Chapter 5

Network Adjustment *(updated September 7, 2009)*

Network Overview

The NETWORK module allows you to adjust 1D vertical (levelling), 2D geodetic, 3D geodetic, 3D ECEF XYZ, 2D State Plane, 3D State Plane, 2D UTM, 3D UTM, 2D local NE and 3D local NEE networks.

GPS and terrestrial observations can be used in 3D networks, while most terrestrial observations can be used 2D networks. For 1D vertical networks, height difference and delta up observations can be used.

Before performing a network adjustment, all network project data (stations and observations) must be entered (or loaded) into COLUMBUS. There are a variety of ways to get your data into COLUMBUS. Consult the FILE MANAGEMENT and DATA chapters of this manual for more information.

Before continuing, please review the General Discussion section of Chapter 3 - Views.

Why Use Network Adjustment

In a perfect world, there would be no random, systematic or blunder errors in measured observations. The computed coordinates for each station would not require adjustment, because they would be exactly the same - no matter what path (or course) was used to compute each station.

However, because errors are associated with measurements of any kind, adjustment is necessary to distribute these errors in the best way possible and to resolve only one coordinate position for each station in the survey.

Only random errors can be properly distributed in a survey. Systematic and blunder errors should be corrected (removed) before performing a final network adjustment. The network adjustment process can often aid in the detection of systematic and blunder based errors, but sometimes it can be difficult to distinguish between small errors (random, systematic, or blunder errors). Therefore, it is up to the surveyor to identify systematic and blunder errors prior to adjustment "when" possible. This can usually be accomplished by testing your equipment against known results and through loop closures (see TOOLS chapter).

For random errors, the relative amount of adjustment is a function of the expected random error associated with each observation. An observation with a larger error estimate (as reflected in its *apriori* standard deviation), may be adjusted more than an observation with a relatively small error estimate.

For any given network, the amount of adjustment expected should be on the same order of magnitude as the random errors predicted for the observations. For example, for a 1D Vertical network, if the height difference between two stations is measured to be 10.000 feet plus or minus 0.003 feet (with an assumed standard deviation of 0.003 feet), we would expect the adjusted height difference to be within 9.997 and 10.003 feet. If the height difference observation was adjusted by 0.030 feet, we would suspect a mistake in the error estimate (*a priori* standard deviation, 0.003 feet) of the observation, or a larger than expected error in the observation (measurement) itself, or possibly some other contributing error.

For a 2D or 3D networks, if the chord distance between two stations is known to be 10000.000 meters plus or minus 0.005 meters, we would expect the adjusted chord distance to be between 9999.995 and 10000.005 meters. If the chord distance was adjusted by 0.050 meters, we would suspect a mistake in either the error estimate (*a priori* standard deviation of 0.005) of the observation, an error in the observation itself, or some other contributing error within the network.

Indirect Observations

COLUMBUS adjusts survey networks by the method of Indirect Observations. On each iteration, COLUMBUS computes corrections to the current coordinate components for each floating station. The corrections applied to the floating stations should rapidly decrease (on each new iteration) as the system converges to an optimal solution. When the corrections applied are less than the convergence criteria established in the OPTIONS - GLOBAL SETTINGS dialog, the adjustment is said to have converged. The closer the initial approximate coordinates are to their adjusted positions, the faster (less iterations required) the adjustment will converge to a final solution.

When a network adjustment has converged, the sum of the squared residuals (for all observations) has been minimized for the network as a whole. Put another way, the random errors have been optimally distributed throughout the network.

Guidelines for Solving 1D, 2D and 3D Networks

Simple guidelines should be followed when solving the various network types. They are listed below:

1D Vertical Network

1. Any station held fixed must have a known height. If your network is based on orthometric height (differences in orthometric height between stations), be sure your control stations are set to orthometric height values. If your network is based on ellipsoidal height (differences in ellipsoidal height between stations), be sure your control stations are set to ellipsoidal height values. Most 1D vertical networks will be based on differences in orthometric height (elevation).

2. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

3. Networks can be weighted by the distance between stations, the number of setups between stations or the standard deviation of each observation between stations. The weighting strategy you choose can be selected in the OPTIONS - NETWORK OPTIONS - NETWORK SETTINGS dialog. **You cannot combine weighting methods within the same network.**

If you weight each observation by the distance between stations or the number of setups between stations, the weight for each observation is equal to:

$$\frac{1}{distance} \quad \text{or} \quad \frac{1}{number\ of\ setups}$$

Notice that as you increase the distance or the number of setups, the computed weight will decrease, resulting in possibly more adjustment to the observation.

The maximum value that can be entered into the standard deviation field is 30.0 meters. When weighting an adjustment by number of setups or distances, you may need to scale the values to make them smaller. For example, when using distances that range from 30.0 meters to 1000.0 meters (as a weighting strategy), you will need to scale them down by at least 100 (to 0.30 to 10.0 respectively).

If you weight each observation using the standard deviation (i.e., standard deviation of height difference or of the local delta Up observation), the weight is equal to:

$$\frac{1}{standard\ deviation^2} \quad \text{or} \quad \frac{1}{variance}$$

The smaller the standard deviation, the larger the computed weight; therefore, the observation may be adjusted less.

2D Geodetic Networks

1. Any station held fixed must have a known geodetic (latitude and longitude) coordinate. These components can be entered/modified in the DATA - STATIONS - GEODETIC grid or set up in your project file using an external text editor. An average project height should be set up in the OPTIONS - GLOBAL SETTINGS - 2D Height field.

2. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

3. Terrestrial observations are not corrected for deflections of the vertical, refraction or mark-to-mark reductions, since these corrections have little or no effect on a 2D adjustment performed at an average project height. GPS observations are not supported within 2D adjustments.

4. Zenith angles are only used to correct slope (chord) distances to a horizontal distance. They are not used in the actual adjustment; therefore, the degrees of freedom will not be affected by their presence. The horizontal distance is based on the AT station. If a chord distance has been entered without a corresponding zenith angle, the chord distance is assumed to be a horizontal distance.

3D Geodetic Networks

1. Any station held fixed in three dimensions must have a known geodetic (latitude, longitude, orthometric height or ellipsoidal height) coordinate. These components can be entered/modified in the DATA - STATIONS - GEODETIC grid or set up in your project file using an external text editor.

2. Any station held fixed in two dimensions (2D) must have a known latitude and longitude coordinate. Because the height component (orthometric or ellipsoidal) is allowed to float during adjustment, these stations are considered to be both floating and fixed.

3. Any station held fixed in one dimension (1D) must have a known height (orthometric or ellipsoidal). Because the latitude and longitude are allowed to float during adjustment, these stations are considered to be both floating and fixed.

4. When adjusting networks that contain terrestrial observations, corrections due to deflection of the vertical can be computed if the deflection of the vertical values are provided for each geodetic station (or approximated for the project). You can assign known deflection of the vertical values within the DATA - STATIONS - GEODETIC grid or they can be set up in your project file using an external text editor. Deflection of the vertical values can be modeled in the TOOLS - DEFLECTION MODELING dialog (using the NGS Deflec99 grid files) for portions of North America. When creating terrestrial networks, the stations with unknown positions will typically be entered with their latitude, longitude and height (orthometric, geoidal and ellipsoidal) components equal to zero (since they are unknown). If the deflections are known or can be estimated for these stations, enter these deflections instead of zeros. A zero entry instructs COLUMBUS to treat the gravitational normal and ellipsoidal normal as being the same; thus, no corrections to the field observations (from Astronomic to Geodetic) will be applied. You can also apply project wide deflection of the vertical corrections by entering the corresponding entries in the OPTIONS - GLOBAL SETTINGS dialog. **In general, deflection of the vertical corrections should only be applied when using terrestrial observations in a 3D geodetic network based on ellipsoidal height.** To disable the usage of the deflection of the vertical values (if any) in your current project, enter the OPTIONS - NETWORK OPTIONS - NETWORK SETTINGS dialog and uncheck the **Use Deflec Of Vertical Values** checkbox.

5. When building GPS networks, the receiver post-processing baseline data usually will be extracted using the FILE - CONVERT THIRD PARTY FILES - GPS RECEIVER FILES option, the TRIMBLE GEO OFFICE option, or one of the separate file conversion programs downloaded from our web site or shipped with COLUMBUS. The resulting ASCII (Text) file can be opened directly using the FILE - OPEN or FILE - APPEND command. Once opened into the project, you will need to modify the coordinates for all stations being used as control, since the coordinates for each GPS measured station are usually only approximate. Alternatively, you could edit the last instance of each control station in the ASCII (Text) file prior to loading the file into COLUMBUS.

6. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

COLUMBUS allows you to perform 3D geodetic adjustments using **either** orthometric or ellipsoidal height. If you wish to use orthometric height, set the 3D Geodetic Height option in the OPTIONS - GLOBAL SETTINGS dialog to Orthometric Height. If you wish to use ellipsoidal height, set the 3D Geodetic Height option to Ellipsoidal Height. For each geodetic control station, enter the elevation in the Orthometric Height field and the ellipsoidal height in the Ellipsoidal Height field.

3D ECEF (Earth Centered Earth Fixed) XYZ Networks

1. Any station held fixed in three dimensions must have a known ECEF X, Y, Z. These components can be entered/modified in the DATA - STATIONS - ECEF Cartesian grid or set up in your project file using an external text editor.

2. When adjusting networks that contain terrestrial observations, corrections due to deflection of the vertical can be computed if the deflection of the vertical values are provided for each ECEF XYZ (or approximated for the project). You can assign known deflection of the vertical values within the DATA - STATIONS - GEODETIC grid or they can be set up in your project file using an external text editor. Deflection of the vertical values can be modeled in the TOOLS - DEFLECTION MODELING dialog (using the NGS Deflec99 grid files) for portions of North America. When creating terrestrial networks, the stations with unknown positions will typically be entered with their ECEF XYZ components equal to zero. If the deflections are known or can be estimated for these stations, enter these deflections instead of zeros. A zero entry instructs COLUMBUS to treat the gravitational normal and ellipsoidal normal as being the same; thus, no corrections to the field observations (from Astronomic to Geodetic) will be applied. You can also apply project wide deflection of the vertical corrections by entering the corresponding entries in the OPTIONS - GLOBAL SETTINGS dialog.

3. When building GPS networks, the receiver post-processing baseline data usually will be extracted using the FILE - CONVERT THIRD PARTY FILES - GPS RECEIVER FILES option, the TRIMBLE GEO OFFICE option, or one of the separate file conversion programs downloaded from our web site or shipped with COLUMBUS. The resulting ASCII (Text) file can be opened directly using the FILE - OPEN or FILE - APPEND command. Once opened into the project, you will need to modify the coordinates for all stations being used as control, since the coordinates for each GPS measured station are usually only approximate. Alternatively, you could edit the last instance of each control station in the ASCII (Text) file prior to loading the file into COLUMBUS.

4. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

2D State Plane Networks

1. Any station held fixed must have a known State Plane (grid north and east) coordinate. These components can be entered/modified in the DATA - STATIONS - STATE PLANE grid or set up in your project file using an external text editor. An average project height should be set up in the OPTIONS - GLOBAL SETTINGS - 2D Height field.

2. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

3. Terrestrial observations are not corrected for refraction or mark-to-mark reductions, since these corrections have little or no effect on a 2D adjustment performed at an average project height.

4. GPS observations are not supported within 2D adjustments.

5. Zenith angles are only used to correct slope (chord) distances to a horizontal distance. They are not used in the actual adjustment; therefore, the degrees of freedom will not be affected by their presence. The horizontal distance is based on the AT station. If a chord distance has been entered without a corresponding zenith angle, the chord distance is assumed to be a horizontal distance.

3D State Plane Networks

1. Any station held fixed in three dimensions must have a known State Plane (grid north, east and orthometric height) coordinate. These components can be entered/modified in the DATA - STATIONS - STATE PLANE dialog or set up in your project file using an external text editor.

2. Any station held fixed in two dimensions (2D) must have a known State Plane (grid north and east) coordinate. Because the orthometric height component is allowed to float during adjustment, these stations are considered to be both floating and fixed.

3. Any station held fixed in one dimension (1D) must have a known orthometric height. Because the grid north and east coordinate are allowed to float during adjustment, these stations are considered to be both floating and fixed.

4. **Deflection of the vertical corrections are not applicable to State Plane adjustments, because this adjustment type assumes you are using orthometric height**.

5. When building GPS networks, the receiver post-processing baseline data usually will be extracted using the FILE - CONVERT THIRD PARTY FILES - GPS RECEIVER FILES option, the TRIMBLE GEO OFFICE option, or one of the separate file conversion programs downloaded from our web site or shipped with COLUMBUS. The resulting ASCII (Text) file can be opened directly using the FILE - OPEN or FILE - APPEND command. Once opened into the project, you will need to modify the coordinates for all stations being used as control, since the coordinates for each GPS measured station are usually only approximate. Alternatively, you could edit the last instance of each control station in the ASCII (Text) file prior to loading the file into COLUMBUS.

6. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

2D UTM Networks

1. Any station held fixed must have a known UTM (grid north and east) coordinate. These components can be entered/modified in the DATA - STATIONS - UTM grid or set up in your project file using an external text editor. An average project height should be set up in the OPTIONS - GLOBAL SETTINGS 2D Height field.

2. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

3. Terrestrial observations are not corrected for refraction or mark-to-mark reductions, since these corrections have little or no effect on a 2D adjustment performed at an average project height.

4. GPS observations are not supported within 2D adjustments.

5. Zenith angles are only used to correct slope (chord) distances to a horizontal distance. They are not used in the actual adjustment; therefore, the degrees of freedom will not be affected by their presence. The horizontal distance is based on the AT station. If a chord distance has been entered without a corresponding zenith angle, the chord distance is assumed to be a horizontal distance.

3D UTM Networks

1. Any station held fixed in three dimensions must have a known UTM (grid north, east and orthometric height) coordinate. These components can be entered/modified in the DATA - STATIONS - UTM dialog or set up in your project file using an external text editor.

2. Any station held fixed in two dimensions (2D) must have a known UTM (grid north and east) coordinate. Because the orthometric height component is allowed to float during adjustment, these stations are considered to be both floating and fixed.

3. Any station held fixed in one dimension (1D) must have a known orthometric height. Because the grid north and east coordinate are allowed to float during adjustment, these stations are considered to be both floating and fixed.

4. **Deflection of the vertical corrections are not applicable to UTM adjustments, because this adjustment type assumes you are using orthometric height**.

5. When building GPS networks, the receiver post-processing baseline data usually will be extracted using the FILE - CONVERT THIRD PARTY FILES - GPS RECEIVER FILES option, the TRIMBLE GEO OFFICE option, or one of the separate file conversion programs downloaded from our web site or shipped with COLUMBUS. The resulting ASCII (Text) file can be opened directly using the FILE - OPEN or FILE - APPEND command. Once opened into the project, you will need to modify the coordinates for all stations being used as control, since the coordinates for each GPS measured station are usually only approximate. Alternatively, you could edit the first instance of each control station in the ASCII (Text) file prior to loading the file into COLUMBUS.

6. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

2D Local Horizon NE Networks

1. The 2D local horizon NE (north, east) network is suitable for 2D projects of limited extent. **We recommend these projects be no larger than 1km square. If you project is larger, you should use one of the other 2D or 3D adjustment models (geodetic, State plane or UTM).**

2. Stations are identified using the Local NEUE station type. The U (up) component is not used and can be set to any value. The E (orthometric height or elevation) component is also not used for the 2D local horizon NE network.

3. In order to model the earth's true shape, you can optionally provide an approximate latitude for the project area. This can be done in the OPTIONS - GLOBAL SETTINGS dialog.

4. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

5. Terrestrial observations are not corrected for refraction or mark-to-mark reductions, since these corrections have little or no effect on a 2D adjustment performed at an average project height.

6. GPS observations are not supported within 2D adjustments.

7. Zenith angles are only used to correct slope (chord) distances to a horizontal distance. They are not used in the actual adjustment; therefore, the degrees of freedom will not be affected by their presence. The horizontal distance is based on the AT station. If a chord distance has been entered without a corresponding zenith angle, the chord distance is assumed to be a horizontal distance.

3D Local Horizon NEE Networks

1. The 3D local horizon NEE (north, east, orthometric height) network is suitable for 3D projects of limited extent. **We recommend these projects be no larger than 1km square. If you project is larger, you should use one of the other 3D adjustment models (geodetic, State Plane, UTM).**

2. Stations are identified using the Local NEUE station type. The U (up) component is not used and can be set to any value. The orthometric height component is used.

3. In order to model the earth's true shape, you can optionally provide an approximate latitude for the project area. This can be done in the OPTIONS - GLOBAL SETTINGS dialog.

4. **Deflection of the vertical corrections are not applicable to UTM adjustments, because this adjustment type assumes you are using orthometric height**.

5. Any station held fixed in two dimensions (2D) must have a known Local North and East coordinate. Because the orthometric height is allowed to float during adjustment, these stations are considered to be both floating and fixed.

6. Any station held fixed in one dimension (1D) must have a known Local orthometric height. Because the north and east are allowed to float during adjustment, these stations are considered to be both floating and fixed.

7. Stations with unknown positions will typically be entered with their north, east and orthometric height components equal to zero (since they are unknown).

8. **GPS observations are not supported in this network type.**

9. COLUMBUS allows for duplicate observations between stations. You can repeat any set of applicable measurements as often as you like.

1D Vertical Networks

A 1D vertical network in COLUMBUS consists of a datum, two or more height type stations, and one or more observations. **Every 1D vertical network must have these three components.** Please examine the VERTICAL.TXT demo file to see one way of creating a 1D vertical network project file.

Datum — For 1D vertical networks the datum is not used in adjustment computations. However, all station and observation data within COLUMBUS must be associated with a datum. Therefore, any datum can fulfill this need.

Stations — The points on the Earth's surface for which heights (orthometric or ellipsoidal) are either known or will be determined. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 1D vertical networks, COLUMBUS supports height difference, local delta Up and coordinate (height) observations. To perform a 1D vertical adjustment using reciprocal vertical angles, you can perform a 3D geodetic network adjustment holding all unknown stations fixed in 2D or you can convert the measured observations to height difference observations using the TOOLS - CONVERT DATA - Zen/Crd -> Vert/Hor Dist tool.

Two methods for creating a 1D vertical network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select a datum to be active (or simply use the current active datum) within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum.

Step 2: **Change the View to 1D Vertical.** Enter all fixed height stations using the DATA - STATIONS - HEIGHT grid. Stations that are to be fixed in height (1D) should have their known height entered exactly. If stations will be left to float (height to be determined during adjustment), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly.

