Trimble Geomatics Office

Network Adjustment User Guide

Trimble

Trimble Geomatics Office

Network Adjustment

User Guide

Version 1.5
Part Number 39933-10-ENG
Revision A
January 2001

Trimble

Corporate Office

Trimble Navigation Limited
Technical Publications Group
645 North Mary Avenue
Post Office Box 3642
Sunnyvale, CA 94088-3642
U.S.A.
Phone: +1-408-481-8940, 1-800-545-7762
Fax: +1-408-481-7744
www.trimble.com

Copyright

Release Notice

This is the January 2001 release (Revision A) of Volume 1 of the *Trimble Geomatics Office – Network Adjustment User Guide*, part number 39933-10-ENG, and component of the Trimble Geomatics Office™ software. It applies to version 1.5 of the Network Adjustment software.

Patents

The Trimble Geomatics Office software is covered by the following U.S. patents: 5614913, 5969708, 5986604, and other patents pending.

The following limited warranties give you specific legal rights. You may have others, which vary from state/jurisdiction to state/jurisdiction.

Software and Firmware Limited Warranty

Trimble warrants that this Trimble software product (the “Software”) shall substantially conform to Trimble’s applicable published specifications for the Software for a period of ninety (90) days, starting from the date of delivery.

Warranty Remedies

Trimble's sole liability and your exclusive remedy under the warranties set forth above shall be, at Trimble’s option, to repair or replace any Product or Software that fails to conform to such warranty ("Nonconforming Product") or refund the purchase price paid by you for any such Nonconforming Product, upon your return of any Nonconforming Product to Trimble.

Warranty Exclusions

These warranties shall be applied only in the event and to the extent that: (i) the Products and Software are properly and correctly installed, configured, interfaced, stored, maintained and operated in accordance with Trimble's relevant operator's manual and specifications, and; (ii) the Products and Software are not modified or misused. The preceding warranties shall not apply to, and Trimble shall not be responsible for, any claim of warranty infringement is based on (i) defects or performance problems that arise from the combination or utilization of the Product or Software with products, information, systems or devices not made, supplied or specified by Trimble; (ii) the operation of the Product or Software under any specification other than, or in addition to, Trimble's standard specifications for its products; (iii) the unauthorized modification or use of the Product or Software; (iv) damage caused by lightning, other electrical discharge, or fresh or salt water immersion or spray; or (v) normal wear and tear on consumable parts (e.g., batteries).

THE WARRANTIES ABOVE STATE TRIMBLE'S ENTIRE LIABILITY AND YOUR EXCLUSIVE REMEDIES PERFORMANCE OF THE PRODUCTS AND SOFTWARE. EXCEPT AS EXPRESSLY PROVIDED IN THIS AGREEMENT, TRIMBLE FURNISHES THE PRODUCTS AND SOFTWARE AS-IS, WITH NO WARRANTY, EXPRESS OR IMPLIED, AND THERE IS EXPRESSLY EXCLUDED THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE STATED EXPRESS WARRANTIES ARE IN LIEU OF ALL OBLIGATIONS OR LIABILITIES ON THE PART OF TRIMBLE ARISING OUT OF, OR IN CONNECTION WITH, ANY PRODUCTS OR SOFTWARE. SOME STATES AND JURISDICTIONS DO NOT ALLOW LIMITATIONS ON DURATION OF AN IMPLIED WARRANTY, SO THE ABOVE LIMITATION MAY NOT APPLY TO YOU.

Limitation of Liability

TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, TRIMBLE SHALL NOT BE LIABLE TO YOU FOR ANY INDIRECT, SPECIAL, OR CONSEQUENTIAL DAMAGES OF ANY KIND OR UNDER ANY CIRCUMSTANCE OR LEGAL THEORY RELATING IN ANY WAY TO THE PRODUCTS OR SOFTWARE, REGARDLESS WHETHER TRIMBLE HAS BEEN ADVISED OF THE POSSIBILITY OF ANY SUCH LOSS AND REGARDLESS OF THE COURSE OF DEALING WHICH DEVELOPS OR HAS DEVELOPED BETWEEN YOU AND TRIMBLE. BECAUSE SOME STATES AND JURISDICTIONS DO NOT ALLOW THE EXCLUSION OR LIMITATION OF LIABILITY FOR CONSEQUENTIAL OR INCIDENTAL DAMAGES, THE ABOVE LIMITATION MAY NOT APPLY TO YOU.

IN ANY CASE, TRIMBLE'S SOLE LIABILITY, AND YOUR SOLE REMEDY UNDER OR FOR BREACH OF THIS AGREEMENT, WILL BE LIMITED TO THE REFUND OF THE PURCHASE PRICE OR LICENSE FEE PAID FOR THE PRODUCTS OR SOFTWARE.

Contents

3 Viewing the Network Adjustment Report

About This Manual

Welcome to the *Trimble Geomatics Office – Network Adjustment User Guide*. This manual describes how to adjust your GPS observations and relate your measurements to published or assumed coordinates.

Even if you have used other Global Positioning System (GPS) products before, Trimble recommends that you spend some time reading this manual to learn about the special features of this product.

If you are not familiar with GPS, visit our web site for an interactive look at Trimble and GPS at:

- www.trimble.com

Trimble assumes that you are familiar with Microsoft Windows and know how to use a mouse, select options from menus and dialogs, make selections from lists, and refer to online help.

The following sections provide you with a guide to this manual, as well as to other documentation that you may have received with this product.

Related Information

Other manuals in this set include:

- *Trimble Geomatics Office User Guide, Volumes 1 and 2*

  This manual describes how to use the Trimble Geomatics Office™ software. It is a complete user guide, providing operating instructions for the Trimble Geomatics Office software. The Trimble Geomatics Office software lets you process the fieldwork from the Trimble Survey Controller software.

- *Trimble Geomatics Office – DTMLink User Guide*

  This manual describes how to set up and use the DTMLink™ software. This software is a powerful tool for creating new surfaces and editing previously created surfaces.

- *Trimble Geomatics Office – RoadLink User Guide*

  This manual introduces you to the RoadLink™ software. The RoadLink software is part of the Trimble Geomatics Office software. It is a powerful reduction and processing package that calculates cut and fill volumes for earthworks between the road design and the Contour Surface Model.

- *Trimble Geomatics Office – WAVE Baseline Processing User Guide*

  This manual describes how to set up and use the Trimble WAVE™ Baseline Processing module if you have this module installed. This module lets you process raw GPS field data collected using Static, FastStatic, or Kinematic survey techniques.

As well as being supplied in hardcopy, these manuals are also available in portable document format (PDF).

Other sources of related information are:

- Help – The software has built-in, context-sensitive help that lets you quickly find the information you need. Access it from the Help menu. Alternatively, click the *Help* button in a dialog, or press F1.
- Release Notes – The release notes describe new features of the product, information not included in the manuals, and any changes to the manuals. They are provided as a PDF file on the CD. Use Adobe Acrobat Reader to view the contents of the release notes.
- ftp.trimble.com – Use the Trimble FTP site to send files or to receive files such as software patches, utilities, service bulletins, and FAQs. Alternatively, access the FTP site from the Trimble web site at www.trimble.com/support/support.htm.
- Trimble training courses – Consider a training course to help you use your GPS system to its fullest potential. For more information, visit the Trimble web site at www.trimble.com/support/training.htm.

Technical Assistance

If you have a problem and cannot find the information you need in the product documentation, *contact your local Distributor.* Alternatively, do one of the following:

- Request technical support using the Trimble website at www.trimble.com/support/support.htm

Your Comments

Your feedback about the supporting documentation helps us to improve it with each revision. To forward your comments, do one of the following:

- Send an e-mail to ReaderFeedback@trimble.com.
- Complete the Reader Comment Form at the back of this manual and mail it according to the instructions at the bottom of the form.

If the reader comment form is not available, send comments and suggestions to the address in the front of this manual. Please mark it *Attention: Technical Publications*.

Document Conventions

The document conventions are as follows:

Convention	Definition
Italics	Identifies software menus, menu commands, dialog boxes, and the dialog box fields.
Helvetica Narrow	Represents messages printed on the screen.
Helvetica Bold	Identifies a software command button, or represents information that you must type in a software screen or window.
"Select *Italics* / *Italics*"	Identifies the sequence of menus, commands, or dialog boxes that you must choose in order to reach a given screen.
Ctrl	Is an example of a hardware function key that you must press on a personal computer (PC). If you must press more than one of these at the same time, this is represented by a plus sign, for example, Ctrl+C.

CHAPTER

1

Introduction

In this chapter:

- Introduction
- Before you begin your network adjustment
- Adjustment menu
- Supported data types

Introduction

When surveying, it is good practice to collect extra data to check the integrity of your observations. When a survey has extra observations (redundancy), you can use them to minimize the effects of inherent errors before producing final results.

The optional Network Adjustment module for the Trimble Geomatics Office™ software provides a comprehensive set of tools that you can use to:

- detect blunders and large errors in your measurements
- account for systematic errors
- estimate and model random errors
- constrain your measurements to a published or assumed coordinate system, allowing you to account for datum transformations
- report estimated errors in your adjusted coordinates, adjusted observations, and transformation parameters.

The Network Adjustment module was designed specifically for use with the Trimble Geomatics Office software to provide a fully integrated, straight-forward, easy-to-use workflow to accomplish these tasks. It uses the rigorous and proven least-squares techniques that are incorporated into the earlier TRIMNET™ Plus software. These same algorithms were used as the basis for building the underlying geodetic foundations of the new Network Adjustment module. The Trimble Geomatics Office software, together with the Network Adjustment module, helps you attain the highest levels of precision and accuracy required for your projects.

Table 1.1 lists the functionality that the Network Adjustment module adds to your Trimble Geomatics Office software.

Table 1.1 Network Adjustment module

Name	Description
Network Adjustment program (available from the *Adjustment* menu or the project bar)	Use to perform a network adjustment for GPS and terrestrial observations, analyze the results, edit the network parameters, and readjust the network. Use to set variance groups, weighting strategies, and select observations to include in the adjustment.
Network Adjustment styles	Use to specify different controls for the network adjustment and to save the control sets as named styles.
Network Adjustment report	Use to review the results of the adjustment in an HTML report and perform quality-control checks.
Adjustment group in project bar	Use for quick access to commonly used network adjustment procedures.
Ellipses toolbar	Use to configure the appearance of error ellipses in the graphic window after a network adjustment has been performed.

Before You Begin Your Network Adjustment

Before your begin your network adjustment, please read Appendix A, A Guide to Least-Squares Adjustments. This information will give you a better understanding of network adjustment requirements and the procedures to correctly perform the adjustment.

In addition, see the document flowchart, Figure 1.1, to review the flow of work with the Trimble Geomatics Office software.

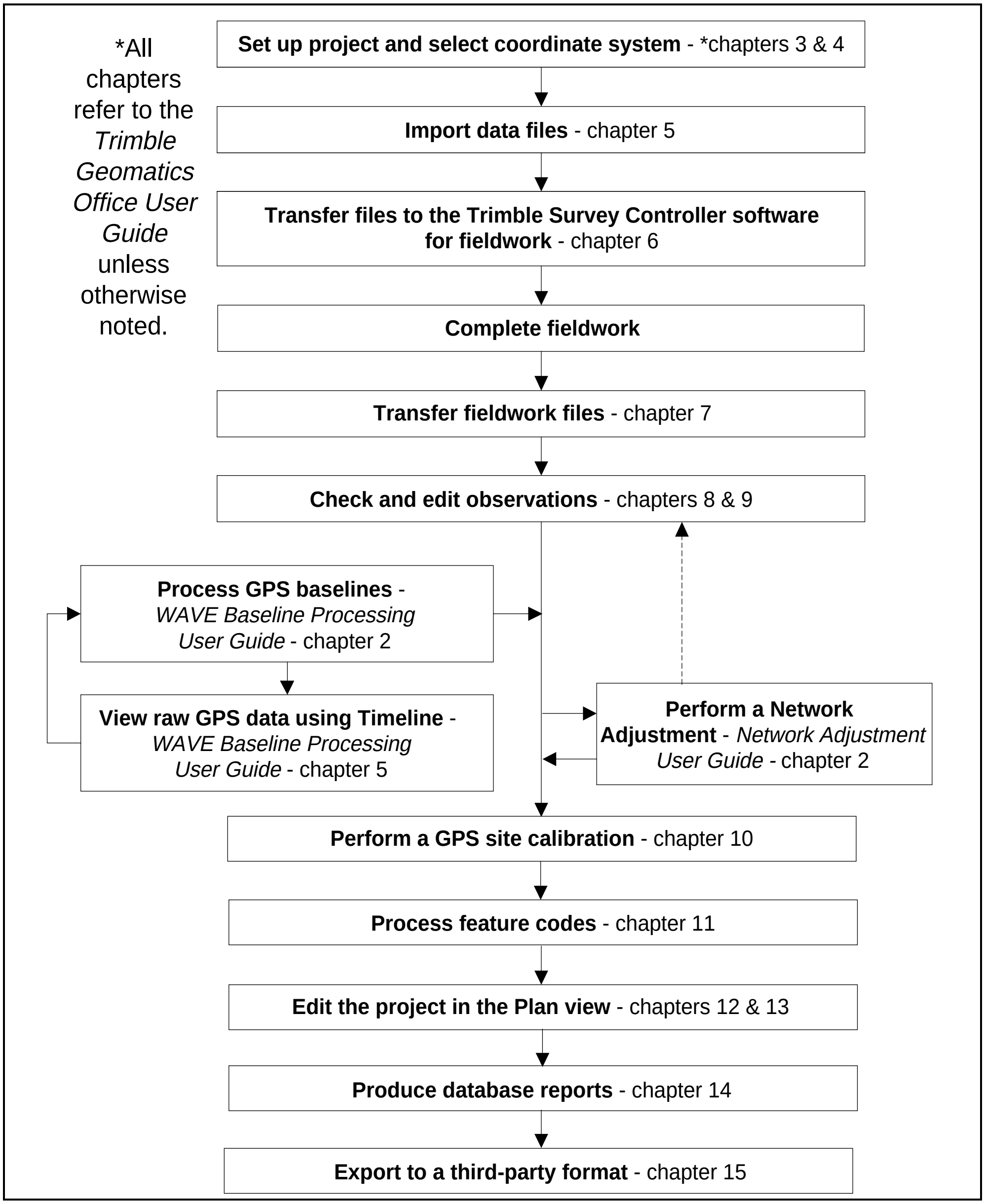


Figure 1.1 Trimble Geomatics Office software document workflow

Adjustment Menu

The *Adjustment* menu gives you all the tools required to perform a complete network adjustment. You can select each menu item individually, in the order you prefer.

Supported Data Types

The network adjustment software supports a range of data types:

- Postprocessed GPS – comes directly from your GPS survey
- Real-time kinematic (RTK) GPS with Quality Control (QC2) records – comes directly from your GPS survey
- Terrestrial observations – can include conventional and leveling observations
- Geoid observations – extracted from a geoid model selected for the Trimble Geomatics Office project

Each data type is described in the following sections.

Postprocessed GPS Data

Typically, when establishing survey control for a site, you use postprocessed data.

Generate postprocessed data after using static, FastStatic, and kinematic surveying techniques. Use the following procedures for these surveying techniques:

1. Collect the GPS raw data in the field.
2. Store the data in the receiver or data collector.
3. Transfer the data to the Trimble Geomatics Office project. (For information, refer to the *Trimble Geomatics Office User Guide*.)
4. Process the data using the WAVE™ baseline processor.

The baseline processor produces the baselines and their error estimates. You can then adjust these postprocessed baselines. For more information on processing GPS baselines, refer to the *WAVE Baseline Processing User Guide*.

Real-Time Kinematic GPS Data

Real-Time Kinematic (RTK) surveying is most often used for collecting topographic data or staking out design points. It also can be used for establishing secondary control points for your survey.

Collect real-time kinematic data using your Trimble GPS Total Station. The procedure for surveying using RTK techniques is:

1. Configure your data collector to collect QC2 records for your survey. (For more information on collecting QC2 records, refer to your *Survey Controller* documentation.)
2. Collect vectors, including the QC2 records, to each point you are planning to use in an adjustment. The QC2 record contains the errors associated with the observations used by the adjustment.
3. Transfer the data to the Trimble Geomatics Office project for adjustment.

