Template Form** window)

Then, under Chemical Template choose VOCs as the template for analysis.

Now, we are going to add several Series to the Chart.

☞ **Add** (from the Chart Series window)



A new series will be added as **1. undefined**

Under **Definition** we must choose a **Chemical** and an **Event**.

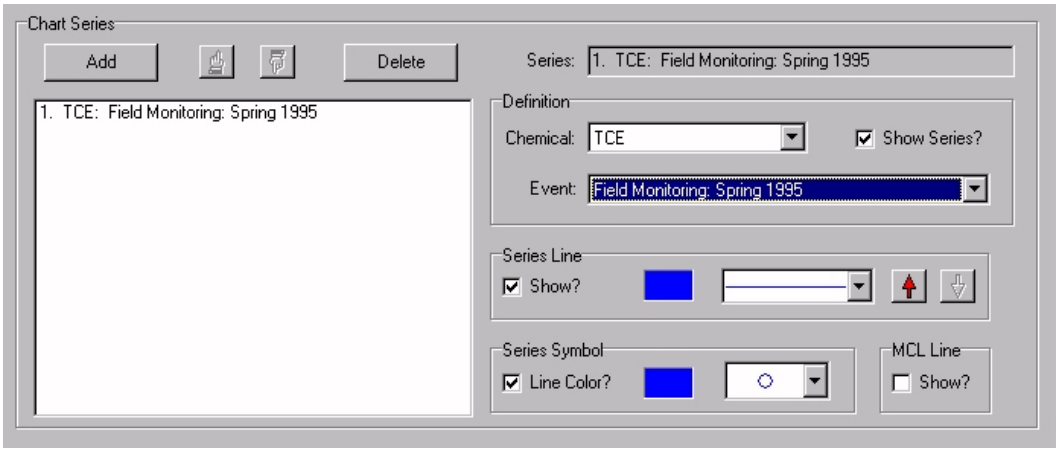
☞ **Chemical**
☞ **TCE**

Note that the only chemicals available are the VOCs that were defined in the Chemicals Template.

☞ **Event**
☞ **Field Monitoring: Spring 1995**

Under Series Line in the Color Box choose **Blue.**

This will produce the following window:



☞ **Add** (to add another series to the **Chart Series**)

Repeat these steps choosing:

- **DCE** **Field Monitoring: Spring 1995** **Red**
- **VC** **Field Monitoring: Spring 1995** **Green**
- **BTEX** **Field Monitoring: Spring 1995** **Mustard**

We are now ready to check the **Data** and look at the **Chart**.

Check the data by clicking on the **Data** tab.

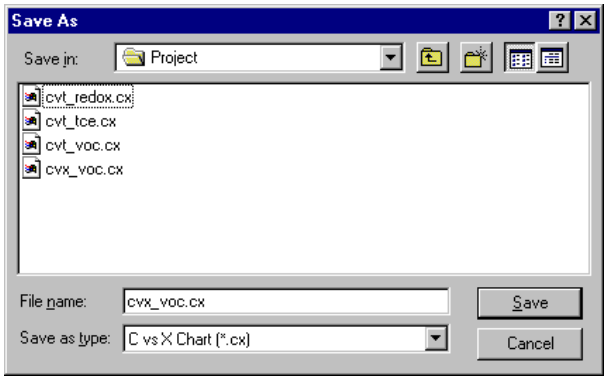
☞ **Data**

This will show a table of Monitoring Points and Events. This can also be exported to an external text file (**File/Export Table**) for further analysis.

At this point it is appropriate to save these results as a C vs. X file.