Step 3: Enter the observations between each station pair using the DATA - OBSERVATIONS - HGT DIFF or LOCAL NEU grid. For local NEU, you only need to enter the Up observation (not the north and east components). **When you specify a station name that has not already been entered, COLUMBUS will automatically create a Height station (based on the selected View context 1D Vertical).**

Step 4: Coordinate observations (height for 1D vertical networks) are set up in the DATA - STATIONS - HEIGHT grid. They may already be included in your network from Step 2. However, be sure they each have a valid Height Standard Deviation. For 1D networks, the use of coordinate observations can be activated by selecting the **Constrained Stations** command just prior to adjustment and then selecting the applicable stations (please see the CONSTRAINED STATIONS section in this chapter). These are only applicable for 1D networks weighted by observation standard deviations.

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file VERTICAL.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample 1D vertical network format (shown in the VERTICAL.TXT demo project file) as a guide. All the keywords shown in this file are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

If you elect to use the North/East/Up observation set (using the $NEU or $NEU_COMPACT keyword), be sure to set the North and East fields to **NOOBS**. This indicates to COLUMBUS that these observations were not measured. Better yet, simply use the $HGTDIFF or $HGTDIFF_COMPACT keyword to avoid confusion.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command.

Both methods can be used separately or in combination to build a 1D vertical network. For example, part of the network could be entered online, with the remainder of the network appended from an ASCII (Text) file using the FILE - APPEND command.

When a 1D vertical network is loaded into COLUMBUS, an arbitrary 2D coordinate system is created in order to graphically display the stations and observations. This 2D coordinate system does **not** represent the actual position of each station (as it occurs in the field), but it does allow you to see how each station is connected to one another by the observations. The color of each station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

2D Geodetic Networks

A 2D geodetic network in COLUMBUS consists of a datum, two or more geodetic stations and two or more observations. **Every 2D geodetic network must have these three components.** Please examine the TERRONLY.TXT or BEAR2D.TXT demo files to review two sample 2D geodetic network projects.

Datum — The reference ellipsoid the adjusted geodetic positions will be based upon. 2D geodetic adjustments are performed in 3D geodetic space at a fixed height.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses geodetic stations in geodetic network adjustments. If your control stations have published State Plane coordinates, these can be transformed to geodetic (latitude and longitude) from within the TOOLS - TRANSFORMATION - STATE PLANE <--> GEODETIC dialog. The resulting coordinates can then be used in the network adjustment. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 2D geodetic networks, COLUMBUS supports 13 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, local horizon delta north, local horizon delta east, and latitude/longitude coordinates.

Two methods for creating a 2D geodetic network.

Method 1

In this scenario, the network is constructed using the data grids.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum.

Step 2: **Change the View to 2D Geodetic**. Enter all fixed 2D geodetic stations using the DATA - STATIONS - GEODETIC grid. Stations that are to be fixed in 2D should have their known latitude and longitude entered exactly. If stations will be left to float (latitude and longitude determined during adjustment), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. COLUMBUS will compute approximate coordinates for all floating stations (from the selected observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you enter reasonably good approximate coordinates for these stations.

Step 3: Enter all the observations between each station pair using the applicable DATA - OBSERVATIONS grid. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a Geodetic station (based on the selected View context - 2D Geodetic).**

Step 4: Coordinate observations (latitude and longitude for 2D geodetic networks) are set up in the DATA - OBSERVATIONS - GEO COORD grid.

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file TERRONLY.TXT or BEAR2D.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample 2D geodetic network format (shown in the demo files mentioned above) as a guide. All the keywords shown in these files are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command.

Both methods can be used separately or in combination to build a 2D geodetic network. For example, part of the network could be entered online, with the remainder of the network appended from an ASCII (Text) file using the FILE - APPEND command.

When a 2D geodetic network is loaded into COLUMBUS, any geodetic station with both the latitude and longitude set to zero are assigned arbitrary 2D coordinates for graphical display. The assumption is no survey points are located at latitude and longitude of zero, since it falls within the Atlantic ocean. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color of each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

3D Geodetic Networks

A 3D geodetic network in COLUMBUS consists of a datum, two or more geodetic stations and three or more observations. **Every 3D geodetic network must have these three components.** Please examine the GPSONLY.TXT, MIXED.TXT, or BIGBASIN.TXT demo files to review sample 3D geodetic network projects.

Datum — The reference ellipsoid the adjusted geodetic positions will be based upon. 3D geodetic adjustments are performed in 3D geodetic space.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses geodetic stations in geodetic network adjustments. If your control stations have published State Plane coordinates, these can be transformed to geodetic (latitude and longitude) from within the TOOLS - TRANSFORMATION - STATE PLANE <--> GEODETIC dialog. The resulting coordinates can then be used in the network adjustment. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 3D geodetic networks, COLUMBUS supports 19 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, height difference, GPS dX, dY, dZ, local horizon delta north, delta east, delta up, and latitude/longitude/height coordinates (orthometric or ellipsoidal). Terrestrial, GPS and coordinate observations can be freely mixed within a 3D network.

Three methods for creating a 3D geodetic network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum.

Step 2: **Change the view to 3D Geodetic**. Enter all fixed 3D geodetic stations using the DATA - STATIONS - GEODETIC grid. Stations that are to be fixed in any component (latitude, longitude, or height) must have that coordinate component entered exactly. If stations will be left to float (latitude, longitude, and height), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. COLUMBUS will compute approximate coordinates for all floating stations (from the supplied observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you have entered reasonably good approximate coordinates for these stations.

Step 3: Enter the observations between each station pair using the applicable DATA - OBSERVATIONS grid. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a Geodetic station (based on the selected View context - 3D Geodetic).**

Step 4: Coordinate observations (latitude, longitude and height) are set up in the DATA - OBSERVATIONS - GEO COORD grid.

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file MIXED.TXT, GPSONLY.TXT, or BIGBASIN.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample 3D geodetic network format (shown in the demo files mentioned above) as a guide. All the keywords shown in these files are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command.

Method 3

In this scenario, receiver specific GPS baseline data is converted to a COLUMBUS compatible ASCII (Text) format, then loaded into COLUMBUS. COLUMBUS currently supports GPS file conversions for Ashtech, Leica, Topcon, and Trimble GPS baseline files. We also support converting GPS and terrestrial data from other third party files as well.

Step 1: To get the various GPS post processing files into a COLUMBUS compatible ASCII (Text) format, use one of the options in the FILE - CONVERT 3RD PARTY FILES dialogs or one of our stand alone file conversion tools shipped with COLUMBUS (or downloadable from our web site at: www.bestfit.com).

Step 2: Load the resulting ASCII (Text) file directly into COLUMBUS using the FILE - OPEN command.

All three methods can be used separately or in combination to build a 3D geodetic network. For example, a project containing GPS and terrestrial data could be constructed using methods two and three (resulting in two separate input files called **GPS.TXT** and **TERR.TXT**). A third file called **MAIN.TXT** is then created which simply includes **GPS.TXT** and **TERR.TXT** (see the **$INCLUDE_FILE** keyword in Appendix A). **MAIN.TXT** is then loaded with the FILE - OPEN command, which then automatically loads the other two files into COLUMBUS.

When a 3D geodetic network project is loaded into COLUMBUS, any geodetic station with both the latitude and longitude set to zero are assigned arbitrary 2D coordinate for graphical display. The assumption is no survey points are located at latitude and longitude of zero, since it falls within the Atlantic ocean. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color for each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

3D ECEF (Earth Centered Earth Fixed) XYZ Networks

A 3D ECEF XYZ network in COLUMBUS consists of a datum, two or more ECEF XYZ stations and three or more observations. **Every 3D ECEF XYZ network must have these three components.**

Datum — The reference ellipsoid the adjusted ECEF XYZ positions will be based upon. 3D ECEF XYZ adjustments are performed in 3D ECEF XYZ space.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses ECEF XYZ stations in ECEF XYZ network adjustments. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 3D ECEF XYZ networks, COLUMBUS supports 19 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, height difference, GPS dX, dY, dZ, local horizon delta north, delta east, delta up, and latitude/longitude/height coordinates (ellipsoidal). Terrestrial, GPS and coordinate observations can be freely mixed within a 3D network.

Three methods for creating a 3D ECEF XYZ network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum.

Step 2: **Change the view to Cartesian XYZ**. Enter all fixed ECEF XYZ stations using the DATA - STATIONS - ECEF Cartesian grid. COLUMBUS will compute approximate coordinates for all floating stations (from the supplied observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you have entered reasonably good approximate coordinates for these stations.

Step 3: Enter the observations between each station pair using the applicable DATA - OBSERVATIONS grid. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a ECEF XYZ station (based on the selected View context - Cartesian XYZ).**

Step 4: Coordinate observations (latitude, longitude and ellipsoidal height) are set up in the DATA - OBSERVATIONS - GEO COORD grid.

Method 2

In this scenario, the network project file is created using an external text editor.

Step 1: Enter your data into an ASCII (Text) file. All the keywords shown in these files are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command.

Method 3

In this scenario, receiver specific GPS baseline data is converted to a COLUMBUS compatible ASCII (Text) format, then loaded into COLUMBUS. COLUMBUS currently supports GPS file conversions for Ashtech, Leica, Topcon, and Trimble GPS baseline files. We also support converting GPS and terrestrial data from other third party files as well.

Step 1: To get the various GPS post processing files into a COLUMBUS compatible ASCII (Text) format, use one of the options in the FILE - CONVERT 3RD PARTY FILES dialogs or one of our stand alone file conversion tools shipped with COLUMBUS (or downloadable from our web site at: www.bestfit.com).

Step 2: Load the resulting ASCII (Text) file directly into COLUMBUS using the FILE - OPEN command.

All three methods can be used separately or in combination to build a 3D ECEF XYZ network. For example, a project containing GPS and terrestrial data could be constructed using methods two and three (resulting in two separate input files called **GPS.TXT** and **TERR.TXT**). A third file called **MAIN.TXT** is then created which simply includes **GPS.TXT** and **TERR.TXT** (see the **$INCLUDE_FILE** keyword in Appendix A). **MAIN.TXT** is then loaded with the FILE - OPEN command, which then automatically loads the other two files into COLUMBUS.

When a 3D ECEF XYZ network project is loaded into COLUMBUS, any ECEF XYZ station with coordinates of zero assigned arbitrary 2D coordinate for graphical display. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color for each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

2D State Plane Networks

A 2D State Plane network in COLUMBUS consists of a datum, two or more State Plane stations and two or more observations. **Every 2D State Plane network must have these three components.** Please examine the STATEPLANE.TXT demo file to review a sample 2D State Plane network project.

Datum — The reference ellipsoid the adjusted State Plane positions will be based upon. 2D State Plane adjustments are performed in 3D geodetic space at a fixed height.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses State Plane stations in State Plane network adjustments. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 2D State Plane networks, COLUMBUS supports 11 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, local horizon delta north, and local horizon delta east coordinates.

Two methods for creating a 2D State Plane network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum. Select the correct State Plane Zone (or set up a custom State Plane projection) in the OPTIONS - PROJECTION ZONES - STATE PLANE ZONES dialog.

Step 2: **Change the view to 2D State Plane.** Enter all fixed 2D State Plane stations using the DATA - STATIONS - STATE PLANE grid. Stations that are to be fixed in 2D should have their known grid north and east entered exactly. If stations will be left to float (north and east determined during adjustment), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. COLUMBUS will compute approximate coordinates for all floating stations (from the selected observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you enter reasonably good approximate coordinates for these stations.

Step 3: Enter all the observations between each station pair using the applicable DATA - OBSERVATIONS grid. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a State Plane station (based on the selected View context - 2D State Plane).**

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file STATEPLANE.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample 2D State Plane network format (shown in the demo file mentioned above) as a guide. All the keywords shown in these files are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command. Select the correct State Plane Zone (or set up a custom State Plane projection) in the OPTIONS - PROJECTION ZONES - STATE PLANE ZONES dialog.

Both methods can be used separately or in combination to build a 2D State Plane network. For example, part of the network could be entered online, with the remainder of the network appended from an ASCII (Text) file using the FILE - APPEND command.

When a 2D State Plane network is loaded into COLUMBUS, any State Plane station with both the north and east set to zero are assigned arbitrary 2D coordinates for graphical display. The assumption is no survey points are located at north and east of zero. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color of each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

3D State Plane Networks

A 3D State Plane network in COLUMBUS consists of a datum, two or more State Plane stations and three or more observations. **Every 3D State Plane network must have these three components.** Please examine the STATEPLANE.TXT demo file to review sample 3D State Plane network project.

Datum — The reference ellipsoid the adjusted State Plane positions will be based upon. 3D State Plane adjustments are performed in 3D State Plane space.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses State Plane stations in State Plane network adjustments. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 3D State Plane networks, COLUMBUS supports 16 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, height difference, GPS dX, dY, dZ, local horizon delta north, delta east, and delta up. Terrestrial and GPS observations can be freely mixed within a 3D network.

Three methods for creating a 3D State Plane network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum. Select the correct State Plane Zone (or set up a custom State Plane projection) in the OPTIONS - PROJECTION ZONES - STATE PLANE ZONES dialog.

Step 2: **Change the view to 3D State Plane.** Enter all fixed 3D State Plane stations using the DATA - STATIONS - STATE PLANE grid. Stations that are to be fixed in any component (north, east, or orthometric height) must have that coordinate component entered exactly. If stations will be left to float (north, east, and orthometric height), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. COLUMBUS will compute approximate coordinates for all floating stations (from the supplied observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you have entered reasonably good approximate coordinates for these stations.

Step 3: Enter all the observations between each station pair using the applicable DATA - OBSERVATIONS grid. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a State Plane station (based on the selected View context - 3D State Plane).**

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file STATEPLANE.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample 3D State Plane network format (shown in the demo file mentioned above) as a guide. All the keywords shown in these files are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command. Select the correct State Plane Zone (or set up a custom State Plane projection) in the OPTIONS - PROJECTION ZONES - STATE PLANE ZONES dialog.

Method 3

In this scenario, receiver specific GPS baseline data is converted to a COLUMBUS compatible ASCII (Text) format, then loaded into COLUMBUS. COLUMBUS currently supports GPS file conversions for Ashtech, Leica, Topcon, and Trimble GPS baseline files. We also support converting GPS data from other third party files as well (such as NGS Blue Book 'G' Files and others).

Step 1: To get the various GPS post processing files into a COLUMBUS compatible ASCII (Text) format, use one of the options in the FILE - CONVERT 3RD PARTY FILES dialogs or one of our stand alone file conversion tools shipped with COLUMBUS (or downloadable from our web site at: www.bestfit.com).

Step 2: Load the resulting ASCII (Text) file directly into COLUMBUS using the FILE - OPEN command. Select the correct State Plane Zone (or set up a custom State Plane projection) in the OPTIONS - PROJECTION ZONES - STATE PLANE ZONES dialog.

Step 3: Transform all geodetic station coordinates to State Plane coordinates from within the TOOLS - TRANSFORMATION - STATE PLANE <--> GEO dialog

All three methods can be used separately or in combination to build a 3D State Plane network. For example, a project containing GPS and terrestrial data could be constructed using methods two and three (resulting in two separate input files called **GPS.TXT** and **TERR.TXT**). A third file called **MAIN.TXT** is then created which simply includes **GPS.TXT** and **TERR.TXT** (see the **$INCLUDE_FILE** keyword in Appendix A). **MAIN.TXT** is then loaded with the FILE - OPEN command, which then automatically loads the other two files into COLUMBUS.

When a 3D State Plane network project is loaded into COLUMBUS, any State Plane station with both the north and east set to zero are assigned arbitrary 2D coordinate for graphical display. The assumption is no survey points are located at north and east of zero. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color for each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

2D UTM Networks

A 2D UTM network in COLUMBUS consists of a datum, two or more UTM stations and two or more observations. **Every 2D UTM network must have these three components.** Please examine the UTM.TXT demo file to review a sample 2D UTM network project.

Datum — The reference ellipsoid the adjusted UTM positions will be based upon. 2D UTM adjustments are performed in 3D space at a fixed height.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses UTM stations in UTM network adjustments. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 2D UTM networks, COLUMBUS supports 11 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, local horizon delta north, and local horizon delta east coordinates.

Two methods for creating a 2D UTM network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum. Set up the correct UTM Zone in the OPTIONS - PROJECTION ZONES - UTM ZONE SETUP dialog.

Step 2: **Change the view to 2D UTM**. Enter all fixed 2D UTM stations using the DATA - STATIONS - UTM grid. Stations that are to be fixed in 2D should have their known grid north and east entered exactly. If stations will be left to float (north and east determined during adjustment), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. COLUMBUS will compute approximate coordinates for all floating stations (from the selected observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you enter reasonably good approximate coordinates for these stations.

Step 3: Enter all the observations between each station pair using the applicable DATA - OBSERVATIONS grid. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a UTM station (based on the selected View context - 2D UTM).**

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file UTM.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample 2D UTM network format (shown in the demo file mentioned above) as a guide. All the keywords shown in these files are described in

Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command. Set up the correct UTM Zone in the OPTIONS - PROJECTION ZONES - UTM ZONE SETUP dialog.

Both methods can be used separately or in combination to build a 2D UTM network. For example, part of the network could be entered online, with the remainder of the network appended from an ASCII (Text) file using the FILE - APPEND command.

When a 2D UTM network is loaded into COLUMBUS, any UTM station with both the north and east set to zero are assigned arbitrary 2D coordinates for graphical display. The assumption is no survey points are located at north and east of zero. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color of each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

3D UTM Networks

A 3D UTM network in COLUMBUS consists of a datum, two or more UTM stations and three or more observations. **Every 3D UTM network must have these three components.** Please examine the UTM.TXT demo file to review sample 3D UTM network project.

Datum — The reference ellipsoid the adjusted UTM positions will be based upon. 3D UTM adjustments are performed in 3D UTM space.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses UTM stations in UTM network adjustments. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 3D UTM networks, COLUMBUS supports 16 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, height difference, GPS dX, dY, dZ, local horizon delta north, delta east, and delta up. Terrestrial and GPS observations can be freely mixed within a 3D network.

Three methods for creating a 3D UTM network.

Method 1

In this scenario, the network is constructed using the online data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum. Set up the correct UTM Zone in the OPTIONS - PROJECTION ZONES - UTM ZONE SETUP dialog.

Step 2: **Change the view to 3D UTM**. Enter all fixed 3D UTM stations using the DATA - STATIONS - UTM grid. Stations that are to be fixed in any component component (north, east, or orthometric height) must have that coordinate component entered exactly. If stations will be left to float (north, east, and orthometric height), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. . COLUMBUS will compute approximate coordinates for all floating stations (from the supplied observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you have entered reasonably good approximate coordinates for these stations.