Terrestrial Observations

Terrestrial observations are collected using a range of instruments, such as conventional instruments and levels. Generally, the terrestrial data consists of the following observations:

- Horizontal angles
- Vertical angles
- Delta elevations
- Slope distances
- Normal section forward or grid azimuths

***Note –** Astronomic azimuths are not supported in the Trimble Geomatics Office software.*

Use the following procedure for terrestrial observations:

1. In the field, collect and store terrestrial data in your data collector.
2. Transfer the data to the Trimble Geomatics Office software.
3. Check the observations in the software.
4. If necessary, perform a network adjustment.

***Note –** If you intend to perform a network adjustment using data transferred from the Trimble Survey Controller software, when you are performing the survey, enter the following values for the Survey Controller survey style:pressure, temperature, and correction for curvature and refraction. For more information, refer to the Trimble Survey Controller documentation.*

***Note –** Partial observations (for example, imported horizontal angles) can be adjusted in the Trimble Geomatics Office software. However, they are not used in a recomputation.*

Geoid Observations

A geoid observation (or geoid separation) represents the separation between the ellipsoid and geoid at a point.

Geoid observations are:

- extracted from a geoid model covering your survey area
- applied to the observed height to provide an estimated elevation

The Trimble Geomatics Office software generates geoid observations from a model using the positions of the points included in the adjustment (network points). Several geoid models are included with the Trimble Geomatics Office software. Other, more detailed, models may also be available from local or national government surveying agencies. The models were developed from governmental agency surveys and are mathematical representations of a geoid surface that approximates mean sea level (MSL).

The network adjustment software properly models all errors associated with the geoid model and observed ellipsoid heights.

CHAPTER

2

Performing a Network Adjustment

In this chapter:

- Introduction
- When to perform a network adjustment
- Network adjustment workflow
- Selecting and editing the adjustment styles
- Selecting observations for use in the adjustment
- The minimally constrained adjustment
- Viewing the Minimally Constrained Adjustment report
- Troubleshooting the minimally constrained adjustment
- Starting the fully constrained adjustment
- The fully constrained adjustment
- Viewing a Fully Constrained Adjustment report
- Troubleshooting the fully constrained adjustment
- Generating a final Network Adjustment report
- Combining GPS, terrestrial and geoid observations in an adjustment
- Additional adjustment considerations
- Removing a Network Adjustment

Introduction

This chapter provides an overview of performing a network adjustment using the Trimble Geomatics Office software.
The step-by-step procedures, along with sample dialogs and work flowcharts, will help you become familiar with performing a network adjustment. The chapter also includes information for troubleshooting network adjustments.

When to Perform a Network Adjustment

Perform a network adjustment after:

- postprocessing your GPS raw data
- importing your RTK baselines (with QC2 data)
- importing and checking your terrestrial data

Use the adjustment to:

- analyze the errors in your GPS and terrestrial observations
- detect mistakes (blunders) and large errors
- distribute the random error in your observations using least squares principles
- transform your observations to your local coordinate system

Note – *Trimble recommends that you read Appendix A, A Guide to Least-Squares Adjustments, before starting an adjustment.*

Figure 2.1 shows the Survey view of a sample network of FastStatic GPS observations.

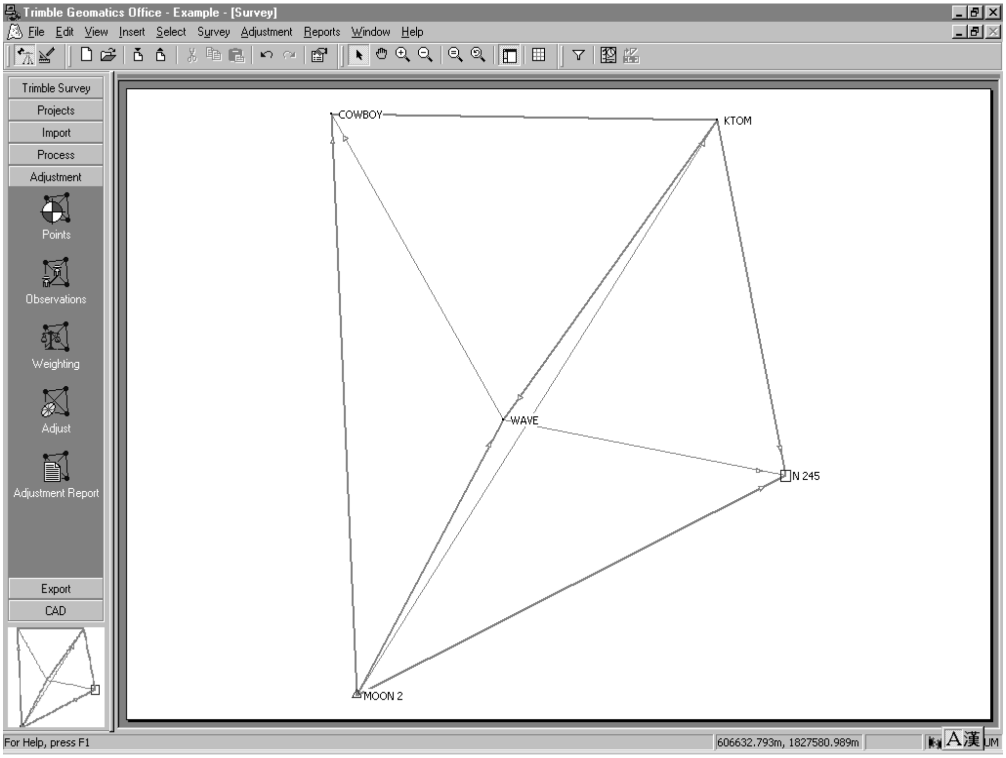


Figure 2.1 Survey view – sample network of FastStatic GPS observations

The project bar contains an *Adjustment* group.

Network Adjustment Workflow

Two major steps are used to perform a network adjustment:

- the minimally constrained adjustment
- the fully constrained adjustment

This chapter describes the procedures for both steps, starting with a minimally constrained adjustment, then moving on to the fully constrained adjustment. Figure 2.2 shows the typical workflow for a minimally constrained adjustment, and indicates the appropriate chapter sections for performing the procedures.

Note – *These steps will be used if you have GPS, terrestrial, or geoid observations, or a combination of observation types.*

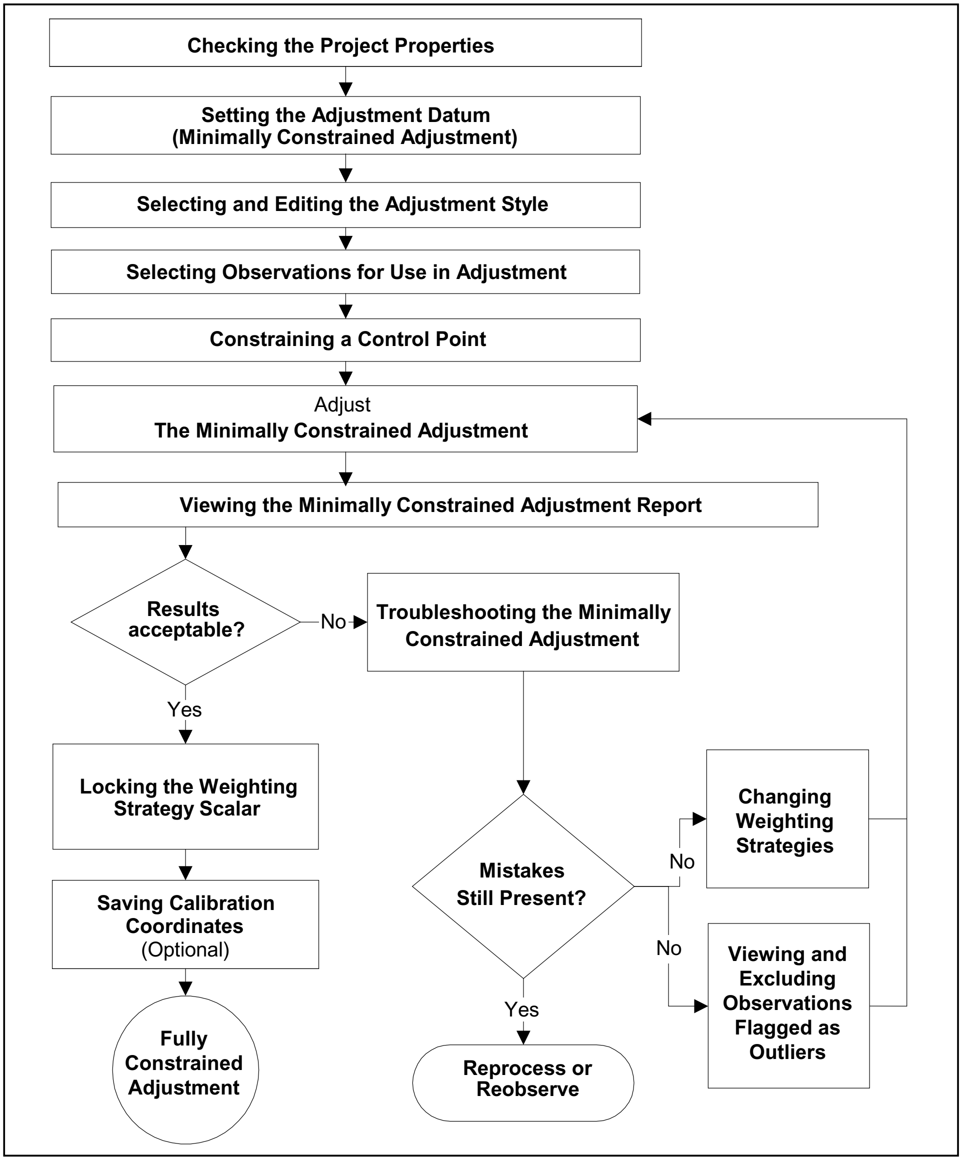


Figure 2.2 Minimally constrained adjustment flow

The Importance of Coordinate Homogenization

Before you adjust data in your Trimble Geomatics Office project, you must first import control points of a good quality. This is because after you import your data into the software, you need to perform a recomputation to determine the *calculated* position of the imported points.

Poorly seeded coordinates can lead to improper scaling of observations during baseline modeling, which then causes erroneous results in the network adjustment. Vertical coordinate errors produce scaling errors during modeling.

To prevent poor coordinates from being passed to adjustment, make sure that:

- the observations flow from a high quality coordinate
- the coordinates are homogeneous; that is, no large closure errors exist in the data

If you try to perform an adjustment while closure errors exist in your project, the *Non-homogeneous data warning* dialog appears. Remove non-homogeneities before proceeding with your minimally constrained adjustment.

Note – *It is only during an adjustment with default scalars that the software checks for non-homogeneity. If you edit data and intend to perform another adjustment, make sure that the Default scalar option (in the GPS, Terrestrial, and Geoid tabs) in the Weighting Strategies dialog is set.*

For more information on recomputation, refer to the *Trimble Geomatics Office User Guide*.

Checking the Project Properties

The adjustment produces the final results (point coordinates) in the current project coordinate system and units. Before starting the adjustment, make sure that these are set correctly in the project properties.

To do this:

1. Start the Trimble Geomatics Office software.
2. Open the project that contains the network of processed baselines you are about to adjust.
3. Verify that the coordinate system and units are set correctly:
   a. Select *File* / *Project Properties*. The *Project Properties* dialog appears.
   b. In the *Coordinate System* tab, check the coordinate system details.
   c. In the *Units and Format* tab, check the unit details.
4. Click **OK**.

You can edit the project properties at any time while working on your project. For more information on the *Project Properties* dialog, refer to the *Trimble Geomatics Office User Guide* or the Help.

Setting the Adjustment Datum (Minimally Constrained Adjustment)

Set the adjustment *datum* before performing an adjustment. You can use either of the following datums:

- WGS-84
- project

As GPS observations are made on the WGS-84 datum, use this datum for a minimally constrained adjustment of GPS observations. When the minimally constrained adjustment is completed, you can easily switch the adjustment to your project datum for the fully constrained adjustment.

For terrestrial observations, use the project datum for performing a minimally constrained adjustment.

To change the adjustment datum:

- From the Survey view, select *Adjustment* / *Datum* / *WGS-84.*

  The check mark indicates the selected datum.

***Note –** Selecting WGS-84 as the adjustment datum has no effect on the Grid and Local coordinates in the Properties window. These coordinates are displayed in the project coordinate system.*

Warning – Using a datum other than WGS-84 for adjusting GPS observations produces different weighting results. This is because datum differences are embedded into the observations during the baseline modeling process.

Selecting and Editing the Adjustment Styles

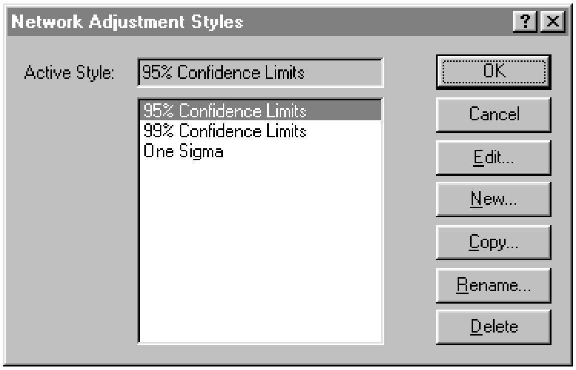
For the next step, select an adjustment style, check the settings and make any required edits. Adjustment styles are useful for configuring the adjustment settings to your requirements, then saving the style for use on other projects. Use the *Network Adjustment Styles* dialog to set the *Active Style* and the following style information:

- General – sigma scalars and tolerances
- Covariance Display – reporting precision for both horizontal (2D) and three-dimensional (3D) covariant terms
- Terrestrial Controls – set terrestrial error estimates
- Setup Errors – estimated errors for the GPS antenna height measurements, GPS antenna centering (plumbing), height of instrument, and instrument centering.

***Note –** All Trimble-supplied adjustment styles contain default settings. Consult your project specifications for the required settings for your reported results.*

To select and view the adjustment styles:

1. From the Survey view, select *Adjustment* / *Adjustment Styles*. The following dialog appears:



2. Select the style that you are using for this adjustment. For most surveys, set it to 95% Confidence Limits.

Tip – You can edit the styles supplied with the Trimble Geomatics Office software or create a new style and then make the required edits. Click **New** and enter the style name to create a new style. The *95% Confidence Limits* settings are used to create the new style.

3. Click **Edit** to open a dialog for the selected style and begin viewing the style settings.

Viewing the General Settings

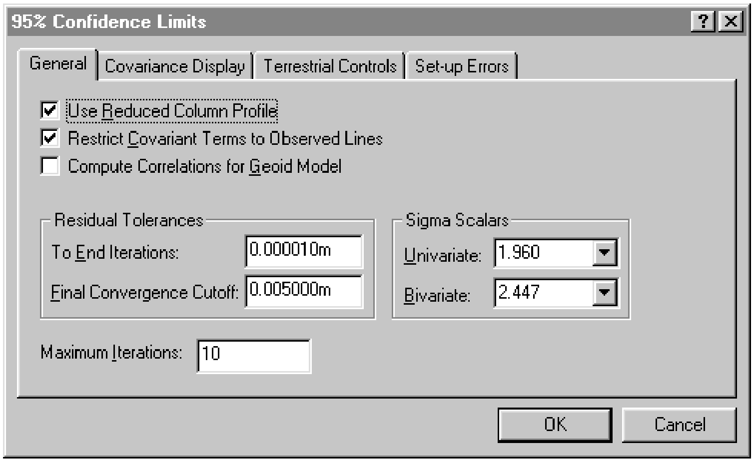
After clicking **Edit** from the *Network Adjustment Styles* dialog, the dialogs for your selected style appear. The active tab is always the last tab viewed.