☞ **File**
☞ **Save**

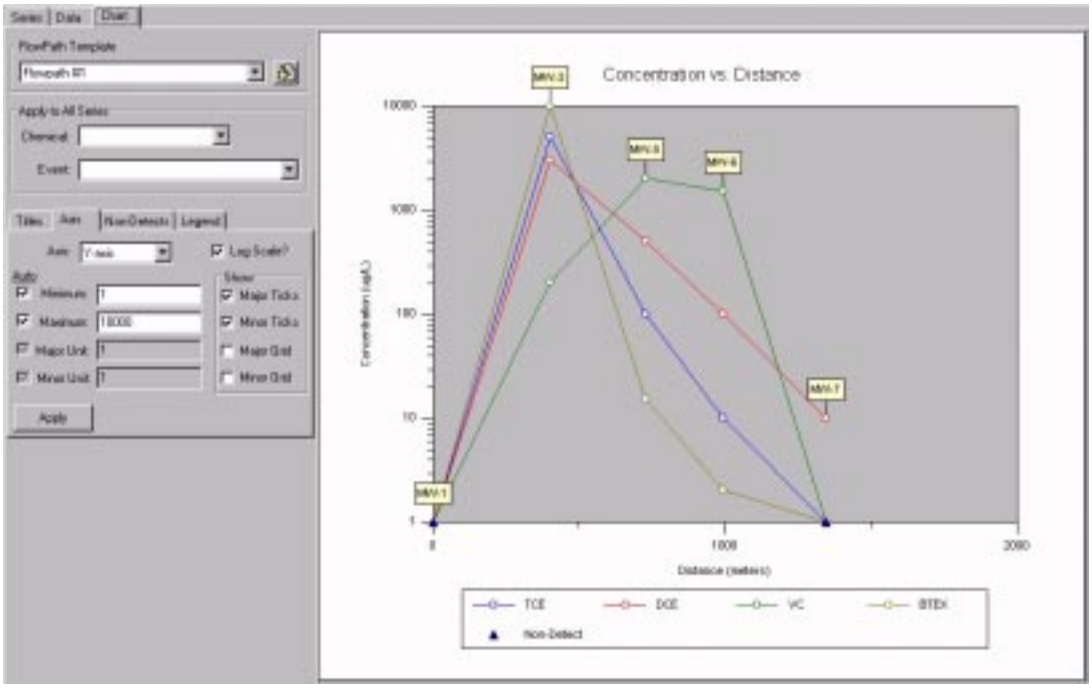
Type **cvx_voc**



☞ **Save**

Now, click on the **Chart** and view the concentration versus distance trends.

☞ **Chart** tab



We can interpret a number of points from this chart:

- MW-3 is near the source area, and there are high concentrations of TCE, DCE and BTEX in this well
- the concentrations of TCE and DCE reduce downgradient of MW-3 (loss of parent species)
- the concentration of BTEX reduces downgradient MW-3 (used as a carbon source)
- VC is produced downgradient of MW-3 (production of a daughter product)

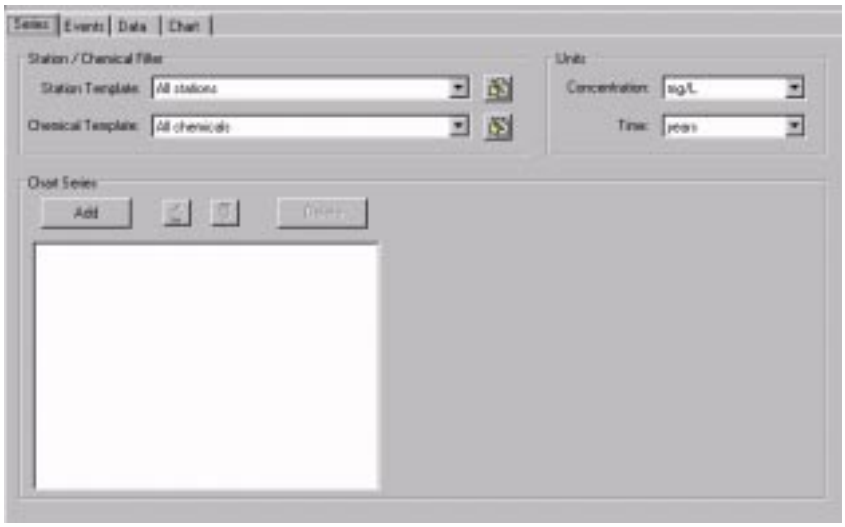
Now we can go on to analyze some temporal trends in the data.

4.5 Analyzing Temporal Trends in Concentration

☞ **Biotrends** (from the top menu bar)
☞ **C vs. T trends** (from the pulldown menu)

An initial window similar to the one for C vs. X appears. There are 4 tabs at the top of the C vs. T window: **Series**, **Events**, **Data** and **Chart** tabs.

Under the Series tab we will be defining the monitoring events to be analyzed. Let's look at TCE and DCE, at MW-3 and MW-6, for the three monitoring events.