Step 3: Enter all the observations between each station pair using the applicable DATA - OBSERVATIONS dialog. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a UTM station (based on the selected View context - 3D UTM).**

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file

UTM.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample 3D UTM network format (shown in the demo file mentioned above) as a guide. All the keywords shown in these files are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command. Set up the correct UTM Zone in the OPTIONS - PROJECTION ZONES - UTM ZONE SETUP dialog.

Method 3

In this scenario, receiver specific GPS baseline data is converted to a COLUMBUS compatible ASCII (Text) format, then loaded into COLUMBUS. COLUMBUS currently supports GPS file conversions for Ashtech, Leica, Topcon, and Trimble GPS baseline files. We also support converting GPS data from other third party files as well (such as NGS Blue Book ‘G’ Files and others).

Step 1: To get the various GPS post processing files into a COLUMBUS compatible ASCII (Text) format, use one of the options in the FILE - CONVERT 3RD PARTY FILES dialogs or one of our stand alone file conversion tools shipped with COLUMBUS (or downloadable from our web site at: www.bestfit.com).

Step 2: Load the resulting ASCII (Text) file directly into COLUMBUS using the FILE - OPEN command. Set up the correct UTM Zone in the OPTIONS - PROJECTION ZONES - UTM ZONE SETUP dialog.

Step 3: Transform all geodetic station coordinates to UTM coordinates from within the TOOLS - TRANSFORMATION - UTM <--> GEO dialog

All three methods can be used separately or in combination to build a 3D UTM network. For example, a project containing GPS and terrestrial data could be constructed using methods two and three (resulting in two separate input files called **GPS.TXT** and **TERR.TXT**). A third file called **MAIN.TXT** is then created which simply includes **GPS.TXT** and **TERR.TXT** (see the **$INCLUDE_FILE** keyword in Appendix A). **MAIN.TXT** is then loaded with the FILE - OPEN command, which then automatically loads the other two files into COLUMBUS.

When a 3D UTM network project is loaded into COLUMBUS, any UTM station with both the north and east set to zero are assigned arbitrary 2D coordinate for graphical display. The assumption is no survey points are located at north and east of zero. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color for each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

2D Local Horizon NE Networks

A 2D local horizon NE network in COLUMBUS consists of a datum, two or more local north/east stations and two or more observations. **Every 2D local horizon NE network must have these three components.** Please examine the NEE.TXT demo file, which can be solved as either a 2D or 3D local horizon NE (or NEE) network.

Datum — The reference ellipsoid the adjusted local horizon coordinates will be based upon when accounting for curvature (only for 3D NEE networks) and convergency. 2D local horizon NE adjustments are performed in 3D NEE space at a fixed height.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses local north/east stations in this network adjustment. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 2D local horizon NE networks, COLUMBUS supports 11 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, local horizon delta north, and local horizon delta east. Coordinate observations are not supported for this network type.

Two methods for creating a 2D local horizon NE network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum. Enter the approximate latitude (+-10 minutes) for the project area within the OPTIONS - GLOBAL SETTINGS dialog.

Step 2: **Change the view to 2D Local NE.** Enter all fixed 2D Local NE stations using the DATA - STATIONS - LOCAL NEUE grid. Stations that are to be fixed in 2D must have their known north and east components entered exactly. If stations will be left to float (north and east determined during adjustment), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. COLUMBUS will compute approximate coordinates for all floating stations (from the selected observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you enter reasonably good approximate coordinates for these stations. The Up and Orthometric Height coordinate components are not used in this network type.

Step 3: Enter all the observations between each station pair using the applicable DATA - OBSERVATIONS dialog. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a Local NE station (based on the selected View context - 2D Local NE).**

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file NEE.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample network format (shown in NEE.TXT) as a guide. All the keywords shown in this file are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command. Enter the approximate latitude (+-10 minutes) for the project area within the OPTIONS - GLOBAL SETTINGS dialog.

Both methods can be used separately or in combination to build a 2D local horizon NE network. For example, part of the network could be entered online, with the remainder of the network appended from an ASCII (Text) file using the FILE - APPEND command (or the reverse)

When a 2D local horizon NE network is loaded into COLUMBUS, any local NEUE station with both the north and east component set to zero are assigned arbitrary 2D coordinates for graphical display. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color of each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

3D Local Horizon NEE Networks

A 3D local horizon NEE network in COLUMBUS consists of a datum, two or more local north/east/ orthometric height stations and three or more observations. **Every 3D local horizon NEE network must have these three components.** Please examine the NEE.TXT demo file to review a sample 3D local horizon NEE network project.

Datum — The reference ellipsoid the adjusted local horizon coordinates will be based upon when accounting for curvature and convergency. 3D local horizon NEE adjustments are performed in 3D NEE space.

Stations — The points on the Earth's surface for which coordinates are either known or will be determined. COLUMBUS only uses local north/east/orthometric height stations in this network adjustment. COLUMBUS does not allow duplicate station names for the same coordinate type unless they are each associated with a different datum. Every station associated with the same datum, must have a unique name.

Observations — For 3D local horizon NEE networks, COLUMBUS supports 13 types of observations: azimuth, direction, horizontal angle, bearing, zenith angle, horizontal distance, geodesic distance, geodetic chord distance, chord distance, height difference, local horizon delta north, delta east, and delta up). GPS and coordinate observations are not supported in this network type.

Two methods for creating a 3D local horizon NEE network.

Method 1

In this scenario, the network is constructed using the data grid dialogs.

Step 1: Open a new project using the FILE - NEW command. Select the correct datum to be active within the OPTIONS - DATUMS dialog. All entered data will be associated with this datum. Enter the approximate latitude (+-10 minutes) for the project area within the OPTIONS - GLOBAL SETTINGS dialog.

Step 2: Enter the 3D positions for all stations using the DATA - STATIONS - LOCAL NEUE dialog. Stations that are to be fixed in either north/east or orthometric height, must have those coordinate components entered exactly. If stations will be left to float (north and east, or orthometric height determined during adjustment), you may enter them with any value (e.g., zeros) or proceed to Step 3 below and create them indirectly. COLUMBUS will compute approximate coordinates for all floating stations (from the supplied observations) during the adjustment. If COLUMBUS cannot compute an approximate coordinate for any station, be sure you have entered reasonably good approximate coordinates for these stations. The Up coordinate component is not used in this network type.

Step 3: Enter all the observations between each station pair using the applicable DATA - OBSERVATIONS dialog. For observations that have not been measured, leave their fields blank. **When you specify a station name that has not already been entered, COLUMBUS will automatically create a Local NEE station (based on the selected View context - 3D Local NEE).**

Method 2

In this scenario, the network project file is created using an external text editor (see the sample file NEE.TXT).

Step 1: Enter your data into an ASCII (Text) file, using the sample network format (shown in NEE.TXT) as a guide. All the keywords shown in this file are described in Appendix A. The datum should appear first, followed by the units, stations, then observations.

For any given observation set, if one or more observations were not measured, enter the text **NOOBS** within its observation and standard deviation field. This indicates to COLUMBUS that these observations were not measured.

Step 2: Load this project file into COLUMBUS using the FILE - OPEN command. Enter the approximate latitude (+-10 minutes) for the project area within the OPTIONS - GLOBAL SETTINGS dialog.

Both methods can be used separately or in combination to build a 3D local horizon NEE network. For example, part of the network could be entered online, with the remainder of the network appended from an ASCII (Text) file using the FILE - APPEND command.

When a 3D local horizon NEE network is loaded into COLUMBUS, any local NEUE station with both the north and east component set to zero are assigned arbitrary 2D coordinates for graphical display. Stations assigned these arbitrary 2D coordinates will not be represented on-screen as they occur in the field, but it does allow you to see how each is connected to other stations. The color of each such station name will match the color setting for the **Station Names with Coords of Zero** option, set up in the OPTIONS - COLORS dialog.

Tip: Any time you add or modify data within the current project, you should periodically save the data to disk using the FILE - SAVE or FILE - SAVE AS command.

Summary of Instructions For Solving Networks

The following sections contain summaries of the steps recommended to solve 1D vertical, 2D geodetic, 3D geodetic, 3D ECEF XYZ, 2D State Plane, 3D State Plane, 2D UTM, 3D UTM, 2D local horizon NE, and 3D local horizon NEE networks. The steps are provided as an outline to aid you in becoming familiar with COLUMBUS. Each sample project file shipped with COLUMBUS also contains similar steps for adjustment.

1D Vertical Networks

The 1D vertical network example used in this section is contained within the VERTICAL.TXT project file shipped with COLUMBUS. To duplicate our results, open this project file into COLUMBUS using the FILE - OPEN command. Next, select the VIEW menu. Notice the active view type is 1D Vertical (there should be a check mark next to it). Selecting 1D Vertical as the active view type puts the network adjustment context into 1D Vertical mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the VERTICAL.TXT network, we used the following non-default settings:

   Linear Units set to Meters (UNITS dialog)
   1D Network Type set to Distance Weighted (NETWORK OPTIONS - NETWORK SETTINGS dialog). For this network, the distances are expressed in kilometers.

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, invoke the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Stations **BOB** and **FAYE** to be fixed in 1D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADJUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to examine a **report style** look at the view.

   To examine the Height Confidence Intervals for any adjusted station or between stations, double click within the applicable vertical bars in the Adjusted Network View.

To examine the adjusted height for a station, double click on the station symbol in the Adjusted Network View.

To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with your results.

2D Geodetic Networks

The 2D geodetic network example used in this section is contained within the BEAR2D.TXT project file shipped with COLUMBUS. To duplicate our results, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to 2D Geodetic. This puts the network adjustment context into 2D Geodetic mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the BEAR2D.TXT network, we used the following non-default settings:

   Linear Units set to U.S. Survey Feet (UNITS dialog)
   2D Height to 6000.0 feet (GLOBAL SETTINGS dialog)
   Rotate Bearings enabled (NETWORK OPTIONS - NETWORK SETTINGS dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, invoke the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Station **1** to be fixed in 2D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable ellipse in the Adjusted Network View.

   To examine the adjusted latitude and longitude for a station, double click on the station symbol in the Adjusted Network View. The height component is fixed in a 2D geodetic adjustment.

   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with your results.

3D Geodetic Networks

The 3D geodetic network example used in this section is contained within the BIGBASIN.TXT project file shipped with COLUMBUS. To duplicate our results, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to 3D Geodetic. This puts the network adjustment context into 3D Geodetic mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the BIGBASIN.TXT network, we used the following non-default settings:

   Linear units set to Meters (UNITS dialog)
   3D Geodetic Height set to Ellipsoidal Height (GLOBAL SETTINGS dialog)
   GPS Scale and Rotation parameters enabled (NETWORK OPTIONS - NETWORK SETTINGS dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, choose the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Stations **CARBON**, **CHANEY**, **FORT LEWIS** and **LA PLATA** to be fixed in 3D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable adjusted error ellipse in the Adjusted Network View.

   To examine the adjusted geodetic coordinates for a station, double click on the station symbol in the Adjusted Network View.

   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with the results.

3D ECEF XYZ Networks

The 3D ECEF XYZ network example used in this section is contained within the BIGBASIN.TXT project file shipped with COLUMBUS. To duplicate our results, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to Cartesian XYZ. This puts the network adjustment context into ECEF XYZ mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the BIGBASIN.TXT network, we used the following non-default settings:

   Linear units set to Meters (UNITS dialog)
   GPS Scale and Rotation parameters enabled (NETWORK OPTIONS - NETWORK SETTINGS dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, choose the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Stations **CARBON**, **CHANEY**, **FORT LEWIS** and **LA PLATA** to be fixed in 3D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable adjusted error ellipse in the Adjusted Network View.

   To examine the adjusted ECEF XYZ coordinates for a station, double click on the station symbol in the Adjusted Network View.

   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with the results.

2D State Plane Networks

The 2D State Plane network example used in this section is based on the data contained within the STATEPLANE.TXT project file shipped with COLUMBUS. We have provided 3D results for this project, but you can also use this file for a 2D adjustment as well. To adjust in 2D, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to State Plane (2D). This puts the network adjustment context into 2D State Plane mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the STATE.TXT network, we used the following non-default settings:

   Linear Units set to Meters (UNITS dialog)
   2D Height to 2000.0 meters (GLOBAL SETTINGS dialog)
   State Plane Zone to IDAHO 1103 (PROJECTION ZONES - STATE PLANE ZONES dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, invoke the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Station **A** and **F** to be fixed in 2D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable ellipse in the Adjusted Network View.

   To examine the adjusted north and east for a station, double click on the station symbol in the Adjusted Network View. The height component is fixed in a 2D State Plane adjustment.

   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue

through the remaining steps. Continue this process until you are satisfied with your results.

3D State Plane Networks

The 3D State Plane network example used in this section is contained within the STATEPLANE.TXT project file shipped with COLUMBUS. To duplicate our results, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to State Plane (3D). This puts the network adjustment context into 3D State Plane mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the BIGBASIN.TXT network, we used the following non-default settings:

   Linear units set to Meters (UNITS dialog)
   State Plane Zone to IDAHO 1103 (PROJECTION ZONES - STATE PLANE ZONES dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, choose the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Stations **A** and **F** to be fixed in 3D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable adjusted error ellipse in the Adjusted Network View.

   To examine the adjusted north, east, and orthometric height coordinates for a station, double click on the station symbol in the Adjusted Network View.

   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with the results.

2D UTM Networks

The 2D UTM network example used in this section is contained within the UTM.TXT project file shipped with COLUMBUS. We have provided 3D results for this project, but you can also use this file for a 2D adjustment as well. To adjust in 2D, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to UTM (2D). This puts the network adjustment context into 2D UTM mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the UTM.TXT network, we used the following non-default settings:

   Linear Units set to Meters (UNITS dialog)
   2D Height to 2000.0 meters (GLOBAL SETTINGS dialog)
   Central Meridian to -117.0 degrees (PROJECTION ZONES - UTM ZONE SETUP dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, invoke the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Station **A** and **F** to be fixed in 2D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable ellipse in the Adjusted Network View.

   To examine the adjusted north and east for a station, double click on the station symbol in the Adjusted Network View. The height component is fixed in a 2D UTM adjustment.

   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with your results.

3D UTM Networks

The 3D UTM network example used in this section is contained within the UTM.TXT project file shipped with COLUMBUS. To duplicate our results, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to UTM (3D). This puts the network adjustment context into 3D UTM mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the UTM.TXT network, we used the following non-default settings:

   Linear units set to Meters (UNITS dialog)
   Central Meridian to -117.0 degrees (PROJECTION ZONES - UTM ZONE SETUP dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, choose the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Stations **A** and **F** to be fixed in 3D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable adjusted error ellipse in the Adjusted Network View.

   To examine the adjusted north, east, and orthometric height coordinates for a station, double click on the station symbol in the Adjusted Network View.

   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with the results.

2D and 3D Local Horizon Networks

COLUMBUS supports both local horizon 2D NE (north, east) and 3D NEE (north, east, orthometric height) adjustments. Curvature and convergency corrections are automatically applied (based on the approximate network latitude) resulting in very accurate adjustments when projects are confined to a small area (**recommended size should be less than 1km square**). For projects larger than 1km square, we recommend you use a 2D/3D geodetic, 2D/3D State Plane or 2D/3D UTM adjustment.

2D Local Horizon NE Networks

The 2D local horizon NE network example used in this section is contained within the NEE.TXT project file shipped with COLUMBUS. **This project can be adjusted as either a 2D local horizon NE network or as a 3D local horizon NEE network.** To duplicate our results, open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to Local NE. This puts the network adjustment context into 2D Local Horizon NE mode. **The adjustment results contained in the NEE_RPT.TXT report file are based on a 3D local horizon NEE adjustment, not the 2D local horizon NE adjustment.**

1. Set up the following network parameters within the OPTIONS dialogs. For the NEE.TXT network, we used the following non-default settings:

   Linear Units set to Meters (UNITS dialog)
   2D Height to 1000.0 meters (GLOBAL SETTINGS dialog)
   Approximate Latitude to 45.0 (GLOBAL SETTINGS dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, invoke the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Station **A** to be fixed in 2D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable ellipse in the Adjusted Network View.

To examine the adjusted north and east coordinates for a station, double click on the station symbol in the Adjusted Network View. The height component is fixed in a 2D local horizon NE adjustment.

To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with your results.

3D Local Horizon NEE Networks

The 3D local horizon NEE network example used in this section is contained within the NEE.TXT project file shipped with COLUMBUS. **This project can be adjusted as either a 2D local horizon NE network or as a 3D local horizon NEE network.** To duplicate our results (found in the NEE_RPT.TXT file), open this project file into COLUMBUS using the FILE - OPEN command. Change the active view type in the VIEW menu to Local NEUE. This puts the network adjustment context into 3D Local Horizon NEE mode.

1. Set up the following network parameters within the OPTIONS dialogs. For the NEE.TXT network, we used the following non-default settings:

   Linear units set to Meters (UNITS dialog)
   Approximate Latitude to 45.0 (GLOBAL SETTINGS dialog)

2. Define the stations and observations that will be used in the current adjustment. Stations not selected (to be in the network) will not be used in the adjustment.

   Enter the NETWORK menu and select the NETWORK STATIONS command. Alternatively, choose the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button.

3. Enter the NETWORK menu and select the FIXED STATIONS command. Alternatively, invoke the SELECT FIXED STATIONS toolbar button. Click on Stations **A** to be fixed in 3D. Click on the **OK** button.

4. Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, invoke the SELECT OBS toolbar button. Click on the **Select All** button to select all the observations to be used in the current adjustment. Only observations linked to the selected network stations will be presented. The observations in this window are ordered alphabetically by the AT and TO station names. Click on the **OK** button.

5. Begin the network adjustment by selecting the ADUSTMENT command form the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step. After the adjustment is completed, review the adjustment summary view. Select the ADJUSTED NETWORK VIEW command from the RESULTS menu to graphically review the adjusted network.

6. The following views and several others can be brought up from within the RESULTS menu. For each view, try the PRINT PREVIEW command to see a **report style** look at the view.

   To examine the Error Ellipses for any adjusted station or between stations, double click within the applicable adjusted error ellipse in the Adjusted Network View.

   To examine the adjusted Local NEE coordinates for a station, double click on the station symbol in the Adjusted Network View.