Use the *General* tab to set or define the following options:

- Use reduced column profile
- Restrict covariant terms to observed lines
- Compute correlations for a geoid model
- Residual tolerances for the adjustment
- Sigma scalars (confidence level) used to report the estimated error in your observations and points displayed in the adjustment report
- Maximum iterations allowed to converge the adjustment

To view the *General* settings:

1. Select the *General* tab, as shown below:



2. Check and edit the *General* settings.

   Typically, your only concern will be the *Sigma Scalars*. The sigma values for the 95% confidence level are:

   – 1.960 for the *Univariate* (1D) scalar – used for azimuth, distance and difference in height errors

   – 2.447 for the *Bivariate* (2D) scalar – used for error ellipses.

3. To make changes (if necessary), select a field to edit and do one of the following:

   – Select from a list.

   – Select or clear a check box.

   – Enter an appropriate value in the field.

4. Click **OK** to apply your changes.

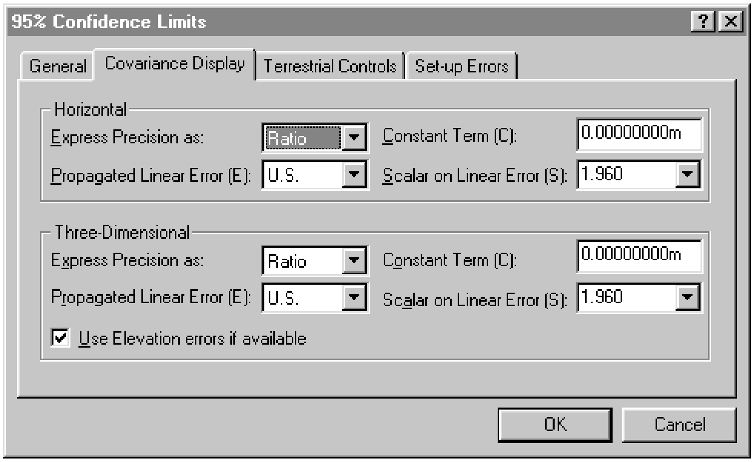
Viewing the Covariance Display Settings

Use the *Covariance Display* tab to define:

- the confidence levels – *Scalar on Linear Error (S)*
- the method used to calculate and display the covariant terms in the adjustment reports
- the constant term applied to the covariant terms.

To view the settings:

1. Select the *Covariance Display* tab, as shown below:



2. Check and edit the *Covariance Display* settings.

   Typically, you will need to edit the *Scalar on Linear Error (S)* for your project requirements. Most surveys require a confidence level of 95 percent.

   Note – *Consult your project specifications for the required confidence levels for your reported results.*

3. To make changes (if necessary), select a field to edit and do one of the following:
   - Select from a list.
   - Select or clear the check box.
   - Enter an appropriate value in the field.
4. Click **OK** to apply your changes.

For more information about the propagated linear error, scalar on linear error, and constant term, refer to the Help.

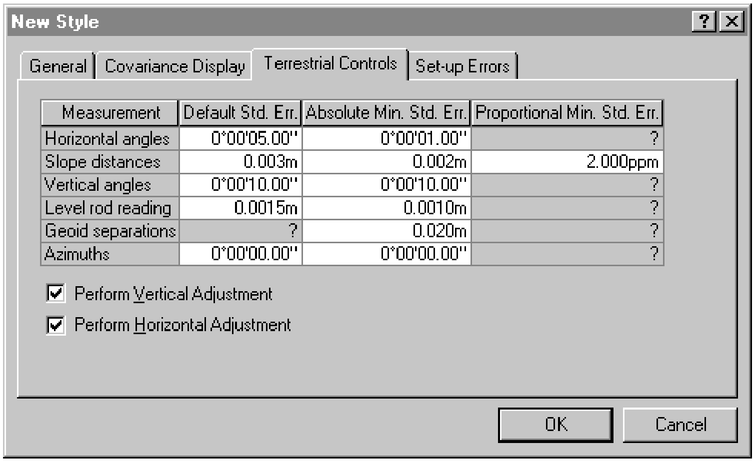
Viewing the Terrestrial Controls

Use the *Terrestrial Controls* tab to:

- define standard errors for terrestrial measurements
- specify whether to perform a horizontal or vertical adjustment

To view the settings:

1. Select the *Terrestrial Controls* tab, as shown below:



2. Check and edit the *Terrestrial Controls* settings.

The default standard error, absolute minimum standard error, and proportional minimum standard errors are listed for a range of terrestrial observations.

If you do not specify error estimates for your observations, the software uses the default standard error. The error estimate value must always be greater than the minimum standard error. The absolute minimum and proportional minimum standard errors are used when they are larger than the standard errors that are provided with the observations.

Viewing Setup Errors Settings

With surveys or measurements there are inherent errors in the equipment setup. You must account for these errors.

Use the *Setup Errors* tab to enter realistic error estimates for the GPS and terrestrial equipment setup:

- Error in height of antenna – measuring the antenna height
- errors – centering (plumbing) your antenna over the survey point
- Error in height of instrument – measuring the instrument height
- Terrestrial centering error – centering (plumbing) your instrument over the survey point.

When estimating your setup errors, be careful not to overestimate the error.

For a typical survey using Trimble-provided height measurement rods and well-calibrated tribrachs with optical plummet, use the guidelines listed in Table 2.1.

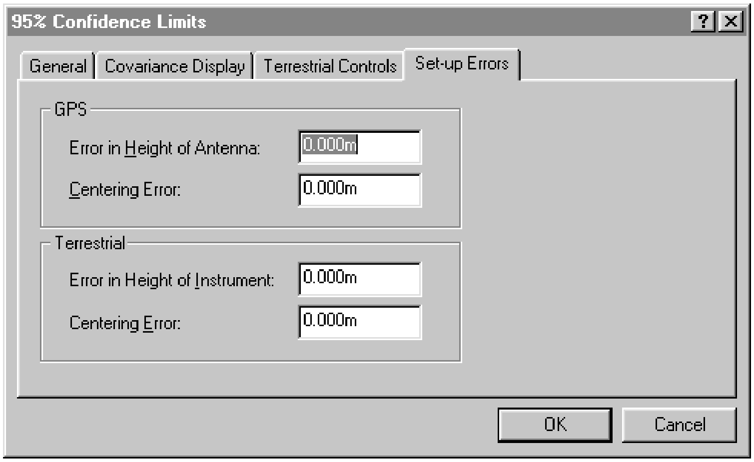
Table 2.1 Setup error estimating guidelines

Setup error type	Minimum value	Maximum value
Error in height of antenna	0.000 m (0.000 sft)	0.004 m (0.013 sft)
GPS centering error	0.000 m (0.000 sft)	0.003 m (0.010 sft)
Error in height of instrument	0.000 m (0.000 sft)	0.004 m (0.013 sft)
Terrestrial centering error	0.000 m (0.000 sft)	0.003 m (0.010 sft)

Note – *These values are only guidelines and may need to be changed to suit your application.*

To view setup errors:

1. Select the *Setup Errors* tab, as shown below:



2. Check the settings.

   To make any required edits:

   a. Click in the field to edit.

   b. Enter the appropriate value in the field.

   c. Click **OK** to accept the style.

3. Click **OK** to continue.

The adjustment style now becomes the active adjustment style. These settings are used globally throughout your adjustment.

Selecting Observations for Use in the Adjustment

Typically, your project will contain different types of observations:

- GPS Postprocessed Static, FastStatic, Stop-and-Go Kinematic, and Continuous Kinematic
- GPS Real-Time Kinematic (with and without QC2 records) and Real-Time Continuous Kinematic
- Terrestrial observations – horizontal angle, vertical angle, distance, azimuth, and delta elevation observations.

Some of the observations require adjustment while some other observations need only the generated adjustment parameters (*transformation parameters*) applied to them. Consider the following:

- The observations used to establish control points are adjusted to detect and eliminate large errors, distribute the random error, and generate error estimates for the points established.
- Observations for secondary control points and other points may only need the transformation parameters applied to transform them to the local (project) datum.

Before you begin your adjustment, you must select the observations to include in the adjustment. The Trimble Geomatics Office software automatically selects certain types of observations for adjustment after importing or postprocessing.

Table 2.2 shows the observations that are automatically selected and when they are selected. The remaining observations are selected manually for inclusion in the adjustment.

Table 2.2 Observations selected automatically

These observation types ...	are selected when ...
Postprocessed: Static FastStatic Kinematic (Stop-and-Go only)	saving the postprocessed solution
Real-Time Kinematic (with QC2) (Stop-and-Go only)	importing a .dc file
Imported postprocessed .ssf and .ssk Files: Static Fast Static Kinematic (Stop-and-Go only)	importing an .ssf or .ssk file
Leveling observations	importing a .raw or .dat file

Postprocessed Continuous Kinematic, Real-Time Continuous Kinematic (with QC2), and Imported Postprocessed Continuous Kinematic observations are displayed in the *Observations* dialog of the network adjustment. However, they must be manually selected for use in the network adjustment by selecting the check box in the *Use* column.

Since the Trimble Geomatics Office software automatically selects observations for you, you will need to manually unselect the observations you choose not to adjust.

Note – *When you are performing an adjustment in a non-geocentric datum, and the ellipsoid heights (but not elevations) are fixed in the Points dialog, Trimble recommends that you include all sideshot vectors in the adjustment. This ensures that the best possible heights are determined for those sideshot points.*

Selecting or Unselecting the Observations

There are several ways to select an observation for use in the network adjustment. The same methods are used to unselect an observation.

To select or unselect observations for use in the network adjustment use one of the following methods.

From the *Properties* window:

1. From the Survey view, select the observation to use (or not use).

   The observation is highlighted.

2. To view the observation's properties, do one of the following:

   – Select *Edit* / *Properties*.

   – Select the *Edit Properties* icon.

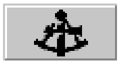
   – Press [Alt] + [Enter].

   – Double-click on the observation.

   The *Properties* window appears with the observation(s) listed in the *Selection* window.

3. If there are multiple observations in the *Selection* window, then select the observation.

4. The observations properties are displayed in the *Summary* page of the *Survey* tab. If there is a warning associated with the observation, then the *Warning* page is shown.

   To open the *Summary* page, click the *Summary*  button.

   Select the *Use in the Network Adjustment* check box to select or unselect for adjustment.

   The observation is selected for use in the network adjustment when the check box is selected.

   The observation is not selected for use in the network adjustment when the check box is cleared.

Using the Multiple Edit Command

You can select multiple observations for use in the network adjustment and make multiple edits at one time. (The method used to unselect is in parentheses.)

To make multiple edits:

1. Select all the observations to use (or not use) in the network adjustment. For more information, refer to the *Trimble Geomatics Office User Guide*.

Tip – You can use view filters to show adjustable observations.

2. In the Survey view, select *Edit* / *Multiple Edit.* The *Multiple Edit* dialog appears.
3. Select the *Survey* tab.
4. In the *Perform these edits to the selected observations* group, select the *Use in Network Adjustment* check box. The *Use* option becomes available.

   Note – *The Use in Network Adjustment check box is unavailable if the selection includes observations that you cannot adjust.*

5. Select Yes (or No to deselect).
6. Click **OK** to apply the edits to the selected observations.

The project status of all observations in the selection is changed to use (or not use) in network adjustment.

To use the *Observations* dialog to unselect observations for use in the network adjustment:

1. Select all the observations to use (or not use) in the network adjustment.

   For more information, refer to the *Trimble Geomatics Office User Guide*.

2. In the Survey view, select *Adjustment* / *Observations*. The *Observations* dialog appears. Observations that are selected in the Survey view are also selected in this dialog.
3. Select the *GPS* tab or the *Terrestrial* tab.
4. Locate the observation to select or deselect.

Tip – When selecting or unselecting more than one observation, click **Filter** to hide observation types that are not involved with the process. You can also use the standard Windows selection methods to select multiple observations (Shift or Ctrl + click), then select one of the check boxes for the group.

5. Select the check box to select or unselect an observation.

   The observation is selected for use in the network adjustment when the check box is checked.

   The observation is not selected for use in the network adjustment when the check box is cleared.

6. Click **OK** to exit the *Observations* dialog.

Constraining a Control Point

At this point in the adjustment, you must decide whether you will use inner constraints (free adjustment) or constrain (fix) one of the control points in the adjustment. With inner constraints, the program does not constrain a point, but minimizes the amount of shifts to the coordinates of the points from their preadjustment values.

Using either method will produce the same statistics for your observations, but there are advantages to constraining a control point.

Table 2.3 shows the advantages of constraining a point.

Table 2.3 Advantages of constraining a control point

Allows for the use of ...	Advantage
the *Reduce column profile* option. If your network has a large number of points and observations, constraining a control point will allow you to use the Reduce column profile option within the adjustment style.	Reduces: - the amount of computer memory required to adjust a network, possibly decreasing the amount of time required to complete an adjustment - the number of *covariant terms* computed for the observed lines within the network, decreasing the length of the list of terms.
more accurate coordinates to extract geoid separations.	The coordinates used to extract geoid separations from the geoid model should be as accurate as possible. Constraining a point will fix the network of observations and points to the correct place on the datum. Then, later in the adjustment, you will use the best possible coordinates when loading geoid observations.

You may decide to fix a point in the network adjustment that does not have a coordinate referenced to the adjustment datum (WGS-84) for a minimally constrained adjustment. The Trimble Geomatics Office software allows you to enter the local datum control values (grid or geographic), then transform the coordinates to WGS-84 automatically to match the adjustment datum.

Warning – Be careful when entering the ellipsoid height. If you enter the local horizontal coordinate, make sure that you enter the local ellipsoid height. Do not fix an ellipsoid height if you do not have a published ellipsoid height for your control point. The Trimble Geomatics Office software uses an inner constraint for the ellipsoid height if one is not entered.

Identifying Control Quality

The *Points* dialog (accessible from the *Adjustment* menu) will identify all control quality components of a point (in the adjustment) by placing the corresponding NE, LL, e, or h symbol with parenthesis in the *Fixed* column. The fixed component identifiers are automatically placed in the *Fixed* column when importing information from:

- an NGS Datasheet
- an ASCII file when the *Quality for Import data* field of the *Import* dialog is set to *Control quality*. For more information, refer to the *Trimble Geomatics Office Software User Guide*.

An example is shown in the *Points* dialog on page 32.

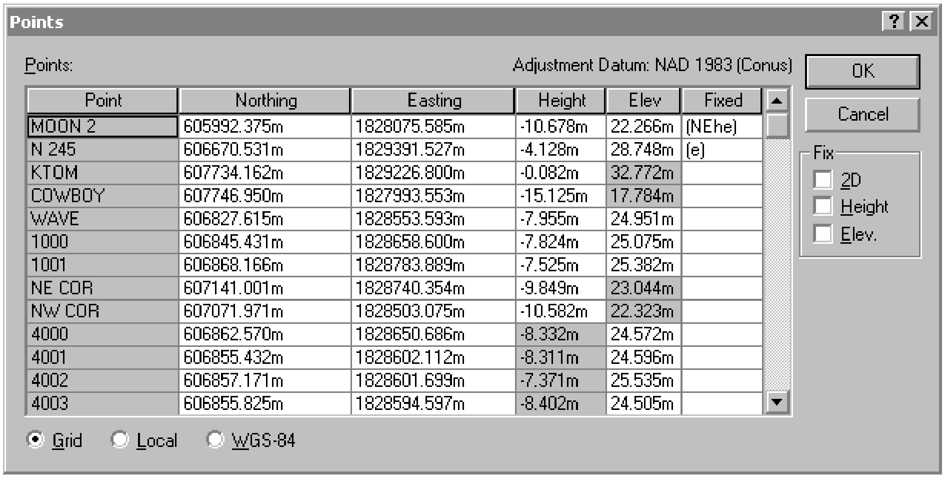
***Note –** The geoid observations are usually loaded after completing your minimally constrained adjustment and just before you start the fully constrained adjustment.*

Fixing a Point (Minimally Constrained Adjustment)

If you are performing a *free* adjustment, the steps in this section are not necessary. You can continue with the free adjustment starting on page 34 below.