☞ **Add**

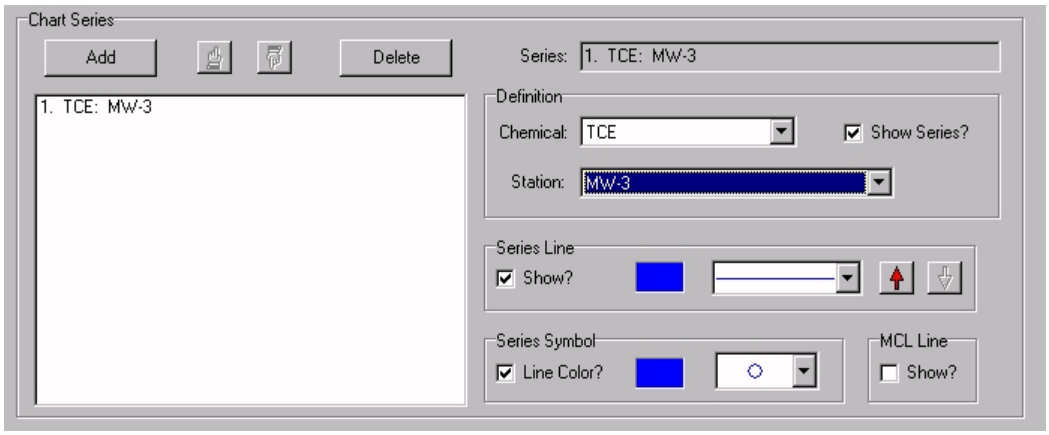
A new series will be added as **1. undefined**

Under **Definition** we must choose a **Chemical** and a **Station**.

☞ **Chemical**
☞ **TCE**
☞ **Station**
☞ **MW-3**

Under Series Line in he Color Box choose **Blue**

This will produce the following window:



☞ **Add** (to add another chemical to the **Chart Series**)

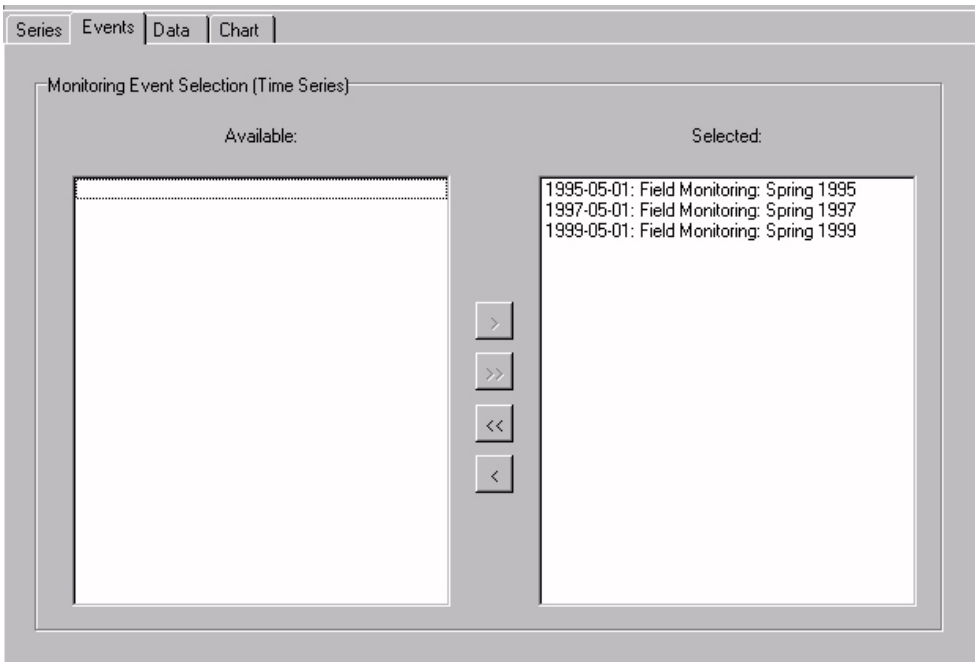
Repeat these steps choosing:

- **DCE** **MW-3** **Blue**
- **TCE** **MW-6** **Red**
- **DCE** **MW-6** **Red**

We are now ready to define the events to be analyzed.

☞ **Events** tab

Choose all three monitoring events (1995, 1997, and 1999).



You can now check the data by clicking on the Data tab.