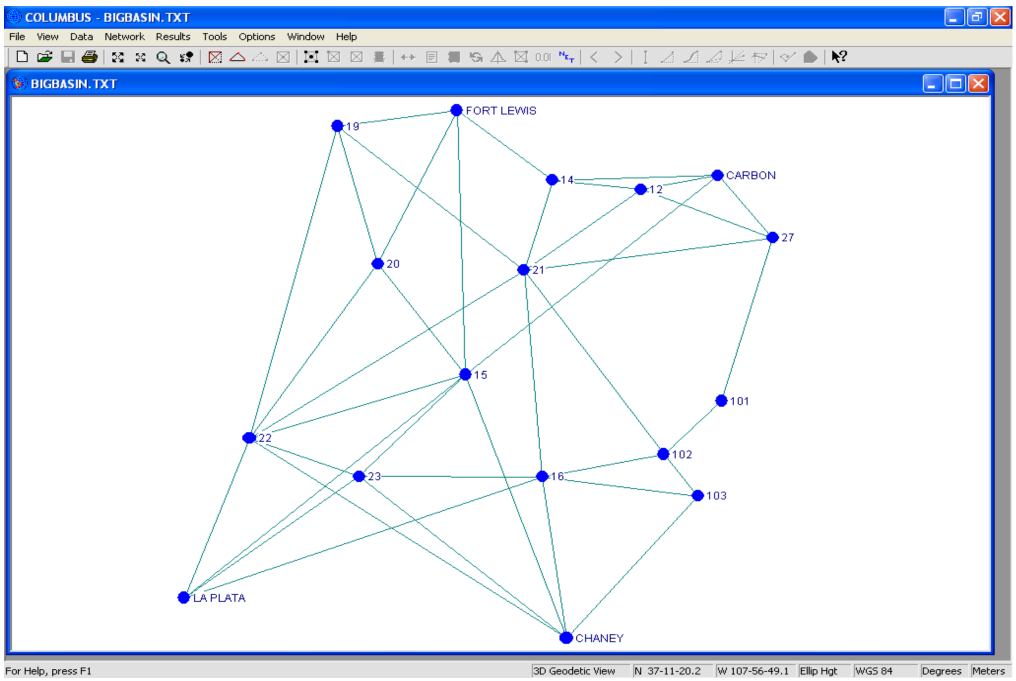
   To examine the adjusted observation between any two stations, double click on the line connecting the station pair in the Adjusted Network View.

7. Return to any of the steps, make modifications (e.g., add or remove observations), then continue through the remaining steps. Continue this process until you are satisfied with the results.

Load BIGBASIN.TXT Sample Network

For the remainder of this chapter, the discussion will focus on 3D Geodetic network adjustment and 3D Geodetic network pre-analysis. Where appropriate, 1D Vertical and 2D Geodetic network adjustment topics will be mentioned where they differ from the 3D Geodetic model.

You can think of a 3D geodetic network adjustment/pre-analysis as a superset of 1D and 2D networks. The steps for performing 1D network adjustments and 2D network adjustments/pre-analyses are very similar to those required for performing 3D geodetic network adjustments/pre-analyses, but fewer results are applicable.



The discussion for the remainder of this chapter and the next (NETWORK RESULTS) is based on the **BIGBASIN.TXT** project shipped with your copy of COLUMBUS. You will also find a project file called **BIGBASIN_NET.TXT** as part of the installation. This file is identical in data content to BIGBASIN.TXT, but it also includes all the predefined Options Settings that we ask you to make below when using BIGBASIN.TXT. This file also identifies the pre-selected network stations, those that will be held fixed, and the observations that are to be used.

Enter the OPTIONS - LIBRARY MANAGER and set the default option set to **Columbus Initial Options.** If you currently have a library set called **Columbus Initial Options (mod)**, *rename the set before continuing*.

Load BIGBASIN.TXT using the FILE - OPEN command and set the following OPTIONS settings:

Linear Units set to meters (UNITS dialog)
GPS Scale and Rotation parameters enabled (NETWORK OPTIONS - NETWORK SETTINGS dialog)
3D Geodetic Height to ellipsoidal height (GLOBAL SETTINGS dialog)
State Plane Zone to COLORADO S 503 (PROJECTION ZONES - STATE PLANE ZONES)
UTM Central Meridian to -105.0 degrees (PROJECTION ZONES - UTM ZONE SETUP)

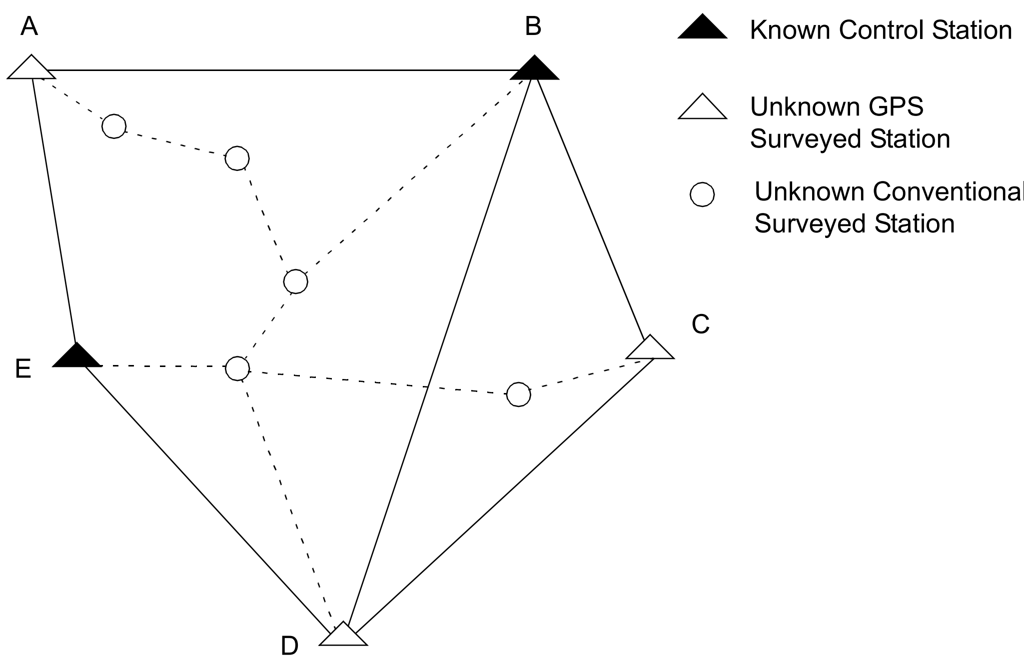
Selecting the Network Data

After loading your project file, COLUMBUS allows you to interactively select station and observation data for the adjustment. There is no need to change your project file to make these changes. You project file never changes unless to invoke one of the SAVE options in COLUMBUS.

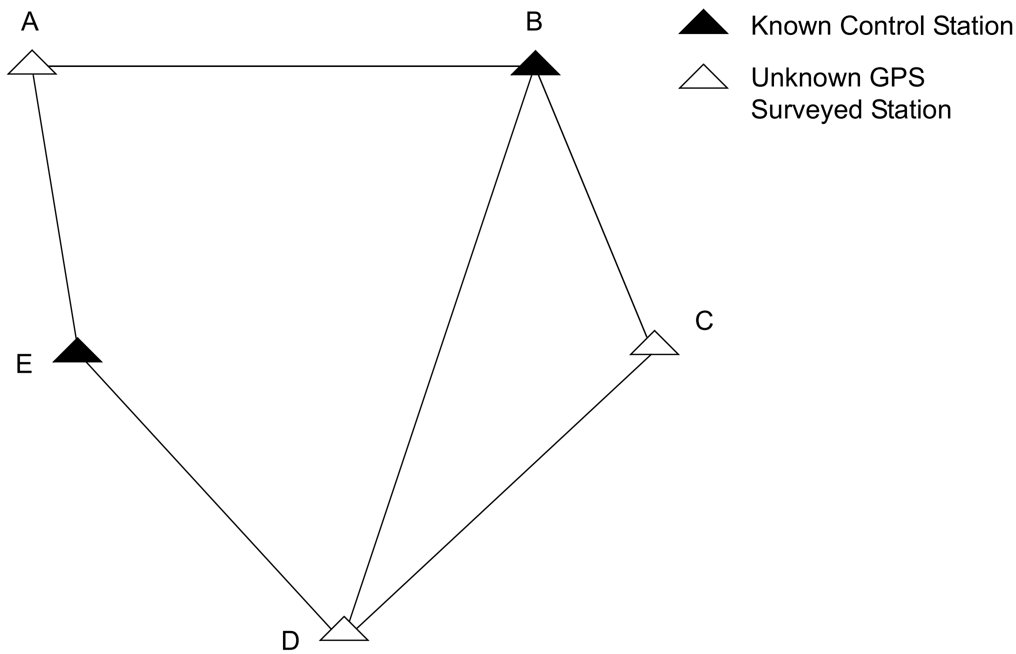
It is not necessary to use all the stations and observations (within the project) for the current adjustment. Suppose a network is adjusted that contains a bad observation. You can easily omit this observation from the network, then readjust without changing your project file. You may also select any number of combinations of subnetworks to adjust by selecting the appropriate stations. COLUMBUS was developed to facilitate this type of **"what-if"** analysis by solving subnetworks on-the-fly.

If you omit any station from the current adjustment, all observations linked to this station will automatically be ignored.

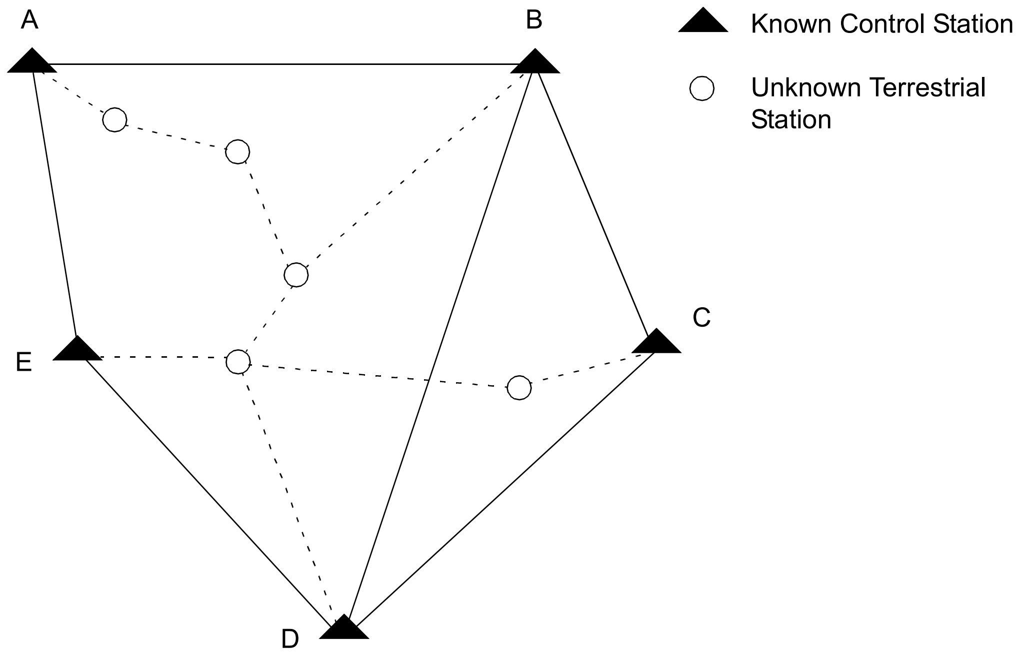
The figure below displays what is meant by solving a 3D network as a series of subnetworks. This network consists of six GPS baselines (solid lines) and several terrestrial observations (dashed lines). Two of the stations (B and E) are 3D control stations with known geodetic positions. The remainder of the station positions are unknown.



Suppose you wish to adjust the GPS portion of this network independently of the terrestrial portion. One way to do this is to select only the GPS stations to be in the network, then select Stations B and E as 3D control stations. Only the GPS observations would be applicable. After the adjustment of this subnetwork, you can Keep the adjusted coordinates for Stations A, D and C into the project to hold fixed in the next adjustment phase.

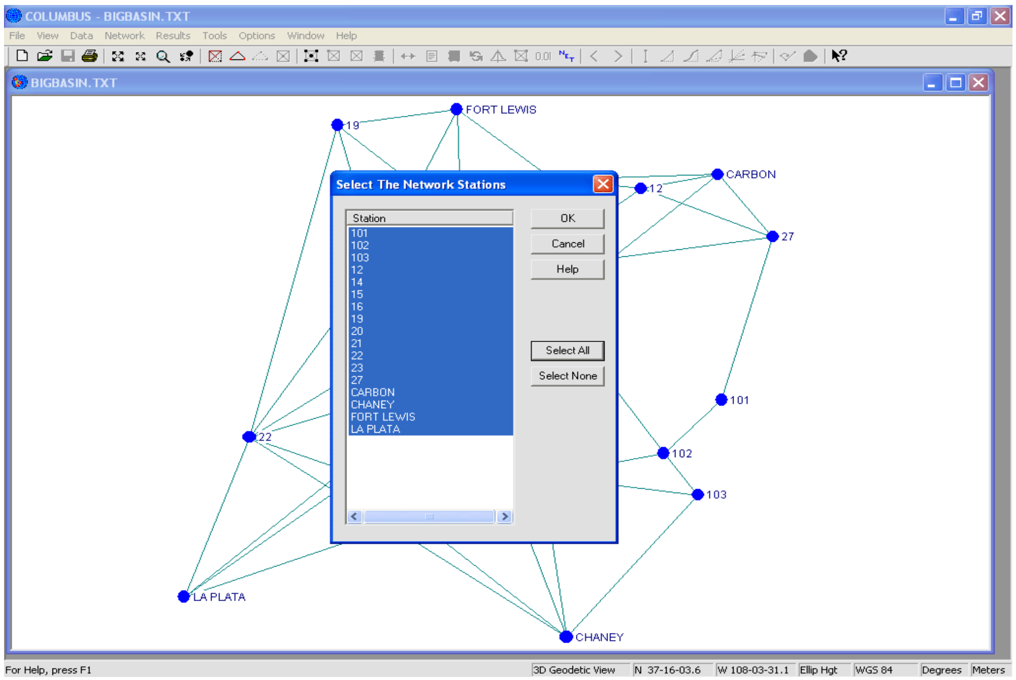


To complete the project, select all stations to be included in the network and hold the GPS stations computed earlier (Stations A, B, C, D, E) to be fixed in 3D. Within the SELECT OBSERVATIONS dialog simply disable the GPS observations, since they are not needed for this adjustment.



Network Stations

To define the stations that will be included in the current adjustment, enter the NETWORK menu and invoke the NETWORK STATIONS command. Alternatively, click on the SELECT NETWORK STATIONS toolbar button. Click on the **Select All** button to select all the stations to be used in the current adjustment. Click on the **OK** button to accept the changes and close the dialog.



Any station selected is now part of the network you plan to adjust. Any station not selected is removed from the adjustment. Any observations linked to unselected stations will not be part of the adjustment. Stations and observations, that are not part of the current adjustment, are still in the project. They will continue to be visible within the project view. They will **not** be visible within the ADJUSTED NETWORK VIEW described in the RESULTS chapter.

For the BIGBASIN.TXT network, select all stations to be included in the adjustment.

Fixed Stations

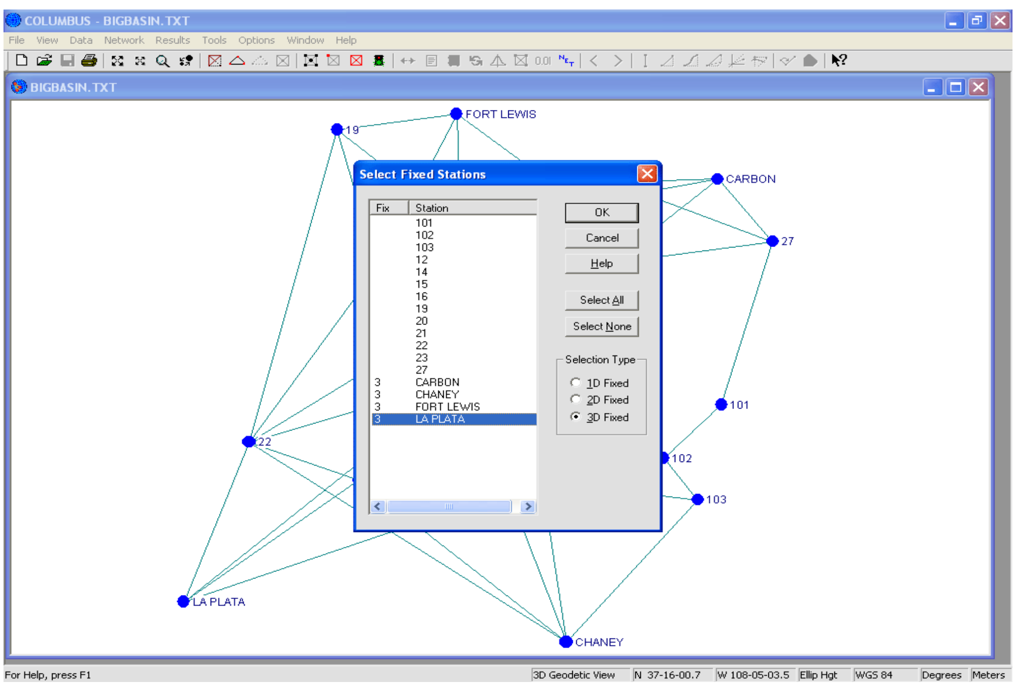
Enter the NETWORK menu and invoke the FIXED STATIONS command. Alternatively, click on the SELECT FIXED STATIONS toolbar button. A list of all available network stations (selected above) will be presented. To select a fixed station, first click on the **Selection Type**, then click the station name.

1D Vertical — Stations set to 1D will have their height held fixed. Select one or more 1D stations by clicking on each with the mouse. The known heights for these stations must be defined in the project prior to the adjustment.

For the VERTICAL.TXT network, we selected stations **BOB** and **FAYE** to be fixed in 1D.

2D Geodetic — Stations set to 2D will have their latitude/longitude or north/east (depending on network type) held fixed. Select one or more 2D stations by clicking on each with the mouse. The known latitude/longitude or north/east must be defined in the project prior to adjustment.

For the BEAR2D.TXT network, we selected Station **1** to be fixed in 2D. To fix only the latitude for a station, but not its longitude, please see the next section, CONSTRAINED STATIONS.



3D Geodetic — Stations held fixed in 3D must have their known latitude, longitude (or north or east, depending on the adjustment type) and/or height (orthometric or ellipsoidal, depending on adjustment type) components already defined in the project. For the BIGBASIN.TXT network, we selected Stations **CARBON**, **CHANEY**, **FORT LEWIS** and **LA PLATA** to be fixed in 3D. To fix only the latitude for a station, but not its longitude, please see the next section, CONSTRAINED STATIONS.