Use the *Points* dialog for the next steps in the adjustment to view, edit (if necessary), and fix the coordinates of the points in the network:

1. In the Survey view, select *Adjustment* / *Points*. The following dialog appears:



All points in the network adjustment are listed. The *Points* dialog list will not include all the points in the project database. The list includes only the points that are connected to observations used in the network adjustment (networked). The list will not include points exclusively connected to observations not included in the network adjustment (non-networked).

2. Select the coordinate display option that corresponds to your control coordinates: *Grid*, *Local*, or *WGS-84*. The default is the *Grid* option.

   The coordinates are displayed using the selected option.

3. Select the point to fix. The point information is highlighted.

4. From the *Fix* group, select the coordinates components to fix: *2D* (NE or LL) and *Height* (h).

Note – *In the WGS-84 datum, do not fix more than one grid coordinate; otherwise observations are constrained in the wrong datum.*

5. One of the following will occur:

   – If coordinate components of the highlighted point were imported as control quality, the parentheses are removed from the corresponding component (NE or LL, h). The control values are displayed in the coordinate component fields. The coordinate fields are available for editing, but no editing is required.

   – If no coordinate component of the highlighted point was imported as control quality, the coordinate fields for the highlighted point become available for editing, and NE or LL or h appear in the *Fixed* column of the point.

6. If necessary, enter the control values (coordinates) for the point.

   When you edit a point, the existing keyed-in coordinates for the point are overwritten.

7. Click **OK** to continue with the minimally constrained adjustment.

Note – *As you fix the coordinate components (2D or Height) of a point with an imported quality other than control, the software creates a coordinate page for it in the Properties window. This page shows the constrained component and value, along with "?" in the unconstrained components. The keyed-in value takes precedence over all other coordinate component values for the point.*

Tip – If you edit a coordinate component, the coordinate component in the *Fix* group is automatically selected. If you "unfix" the coordinate component, the edits that you made are removed and the coordinate component reverts to the original value.

The Minimally Constrained Adjustment

You can now start the minimally constrained adjustment of your network observations. You have completed the following:

- defined your adjustment datum
- selected the adjustment style
- selected observations for adjustment
- constrained a point or allowed for a free adjustment

You can now perform the adjustment and analyze your observations.

Perform an Adjustment

To start the network adjustment:

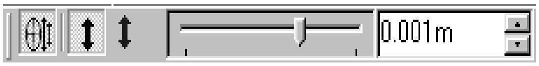
1. Do one of the following:
   - From the Survey view, select *Adjustment* / *Adjust*.
   - Press F10.
   - In the Trimble Geomatics Office project bar *Adjustment* group, select the *Adjust* icon.
2. View the status bar to determine the status of your network adjustment.

   The status bar displays the current iteration of the adjustment. The adjustment will perform as many iterations as required (up to the maximum set in the adjustment style) to meet residual tolerance.

   If the adjustment fails to pass the *Residual Tolerance* (does not converge), see Troubleshooting the Minimally Constrained Adjustment, page 40.

3. Once the adjustment passes the residual tolerance (converges), the software performs the following functions:
   - Updates the coordinates of the adjusted points.
   - Retains the constrained point's coordinates and point quality (control).
   - Performs a recomputation. The recomputation determines new coordinates for all non-networked points. The new coordinates are computed using the non-networked observations, propagating from the adjusted (and fixed) coordinates.
   - Changes the symbol for the adjusted points. If you have a black background, the symbols are white. If you have the default background, the symbols are blue.
   - Generates error ellipses and arrows for each point in the network adjustment.
4. To display the *Ellipse Controls* toolbar:
   - Select *View* / *Toolbars*, then select *Ellipse Controls*.

   The *Ellipse Control* toolbar appears in the Trimble Geomatics Office window.

   Use the toolbar to control the size and display of the error ellipses and arrows.

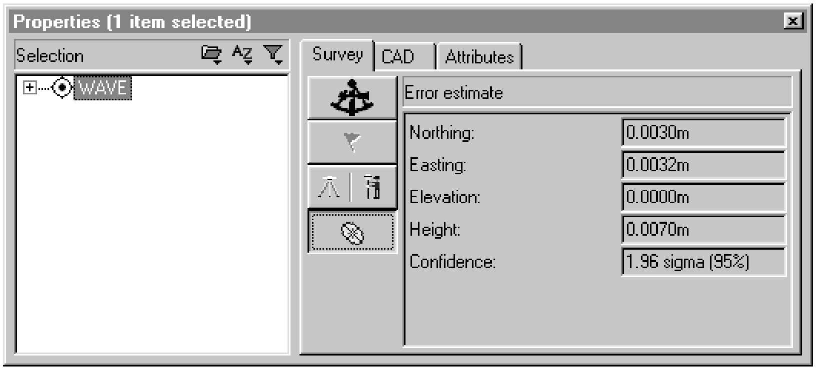
Tip – You can also view the error ellipse controls in the *Error Ellipse* tab of the *View Options* dialog (select *View* / *Options*).

While in the Survey view, you can use the toolbar to make the adjustments as described in Table 2.4.

Table 2.4 Ellipse Control Toolbar

Action	Do this ...
Change the viewing size of the error ellipses.	Drag the slide bar.
Adjust the error ellipse bar scale ticks.	Enter a value in a field or use the up or down arrows.
Turn on or off the display of error ellipse and arrows.	Select the ellipse and arrow icon.
Turn on or off the height and elevation arrows.	Use the arrow icons.

5. Click the error ellipse and arrows icon to view the error ellipse and arrows at each adjusted point in the survey.
6. Open the *Properties* window to view the Adjusted Values and *Error estimate* (Error ellipse button) for each point.



Now you can begin analyzing the results of the network adjustment by viewing the Network Adjustment report. For more information, see Chapter 3, Viewing the Network Adjustment Report.

Observations and Points after an Adjustment

Once the adjustment is complete, you will have created *adjusted* observations from the network adjustment. Consider the following:

- The *adjusted* observations are available for viewing only in the Network Adjustment report.
- The *observed* (unadjusted) observations are shown as the active solution in the Survey view.
- The *observed* (unadjusted) observation is shown when selecting an observation and viewing its properties in the *Properties* window (*Survey* tab) *Observation Page*.

Also consider:

- When selecting and viewing a point (included in the adjustment) using the *Properties* window, the *adjusted* coordinate values are shown for that point.
- The recompute function uses the *adjusted coordinates* to propagate coordinates to unadjusted points using the *unadjusted* observations to the points not included in the network adjustment.
- The *adjusted* observations are not used by the recompute function.

After performing a fully constrained adjustment (Starting the Fully Constrained Adjustment, page 61), the recompute function uses the *unadjusted* GPS observations and the transformation parameters to propagate coordinates to the GPS points not included in the network adjustment. Applying the adjustment transformation parameters to unadjusted observations will make the *unadjusted* and *adjusted* GPS points homogeneous within your project.

Note – *Transformation parameters are not applied to terrestrial or geoid observations.*

Viewing the Minimally Constrained Adjustment Report

The Network Adjustment report displays the results of the last iteration of the adjustment. The Network Adjustment report is in HTML format and is written to the Trimble Geomatics Office\Projects\<*project name*>\Reports\Netadj folder. You can view the following information in this report:

- Adjustment style settings
  - residual tolerances
  - covariance display
  - adjustment controls
  - setup errors
- Statistical summary, including:
  - number of iterations
  - global statistics
  - observation statistics
  - weighting strategies
- adjusted coordinates with estimated errors (grid and geodetic)
- control coordinate comparisons
- adjusted observations
- histograms of standardized residuals
- point error ellipses
- covariant terms

Note – *For more information and a description of each report section, see Chapter 3, Viewing the Network Adjustment Report.*

To use the Network Adjustment report to analyze and troubleshoot the results of your first and subsequent adjustments:

- From the Survey view, select *Reports* / *Network Adjustment Report*.

  The program opens your HTML viewer and displays the report. A report header (at the top) contains the project properties relevant to the network adjustment. A table of contents listing the sections of the network adjustment results is displayed on the left side of the report.

  Navigate to the sections of interest:

  – To move directly to a section, use the hyperlinks.

  – To navigate back to the top of the report, click Project Details Link on the left of the screen.

Note – *Whenever you view a report (immediately following an adjustment), the Trimble Geomatics Office software creates a new report. It stores the new report in the ...\Netadj folder, and moves the current report to the ...\Netadj-old folder.*

Troubleshooting the Minimally Constrained Adjustment

The next step in the minimally constrained adjustment is to troubleshoot problems you may have with the adjustment.

Adjustment Fails – No Convergence

Typically your adjustment will converge. However, if the residual differences exceed the *Final Convergence Cutoff*, the adjustment fails, indicating that there is a large error in one or more of the observations. A dialog will inform you that the adjustment did not converge.

When the adjustment fails, the adjusted coordinates, adjusted observations, and displayed graphics are not available for analysis.

Successful Adjustment

The adjustment converges when the observation residual check is within the tolerance set in the adjustment styles. The Trimble Geomatics Office software computes the observation residuals using two independent methods, then differences the two sets of residuals.

- When the differences for all residuals are less than the set tolerances (*To End Iterations)*, the adjustment converges. The following message appears in the Network Adjustment report:

  Successful Adjustment in # iteration(s)

- By default, the adjustment iterates a maximum of ten times without passing the *Residual Tolerances: To End Iterations*. If the adjustment does not converge on the tenth iteration, the program uses the *Final Convergence Cutoff* tolerance.

- If the observation residual check for *Final Convergence Cutoff* is within the tolerance, the adjustment converges. The following message appears in the Network Adjustment report:

  Successful Adjustment in # iteration(s) (final convergence cutoff used)

Now you can begin evaluating the network adjustment statistics.

Evaluating the Statistics (Minimally Constrained Adjustment)

When the adjustment converges and you have viewed the global and observation statistics in the Network Adjustment report, decide if you need to troubleshoot the network adjustment. Consider the following indicators:

- The Chi-square test fails.
- One or more observations are flagged as outliers (*Standardized residual* > Critical Tau Value).
- One or more observations have zero degrees of freedom (Redundancy Number = 0.000).
- The combined histogram of standardized residuals is sharply pointed or too flat.

Table 2.5 lists some problems you might see in a minimally constrained adjustment. The table lists the problem and possible cause, and suggests the actions to improve your statistics and overall adjustment.

Table 2.5 Troubleshooting a minimally constrained adjustment

Problem	Possible cause	Action
Adjustment fails to converge after 10 iterations	One or more large errors or mistakes (blunders) exist in the observations. For example, an azimuth that is incorrect by 180 degrees.	With GPS data check suspect baseline solution statistics (Ratio, Reference Variance, RMS). Check the GPS Loop Closures report for suspect baseline. Check the Recompute report. Make sure that your observations flow out from good quality coordinates. Check antenna, instrument and target heights, correct any incorrect heights and perform a recomputation. Exclude (*Not used*) the suspect baseline from network adjustment (if not a critical observation in the network). Once you are confident the baseline is a problem that cannot be fixed, you can *Disable* the observation. Reobserve the suspect baseline (if critical to network redundancy).

Table 2.5 Troubleshooting a minimally constrained adjustment (Continued)

Problem	Possible cause	Action
Chi-square test fails	If no outlier is present: A priori errors for your observations have been underestimated.	Change the weighting strategy to properly weight observations and estimate errors. Use the alternative scalar to scale the estimated errors.
	If outliers are present: Large error(s) may be present in observation(s).	See observation outlier troubleshooting in this table.
	Blunders still exist in one or more observations For example, an azimuth is incorrect by 180 degrees.	In your GPS data, check suspect baseline solution statistics (Ratio, Reference Variance, RMS). Check the GPS Loop Closures report. Check the Recompute report. Make sure that your observations flow out from good quality coordinates. If you are adjusting GPS data, check antenna height measurements, type, and method for each occupation. Correct antenna errors and perform a recomputation. If you are adjusting terrestrial data, check instrument and target heights. If necessary, correct height measurements and perform a recomputation. Exclude (*Not used*) the suspect observation from network adjustment (if not a critical observation in the network). Once you are confident the baseline is a problem that cannot be fixed, you can *Disable* the observation. Reobserve the suspect observation (if critical to network redundancy).

Table 2.5 Troubleshooting a minimally constrained adjustment (Continued)

Problem	Possible cause	Action
Observation Outlier (Standardize Residual > Critical Tau Value)	Noisy GPS baseline solution	Check suspect GPS baseline solution statistics. Troubleshoot and reprocess the suspect baseline. Exclude (*Not used*) the suspect baseline from network adjustment (if not a critical observation in the network). Once you are confident the baseline is a problem that cannot be fixed, you can *Disable* the observation. Reobserve the baseline (if critical to network redundancy).
	Bad antenna, instrument, or target height measurement or plumbing	Check GPS Loop Closures report for bad closures caused by antenna heights. Check field notes against antenna heights, types, and measurement methods for each station occupation. Correct antenna errors and perform a recomputation. Check instrument and target heights in field notes. Correct height error and perform a recomputation. Exclude (*Not used*) the suspect baseline from network adjustment (if not a critical observation in the network). Once you are confident the baseline is a problem that cannot be fixed, you can *disable* the observation. Reobserve the baseline (if critical to network redundancy).

Table 2.5 Troubleshooting a minimally constrained adjustment (Continued)

Problem	Possible cause	Action
Observation with zero Degrees of Freedom (Redundancy Number = 0.000)	The observation is a sideshot (one of the points at either end of the observation has only one observation to it).	Add redundancy to the network at point with one observation (observe additional observations). **NOTE –** The problem, possible cause, and action are only valid when an observation was not intended to be a sideshot. Sideshots can be included in a network adjustment for the purpose of error analysis.

Troubleshooting Action (Minimally Constrained Adjustment)

After analyzing the Network Adjustment report and deciding on a troubleshooting plan, perform one of the troubleshooting actions listed in Table 2.5. Perform each action independently (one-by-one) to assess each problem's effect on the statistics (network reference factor, Chi-square test and degrees of freedom). You may find that correcting one problem will solve several other problems as well.

Note – *You can also view the combined histogram of standardized residuals.*

Keep in mind the following guidelines while resolving the problems with your network adjustment:

- Before excluding an observation, attempt to resolve the observation outlier by using the Alternative scalar weighting strategy to scale the a priori estimated errors. If the observation is still an outlier, or if the scalar that is produced is excessively large, then exclude (or disable) the observation.

- If you decide to exclude an observation after changing your weighting strategy, return to the *Default* scalar (1.00). This returns all observation estimated errors to their initial value, eliminating any scaling introduced by the bad observation.

To begin resolving the problems with your network adjustment, do one of the following:

- Close your HTML viewer.
- If you are still viewing the Network Adjustment report, leave the viewer open and use Alt+Tab to return to the Trimble Geomatics Office program, .

The sections below describe the following actions:

- changing the weighting strategy for GPS observations
- viewing and excluding observations flagged as outliers
- disabling an observation

Changing the weighting strategy for observations

Changing the weighting strategy used for the adjustment is useful for resolving the following problems:

- scaling the estimated errors of an observation outlier in an attempt to bring the observation’s standard errors within the *Tau* criteria
- scaling underestimated a priori errors of the observations, allowing you to get a better idea of the true errors in your observations

Use the *Weighting Strategies* dialog to:

- view the scalar applied to the GPS, terrestrial, and geoid observations
- view the method used to apply the weights
- view the type of scalar used
- lock a value for the scalar

For the first adjustment, the scalar weighting strategy is set as:

- Apply Scalars To: All Observations
- Scalar Type: Default

This strategy applies a scalar of 1.00 to all the observations, thus allowing the adjustment to use the initial a priori error estimates.