☞ **Data** tab

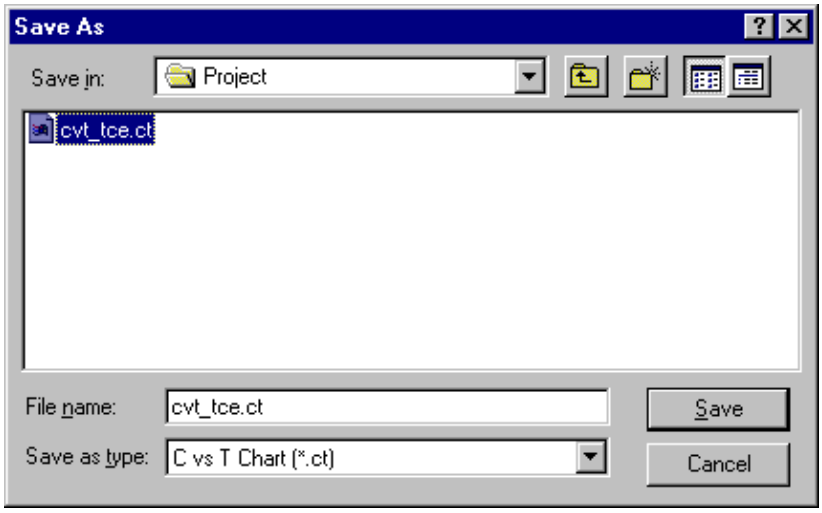
This will show a table of Monitoring Points and Events. This can also be exported to an external text file (**File/Export Table**) for further analysis.

Check to see that the units are in **ug/L**.

If they are not, click the current units and select ug/L from the list that appears. As you will see, the values in the table are updated automatically when you change units. However, the units field (ug/L) is only refreshed by switching tabs.

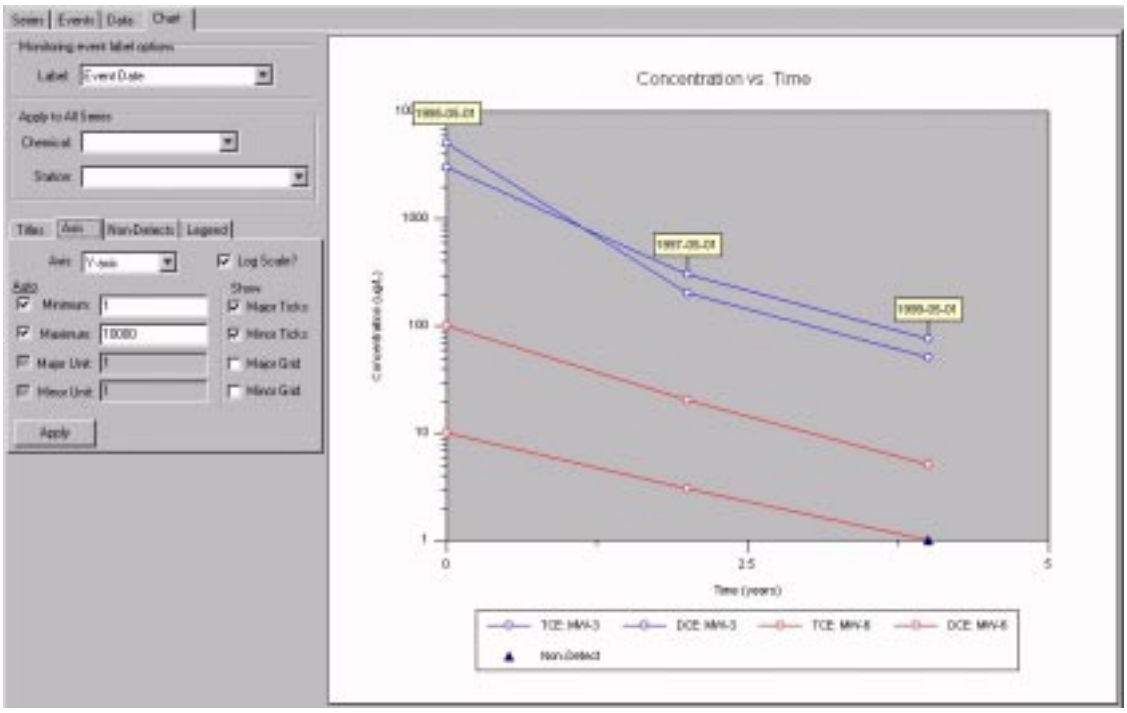
At this point, it is appropriate to save these results as a C vs. T file.