Constrained Stations

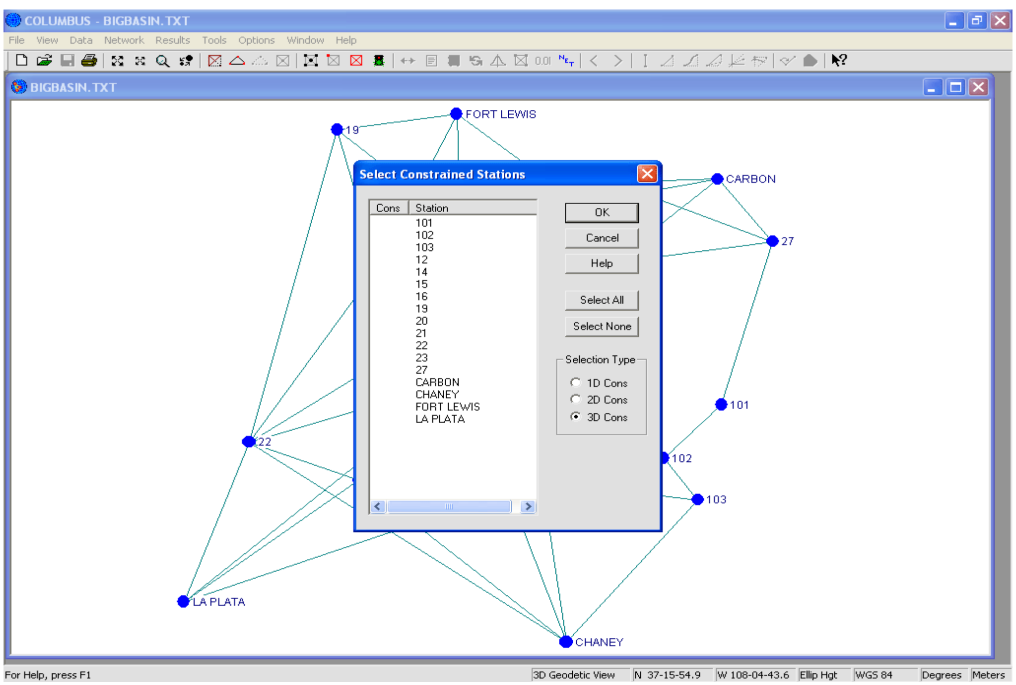
Enter the NETWORK menu and invoke the CONSTRAINED STATIONS command. A list of available network stations will be presented. **This option is not available for 2D/3D State Plane, 2D/3D UTM and 2D/3D local horizon networks.**

1D Vertical — When a station is set to be 1D constrained, a coordinate height observation is created. Select one or more stations to be constrained in 1D by clicking on each with the mouse. The known heights and height standard deviation for these stations must be defined in the project prior to the adjustment.

For the VERTICAL.TXT network, no stations have been set to be constrained.

2D Geodetic — When a station is set to be 2D constrained, two coordinate observations are created (one for latitude and one for longitude). Select one or more stations to be constrained in 2D by clicking on each with the mouse. The known latitude, longitude, and their standard deviation must be defined in the project prior to adjustment.

For the BEAR2D.TXT network, no stations have been set to be constrained.



3D Geodetic — When a station is set to be 3D constrained, three coordinate observations are created (one for latitude, one for longitude, and one for height). The known latitude, longitude, height and their standard deviation must be defined in the project prior to adjustment.

For the BIGBASIN.TXT network, no stations have been set to be constrained.

After choosing the stations to constrain, click on the **OK** button to accept the changes. Any coordinate component selected to be constrained becomes an observation in the network.

Coordinate observations are occasionally used to constrain or hold a station **“relatively”** fixed during an adjustment. We say relatively fixed, because the station can actually move. Like most observations, the magnitude of weight you assign to a coordinate observation is determined by its standard deviation. The smaller the standard deviation, the less the coordinate can move during the adjustment. A large coordinate standard deviation allows the station to move as much as the network dictates. **If your network is very tight and you have a good coordinate for each constrained station, the constrained stations will not move much, no matter how large their standard deviations.**

To define the standard deviation for each applicable coordinate observation, do the following:

1D Vertical — Edit the station height coordinate standard deviation field within the DATA - STATIONS - HEIGHT dialog or directly within the project file. **You 1D vertical network observations should be weighted by standard deviation and not by the distance or number of setups between stations.**

2D Geodetic — Coordinate observations for 2D geodetic networks allow the movement of latitude or longitude for known stations (during a network adjustment). To allow the latitude for each known station to move, but not the longitude, set the station to be constrained instead of fixed. Make sure you have entered a very small standard deviation for each constrained station longitude (for example, 0.0000001 meters). Assign each constrained station latitude a much larger standard deviation (for example, 0.025 meters) so that it may move.

Coordinate observations (for latitude and longitude) and their standard deviations can be modified within the DATA - STATIONS - GEODETIC grid or directly within the project file.

.3D Geodetic — Coordinate observations for 3D geodetic networks also allow the movement of latitude, longitude and/or height (orthometric or ellipsoidal, depending on the adjustment context) for known stations (during a network adjustment). To allow the latitude for each known station to move, but not the longitude, set the station to be constrained in 2D, instead of fixed in 2D. Make sure you have entered a very small standard deviation for each constrained station longitude (for example, 0.0000001 meters). Assign each constrained station latitude a much larger standard deviation (for example, 0.025 meters) so that it may move.

Coordinate observations (for latitude, longitude and height) and their standard deviations can be modified within the DATA - STATIONS - GEODETIC grid or directly within the project file.

If you plan to use coordinate observations, you should fully understand the consequences of doing so. Generally, coordinate observations are used to propagate the uncertainty in adjusted coordinates from a prior survey into your current network adjustment.

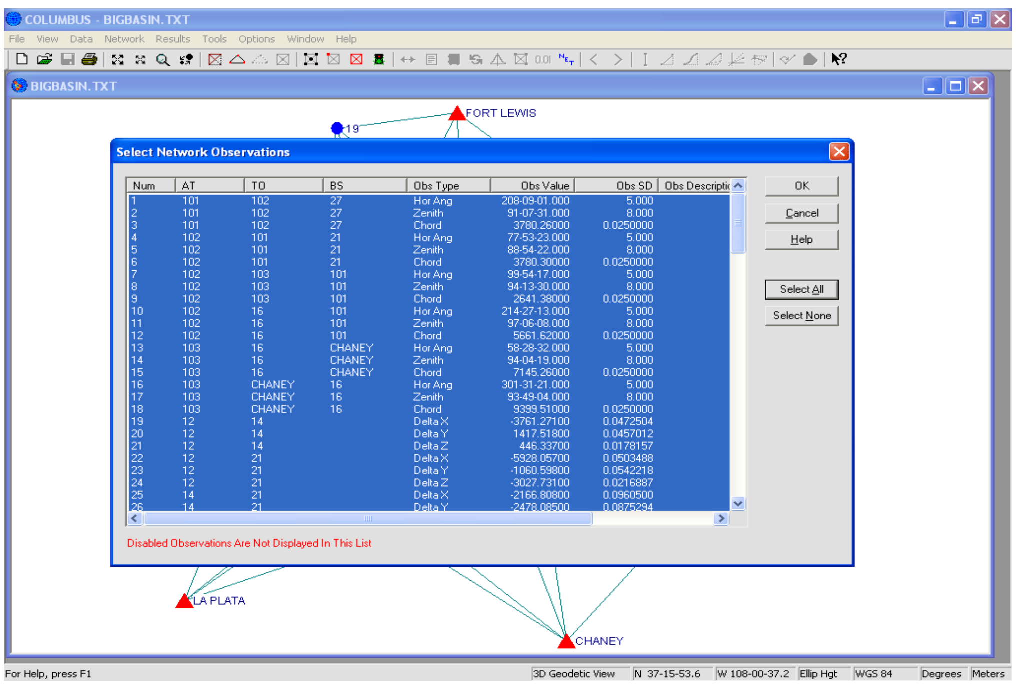
COLUMBUS also supports detail geodetic coordinate observations (with full covariance matrix). One or more coordinate observations can be specified for each station. When using this type of coordinate observation (see the DATA chapter, Editing Geodetic Coordinate Observations) for a station, the station does not need to be fixed or constrained (as described above). The coordinate observation will be automatically integrated into the adjustment.

Observations

The OBSERVATIONS command allows you to select the observations to be included in the network adjustment. When this command is invoked, COLUMBUS gathers all valid observations pertaining to the selected network stations.

Enter the NETWORK menu and select the OBSERVATIONS command. Alternatively, choose the SELECT OBS toolbar button. The observations in this window are ordered alphabetically by the AT and TO station names.

This dialog **must** be invoked if the **network station selections** or **constrained station selections** have been changed. Changing these selections will change the observations that are valid for the network adjustment (hence, it is best to just reselect your observations). If you choose to use all valid observations, simply enter this dialog, click on the **Select All** button, then select the **OK** button. To remove one or more observations from the network adjustment, Ctrl-click on the observations to un-highlight them, then click on the **OK** button.



In the screen shown above, all observations are currently tagged as being part of the network.

Run The Network Adjustment

Begin the network adjustment by selecting the ADJUSTMENT command from the NETWORK menu or by clicking on the START ADJUSTMENT toolbar button. As the adjustment proceeds, COLUMBUS displays each processing step.

1. The connectivity for all the stations within the network is checked. Using one control station (fixed or constrained) as a starting point, COLUMBUS determines whether every other station is connected to this station (directly or indirectly) by at least one valid observation. If this test fails, you may have selected more than one contiguous network. The station names shown in the dialog are not connected to the main network.

2. COLUMBUS then attempts to compute approximate coordinates for all floating stations within the network using the selected observations and control stations. Approximate coordinates are required prior to any 2D or 3D network adjustment to serve as an initial starting solution. The closer the initial solution is to final solution, the faster the adjustment will complete. **Approximate heights are not required for 1D Vertical networks, but COLUMBUS computes them anyway.**

   If COLUMBUS cannot compute the approximate coordinate for any station, you will be given an opportunity to view the current coordinates for those stations. This is not a fatal error. If for any such station, the coordinate currently in the project is reasonably close to its actual position, you can continue with the adjustment process. If the coordinate within the project is not realistic, you should enter a better coordinate in the DATA - STATIONS - GEODETIC grid, otherwise, the adjustment may not converge to a final solution. To use known and computed coordinates together, please review the **Use Known Approx Coords First** checkbox in the OPTIONS - NETWORK OPTIONS - NETWORK SETTINGS tabbed dialog.

3. The ability to invert the covariance matrix for each GPS baseline (if applicable) is verified. The inverse of each covariance matrix becomes the weight matrix for each baseline. Any invalid covariance matrix can be viewed. **Bad GPS baseline covariance matrices must be removed from the network before the adjustment process can continue. This problem rarely occurs.**

4. The degrees of freedom for the selected network is them computed. The degrees of freedom must be greater than zero to perform an adjustment.

5. The available disk space on the drive (defined within the OPTIONS - DIRECTORIES dialog, KBG Work Files Directory) is checked. During network adjustments, a few intermediate data files are created. These files can be identified by their *.KBG extension. COLUMBUS automatically deletes and rebuilds these files with each new adjustment. When you close the current project or begin a new adjustment, these files are automatically deleted. If there is enough disk space available to accommodate these files, COLUMBUS continues to the next step.

6. In order to minimize the number of coefficients generated during the least squares adjustment, an internal reordering of network stations is performed. In doing so, the optimal solution can be determined quicker and often with greater numerical stability.

7. COLUMBUS then checks to be sure that every station has a different set of approximate coordinates. This is done to ensure that only one station definition (for the same point on the ground) is defined.

8. Corrections to terrestrial observations for mark-to-mark reductions, deflections of the vertical, etc., are applied on each iteration. These corrections are made to the original observed measurements. This is performed on each iteration, because accurate coordinates are required to make some of these

corrections. On each iteration, if the adjustment is converging, the coordinates are usually getting better (under normal circumstances) and thus corrections can be re-calculated with greater accuracy. Deflection of the vertical corrections only apply to 3D geodetic networks.

9. Next, the weights for all observations are calculated. They are used on each iteration of the adjustment.

10. When the adjustment has completed, the sums of squared residuals (for all observations) have been minimized. When the adjustment converges to an optimal solution, COLUMBUS computes the inverse matrix for the final system of equations. The inverse matrix is required for all statistical analyses. Because the inverse matrix is typically 100% dense (only the lower diagonal is computed and stored), thousands of computations are involved for large networks. COLUMBUS then computes the residuals for each observation and performs the Chi-square statistical test to evaluate the consistency of the predicted errors (your ***a priori*** standard deviation for each observation) versus the actual errors (***residuals***) found in the network.

When COLUMBUS has completed the adjustment, the summary statistics are displayed. This tells you the results of the Chi-squared test on the *a posteriori* variance factor (i.e., if it is statistically larger or smaller than 1.0). COLUMBUS also indicates the degrees of freedom and the confidence level selected.

As the residuals are being computed, COLUMBUS compares each standardized residual against the Standardized Residual Rejection Constant. The following formula applies:

$$\frac{\textit{residual}}{\textit{residual standard deviation}} = \textit{the standardized residual for each observation}$$

If the observation standardized residual exceeds this constant, the observation is tagged as a **possible** outlier. The total number of standardized residuals exceeding the **Standardized Residual Rejection** constant is shown adjacent to the Standardized Residuals Rejections text.

COLUMBUS also computes the number of observations with residuals significantly larger than their *a priori* standard deviation. The *a priori* standard deviation for each observation is provided by you (typically for conventional observations) or, in the case of GPS, by the receiver manufacturer. This test computes (for each observation) the ratio of its:

$$\frac{\textit{residual}}{\textit{a priori standard deviation}}$$

If this ratio exceeds the **Residual/A Priori Stan Deviation Rejection** constant (set up in the OPTIONS - NETWORK OPTIONS - OUTLIER CONSTANTS dialog), the observation is tagged as a **possible** outlier. The total number of observations with residuals exceeding this test are shown adjacent to the Resid/SD Rejections text.

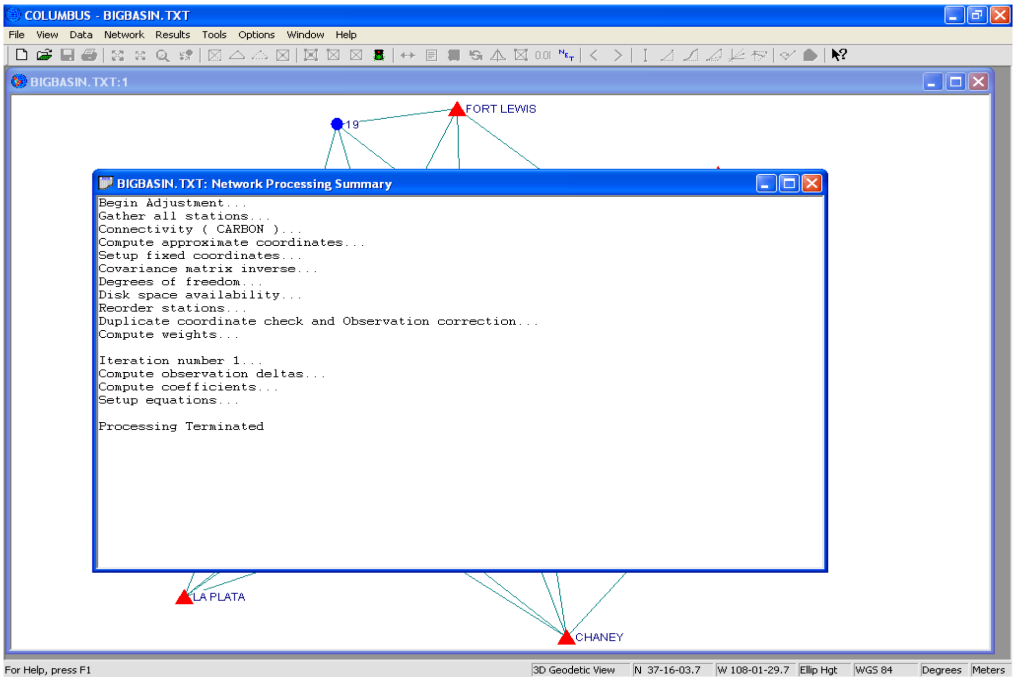
COLUMBUS then determines the number of observations with residuals larger than the each **Observation's Residual Rejection** constant. The total found are shown adjacent to the Residual Rejection text.

COLUMBUS then scans all observations to see if any have a residual of zero. These observations are tagged as **NoCheck** (i.e., flylined, stubbed, sideshot, etc.) observations. NoCheck observations have not been adjusted, indicating they may be tied to a flyline station (**sideshot** stations with no redundant observations measured into them).

Finally, COLUMBUS generates all selected (and applicable) reports that have been set up in the OPTIONS - NETWORK OPTIONS - REPORT SETTINGS dialog. Each report is written (in succession) to the **Network Processing Summary** window. From there, they can be viewed, printed, print previewed or save off to a report file.

Stop Processing

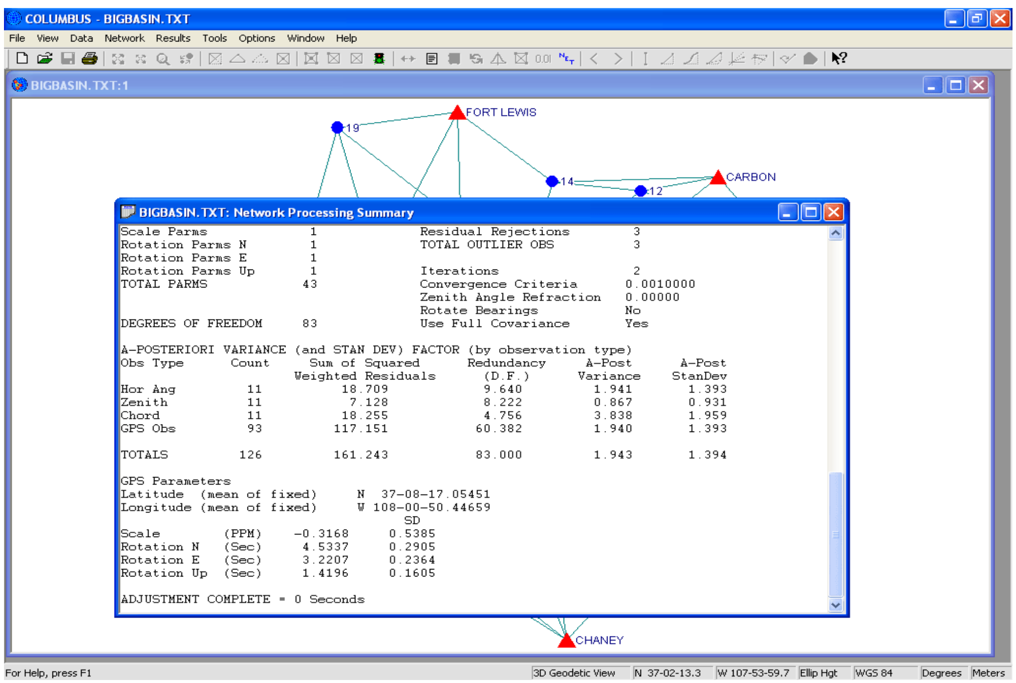
This option allows you to stop the network pre-analysis/adjustment before it has completed. You must close this view in order to change network station and observation selections.