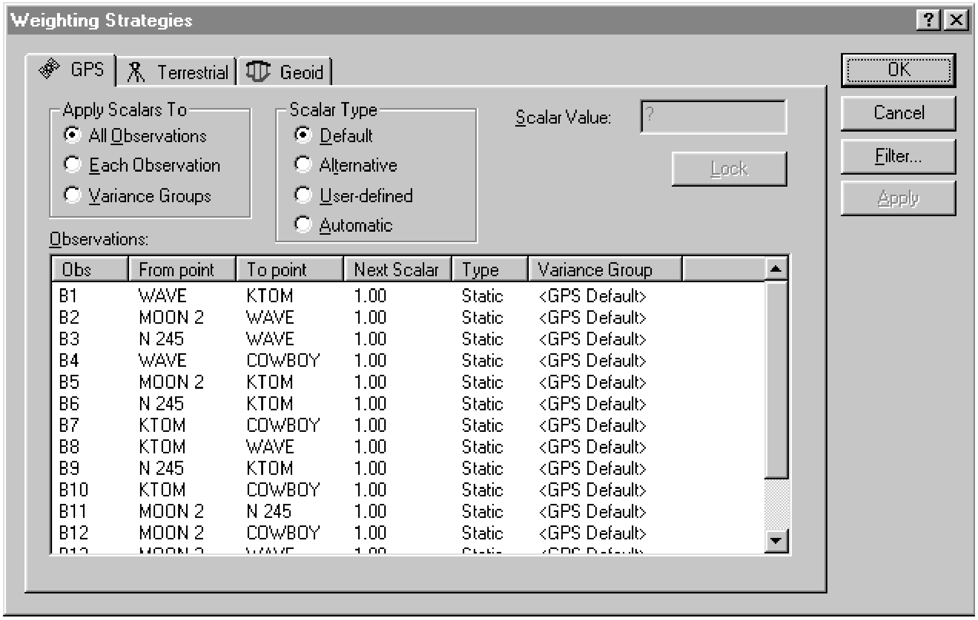
Note – *For a minimally constrained adjustment, you do not need to use the Geoid tab to set the geoid observation scalar weighting strategy, since no observations are loaded.*

As the adjustment progresses, you will make changes to the weighting strategies that will help you to analyze and properly distribute the errors in your network.

Note – *Using the Automatic Scalar Type option, the alternative scalar process is applied to successive adjustment iterations until the Chi-square test passes. Before using the automatic scalar type, make sure that you remove all blunders from your data set. Blunders cause the over-scaling of other observations in the adjustment. For more information, refer to the Network Adjustment Help.*

To access the *Weighting Strategies* dialog:

1. From the Survey view, select *Adjustment / Weighting Strategies*. The following dialog appears:



2. Select the *GPS* tab or the *Terrestrial* tab.

   The observations are listed in along with the scalar value for the *next* adjustment iteration. The scalar applied to the *current* adjustment is shown in the Network Adjustment report.

   The current weighting strategy is shown in the *Apply Scalars To* and *Scalar Type* groups above the *Observations* window.

3. In the *Scalar Type* group, select *Alternative.*

   By selecting this option, the program will multiply the Network Reference Factor from the latest adjustment by the Observations Scalar used in the latest adjustment to determine the scalar for all estimated errors in the next adjustment. This value is shown in the *Next Scalar* column.

4. For GPS Adjustments, leave the *Apply Scalars To* set to *All Observations*.

   For most network adjustments you will evaluate the observations within a cohesive network, thus applying a single scalar to the network (or all observations) as a whole.

5. Click **OK** to accept changes and continue.

Figure 2.3 illustrates the relationship between the scalar and the network reference factor (NRF).

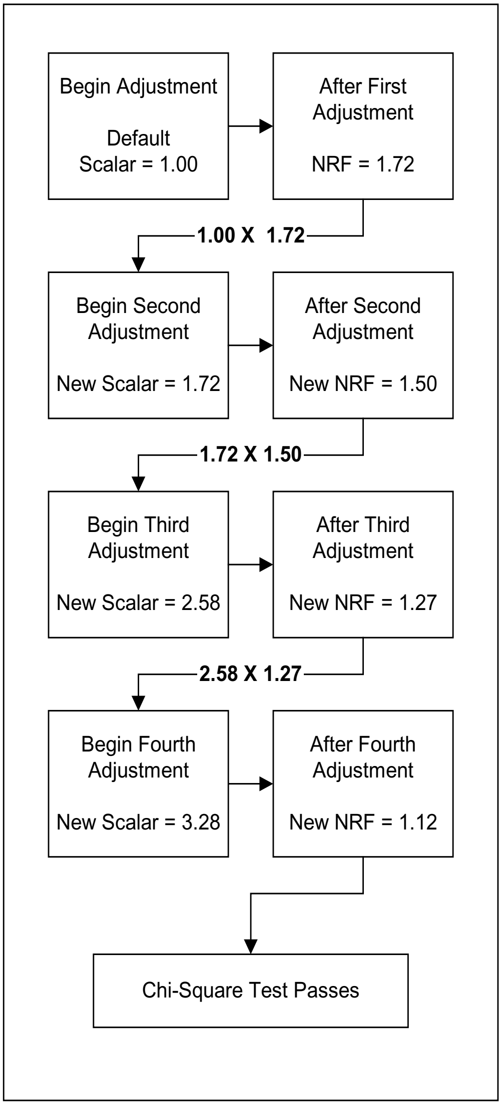


Figure 2.3 Alternative scalar process

Viewing and excluding observations flagged as outliers

Use this troubleshooting action to:

1. View the observations used in the adjustment.
2. Change the network adjustment status for the observation outlier to exclude it from the adjustment.

In the *Observations* dialog *Use* column, a checked observation means it is included (used) in the adjustment.

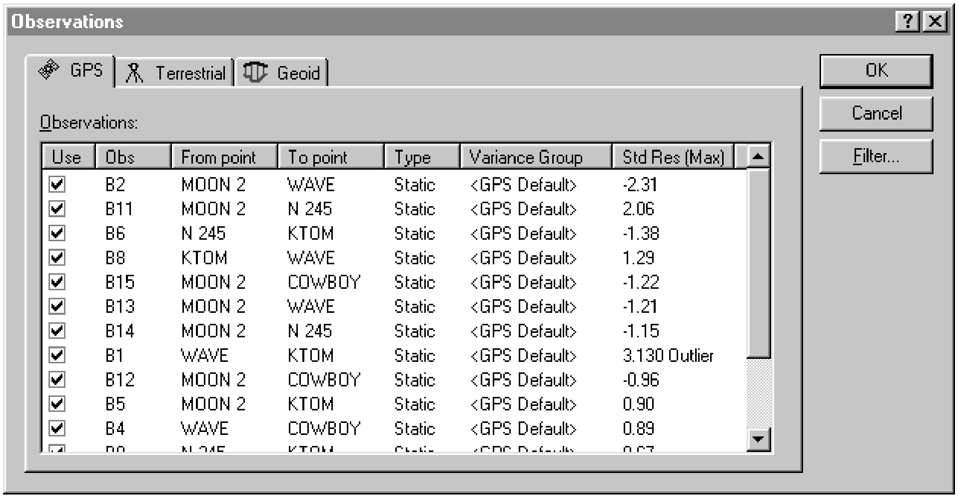
Use the *Observation* dialog to:

- view the observations included in the adjustment
- view the network adjustment status of an observation
- view the maximum (highest) standardized residual *Std Res (Max)* of the three baseline components of each observation
- change the network adjustment status of an observation
- disable an observation.

The *Observations* dialog *Use* column is for *including (use)* or *excluding (do not use)* an observation in the network adjustment only. When the *Use* column of an observation is cleared (not checked), it is excluded only for the adjustment. The observation is still available in the database and is used by the recompute function. To disable the observation from the project, see Disabling an observation, page 54.

To use the *Observations* dialog:

1. From the Survey view, select *Adjustment* / *Observations*. The following dialog appears:



The tabs in the *Observations* dialog are:

- GPS – the GPS observations (those defined as networked observations).
- Terrestrial – the terrestrial observations (those defined as networked observations)
- Geoid – geoid observations (if loaded). Geoid observations from a geoid model typically are not loaded until you perform a fully constrained adjustment.

Tip – Click **Filter** to restrict the types of observations displayed in the *Observations* dialog – *GPS* or *Terrestrial* tab. When using the **Filter** button, the observations omitted from the display are still used in the adjustment.

2. Select the *GPS* or *Terrestrial* tab.

3. Check for observations flagged as outliers; they will have the word *Outlier* next to the *Std Res (Max)* (the standardized residual).

   To find the observations flagged as outliers, do the following:

   – Click the *Std Res (Max)* column label to sort the values from highest to lowest. The outliers will have the highest standardized residuals and are at the top of the list.

     The value listed in the *Std Res (Max)* column of the *Observations* dialog is the highest *standardized residual* of the observations three components: *azimuth, distance,* and *delta height.*

4. In the *Use* column, clear the check box to exclude (not use) the observation in the adjustment.

   This observation is not used in the next and subsequent adjustments. If you later suspect the observation may have been flagged as an outlier based on the influence of other observation outliers, you can include (use) the observation at any time.

   Before excluding an observation, attempt to resolve the observation outlier by using the *Alternative* scalar weighting strategy to scale the a priori estimated errors. If the observation is still an outlier or the scaling appears to be excessive (as seen in the Combined Histogram), then exclude the observation.

5. If necessary, repeat step 3 to exclude each observation outlier one-by-one to determine what influence it has on the other observation outlier and the statistics.

   When excluding observations one-by-one, you may find that correcting one problem will solve several other problems.

6. Click **OK** to accept any changes and continue.

Note – *If you decide to exclude an observation after changing your weighting strategy, return to the Default scalar (1.00). This returns all observation estimated errors to their initial a priori values, eliminating any scaling introduced by the bad observation.*

Disabling an observation

Once you are confident that an observation is bad, you can disable the observation in the project database. Typically, you will not want the recomputation to use the bad observation to compute any points in your project. Disabling the observation will exclude it not only from the adjustment, but from further use by the recompute function.

There are several ways to disable an observation. Use one of the methods listed below.

Using the *Observations* dialog:

1. In the Survey view, select *Adjustment* / *Observations*. The *Observations* dialog appears.
2. Select the *GPS* or *Terrestrial* tab.
3. Locate the observation to disable.
4. Place the cursor over the observation and right-click.

   The selected observation is highlighted and the *Disable Observation* command is available.
5. Select *Disable Observation*.

   The observation is removed from the *Observations* list, its project status is changed to *disabled*. The observation is shown as red in the Survey view.

   Note – *This option is only available for one observation at a time. If more than one observation is selected, then the Disable Observation option is unavailable.*
6. Click **OK** to exit the *Observations* dialog.

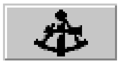
Using the *Properties* window:

1. From the Survey view, select the observation to disable.

   The observation is highlighted.

2. To view the observation's properties, do one of the following:
   - Select *Edit* / *Properties.*
   - Select the *Edit Properties* icon.
   - Press Alt+Enter.
   - Double-click on the observation.

   The *Properties* window appears with the observation(s) listed in the *Selection* window.
3. If there are multiple observations in the *Selection* window, then select the observation to disable.
4. The observations properties are displayed in the *Summary* page of the *Survey* tab. If there is a warning associated with the observation, then the *Warning* page is shown.

   To open the *Summary* page, click the *Summary* button. 
5. In the *Status* field, select Disable.

   The observation's project status is *disabled* and the observation is shown as red in the Survey view.

Using the *Multiple edit* command:

1. Select all the observations to disable
2. From the Survey view, select *Edit* / *Multiple Edit.* The *Multiple Edit* dialog appears.
3. Select the *Survey* tab.
4. In the *Perform these edits to the selected observations* group, select the *Set observation status to*.

   The check box is selected and the *Status* options are available.
5. Select *Disable* option from the list.
6. Click **OK** to apply the edits to the selected observations.

The project status of all observations in the selection changes to *disabled* and the observations appear red in the Survey view.

Note – *If you decide to disable an observation after changing your weighting strategy, return to the Default scalar (1.00). This returns all observation estimated errors to their initial value, and eliminates any scaling introduced by the bad observation.*

Continuing the Minimally Constrained Adjustment

Now that you have determined a troubleshooting plan, proceed with the minimally constrained adjustment by readjusting the network. As you can see from Figure 2.4, you begin to loop through a series of statistical results and decisions until you are confident that you have removed all large errors and properly distributed the error in your observations; they pass the Chi-square test and the combined histogram appears to be normally distributed.

When you are satisfied with your minimally constrained adjustment, you can begin the fully constrained adjustment of your network. As you move on to the fully constrained adjustment, you will be confident that problems that you might see (high network reference factor, outliers, and so on), are related to the control points and how your network fits the control, and ***not*** to incorrect error estimation or bad observations.

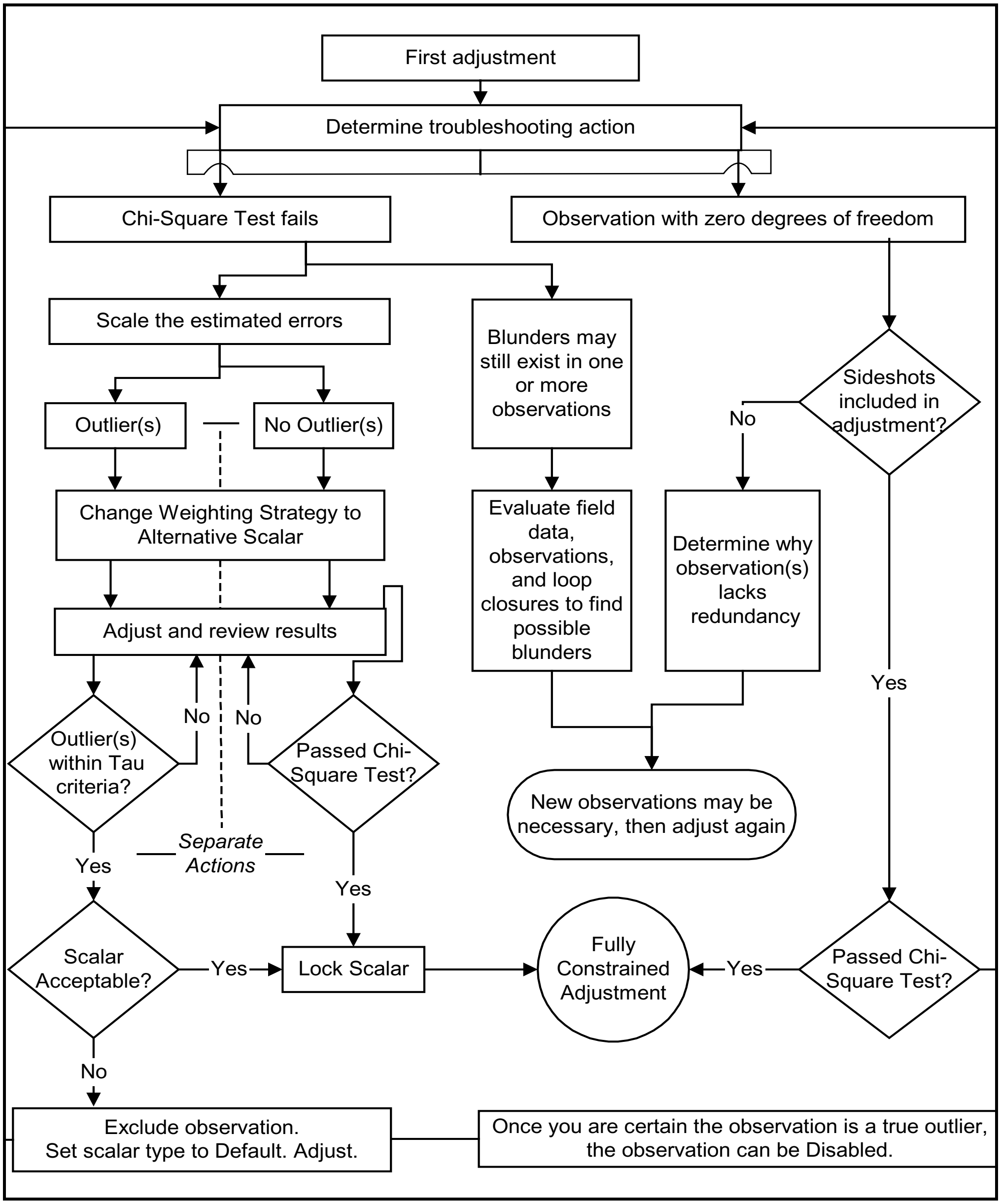


Figure 2.4 Troubleshooting – minimally constrained adjustment loop

Locking the Weighting Strategy Scalar for Observations

If you changed the weighting strategy to alternative scalar, you must now lock the weighting strategies scalar before proceeding to the fully constrained adjustment. The alternative scalar was used to scale the estimated errors of your observations, allowing you to get a better idea of the errors in each observation.