☞ **File**
☞ **Save**
☞ **cvt_tce.ct**



☞ **Save**

Now, click on the **Chart** and view the concentration versus time trends.



We can interpret a number of points from this chart:

- at both stations we see reductions in TCE & DCE concentration over time
  - MW-3 lines are **blue**
  - MW-6 lines are **red**
- degradation rates are similar between the two chemicals

However, what are the quantitative values of biodegradation? We will answer this question in the next section.

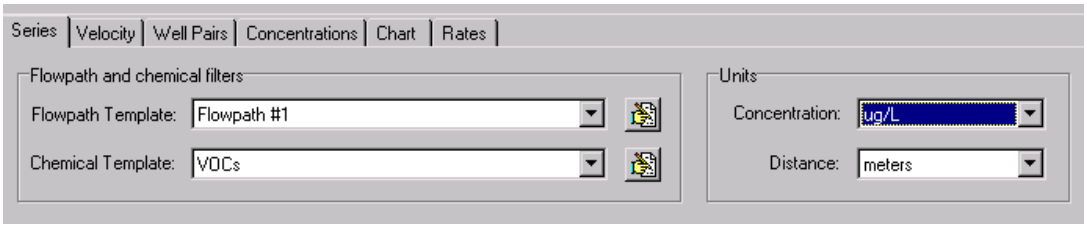
4.6 Determining Biodegradation Rates

☞ **BioTrends** (from the top menu bar)
☞ **Buscheck and Alcantar (1995)** (from the pulldown menu that appears)

There are 6 tabs that need to be analyzed: **Series**, **Velocity**, **Well Pairs, Concentrations, Chart** and **Rates**.

We will be analyzing TCE degradation for all three monitoring events (1995, 1997 and 1999).

Make sure that the Flowpath Template is **Flowpath #1**, the Chemical Template is **VOCs**, the concentrations are in **ug/L**, and that the distance is in **meters** (as seen in the figure on the following page).



Add a new series for TCE in 1995, in a similar manner as was done for C vs. X.

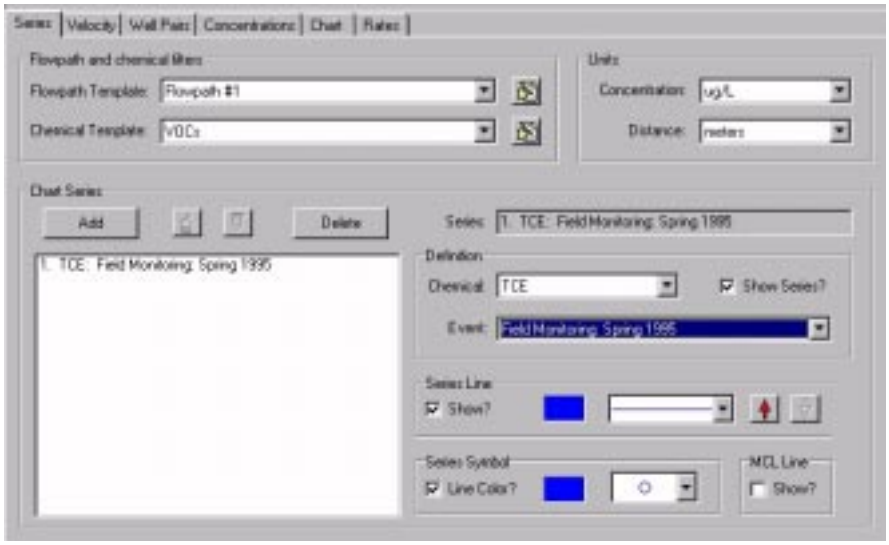
☞ **Add**

A new series will be added as **1. undefined**

Under **Definition** we must choose a **Chemical** and an **Event**.