Network Processing Summary

This view displays real-time status messages for the current pre-analysis/adjustment (as it occurs) and a summary of information after processing has completed. **Closing this view clears all results from the adjustment. Therefore, leave this view open until you are ready to abandon the current visual adjustment results.**

Selected network reports (set up in the OPTIONS - NETWORK OPTIONS - REPORT SETTINGS tabbed dialog) will also be written to the summary view. You can then scroll down through the reports, page through the reports using the FILE - PRINT PREVIEW command, or save the reports to an output file. To save the reports to an output file, use the RESULTS - REPORT command or click on the Report Toolbar button. COLUMBUS will prompt you for the name of a report file. All applicable enabled reports will be written to this file.



The status box above shows the following summary data for the adjusted BIGBASIN.TXT 3D Geodetic network:

- Field Observations
- Coordinate Observations
- Total Observations
- Number of Stations
- Stations Fixed In 1D
- Stations Fixed In 2D
- Stations Fixed In 3D
- Float Coordinate Parameters
- Direction Parameters
- GPS Scale Parameters (see the OPTIONS chapter for more information)
- GPS Rotation Parameters (see the OPTIONS chapter for more information)
- Total Parameters

- Degrees of Freedom
- A Priori variance factor
- A Posteriori variance factor
- Confidence Level
- Chi Square test On Variance factor
- Number Of No Check (sideshots) Observations
- The number of **possible** outlier observations for each of the three outlier tests.
- The number of Iterations and Processing Time

To scroll back through the summary, use the vertical scroll bar. To report the adjustment summary (and any reports in the summary window), click on the REPORT toolbar button or invoke the FILE - PRINT PREVIEW command.

COLUMBUS computes the GPS scale and rotation parameters based on the mean position (latitude and longitude) of the 2D and 3D control stations. During the adjustment, COLUMBUS scales and rotates each GPS observation to better fit the local control in your project (optionally enabled within the OPTIONS - NETWORK OPTIONS - NETWORK SETTINGS dialog). This will often lead to better constrained adjustments when GPS observations are used. Each parameter standard deviation is also computed and displayed.

Rotation and scaling of GPS vectors is commonly used to fit the WGS 84 based GPS vectors to non WGS 84 datums. Good rotation and scaling corrections are usually indicated by standard deviations (for each parameter) significantly less than the parameters themselves. In our example, the rotation standard deviations are significantly smaller than the applied rotation results. Scale, on the other hand, is not. The scale correction may not be improving our adjustment results.

The scale factor is shown in PPM (parts per million). Another way of looking at this number using the example above is:

$$\left(\frac{-0.3168}{1000000.0}\right) + 1.0 = 0.99999968$$

If a parameter is not computed, because it has not been enabled in the OPTIONS module, the result for that parameter will be zero. For our BIGBASIN.TXT network, our rotation seems to have been effective, since the computed Standard Deviations are significantly less than the computed parameters (rotation about North, East and Up). It might be worth while turning off the scaling parameter to see if the adjustment results improve. **Note: This network has built-in distortion for demonstration purposes.**

COLUMBUS also reports the ***a posteriori* variance factor** (see next section) for each observation type (or in the case of GPS or Geo Coord Obs - by observation set). By examining these values, you may infer that certain observations types (or sets in the case of GPS and Geo Coord Obs) are not getting weighted properly given the adjustment results.

For example, if the *a posteriori variance factor* is 37.50 for your horizontal angles and 2.10 for your chord (slope) distances, then you might want to double check the weighting being applied to these observation types (via their standard deviations). It could be that your horizontal angle standard deviations are too optimistic (too small). **There is no hard and fast rule to apply in this situation, but it still may be worth investigating further.**

Aposteriori Variance Factor

When a network is adjusted, a mathematical quantity known as the ***a posteriori variance factor*** is computed. It is also commonly referred to as the ***variance of unit weight***. It is a statistical measure of how well your adjustment results matched your expected results - as given by your ***apriori*** standard errors (standard deviations) for the observations. Another way of expressing this number is by taking its square root, which is commonly referred to as the ***standard error of unit weight.***

The *a posteriori variance factor* for the entire network includes the results from all observations. It is a single value to describe the network as a whole. The *a posteriori variance factor* for inividual observation types, is only for those observation types. The sum total of all *a posteriori variance factor*s for all observation types is equal to the *a posteriori variance factor* for the entire network.

If the *a posteriori variance factor* is significantly different from 1.0, we have statistical evidence for suspecting one of the following:

1. The *a priori* standard deviations for some or all observations have been incorrectly estimated. They may be to small or they may be to large.

2. The model chosen to relate the observations to the unknown parameters (unknown coordinates) was incomplete or not correct, or the observations contain systematic components (errors) which are not modeled properly. **For example:** distances may need to be scaled slightly if the EDM is out of calibration; or you may have reduced (to sea level) your distances, but you are still defining them as slope distances; or you may have a rod man not holding the prism correctly - thus introducing a systematic error at each target.

In many cases, the second reason for failure of this test can be confirmed through outlier detection and the appropriate action taken. In the event that the failure cannot be confirmed, we must assume the *a priori* standard deviations were incorrectly estimated and proceed with further statistical procedures using the *a posteriori variance factor*, since it is now the only information we have about the scaling of the *a priori* standard deviation for each observation.

In general:

- If the *a posteriori variance factor* is statistically larger than 1.0, the predicted errors (*a priori* standard deviations) are too small (for the network as a whole or by observation type - depending on the value you are examining) and the observations were adjusted more than what was expected. **For example:** you indicated that your horizontal angles were good to +- 5 seconds (as defined in the standard deviation for each horizontal angle), but many of the horizontal angles were actually adjusted by 20 seconds. This could be a blunder in some observation (bad distance, angle, GPS baseline, etc.) that causes warping of the horizontal angles or it could be unrealistic horizontal angle expected errors (+- 5 seconds).

- If the *a posteriori variance factor* is statistically smaller than 1.0, the predicted errors (*a priori* standard deviations) are too large (for the network as a whole or by observation type - depending on the value you are examining) and the observations were adjusted less than what was expected. **For example:** you indicated that your slope distances were good to +- 0.010 meter (as defined in the standard deviation for each distance), but many of the distances were actually adjusted by only 0.005 meter. You did better in the field (for this observation type) than you expected to do.

Degrees of Freedom

The Degrees of Freedom (DF) influences all statistical analyses. The degrees of freedom is the number of extra observations you have provided above and beyond the minimum required to define the network. In general, networks with higher degrees of freedom (redundancy) are more useful for detecting blunders and improving their reliability.

1D Vertical — The formula used to compute the degrees of freedom for 1D vertical networks is:

$$DF = (\text{total observations} + \text{number of fixed stations}) - \text{number of network station}$$

Note: Any constrained station counts as one additional observation.

2D Geodetic — The formula used to compute the degrees of freedom for 2D networks is:

*DF = total observations + (2 * number of fixed stations) - (2 * number of network stations) - number of direction observation sets*

Note: Any constrained station component counts as one additional observation for latitude and one for longitude.

3D Geodetic — The formula used to compute the degrees of freedom for a 3D networks is:

*DF = total observations + number of stations fixed in 1D + (2 * number of stations fixed in 2D) + (3 * number of stations fixed in 3D) - (3 * number of network stations) - number GPS parameters computed (scale, rotation N, rotation E, and rotation Up) - number of direction observation sets*

Note: Any constrained station component counts as one additional observation for latitude, one for longitude, and one for height (orthometric or ellipsoidal).

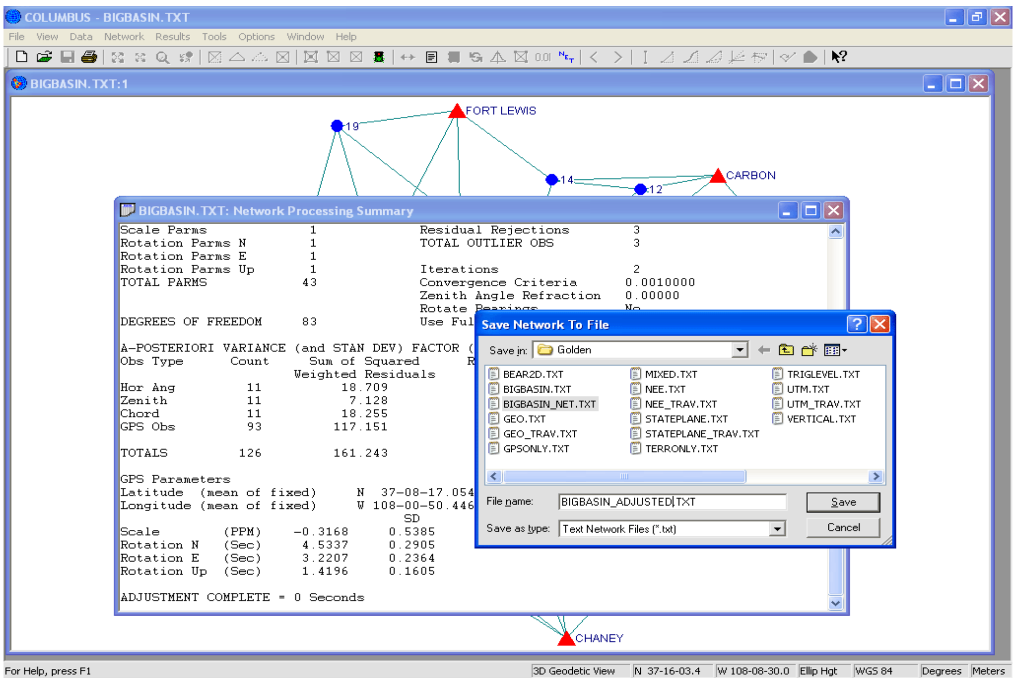
The degrees of freedom reflects the redundancy within the network. To increase the redundancy, add additional observations. Networks that have no redundancy (i.e., DF $\leq$ 0) cannot be adjusted.

You should refer to any modern reference on surveying for further discussion on redundancy and its effects on network analyses. From a strictly conceptual standpoint, the greater the number of pathways for computing each station, the greater the likelihood you will form a strong network with high integrity. Networks which are minimally defined (low degrees of freedom) have a greater chance of containing undetectable errors.

Remember, even networks with high redundancy can be poorly defined. Strong terrestrial networks (using conventional observations) require balanced geometric structure, not simply more observations.

Saving the Adjusted Network

The SAVE NETWORK command allows you to save the current network characteristics to an ASCII (Text) project file for future use. This file can be loaded at a later session using the FILE - OPEN command. It contains all the options settings, stations selections (whether floating, fixed or constrained; 1D, 2D or 3D) and observation selections that where used in the adjustment.



By saving, then later loading this file, you can perform exactly the same adjustment without having to remember exactly what station, observation, and options settings were used. This is very handy when solving many variations of each network (using different station/observation combinations) and you wish to repeat an adjustment that was computed earlier.

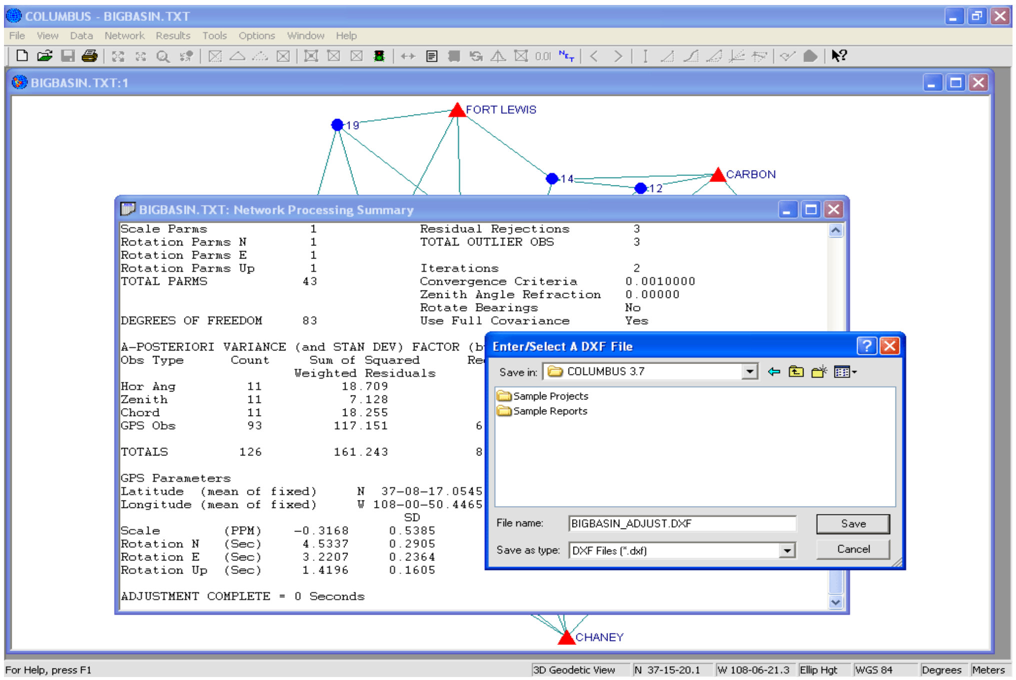
After selecting a file name, you will be asked if you want to only save the actual station and observation data that were used in the adjustment.

Select YES to **only** save project data applicable to the current adjustment.

Select NO to save all data from the project. When NO is selected, stations and observations that are in the project (but not selected to be in the adjustment), will also be saved into the file. When this file is loaded at a later date you can simply ignore the non-network stations and observations.

Create Network DXF

This option allows you to create a DXF file from the current network. You will be prompted for the name of the DXF file. COLUMBUS will not automatically add a DXF extension. Therefore, you should enter the full file name with the DXF extension if your CAD package requires the DXF extension.



DXF file settings can be set up within the OPTIONS - EXPORT FILE SETUP - DXF dialog. Please consult the OPTIONS chapter for a complete discussion of the DXF options available.

For a geodetic network adjustment, the adjusted geodetic coordinates are first transformed to a Local NEU (north, east, up) coordinate system with its origin at the center of the project. The local up component is dropped and each station is assigned the resulting Local North and East coordinate.

Clear Analysis/Adjustment

This option allows you to clear the completed pre-analysis/adjustment. Invoking this command clears all computed data associated with the current project and closes all network result views.

Adjustment (Free - Eliminate Outliers)

One of the many challenges facing surveyors is the identification of bad observations (measurements) in their field data. Loop closure computations can help to isolate poor quality measurements (outliers) and COLUMBUS provides tools to perform loop closures in both GPS, terrestrial, and mixed surveys.

However, even after all known poor quality observations have been removed, occasionally a few remain hidden in the network.

During a least squares network adjustment, any remaining poor quality observations will degrade the quality of your adjustment. One of the downsides of the least squares method is its inherent need to warp your survey to accommodate all measurements, including bad measurements. When this happens, you generally have an idea that some bad measurements exist, but it's not always clear where they are in your survey.

What to do

Check your data first. Before you can go looking for possible outlier observations, it is important to do the following:

1. Check your measurements for obvious blunders.

2. Ensure that your network has adequate redundancy and geometry (minimize very short legs adjacent to long legs, etc.). This is more important when using conventional measurement techniques (non GPS measurements)

3. Double-check the expected errors (standard deviations) you have assigned to each observation. Assigning inappropriate standard deviations to an observation may make it look bad (after adjustment) or could make a nearby observation look bad. If your chord distances have been carefully measured to +/- 0.005 meters, don't assign them a standard deviation of 0.025 meters. **Assigning the appropriate standard deviations to each observation type is absolutely essential to finding poor quality observations and achieving the desired adjustment results.**

4. For 3D networks using terrestrial measurements, be sure to include instrument and target heights for each set of measurements. If the observations have already been reduced to mark-to-mark, instrument and target heights should be set to ZERO. Reduction of measurements to mark-to-mark should be performed using geodetic reduction techniques, not simple trigonometry (unless the stations are very close together; for example, less than a few hundred meters apart).

The Standardized Residual

Outlier detection techniques utilize statistical analysis to identify and isolate bad measurements. Many different outlier detection schemes exist, but only a few really seem to work on a consistent basis.

The National Geodetic Survey (NGS) recommends using the Standardized Residual ratio test as a means for examining each observation in the adjusted network. The Standardized Residual is the ratio of the:

$$\frac{\textit{residual}}{\textit{residual standard deviation}} = \textit{the standardized residual for each observation}$$

The observation residual is the difference between the measured observation and the adjusted observation. It is the correction applied to the original observation to arrive at the adjusted observation. The larger the corrections, the larger the error in your network. The residual standard deviation is a by-product of the least squares adjustment process. It is the computed standard deviation of the residual. At the 68.3% confidence level you can expect the true residual (for the observation) to be between:

the residual (plus or minus) its standard deviation

Also note that the standardized residual is a unitless value; the units are cancelled by forming the ratio. Thus, all observation types, whether linear or angular, are comparable to one cutoff value (see below).

For each observation in the adjusted network, the absolute value of the Standardized Residual is compared against a cutoff value (set up by you or computed automatically by COLUMBUS). If the observation's Standardized Residual (its absolute value) is larger than the cutoff value, that observation is tagged as a **possible** outlier.

To set up the cutoff value in COLUMBUS, enter a value in the **Standardized Residual** field of the OPTIONS - NETWORK OPTIONS - OUTLIER CONSTANTS dialog. If set to **zero**, the constant is calculated using the TAU statistic. The TAU statistic is a function of the number of observations, the degrees of freedom, and the confidence level setting (68%, 95%, 99%, etc.) for the network. By setting the value to a positive **non-zero** number, you control the cutoff value. Over time (and with the same instruments and field crew) you might get comfortable with a value that works for you. Whether you enter your own value or let COLUMBUS compute the TAU-statistic, the resulting cutoff is always displayed in the Network Processing Summary view after the adjustment has completed.

Eliminate External Factors First

Outlier observations should always be isolated and removed before performing a fully-constrained adjustment. We recommend you perform repeated minimally-constrained (free) adjustments to isolate outliers. For a 3D Geodetic network, this means holding only one station fixed in 3D **or** one station fixed in 2D and one station fixed in 1D. Only in this way can you eliminate the introduction of errors from prior surveys into you current project. By only fixing one station (or two, if one is fixed in 2D and the second is fixed in 1D), you can be sure the blunders in your survey are due to the current measured observations and not some additional control, that you may not have established.