You can stop calculating a new scalar before starting the fully constrained adjustment when the adjustment meets the following criteria:

- All blunders have been removed.
- The network adjustment passes the Chi-square test.
- The scalar values are not unreasonably large.
- The combined histogram appears to be normally distributed.
- The observation residuals are acceptable.

To lock the scalar:

1. In the Survey view, select *Adjustment* / *Weighting Strategies*.

   The *Weighting Strategies* dialog appears (page 48). The observations are listed along with the scalar type applied for the next adjustment.

2. Click **Lock** to lock the scalar from the last adjustment.

   The scalar type is automatically changed to *User-defined* and the scalar for the last adjustment appears in the *Scalar Value* field.

3. Click **OK** to save the changes.
4. Perform one adjustment with the scalar locked to make sure that you are ready to proceed to the fully constrained adjustment.

Note – *If you successfully used the automatic scalar option, the Scalar Value field will already contain the correct user-defined scalar.*

Saving Calibration Coordinates

After completing a minimally constrained adjustment, the Trimble Geomatics Office software allows you to save the WGS-84 coordinates of your adjusted points. These WGS-84 coordinates are saved for use as *GPS points* in a GPS site calibration. The *Adjustment Datum* must be set to *WGS-84* to save the calibration coordinates.

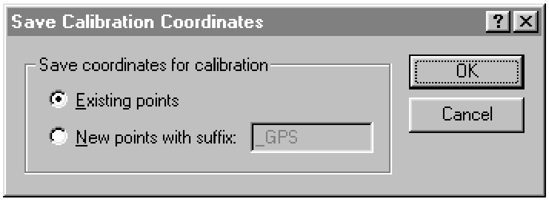
If you are planning to perform a calibration, you must have the following formats for the coordinates of your points:

- WGS-84 latitude, longitude, and ellipsoid height (L, L, h)
- A local grid northing, easting - horizontal only (2D), or elevation - vertical only (1D), or northing, easting, and elevation (3D).

Saving the calibration coordinates after a minimally constrained adjustment satisfies the first requirement. After completing the fully constrained adjustment, you will have the second required coordinate set.

To save the calibration coordinates:

1. From the Survey view, select *Adjustment* / *Calibration Coordinates* / *Save*. The following dialog appears:



2. Select one of the methods for saving the calibration coordinates described below in Table 2.6.

Table 2.6 Saving calibration coordinate options

Option	Action
Existing points	If you choose to save the coordinates under *Existing points*, the coordinates are saved with the same name. View these coordinates in the *Properties* window.
New points with suffix: GPS	If you choose to save the coordinates under *New points with suffix: _GPS*, a new point is created with the point name: *<point name>_GPS*. You can edit the "*_GPS*" suffix in the *New points with suffix* field prior to saving the calibration set.

The calibration coordinates are saved.

***Note –** If you have previously saved the calibration coordinates (using either method), the previous coordinates are overwritten.*

Removing Calibration Coordinates

The *Adjustment* / *Calibration Coordinates* command also allows you to remove the calibration coordinates from a project.

To remove the calibration coordinates:

- From the Survey view, select *Adjustment* / *Calibration Coordinates* / *Remove*.

The calibration coordinates are removed from the project database.

Starting the Fully Constrained Adjustment

The next step in performing the network adjustment is to transform your observations to fit the fixed control point datum (or *Project Datum)*. The fully constrained adjustment process is similar to the minimally constrained adjustment. You will do the following:

1. Adjust.
2. Evaluate the results of the adjustment.
3. Troubleshoot.
4. Determine a troubleshooting plan of action.
5. Adjust.

The difference is that you are fixing control points (as you loop through the fully constrained adjustment) and evaluating how well all of the control points and adjusted observations fit together. The additional procedures you will work through in a fully constrained adjustment are the following:

- Change the *Adjustment Datum* to the *Project Datum* that you selected in the project properties.
- If you are adjusting GPS data, load geoid separations into your adjustment. Elevations (or heights) are determined using geoid separations (observations) interpolated from the geoid model selected in the *Project Properties* dialog.

For GPS-only adjustments, the geoid separations are added to the ellipsoid heights from the GPS observations, resulting in a computed elevation. Typically, elevations are used as the fixed vertical coordinate in a fully constrained adjustment.

For terrestrial-only adjustments, you do not need to load geoid observations.

Note – *You do not need to load geoid observations when performing a 2D (horizontal only) adjustment (that is, an adjustment without GPS observations).*

Note – *If you are performing a combined adjustment with both GPS and terrestrial observations, and you have a sparse terrestrial network, load geoid observations before adjusting your terrestrial data.*

- Generate the necessary transformations by constraining (fixing) the control points you have selected for use in your network. The control points are typically well-established survey marks with high-accuracy horizontal (2D) or vertical (1D) coordinates. In some cases, the point will have both horizontal and vertical (3D) coordinates.

Setting the Adjustment Datum (Fully Constrained Adjustment)

For a fully constrained adjustment, set the adjustment datum to your project datum. You must select the project datum to generate the correct parameters used for transforming the GPS observations to the project (local) datum.

To change the adjustment datum:

- From the Survey view, select *Adjustment* / *Datum* / *Project Datum <Datum name>*.

A check mark appears next to *Project Datum – <Datum name>*.

Figure 2.5 shows the typical workflow in a fully constrained network adjustment.

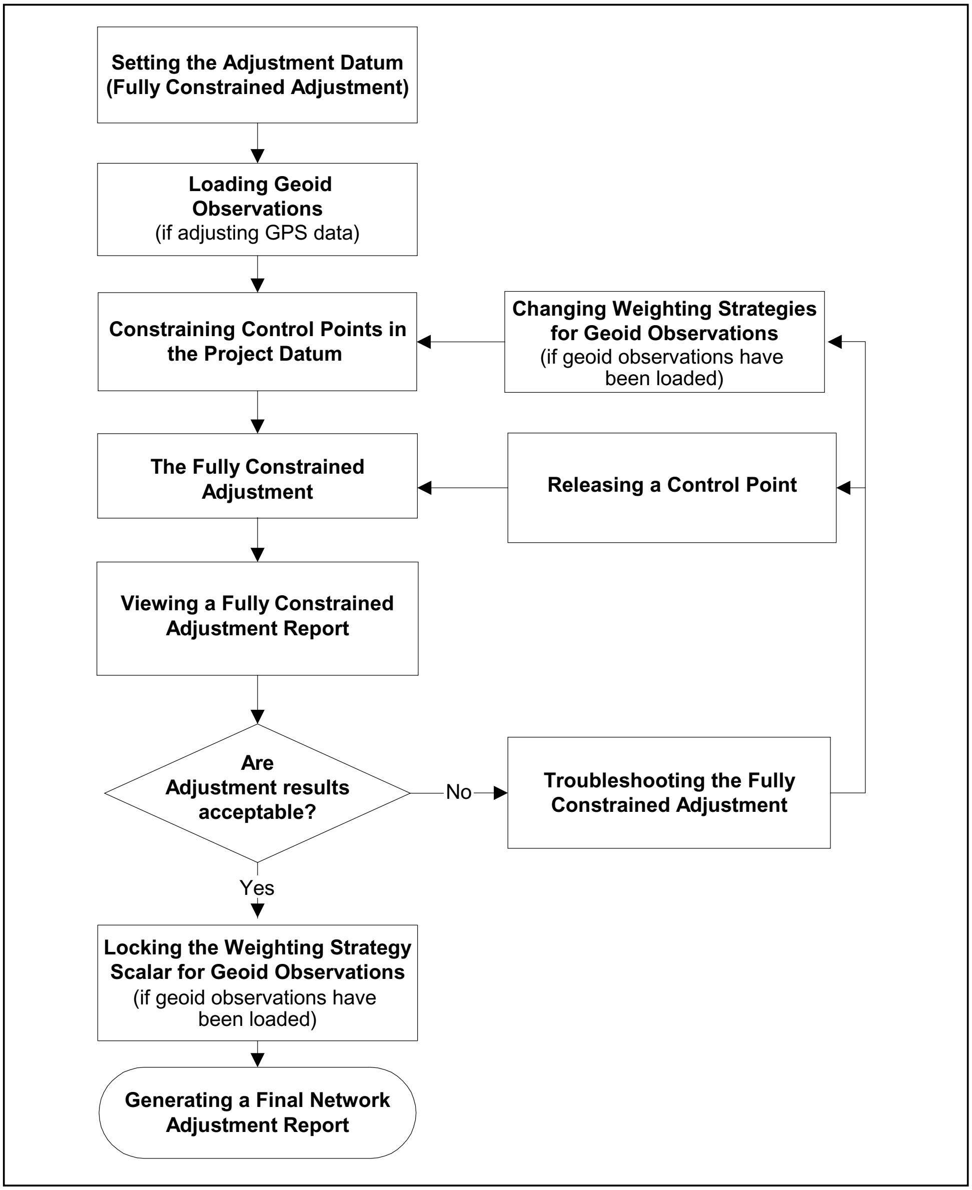


Figure 2.5 Fully constrained adjustment flow

Loading Geoid Observations

When adjusting GPS observations, geoid observations are required to determine elevations on all the points in the adjustment.

You have worked with ellipsoid heights during the minimally constrained adjustment of your GPS observations. During the fully constrained adjustment you will begin fixing elevations to determine elevations for all the points with unknown elevations in the network.

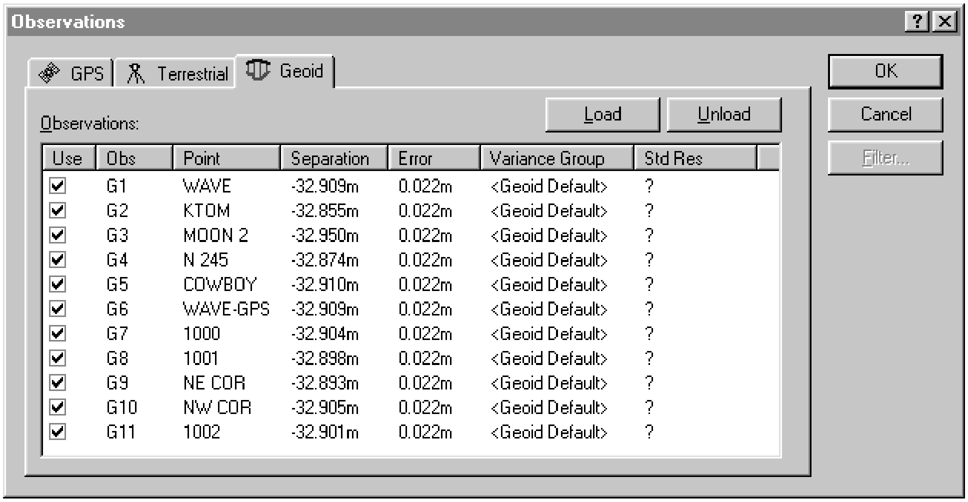
Note – *You do not need to load geoid observations when performing a horizontal adjustment.*

To determine elevations, load geoid observations into the network adjustment. To load geoid observations you must select a geoid model in the *Project Properties* dialog. For more information on selecting geoid models, refer to the *Trimble Geomatics Office User Guide*.

To load geoid observations:

1. From the Survey view, select *Adjustment* / *Observations*. The *Observations* dialog appears (page 52).
2. Select the *Geoid* tab. The geoid observation list is empty. You must load the geoid separations from the geoid model that is selected for the project properties. If no geoid model is selected for the project, the **Load** button is unavailable.
3. Click **Load** to load the geoid observations into the network adjustment.

The program interpolates geoid separations from the geoid model for every point in the network adjustment, along with an estimated error for each separation. The results are shown in the *Geoid* tab, as shown below:



4. Click **OK** to continue.

   The program creates a separate variance group for the geoid observations. This allows for separate analysis, weighting, and scaling of the errors in the geoid observations.

After the separations are loaded, the **Unload** button becomes available. At any time you can unload the geoid observations from the network adjustment.

Constraining Control Points in the Project Datum

Constraining (fixing) control points in the project datum allows you to do the following:

- Generate parameters that will transform your observations to your local coordinate system. As you constrain additional points (horizontally and vertically), transformation parameters are generated.
- Check the quality of the control point coordinates you are using in the network.

Note – *The Trimble Geomatics Office software will* **not** *allow you to have both network adjustment transformation parameters and GPS site calibration parameters in a project. The transformation parameters generated from the fully constrained adjustment are removed from the project when a GPS site calibration is performed and vice versa. Complete all necessary work using the transformation parameters prior to performing a GPS site calibration.*

With the minimally constrained adjustment, you found that the observations are free of large errors, and any remaining error (random) is properly distributed. You also found that the observations fit together very well as a rigid network. So, if you see any problems with the fully constrained adjustment (high network reference factor, outliers, and so on), you know the problem is with the control points that you are fixing, and not with the observations.

Trimble recommends that you use at least three horizontal and four vertical control points to generate transformation parameters with confidence. With the recommended control, you will generate the parameters and have an additional point to check the parameters created.

By default, the status of the following transformation parameters (listed in Table 2.7) are set to *unused*:

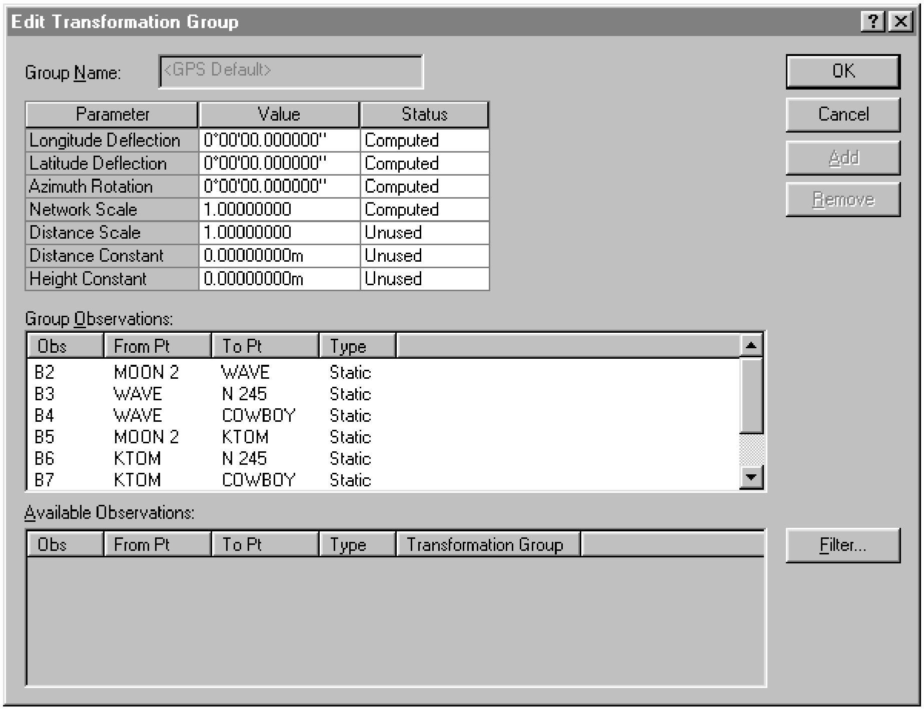
- GPS transformation parameters
  - Distance Scale (DS)
  - Distance Constant (DC)
  - Height Constant (HC)
- Terrestrial transformation parameters
  - All parameters except Azimuth Rotation
- Geoid Transformation Parameters
  - All parameters

Note – *Geoid and terrestrial parameters are not used in a recomputation. If you need these parameters to be applied to certain observations, then those observations must be included in the adjustment (for example, sideshots and azimuths.)*

Use the *Edit Transformation Group* (GPS, terrestrial, and geoid) dialog to change the status of these parameters for use in your network adjustment. Do the following:

1. From the Survey view, select *Adjustment* / *Observation Groups* / *Transformation Groups*. The *Transformation Groups* dialog appears.
2. Select the *GPS*, *Terrestrial*, or *Geoid* tab.
3. Select the group that you want to edit.
4. Click **Edit**.