☞ **Chemical**
☞ **TCE**
☞ **Event**
☞ **Field Monitoring: Spring 1995**

Under Series Line in he Color Box choose **Blue**



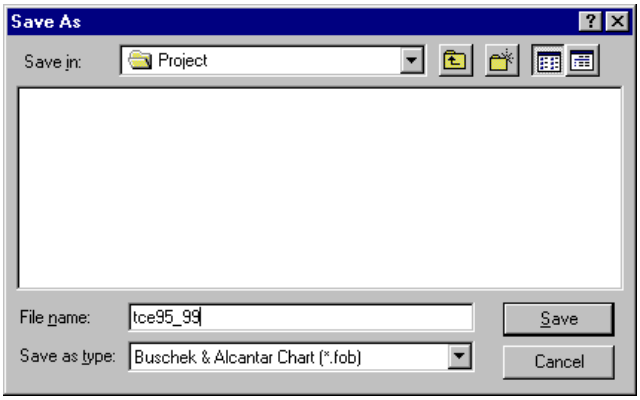
☞ **Add**

Repeat these steps choosing:

- **TCE** **Field Monitoring: Spring 1997** **Red**
- **TCE** **Field Monitoring: Spring 1999** **Green**

At this point it is appropriate to save these results as a Buschech and Alcantar *.fob file.

☞ **File**
☞ **Save**
☞ **tce95_99.fob**

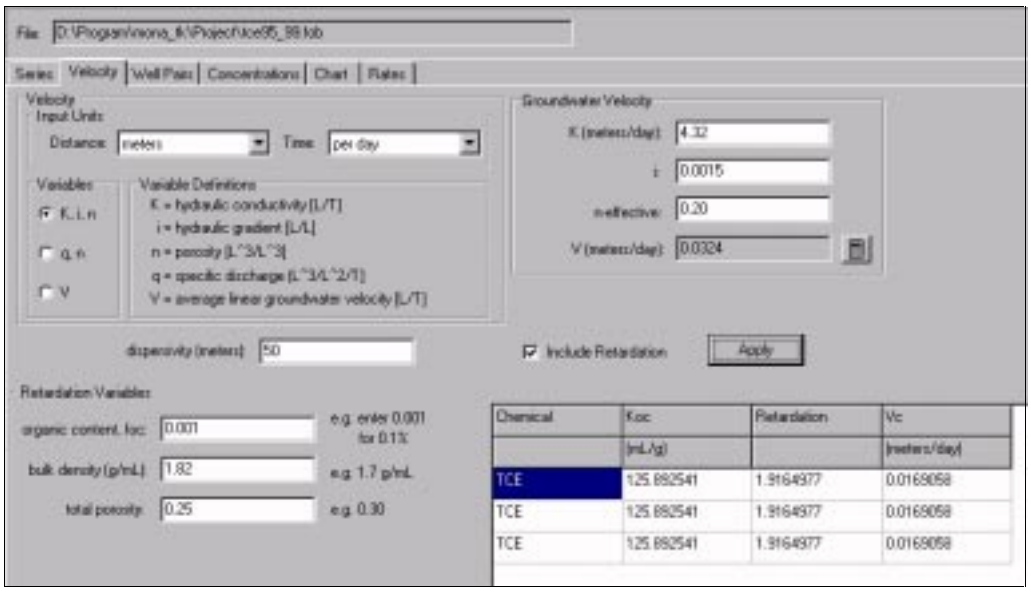


Under the Velocity tab the following parameters need to be entered:

- Hydraulic Conductivity (K) = 5 E-03 cm/s = 4.32 m/day
- Regional Gradient (i) = 0.0015
- Effective Porosity (n_{eff}) = 0.20
- Dispersivity = 50 m
- Organic Content (f_{oc}) = 0.1% = 0.001
- Soil Bulk Density = 1825 kg/m^3 = 1.82 g/mL
- Total Porosity = 0.25

Make sure you check the calculator button beside **V (meters/day)** and the groundwater velocity will be calculated.

The screen that appears should look like the figure below.



Next, we have to identify well pairs for calculating degradation values. We need an upgradient and a downgradient well pair along the flowpath.