Process Of Elimination

Because outlier observations tend to distort a network, one bad observation can make others look bad. Therefore, when searching for outliers, the following process is recommended:

1. Adjust the minimally-constrained (free) network and examine all outliers which fail the Standardized Residual Test.

2. Remove the observation (or baseline, in the case of GPS) for which the Standardized Residual is the largest (observations can be de-selected within the NETWORK - OBSERVATIONS dialog before re-adjustment).

3. On each subsequent adjustment, the largest offender is again removed.

This process is repeated until no more outlier observations are found (based on the Standardized Residual test). **It is important to only remove the largest offender on each run. Do not remove more than one.**

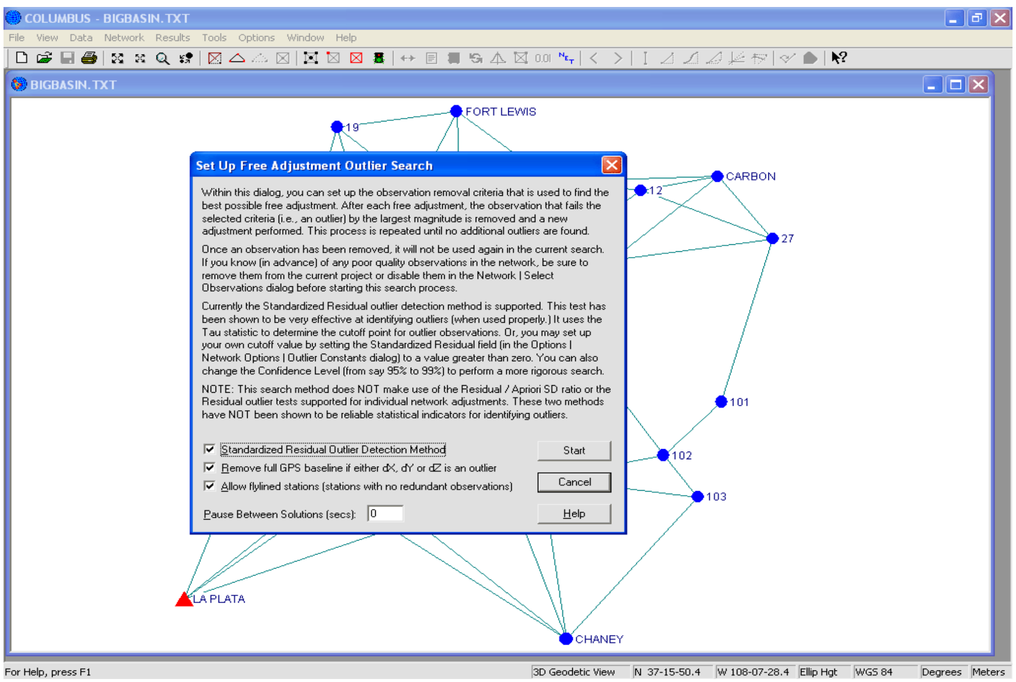
Research suggests that the worst outlier may be causing other observations to be seen as outliers. Often by simply removing a few of the worst offenders, all the remaining outlier observations disappear. This is the result of good observations being distorted by the adjustment that included bad observations.

An Automated Approach

As you can see from the discussion above, the process of identifying and removing outliers is an iterative one. So why not just let the computer do the work? **This process can be automated in COLUMBUS.**

The automated approach requires very little additional work from you. It is very similar to performing the manual process described above, except the automated approach finds and removes the bad observations for you.

To use this feature, simply select your network stations, one fixed station, and the network observations in the usual way. Set up the Standardized Residual cutoff value in the OPTIONS - NETWORK OPTIONS - OUTLIER CONSTANTS dialog to either zero (let COLUMBUS calculate the cutoff) or some non-zero value. Enter the ADJUSTMENT (FREE - ELIMINATE OUTLIERS) dialog and follow the directions.



About The Process

Sometimes when using this option in networks with low degrees of freedom (or some other situation), you may get a partial solution which terminates the process. This simply means not all outlier observations could be removed while still being able to adjust the network. The process may have removed more observations than the minimum required to have a valid network (for example, degrees of freedom may have dropped to zero or below).

Whether you get a partial solution or a complete solution, you can look at the RESULTS - BEST FREE SOLUTIONS view to see a summary of the observations that were removed for each adjustment. The

Network Processing Summary view will indicate if a partial or complete solution has been found. Sometimes you may not get even a partial solution. In this event, you need to fix the reported error before continuing.

If you obtained a complete solution ("**All Found Outlier Observations Successfully Removed**" message), you can then look at the final network adjustment results, accessed from the RESULTS menu (just like when completing the normal network adjustment process).

Additionally, you can save the final network configuration with the SAVE NETWORK command, or you can proceed to do a constrained adjustment by closing the current adjustment, selecting additional fixed stations and then selecting the ADJUSTMENT command.

As long as you do not re-enter the OBSERVATIONS dialog and **Select ALL**, the observations removed will **not** be included during any immediate adjustments. If you are curious, enter the OBSERVATIONS dialog and scroll down to see which observations are now **de-selected**. These observations were removed during the iterative process just completed. They have **not** been removed from memory, only temporarily disabled (while this file is loaded and you have not re-selected them).

Viewing Results

See the NETWORK RESULTS chapter to set up the BIGBASIN.TXT project in order to duplicate the results we generated.

Adjustment (Fixed - All Cases)

COLUMBUS supports an advanced technique to automate the search for the best-fit network adjustment solution. This technique is accessed through the ADJUSTMENT (FIXED - ALL CASES) command. It is based on combinatorial theory, which is applicable to many real-world problems. It can be used for 1D vertical, 2D/3D geodetic, 3D ECEF XYZ, 2D/3D State Plane, 2D/3D UTM and 2D/3D Local NEE networks.

Combinational Theory

Suppose you own a small surveying firm and have just received a GPS control survey contract. To complete this survey on time, you have estimated at least three experienced GPS surveyors must be dedicated to the project. Within your small company, there are five people qualified from which to choose (Tom, Mary, Dave, Alice and Andy). At the moment, all five are free to work on this project. The question, then, is which people should be put on the project? How many combinations of solutions are possible?

You could decide to put only three on the project. Or you might add a fourth or fifth to finish sooner.

Tom, Mary, Dave
Tom, Mary, Alice
Tom, Mary, Andy
Tom, Mary, Dave, Alice
Tom, Mary, Dave, Andy
Tom, Mary, Dave, Alice, Andy

As you might expect, the total number of possible combinations can grow very large. In fact, the actual number of combinations is given by the formula:

$$\frac{N!}{K! \times (N-K)!}$$

where:

! = factorial
N = total number of qualified people available (in this case, five)
K = number of qualified people for any given solution

For this example, the formula needs to be applied **three times**: once for K = 3, once for K = 4 and once for K = 5. The results from each are then added together.

The answer to this example is: 10 + 5 + 1 = 16

Note: 5! = 5 * 4 * 3 * 2 * 1
4! = 4 * 3 * 2 * 1
3! = 3 * 2 * 1

How This Applies To Network Adjustment

For a network adjustment the same type of process can be applied, but instead of different people, we have several different control stations. Each control station is uniquely identified by its known coordinates.

This tool can be used when you are ready to perform a constrained adjustment. Before using, you should have performed several repeated free adjustments and removed any possible bad observations.

If you have several control stations tied to your network, several possible combinations of control station scenarios exist. You could use all the control you have, or you might decide to use a subset of your total available control. Using other adjustment software systems, you would perform several constrained adjustments, altering which stations are set up to be fixed for each adjustment. After finding the most favorable results, you would perform a final adjustment and be done.

The manual process described above would require many hours of user intervention as you change the configuration of control for each combination. Also, you might leave one of the possible combinations out, never knowing if it would have been the best solution. With this tool, COLUMBUS performs these iterative steps for you quickly, easily, and without leaving any possible solution untested! You simply set up the processing parameters, begin processing, then take a coffee break. Meanwhile, you computer continues to work on your behalf.

Example

The sample 3D geodetic network, BIGBASIN.TXT, consists of 17 stations and 126 observations. Assume you have completed the free adjustment process and have removed all poor quality observations. Of the 17 stations in your network, you have known 3D geodetic coordinates for four of the stations and known 1D height for three additional stations. Set the 1D fixed stations **15**, **103**, and **22**. Set the 3D fix stations **CARBON**, **CHANEY**, **FORT LEWIS**, and **LA PLATA**.

For this example, turn OFF the GPS rotation and scaling parameters in the OPTIONS - NETWORK OPTIONS - NETWORK SETTINGS dialog.

Within COLUMBUS, you would then select these stations to be fixed in 1D and 3D, respectively. Select all observations to be in the network (OBSERVATIONS command). Select the ADJUSTMENT (FIXED - ALL CASES) command to bring up the adjustment search dialog as shown below. Here is where you specify the combinations of control configurations that are desirable in any final solution. This is accomplished by setting up the minimum and maximum number of control station types you want to have in each acceptable configuration.

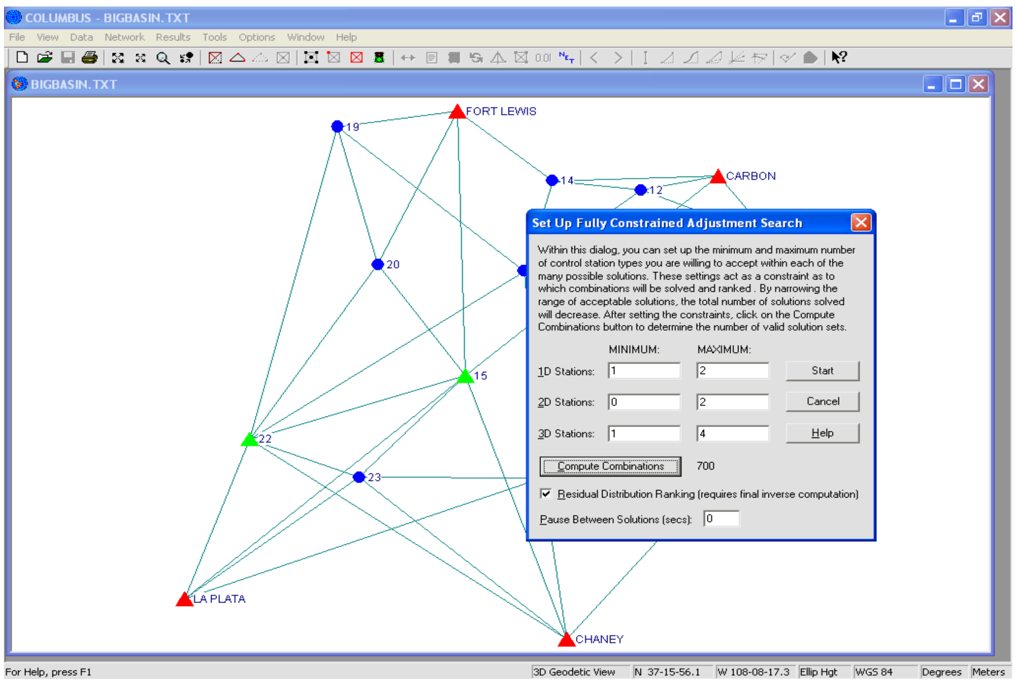
For any constrained 3D geodetic network, you need a minimum of three fixed combination parameters (two fixed parameters are required for 1D or 2D networks). Stations fixed in 1D or 2D count as one parameter. Stations fixed in 3D count as two parameters - since they have both a 1D and 2D component. **This parameter concept is only applicable to solving all combinations**. A constrained 3D geodetic network would require (at a minimum) any of the following:

One 1D fixed station + one 3D fixed station
One 2D fixed station + one 3D fixed station
Two 1D fixed stations + one 2D fixed station
Two 2D fixed stations + one 1D fixed station
Two 3D fixed stations

Note: Three or more stations fixed in only 2D or only 1D will not work, since you need at least 3D worth of control for a 3D constrained adjustment.

By selecting the minimum and maximum number of control stations you are willing to accept in any possible solution, the range of possible solutions can increase or decrease.

For this example, we have decided that each solution must have at least one station fixed in 1D and one station fixed in 3D. Declare this by setting the **Minimum** boxes for 1D and 3D stations to the number **'1'.** Additionally, we have decided we want a maximum of two 1D stations in any given solution. You would declare this by setting the **Maximum** box for 1D stations to the number **'2'**. Finally, for any given solution, we want no more than two stations to be fixed in 2D. You would declare this by setting the **Maximum** box for 2D stations to the number **'2'**.



For the settings above, each combination solved by COLUMBUS will have:

One station fixed in 1D
One station fixed in 3D
No more than two stations fixed in 1D
No more than two stations fixed in 2D
No more than four stations fixed in 3D

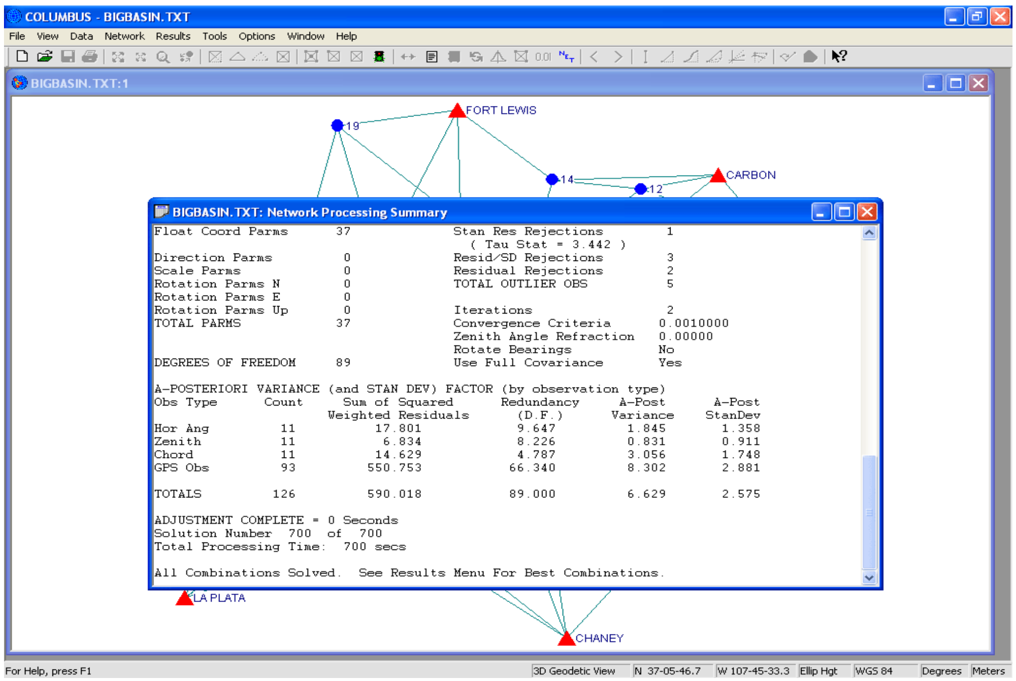
Click on the **Compute Combinations** button to calculate the total number of combinations that will be solved. **For this example, 700 solutions fit the criteria!** Each one of these combinations would satisfy the constraints defined above.

As you can see, there are many possible solutions even with as few control stations as described above. To perform this task manually would be error prone and very time-consuming.

Click on the **Start** button and watch COLUMBUS do the work. After the processing has completed, open the RESULTS - BEST CONSTRAINED COMBOS view to examine each solution. **See the NETWORK RESULTS chapter for the results of this example.**

Why Not Just Use All Known Control?

The answer depends on the quality of the control in your area. Some control points may be more reliable than others, based on how they were established. Some control points may have been disturbed since they were originally surveyed. This could be a result of geological movement, vandalism or even wildlife. Simple instrument centering/height measurement errors could also influence the observed quality of any given control station. You may never know if the control point has these problems, because your first inclination may be to suspect your own observations.



By solving all possible combinations, you have the best opportunity to eliminate control which may be introducing significant errors into your project.

Network Pre-Analysis (Design)

1D Vertical and 2D, 3D Geodetic, State Plane, UTM and Local NEE Networks

The PRE-ANALYSIS tool is a very powerful feature within COLUMBUS. With it you can test your network design to see if it will meet your statistical reliability expectations.

The usage of the PRE-ANALYSIS tool is similar to the ADJUSTMENT tool. Select your stations and observations, validate and analyze the proposed network geometry, then view the statistical results.

Benefits Of Network Design

Surveyors often ask, "What are the benefits of network design for a GPS survey, given that the accuracies of individual GPS baselines are a function of satellite geometry and not survey network geometry?" The short answer is network design helps to provide a measure of confidence in your future survey. That measure of confidence is a function of your network design.

The purpose of network design is to estimate the confidence of your future survey, before you enter the field. Network design allows you to experiment with different variables so as to meet or exceed the stated survey accuracy requirements.

In the case of GPS, it may encourage you to observe static sessions rather than rapid static sessions. For conventional work, it may require you to either improve your network geometry, use your most accurate equipment, and/or take more measurements. **The strongest terrestrial networks will have the appearance of a web, made up of triangles, each with interior angles near 60 degrees. Of course this is optimal, but almost never achievable in the field.**

Design Variables

1. The number and physical location of survey points.

2. The number and types of observations to be measured.

3. The observation standard deviations (standard errors) you expect to achieve in the field.

Altering any one of these variables will change the estimated confidence of your survey. Network design allows you to perform **"what-if"** analysis on these variables so that you can estimate how you will do in the field.

Network Design Goals

1. **Perform each survey in a cost effective way**. If a survey can be performed with fewer points on the ground, while still meeting accuracy requirements, wouldn't it be beneficial? Further, if you could select locations on the ground that were easy to gain access to and make observations from, wouldn't that be beneficial?

2. **Determination of the field procedures and equipment needed to achieve accuracy requirements**. This could be something as simple as using a more accurate total station, or perhaps changing your field procedures a bit to achieve better accuracy (for example, making terrestrial measurements during the cooler times of day, better instrument/target setups, making additional measurements, and so on).

3. **Determination of whether you should take on the project.** Based on the accuracy requirements, you may decide that given the nature of your equipment and/or crew, you may not be able to meet the requirements and therefore should pass on the survey.

4. **Quick completion of the design**. The network design process should require significantly less time than the survey itself; otherwise, the design process may not be worth the effort. For medium-sized projects, a day or two of **"what-if"** analysis may be all that is required.