The *Edit Transformation Group* dialog appears (GPS shown):



5. Make any required edits.

   The *Distance Scale* and *Distance Constant* in the *GPS transformation parameters* can be computed or user-defined. The values for these parameters are used to correct a known systematic error in your measurements.

   Note – *Use of both Network Scale and Distance Scale in a GPS Transformation Group is not recommended. Network Scale is used for datum transformations, and the Distance Scale is used for systematic error modeling.*

6. Click **OK** when you are finished.

Note – *For more information and detailed descriptions of the transformation parameters, refer to the Help.*
For information on the terms used, see Appendix A, A Guide to Least-Squares Adjustments, and the Glossary.

Table 2.7 lists the number of fixed coordinates required to verify fixed control points.

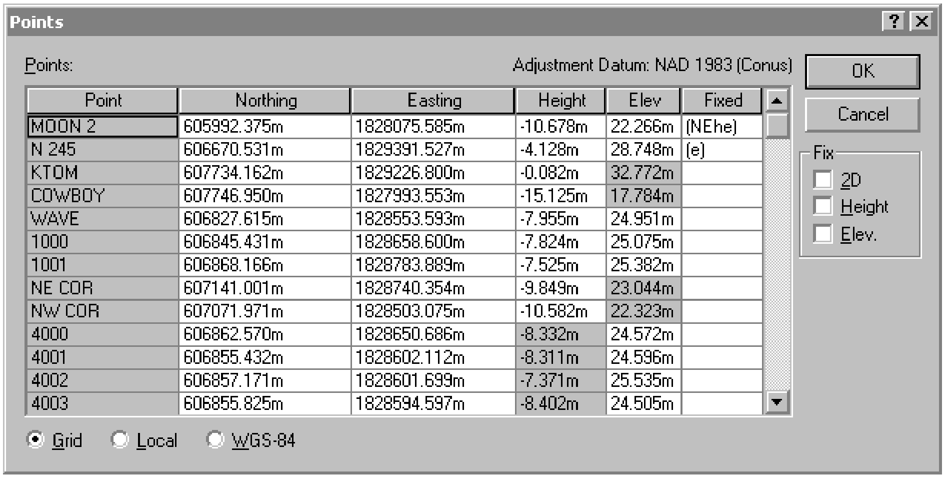
Table 2.7 Coordinate components verified by fixing control points

Number of fixed coordinates			**Check of fixed coordinates**
2D	**Elev (e)**	**Height (h)**	**Component verified**
0–2	4 or >	0–3	Elevation
0–2	0–3	4 or >	Height
0–2	4 or >	4 or >	Elevation & Height
3 or >	0–3	0–3	2D
3 or >	4 or >	0–3	2D & Elevation
3 or >	0–3	4 or >	2D & Height
3 or >	4 or >	4 or >	All

Fixing a Point (Fully Constrained Adjustment)

To fix a control point:

1. From the Survey view, select *Adjustment* / *Points*. The following dialog appears:



Point	Northing	Easting	Height	Elev	Fixed
MOON 2	605992.375m	1828075.585m	-10.678m	22.266m	(NEhe)
N 245	606670.531m	1829391.527m	-4.128m	28.748m	(e)
KTOM	607734.162m	1829226.800m	-0.082m	32.772m	
COWBOY	607746.950m	1827993.553m	-15.125m	17.784m	
WAVE	606827.615m	1828553.593m	-7.955m	24.951m	
1000	606845.431m	1828658.600m	-7.824m	25.075m	
1001	606868.166m	1828783.889m	-7.525m	25.382m	
NE COR	607141.001m	1828740.354m	-9.849m	23.044m	
NW COR	607071.971m	1828503.075m	-10.582m	22.323m	
4000	606862.570m	1828650.686m	-8.332m	24.572m	
4001	606855.432m	1828602.112m	-8.311m	24.596m	
4002	606857.171m	1828601.699m	-7.371m	25.535m	
4003	606855.825m	1828594.597m	-8.402m	24.505m	

The *Points* dialog identifies the control quality of a point by placing the corresponding NE, LL, h, or e symbol with parenthesis in the *Fixed* column. Once you fix the coordinate, the parenthesis are removed and the control values are placed in the coordinate field for that point.

2. Select the first point to be fixed. Typically, it is the point you fixed in the minimally constrained adjustment.

3. In the *Fix* group, select the appropriate check boxes for the coordinates you are constraining.

4. Enter the control (coordinates) for the point, if the control point was not previously imported or keyboard entered as *Control* quality.

5. Click **OK** to continue.

The Fully Constrained Adjustment

1. Adjust the network using one of the following methods:
   - From the Survey view, select *Adjustment / Adjust*.
   - Press F10.
   - In the project bar *Adjust* group, click the *Adjust* icon.
2. View the status bar to determine the status of your network adjustment.

   The status bar displays the current iteration of the adjustment. The adjustment will perform as many iterations (up to the maximum set in the adjustment style) required to meet residual tolerance.

   Note – *If the adjustment fails the residual tolerance (that is, it does not converge), free and/or fix different control values. The adjustment may not be converging due to incorrect coordinate entry or poor coordinates.*

   For more information on the functions performed by the adjustment, see Step 3, page 35.
3. Continue with the fully constrained adjustment by analyzing the initial results and constraining more control points.

Comparing Adjusted and Known Coordinates

After you fix the first point and perform an adjustment, you can compare the adjusted coordinates to the known coordinates of the other control points to determine the differences between the two. This gives you an idea of how well the other control points will *fit* in the adjustment.

Warning – If insufficient coordinates are fixed to calculate transformation parameters during the adjustment, then the comparison between adjusted and known coordinates is only valid when working with a project datum that is similar to WGS-84 (geocentric). Some local datums require a considerable amount of transformation (such as azimuth rotation and network scale) before making a comparison of the coordinates. For this type of project datum, perform the comparison only after fixing the required number of points thus generating the transformation parameters.

When comparing the coordinates, consider the following guidelines:

- If you see large differences between the known and adjusted coordinates on any one control point, you may have problems constraining that point.
- If you see large differences between the known and adjusted coordinate on more than one control point, you may have a problem with the point(s) you have constrained, or you need to transform the network.

Constraining Additional Control Points

To continue with the adjustment, constrain the other available control points. You can constrain any number of control points, as long as you have accurate coordinates for them.

Trimble recommends that you:

- Constrain a minimum of three horizontal and four vertical control points.
- Adjust the network.
- Analyze the results before constraining any additional control points.

Constraining the minimum number of points generates the transformation parameters and allows for a check on those parameters.

***Note –** As you constrain additional control points beyond the minimum, you should constrain them, one-by-one. This allows you to assess the results as each point is constrained.*

Viewing a Fully Constrained Adjustment Report

The Network Adjustment report displays the results of the last adjustment.

***Note –** For more information and a full description of each section in the report, see Chapter 3, Viewing the Network Adjustment Report.*

To use the Network Adjustment report to analyze and troubleshoot the results of your fully constrained adjustment:

1. From the Survey view, select *Reports* / *Network Adjustment Report*.

   The Trimble Geomatics Office software opens your HTML viewer and displays the report.

2. Click the hyperlinks in the table of contents to navigate directly to the section of interest.

   The selected section is displayed.

Troubleshooting the Fully Constrained Adjustment

Use the Network Adjustment report to begin troubleshooting your network adjustment. The troubleshooting procedures for a fully constrained adjustment are essentially the same as those for a minimally constrained adjustment. You will review some of the same statistics, but find that the cause of the problem may be different than in the minimally constrained adjustment. Also, the required troubleshooting actions may differ.

If you have a problem with the adjustment converging, see Adjustment Fails – No Convergence, page 40 for a full explanation of the message you will see.

Evaluating the Statistics (Fully Constrained Adjustment)

Constrain the minimum number of control points (three horizontal and four vertical) to perform a true evaluation of the fully constrained adjustment. If you constrain only two horizontal and three vertical points, you have only defined the parameters necessary to transform the observations to your control (datum). Additional fixed-control points allows you to evaluate or check the defined parameters. You then know that any problems you encounter are related directly to your control points.

When the adjustment converges and you have viewed the Statistical Summary section in the Network Adjustment report, you must decide if you need to troubleshoot.

Consider the following:

- Control coordinate comparisons in the Network Adjustment report
- Large jumps in the reference factor between adjustments

Some problems you might see in a fully constrained adjustment are listed in Table 2.8. The table lists the problem, possible cause and suggests the actions you can perform to improve your statistics and overall adjustment.

Table 2.8 Troubleshooting a Fully Constrained Adjustment

Problem	Possible cause	Action
The adjustment failed to converge after 10 iterations.	One or more large errors or mistakes (blunders) exist in one or more control points, as a result of:	Systematically “unfix” or fix the control points, leaving the minimum number fixed, until the suspect point is found. Then:
	• occupying the wrong point	Verify correct occupation.
	• the condition of the point (moved or disturbed)	Check physical condition of control point.
	• measuring the wrong antenna height on all occupations of the point (vertical)	Check field notes. Check antenna heights, type, and measurement method.
	• measuring the wrong instrument or target height on all occupations of the point.	Check instrument and target heights. Check keyed-in or imported coordinates.
There are large jumps in the reference factor between adjustments.	One or more large errors or mistakes (blunders) exist in one or more control point coordinates, such as:	Verify correct coordinates and datum.
	• coordinate(s) entered incorrectly • wrong coordinate(s) • unreliable coordinates	Check coordinate source.
	Errors in the geoid observations are underestimated.	Apply a scalar (alternative) to the *Geoid Observation* group.

Troubleshooting Action (Fully Constrained Adjustment)

After analyzing the Network Adjustment report and deciding on a troubleshooting plan, perform one of the troubleshooting actions listed in Table 2.8. Perform each action independently (one-by-one) to assess each problem's effect on the network adjustment statistics. You may find that correcting one problem will solve several other problems as well.

To begin resolving the problems with your network adjustment, do one of the following:

- If you are still viewing the Network Adjustment report, close your HTML viewer.
- Leave the viewer open and use Alt+Tab to return to the Trimble Geomatics Office program.

The sections below describe the following actions:

- releasing a control point
- changing the weighting strategy

Releasing a control point

As you constrain control points, you may find one or more that do not fit with the rest of the control points and observations. The reasons for the ill-fitting control point may include:

- The physical control point may have been disturbed (moved).
- There could be a problem with the coordinates, such as keying in the wrong number or errors in the original survey.
- The wrong point may have been occupied.

Once you suspect a control point is bad, you can release the constraints for the point.

To release a constrained control point or component:

1. From the Survey view, select *Adjustment* / *Points*. The *Points* dialog appears (see page 71).
2. Select the suspect constrained control point.

   The *Fix* group check boxes become available. You can release any combination of coordinates components.
3. In the *Fix* group, clear the appropriate check boxes for the coordinates components you are releasing.

   The check mark is removed from the component check box.
4. Click **OK** to continue.
5. Perform another adjustment and review your results to determine if the released control point is causing the problem in your network. Remember that you must have the minimum number of constraints (three horizontal and four vertical) to analyze your result.

In some cases, the bad control points are difficult to find and may take careful analysis to locate. Also, you may find that one component (horizontal, ellipsoid height, or elevation) of the point is good, while another is causing problems with the network. You can release the one questionable component of control point, leaving the other components constrained.

Table 2.8 on page 76 lists examples of some problems you might see while constraining points for a fully constrained adjustment.

Changing the weighting strategy for geoid observations

Changing the weighting strategy used for the adjustment is useful for resolving the following problem: scaling underestimated a priori errors of the observations to allow you to get a better idea of the errors in your observations.

Use the *Weighting Strategies* dialog to do the following:

- View the scalar applied to the geoid observation.
- View the method used to apply the weights.
- View the type of scalar used.
- Lock a value for the scalar.

When the geoid observations are loaded, the scalar weighting strategy for the geoid is set as:

- Apply Scalars To: All Observations
- Scalar Type: Default.

This strategy applies a scalar of 1.00 to all the geoid observations, thus allowing the adjustment to use the initial error estimates.

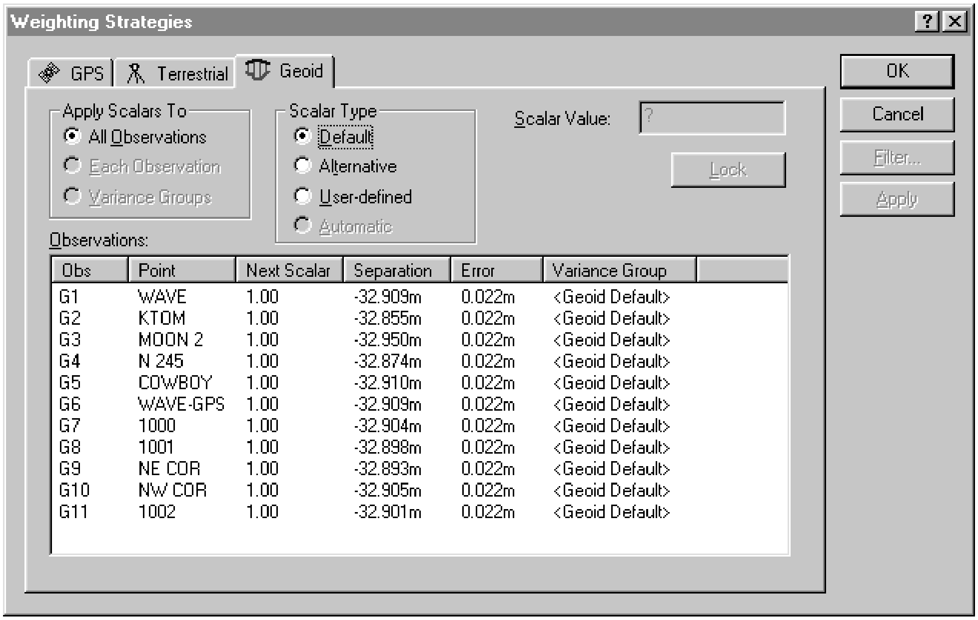
Note – *Do not change the weighting strategies for the GPS or terrestrial observations at this point in the adjustment. The weights have been determined during the minimally constrained adjustment and should not be changed. Geoid observations need constraints set before a weighting strategy can be determined for them.*

As the adjustment progresses, you will make changes to the weighting strategies, which will help you to analyze and properly distribute the error in your geoid observations.

For more information on the *Weighting Strategies* dialog, refer to the Help.

To access the *Weighting Strategies* dialog:

1. In the Survey view, select *Adjustment* / *Weighting Strategies*. The *Weighting Strategies* dialog appears.
2. Select the *Geoid* tab, as shown below:



The geoid observations are listed in the *Geoid* tab along with the scalar value for the *next* adjustment iteration. The scalar applied to the *current* adjustment is shown in the Network Adjustment report.

***Note –** The initial geoid separation error estimate is the standard error of the set of separations. The Trimble Geomatics Office software computes the geoid separations in the adjustment and then determines the standard error of those separations. This is only a starting point for the estimation of the errors in the geoid separation and may require that you scale the errors before a true representation of the estimated errors is achieved.*

The current weighting strategy is shown in the *Apply Scalars To* and *Scalar Type* groups.

3. In the *Scalar Type* group of the *Geoid* tab, select *Alternative*.

   For more information and a full explanation of alternative scaling, see Troubleshooting Action (Minimally Constrained Adjustment), page 45.

4. Leave the *Apply Scalars To* set to *All Observation*.

   For all network adjustments containing geoid observations, evaluate the observations within a cohesive network, thus applying a single scalar to the network (or all observations) as a whole.

5. Click **OK** to accept any changes and continue.

   By selecting these options, the program will multiply the Geoid Model Reference Factor from the latest adjustment by the Geoid Observation Scalar used in the latest adjustment to determine the scalar for all estimated errors in the next adjustment. This value is shown in the *Next Scalar* column.

Note – *For more information and detailed descriptions of the Weighting Strategies dialog, Scalar type group or Apply Scalars To group, refer to the Help.*
For information on the terms used, see Appendix A, A Guide to Least-Squares Adjustments and the Glossary.