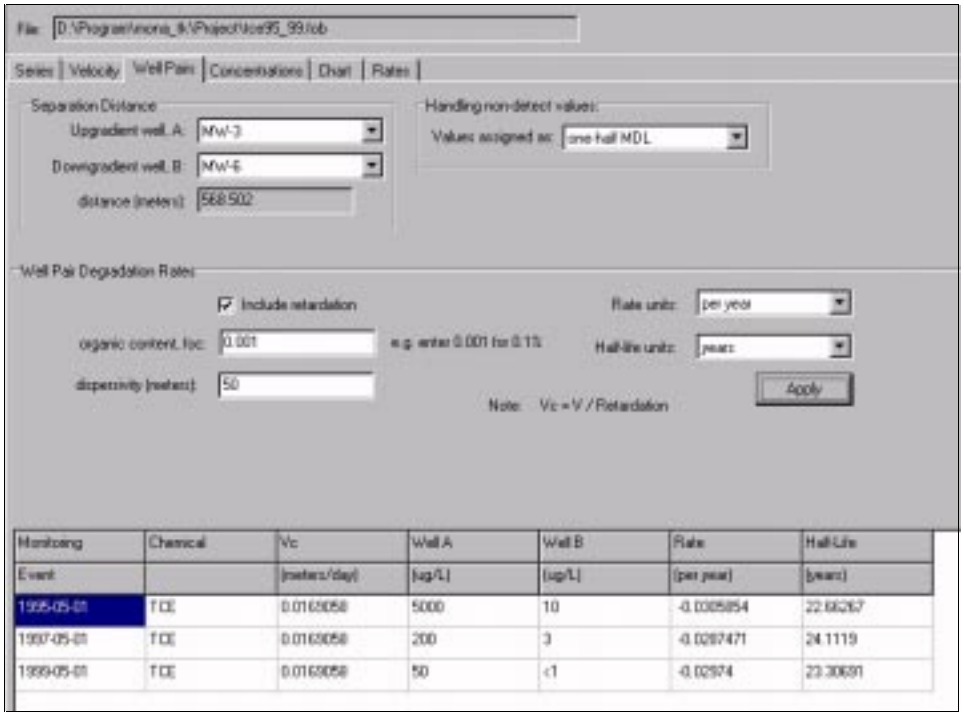
Checking the original DXF map in the Project Database screen we can see that MW-3 and MW-6 are an appropriate well pair along the flowpath (MW-3 at the source area, and MW-6 downgradient of the source area).

Switch to the Well Pairs tab.

Enter the **Upgradient well, A**: MW-3
Enter the **Downgradient well, B**: MW-6

Set the **non-detect value handling** to **one-half MDL**.

Your display should appear as seen below:



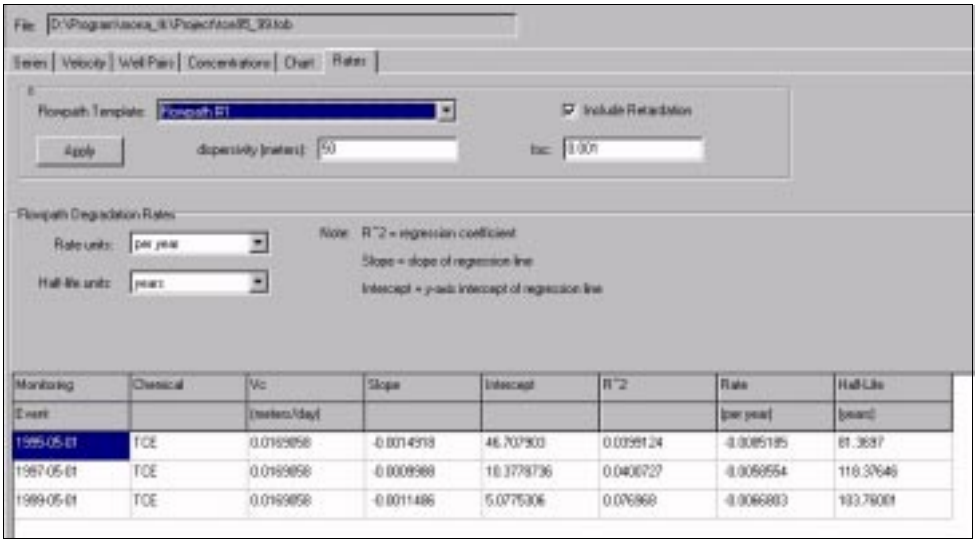
Clicking on the **Apply** button calculates biodegradation values between MW-3 and MW-6 for the three sampling events.

From this analysis, it is evident that the biodegradation rate for TCE is fairly constant from 1995 to 1999 at approximately 0.0296 per year (average)

The **Concentration** tab presents the concentration versus monitoring event table.

The **Chart** tab presents the concentration versus distance graph.

The **Rates** tab presents the flowpath degradation calculations and statistics, as shown in the figure below.



You have reached the end of the **SEQUENCE / BioTrends Lab Exercise**.