Some Thoughts On The Design Process

Network design allows you to achieve the first three goals above by providing you with estimates of the accuracy that will be achieved given the input observation types, their standard deviations and station locations in the survey. After an initial design, you may discover that the accuracy estimated will not meet the survey requirements. Using an iterative process of changing out the variables mentioned above, you may find a way to satisfy the accuracy requirements.

Before bidding on a new project, you might initially set up an elaborate design with many different observation types built in. After running the design and satisfying the confidence requirements, you might then scale back the network with fewer stations and observations. After running the design again, you may happily discover that you are still within the accuracy requirements of the project, but now the project will cost less to perform.

Next, you might consider using only GPS for the project. However, after running your proposed network through the design process you might discover that a problem has emerged that cannot be fixed through GPS alone. In fact, you may need to add terrestrial observations for some portion of the project in order to stay within accuracy requirements. **This might occur in an area in which you have poor satellite visibility or in an area in which the points you need to establish are only a few hundred meters apart**. Perhaps only the terrestrial equipment can give you the accuracy you need in these areas.

After the design is completed, you will have created a blueprint (of sorts) for the field crew. That blueprint will tell them roughly where to locate the stations, the types of observations to measure at each station, and the level of accuracy needed for those observations. You could conceivably use GPS in one section of the project, a 10-second total station in another section, and a one second total station in yet another section or the project. Through the use of network design, you can determine how the survey should proceed.

Of course, the most important element to design is achieving **"in the field"** what you designed in the office. If you are unable to measure angles to +/- 5 seconds or measure distances to +/- 0.004 meters (like you specified in your design), then your project will probably not meet the expectations derived from design. Bottom line: Don't be overly optimistic about what you can achieve in the field. Having said all this, there is no substitution for experience and intuition from prior projects.

Network Design Steps

Below is a summary of the steps required to successfully perform Pre-Analysis. 1D Vertical Pre-Analysis can also be performed in COLUMBUS. Please see **1D Vertical Pre-Analysis Tips** at the end of this section for 1D Vertical Pre-Analysis.

Determine Network Geometry

The first step is to design your network using whatever information you have available. You must tell COLUMBUS what the network geometry will look like. This is achieved by providing COLUMBUS an approximate coordinate (latitude, longitude and height) for each station in the proposed network. For 2D networks, an average project height is used.

For surveys consisting of GPS observations, you will not have to consider line of sight issues when selecting the locations of your stations. For surveys containing terrestrial observations, you will have to consider the line of sight issue. For 2D networks, GPS observations are invalid.

Unlike network adjustments (in which the actual observations have been measured and COLUMBUS can compute approximate coordinates), you must provide the approximate coordinates for 2D and 3D Pre-Analysis. The coordinate positions must be good enough to depict the actual network geometry. To determine the location of your stations, we recommend you utilize topographical maps which cover the project area. Determine as best you can the location for each proposed station on the map. Then, scale the coordinate position (latitude, longitude and height) for each station.

If your network covers a small area (stations less than a few thousand meters apart), these approximate coordinates should be within 10 to 20 meters (the closer the better) of their true position. If the network covers a large area (stations 10,000 to 50,000 meters apart), the coordinates could be off by several hundred meters and still depict the overall network geometry quite well.

Decide On The Observation Types

Next, you must decide what type of observations will be used in the network. This will be dependent on the surveying equipment you have, the amount of time you can afford to spend in the field, and the accuracy requirements desired. Terrestrial observations can provide very good results if you can minimize the number of intermediate stations required. GPS has an advantage here, because intermediate stations are usually not required.

COLUMBUS needs to know what observation types will connect each station pair (in other words, the actual observation types you will measure between each station after you have designed your network). You can use any of the 16 observation types supported for 3D networks when performing 3D pre-analysis. For 2D network pre-analysis, only 11 valid observation types exist. The value of the observation is not needed (after all, you have not measured it yet); however, the expected precision for each observation is critical. For example, if you believe you can measure all chord distances at a level of precision of ±0.005 meters, you should assign each chord distance a standard deviation of 0.005 meters.

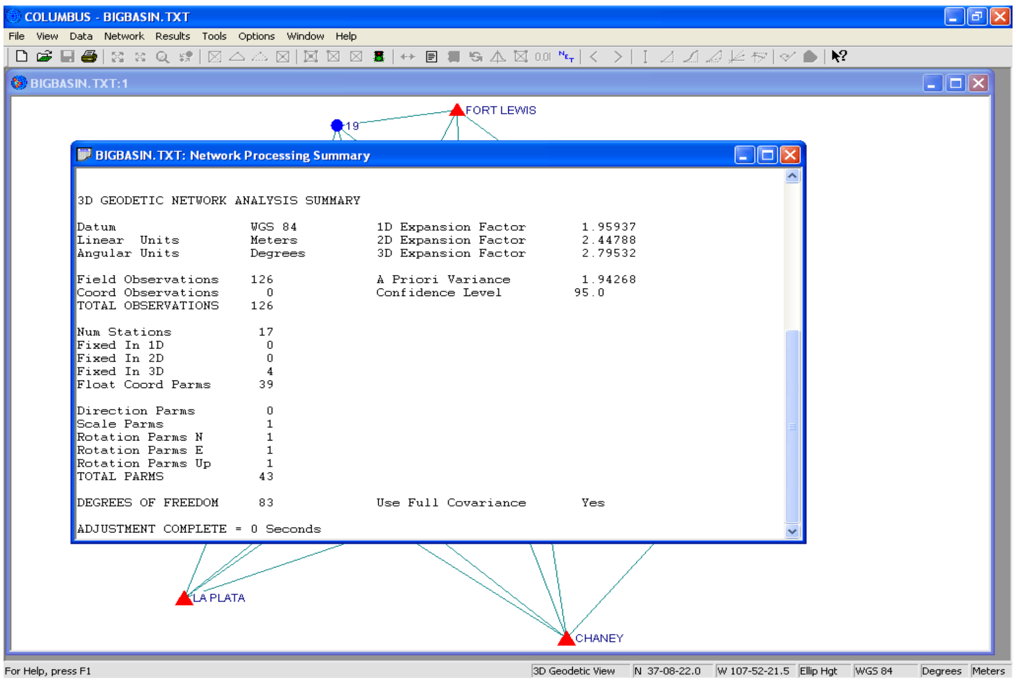
To inform COLUMBUS that an observation type exists between two stations, you should set the observation value to any valid number; we recommend 1.0 (**see the point and click approach below to greatly simplify this process**). Set its standard deviation following the guidelines above. For GPS baselines, you must use a variance instead of a standard deviation. Simply determine an appropriate standard deviation for each component (dX, dY and dZ), then square each to get each variance. You probably will not be able to estimate any of the correlation entries (off diagonal elements of the variance - covariance matrix), so set them to zero.

After you have gathered the proposed network data (approximate coordinates of stations, observation types and estimates of their precision), we suggest you build an ASCII (Text) file with your data. The resulting file should look just like any other network project files (i.e., datum, units, stations and observations), except the estimated approximate coordinate for each station must be assigned (since COLUMBUS cannot compute them). Also, all valid observations are assigned a value of 1.0 as mentioned above.

Load Network And Start Pre-Analysis

Load the network data and select the stations that are to be included in the network. Select the stations which will be fixed in 1D, 2D or 3D. Finally, select the observations which are applicable to the current analysis.

Similar to the ADJUSTMENT option, you must then analyze your network. Unlike a network adjustment that may require several iterations to converge, network pre-analysis requires only one iteration (or no iterations, depending on you frame of mind). The computed inverse contains the results needed to evaluate the proposed network design. Invoke the PRE-ANALYSIS command to start the computations.



View Pre-Analysis Results

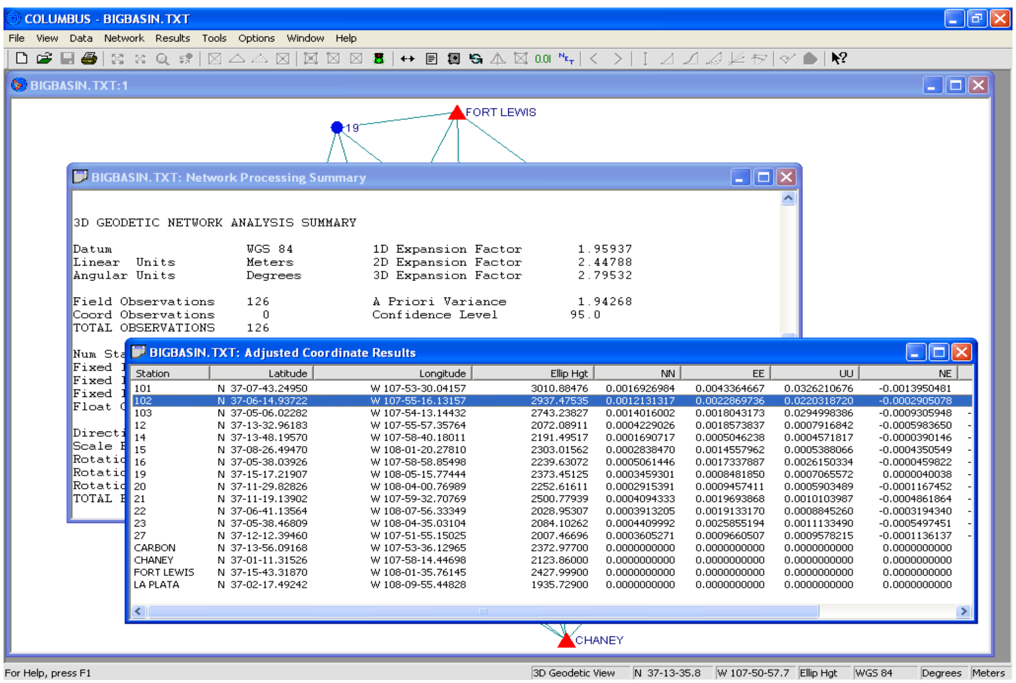
After analysis has completed, you can view the coordinates and the estimated covariance matrix (or standard deviation) for each coordinate component (latitude, longitude and height). The coordinate values are simply the approximate coordinates entered by you. The covariance elements (and therefore, the standard deviations) were computed during the Analysis step. If they seem satisfactory, then your proposed network design may be adequate for your needs.

Enter the Distance Error, Error Circles, 2D Error Ellipse, 3D Error Ellipsoid or ALTA positional Uncertainty views (NETWORK RESULTS chapter). The computed chord distances between stations are based on the approximate coordinates (for each station) provided by you. The PPM and Ratio information are computed during the network analysis. Their magnitude depends on the computed chord distance between the stations. If they seem satisfactory, then the proposed network design may be adequate for you needs.

In the screen below, the analyzed coordinate results for Station 102 are displayed. Compare the results here with the adjusted coordinate results earlier in this chapter. Notice the statistical results look similar.

For this example, we used the BIGBASIN.TXT project file using the same options settings, station settings, and observations that were used in the 3D geodetic adjustment earlier in this chapter. This file contains and actual field measured network, **but for pre-analysis we will only be utilizing the approximate coordinates for each station (they happen to be the actual adjusted coordinate in this case, since that is what we have stored in the BIGBASIN.TXT file), the observation types for each station, and the estimated precision of each observation.**

This network consists of several observation types between stations. From the network adjustment summary results presented earlier in this chapter, the *a posteriori* variance factor was 1.94268. This indicates that our original estimates of the observation standard deviations (for the network as a whole) were too optimistic (since the *a posteriori* variance factor is greater than 1.0). Normally, you would not know this, since you would perform network design before network adjustment. However, for demonstration purposes, we will multiply the variance (standard deviation squared) for each observation by the computed *a posteriori* variance factor, thus making them larger.



An easy way to do this for the network pre-analysis is to change the A Priori Network Variance scaler in the OPTIONS - NETWORK OPTIONS - SCALERS dialog from 1.0 to 1.94268. During network analysis, every observation variance (standard deviation squared) will be scaled by this value. This is exactly what we did here. Notice the analyzed covariance matrix elements for Station 102 match those given for the adjusted coordinate for Station 102 earlier in this chapter.

Again, normally you would not have this information. Try performing the analysis without setting the A Priori Network Variance scaler to 1.94268 (i.e., use 1.0). Your analyzed statistical results will appear more optimistic than what the actual survey produced (as seen from the network adjustment results earlier in this chapter).

Strengthen Network If Needed

After reviewing your results, you may decide that the network is not sufficiently adequate to meet your accuracy expectations. The design of solid networks requires continual refinement. You must continue this refinement until the results satisfy your needs.

To strengthen your network (and improve your results), you might try changing the network geometry by moving stations to other locations or adding additional stations.

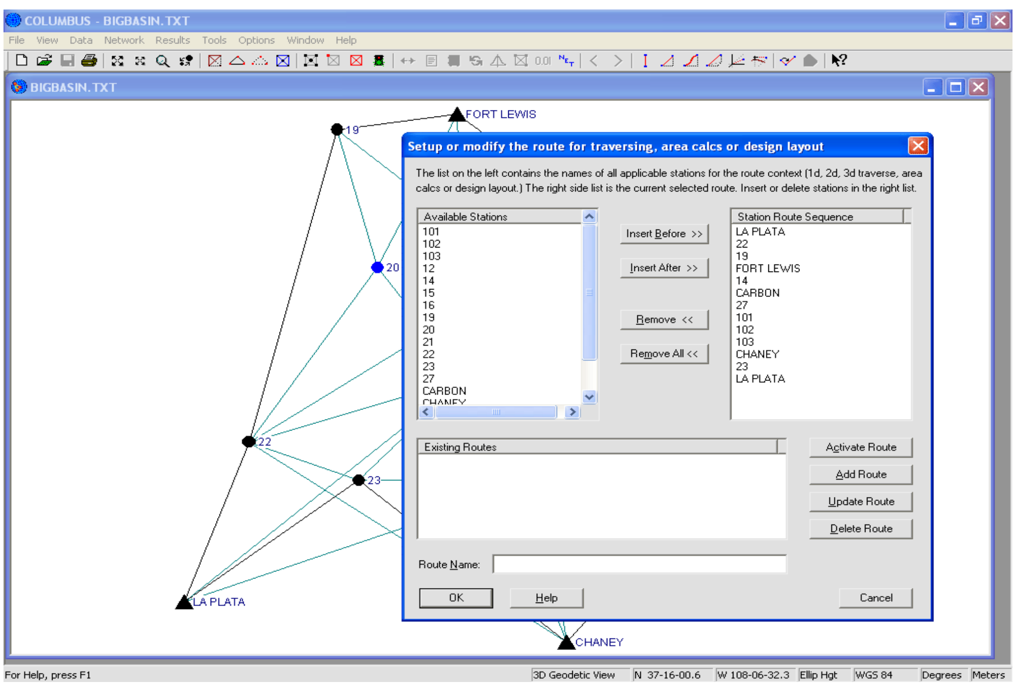
You also might try adding additional observations or changing the observation types in use. If you believe you can measure your observations with greater precision (as expressed in their standard deviations) than you specified, modify the expected precision of those observations (i.e., make their standard deviations smaller). If you like, you can assign a Global Standard Deviation to each observation type (see the OPTIONS - NETWORK OPTIONS - DEFAULT OBS SDS dialog).

The important thing to remember is to be realistic. Don't assign a chord distance a standard deviation of 0.001 meters if you cannot achieve this in the field.

Point And Click Observation Creation

Instead of manually creating observations between your proposed stations, COLUMBUS can help you quickly set up the observations (and their estimates of precision) using your mouse or keyboard.

COLUMBUS greatly simplifies Network Design layout. You simply provide the approximate coordinates for your 2D or 3D network, then **"point and click"** to define the observation types that form each leg of the network (or several legs at the same time).



Station coordinates can be entered either online through the DATA - STATIONS - GEODETIC grid, or defined within a COLUMBUS compatible ASCII (Text) file (see Appendix A for an explanation of these keywords). Once the stations are visible in the display, change the View to the applicable context (e.g., 2D Geodetic, 3D Geodetic, 2D State Plane, etc.) depending on the type of network you plan to design.

Using the right mouse button, point and click on successive stations to establish a route between station pairs (or enter the VIEW - SETUP COGO/DESIGN ROUTE dialog to create a route). After selecting the route, invoke the NETWORK - SETUP DESIGN LEG command or click on the SETUP DESIGN LEG toolbar button. Inside the dialog, you can identify the observation types and their expected standard deviations you plan to measure in the field along the route you just defined. Click on the OK button after selecting the observation types and entering the desired standard deviations. COLUMBUS will automatically create the necessary observation types. For Network Design, the value of each observation is not important, only its expected precision as expressed by its standard deviation. COLUMBUS automatically sets each observation value to one (1.0). **Caution:** Do not use this data in a network adjustment.

Continue selecting legs and observations until your entire network has been defined. Save your design layout to a COLUMBUS ASCII (Text) file using the FILE - SAVE or FILE - SAVE AS command. **Tip: Use a file naming convention that makes it easy for you to distinguish your network design project files from your regular network adjustment project files.**

1D Vertical Pre-Analysis Tips

To perform 1D Vertical Network Design in COLUMBUS, you use the 3D geodetic model. The main differences are described below.

1. Use geodetic coordinates with latitude, longitude, and height set to zero for all stations. COLUMBUS will display these stations on the screen in a spiral pattern so that they are not all on top of one another.

2. Select only Hgt Difference observations as the observation type.

3. Select at least one or more stations to be fixed in 3D. Select all remaining stations to be fixed in 2D.

4. You may be prompted with a message (depending on the **Disable Same Coords** setting in the OPTIONS - NETWORK OPTIONS - NETWORK SETTINGS dialog) indicating that one or more stations have the same coordinates. They all have the same coordinates (zeros) so just click YES to continue processing.

Summary

PRE-ANALYSIS can be an invaluable tool for designing surveys that will meet or exceed the your reliability requirements. However, the usefulness of Pre-Analysis is completely dependent on you. If you are realistic, the results obtained will match those measured in the field.

For example, suppose your survey will consist of horizontal angles, zenith angles and slope (chord) distances. If you indicate during pre-analysis that all horizontal angles will be measured to ±5.0 seconds, zenith angles will be measured to ±10.0 seconds and all slope distances will be measured to ±0.025 meters, your future field measurements must meet this expectation in order for the pre-analysis results to be meaningful.

If your field measurements exceed this expectation (i.e., horizontal angles are measured with accuracy better than ±5.0 seconds, zenith angles are measured with accuracy better than ±10.0 seconds and chord distances are measured with accuracy better than ±0.025 meters), your adjusted network will generally be statistically better than what it was designed to be. However, this will also depend on the quality of the local control stations you select, i.e., first order, second order, etc. On the other hand, if you are not able to meet this expected precision, your actual survey will fall short of your design plans.

With this in mind, it is probably better to be somewhat conservative when estimating the precision you expect to achieve in the field during network design.