Continuing a Fully Constrained Adjustment

Now that you have determined and set a troubleshooting plan, proceed in the same manner as the minimally constrained adjustment. You will re-adjust the network after constraining each point, evaluate the results, and continue with the same troubleshooting action or change to another as you progress.

You begin to loop through a series of statistical results and decisions until you are confident that you have removed all large errors, properly distributed the error in your geoid observations, and correctly defined the transformation parameters.

Locking the Scalar for Geoid Observations

If you have changed the geoid observation weighting strategy to alternative scalar, you must now lock the weighting strategies scalar for geoid observations.

You can stop calculating a new scalar in your geoid observations when your adjustment meets the following criteria:

- All vertical control points are constrained.
- The geoid observation reference factor and network reference factor are around 1.00.
- The geoid model reference factor is around 1.0 and the following message appears:

  The GPS height errors exceed the geoid errors

  In this case, further scaling of the geoid error is not recommended.

To lock the scalar:

1. From the Survey view, select *Adjustment* / *Weighting Strategies*. The *Weighting Strategies* dialog appears.
2. Select the *Geoid* tab. The geoid observations are listed in the *Geoid* tab along with the scalar for the next adjustment.

3. Click **Lock** to lock the scalar for the next adjustment.

   The *Scalar Type* is automatically changed to *User-defined* and the scalar from the current adjustment is placed in the *Scalar Value* field.

4. Click **OK** to save the changes and continue.

5. Perform one adjustment with the scalar locked to preserve the weighting strategy and update the report.

Generating a Final Network Adjustment Report

At the completion of the network adjustment, you can generate a final report. For information on viewing and analyzing the report, see Chapter 3, Viewing the Network Adjustment Report. For information on formatting and exporting the information in your report, refer to the Help.

Combining GPS, Terrestrial, and Geoid Observations in an Adjustment

The previous sections describe the basic principles of performing a network adjustment. The network adjustment involves performing a minimally constrained adjustment and then a fully constrained adjustment.

In the Trimble Geomatics Office software, there are three classes of observations available for simultaneous adjustment:

- GPS
- Terrestrial
- Geoid

This section describes how a control network containing combinations of data can be adjusted. When combining observations, you must check each set of observations before performing a fully constrained adjustment. This helps you detect errors more easily.

Tip – To select different data types when performing a combined adjustment, use a selection set.

Tip – To perform a combined adjustment, you must tie terrestrial observations into the GPS network. To do this, measure angles and distances at points that are common with the GPS network. You need to set up on at least two common points (points observed in both the GPS and terrestrial data sets, or control points) that can tie the two data sets together. This prevents a terrestrial traverse from “hanging off” a GPS observation by one point.

For more information on performing a network adjustment with a combination of observation types, refer to the Help.

Import your data

If you have control quality points associated with your project, import these points into your Trimble Geomatics Office project first. This ensures that the control coordinates are used as starting points in a recomputation. For more information, see The Importance of Coordinate Homogenization, page 14.

Import and check any other data sets in your project. Make sure that any error flags are investigated. For more information on importing data, refer to the Help.

Note – *When you import data, and you do not have the Always merge duplicate points option selected in the Duplicate Point Options dialog, you need to merge duplicate points.*

Prepare the GPS data

To perform a minimally constrained adjustment of your GPS observations, do the following:

1. Select your GPS data in the graphics window.
2. Process your GPS data. For more information on processing GPS data, refer to the *WAVE Baseline Processing User Guide*.
3. Perform a GPS loop closure and view the GPS Loop Closures report to ensure that the GPS data set is suitable for adjustment.
4. Remove any out-of-tolerance flags. These can appear because of incorrect control coordinates, bad antenna heights, or wrong point naming.
5. Select independent GPS baselines. For more information about selecting independent baselines, refer to the Help or the *WAVE Baseline Processing User Guide*.
6. Select the WGS-84 datum. To do this, select *Adjustment* / *Datum* / *WGS-84*.
7. If necessary, in the *Network Adjustment Style* dialog, change the adjustment style settings.
8. In the *Observations* dialog – *GPS* tab, select the GPS observations to be included in the adjustment.

Tip – Use the **Filter** button in the *Observations* dialog to filter GPS observation types.

9. If necessary, define observation groups (variance and/or transformation groups) for the data.
10. Fix a control point in the *Points* dialog. (This is optional).
11. Set the weighting strategy. For the initial adjustment, set the *Apply Scalar to* group to *All Observations* and the *Scalar Type* group to the default option.

12. Perform a minimally constrained adjustment. For more information on performing a minimally constrained adjustment, see The Minimally Constrained Adjustment, page 34.
13. View the statistical summary and the adjustment details in the Network Adjustment report.
14. If necessary, perform step 12 and step 13 again, and any troubleshooting, until the Chi-square test passes and you are satisfied with the adjustment results. If you have selected the Alternative Scalar option, lock the scalar value in the *Weighting Strategies* dialog.

Note – *If you have selected the automatic scalar type option in the Weighting Strategies dialog, the adjustment iterations are performed until the Chi-square test passes.*

Note – *If you want to perform a calibration, save calibration coordinates at this stage of the adjustment. View the saved WGS-84 calibration coordinates in the Properties window.*

Your GPS data is now ready for a fully constrained adjustment.

Prepare the terrestrial data

To perform a minimally constrained adjustment on your terrestrial data, do the following:

1. Select the terrestrial observations in the graphics window.

Tip – You can use the view filters to view only terrestrial observations.

2. Select the project datum. To do this, select *Adjustment* / *Datum* / *Project Datum – <Datum Name>*
3. In the *Observations* dialog – *Terrestrial* tab, select the observations to be included in the adjustment.

Note – *If your terrestrial data does not consist of a closed traverse (that is, the terrestrial observations are hanging from the GPS observation network), you also need to load geoid observations to ensure that the GPS and terrestrial observations can be linked together using the geoid. If you incorporate geoid data into your terrestrial adjustment at this stage, you do not need to follow the "Incorporate geoid observations into your adjustment" step, which is outlined in the next section.*

4. If necessary, define observation groups (variance and/or transformation groups) for the data.
5. Set the weighting strategy. For the initial adjustment, set the *Apply Scalar To* group to All Observations and the *Scalar Type* group to default.

   Note – *If you set the Apply Scalar To group to Variance groups, your observations will be automatically separated into the appropriate groups.*
6. Fix point(s) in the *Points* dialog.

   Note – *To perform a combined adjustment, the point that you fix should be one of the points that is common between the GPS and the terrestrial network.*
7. Perform a minimally constrained adjustment. For more information, see The Minimally Constrained Adjustment, page 34.
8. View the adjustment details in the Network Adjustment report.
9. If necessary, perform another adjustment until you are satisfied with the adjustment results. If you have selected the alternative scalar type, lock the scalar value in the *Weighting Strategies* dialog.

Note – *If you have selected the Automatic scalar type option in the Weighting Strategies dialog, the adjustment iterations are performed until the Chi-square test passes.*

Incorporate geoid observations into your adjustment

Geoid errors are scaled in a constrained adjustment of the observations. To perform a vertically constrained adjustment of your geoid data, do the following:

1. Make sure that a geoid model has been selected for the project. Check the coordinate system details in the *Project Properties* dialog.
2. In the *Observations* dialog, select the *Geoid* tab and load the Geoid observations.
3. Set the weighting strategy in the *Weighting Strategies* dialog – *Geoid* tab. For the initial adjustment, set the *Scalar Type* group to the default.
4. Fix elevations (and/or heights) in the *Points* dialog. Use at least three constraints.
5. Select *Adjustment* / *Adjust*.
6. View the adjustment details in the Network Adjustment report.

If necessary, select the *Alternative* scalar type option, perform another adjustment, and review the results in the Network Adjustment report. Do this until the Chi-square test passes and you are satisfied with the results. If you have selected the *Alternative Scalar Type* option, lock the scalar value in the *Weighting Strategies* dialog.

Perform the fully constrained adjustment

Once you have locked in the error scaling in the minimally constrained adjustment, you can perform a fully constrained adjustment:

1. Make sure the project datum is still selected.
2. Fix control points in the *Points* dialog.

   Note – *To perform a combined adjustment, fix at least two GPS points horizontally. If possible, these points should be the common points between the GPS and the terrestrial network.*

3. Select *Adjustment* / *Adjust*.
4. View the results of the adjustment in the Network Adjustment report.
5. If necessary, perform further adjustments until you are satisfied with the adjustment results.

After the adjustment, a set of coordinates is saved for each point in the adjustment. View these coordinates in the *Properties* window.

Tip – If the adjustment does not converge because the Chi-square test fails or the reference factor is not acceptable, then there may be problems with your control coordinates. “Unfix” points (one at a time) in the *Points* dialog and perform the fully constrained adjustment again until you find the bad point. For more information on troubleshooting, see Troubleshooting the Fully Constrained Adjustment, page 75.

Adjusting Level Observations

The following steps describe how to adjust terrestrial observations in the Trimble Geomatics Office software. This is not a full description of each step, but a summary of the workflow required.

Import level observations

To import level observations:

1. Select *File* / *Import*. The *Import* dialog appears.
2. In the *Survey* tab, select *Digital Level Files (*.dat, *.raw)*. The *Open* dialog appears.
3. Select the Digital Level file to import. The *Digital Level Import* dialog appears. Use this dialog to check the level observations.
4. Click **OK**. The Digital Level file is imported.

Note – *To view the level information in the Level report, select Reports / Level Reports.*

Viewing level observations

When data from a digital level is imported, there are no horizontal coordinates associated with the elevations, so you cannot view them in the Survey view. However, you can view leveling observations in the *Properties* window. To do this:

1. Select *Select* / *All*.
2. Do one of the following:
   – Select *Edit* / *Properties*.
   – Click [Alt]+[Enter].
   – Select the *Properties* window tool from the toolbar.
3. The leveling observations are displayed in the *Properties* window.

Performing a minimally constrained adjustment

To adjust level observations:

1. Select the project datum.
2. Select the network adjustment style, paying particular attention to the error estimate table in the *Terrestrial* tab.
3. Select the observations to include in the adjustment from the *Observations* dialog – *Terrestrial* tab.
4. If necessary, define observation groups (variance and/or transformation groups) for the data.
5. Set the terrestrial weighting strategy:
   a. In the *Weighting Strategies* dialog, select the *Terrestrial* tab.
   b. In the *Apply Scalars to* and *Scalar Type* groups, select the appropriate options.
6. Perform a minimally constrained adjustment.

Note – *If the levels are run as a simple line between two points, you need to fix elevations for both end points. This provides redundancy so that you can then run an adjustment.*

7. View the results of the adjustment in the Network Adjustment report. If necessary, perform another adjustment until you are satisfied with the adjustment results.
8. If you have used the *Alternative Scalar* option, lock the scalar value in the *Weighting Strategies* dialog.

Perform the fully constrained adjustment

You can now perform the fully constrained adjustment.

1. Make sure the project datum is still selected.
2. Fix control points in the *Points* dialog.
3. Perform a fully constrained adjustment.
4. View the results of the adjustment in the Network Adjustment report.
5. If necessary, perform another adjustment until you are satisfied with the adjustment results.

When the adjustment is completed, a set of coordinates is saved for each point in the adjustment. You can view these coordinates in the *Properties* window.

Additional Adjustment Considerations

There may be times when your adjustment will involve additional considerations and procedures. The following sections discuss two of these additional considerations:

- constraining elevations and ellipsoid heights simultaneously
- adjustments with varying surveying and processing methods

Constraining Elevations and Ellipsoid Heights Simultaneously

There may be conditions in your survey which require constraining elevations and ellipsoid heights simultaneously to determine *Latitude Deflections*, *Longitude Deflections*, and a *Height Constant* for the geoid model. This is necessary when one of the following conditions exists:

- The project geoid model covers a large area and may have small regional variations that may not be accurately modeled.
- The project geoid model is referenced to an ellipsoid which differs from the ellipsoid used by the project datum. An example of this would be using the EGM96 (a worldwide geoid model, referenced to WGS-84) with a local coordinate system (referenced to a local ellipsoid, for example, Bessel). The differences between the two reference ellipsoids must be accounted for using the geoid transformation parameters.

Use the process of simultaneously constraining an elevation and ellipsoid height to detect these variations or systematic errors, then account for them using the deflections and *Height Constant*.

This procedure requires the use of accurate elevations and accurate ellipsoid heights of a control point. A minimum of three constrained elevations and three constrained ellipsoid heights (not necessarily the same points and the constrained elevations) are required to correctly generate the parameters. A fourth constraint in each elevation and ellipsoid height will check the parameters generated. Any number of elevations or ellipsoid heights can be constrained simultaneously.

To set the *Latitude Deflections*, *Longitude Deflections*, and a *Height Constant* to be computed:

1. Select *Adjustment* / *Observation Groups* / *Transformation Groups*. The *Transformation Groups* dialog appears.
2. Select the *Geoid* tab.
3. In the *Groups* field, select <Geoid Default> and then click **Edit**.

4. In the *Edit Transformation Group* dialog, set the status of the *Longitude Deflection*, *Latitude Deflection* and *Height Constant* to Computed. (Each field becomes a drop-down list when you click in it.)

Note – *By default, all parameters in the geoid transformation groups are set to Unused. If you do not set these to Compute, you may receive the following message:* singular matrix error

Removing a Network Adjustment

You can remove a network adjustment and return your network to the configuration you had originally. The following settings change:

- The datum is set to WGS-84.
- No points have a fixed status.
- Error ellipses are removed.
- Geoid observations are unloaded.
- In the *Weighting Strategies* dialog, scalars are reset to *All Observations* and *Default.*

To remove adjusted values:

- Select *Adjustment* / *Remove Adjustment*.

Note – *Observations that were disabled for adjustment, or those for which the Use in network adjustment check box were cleared, are not reset to the previous state.*

CHAPTER

3

Viewing the Network Adjustment Report

In this chapter:

- Introduction
- Customizing the Network Adjustment report
- How to use the Network Adjustment report
- Adjustment header
- Adjustment style settings
- Statistical summary
- Adjusted coordinates
- Control coordinate comparisons
- Adjusted observations
- Histograms of standardized residuals
- Point error ellipses
- Covariant terms
- Subnetwork reporting

Introduction

This chapter provides an overview of the Network Adjustment report. Use the report to review and analyze the results of the network adjustment.

The Network Adjustment report contains:

- a display of the adjustment style settings
- a comprehensive statistical summary
- the adjusted coordinates with estimated error (grid and geodetic)
- control coordinate comparisons
- the adjusted observations with estimated errors
- histograms of standardized residuals
- the point error ellipses
- covariant terms

The Network Adjustment report is in HTML format. You can do the following:

- View the report with your computer’s HTML viewer.
- Navigate from one section of the report to another using links embedded in the report.
- Open the report in Microsoft Word (or another word processor that can import HTML) if you want to make edits to the format of the individual report.
- If you select outliers in the report, then they are also selected in the Survey view.

Customizing the Network Adjustment Report

You can customize the information displayed in the Network Adjustment report using the *Network Adjustment Report Setup* dialog.

To access this dialog:

- Select *Reports* / *Setup* / *Network Adjustment Report.*

You can display the following items in the report:

- Individual GPS observation statistics
- Adjusted grid coordinates
- Adjusted geodetic coordinates
- Coordinate deltas
- Control coordinate comparisons
- Point error ellipses
- Covariant terms

How to Use the Network Adjustment Report

Use the Trimble Geomatics Office software *Reports* menu to view the Network Adjustment report when you have completed a network adjustment.

To view and navigate through the Network Adjustment report:

1. From the Survey view, select the *Reports* / *Network Adjustment Report*.

   The HTML viewer software starts, and the Network Adjustment report appears.

2. To navigate to other sections of the report, use the hyperlinks in the report *Contents*.
3. To navigate back to the top of the report, use the Back to Top hyperlink or your HTML viewer commands.

Note – *The adjustment styles affect the display of the information in the report. For more information, see Selecting and Editing the Adjustment Styles, page 17.*

For more information about analysis and troubleshooting, see Chapter 2, Performing a Network Adjustment.

The rest of this chapter describes the sections of the report and offers information to consider when viewing the statistics.

Note – *Whenever you view a report (immediately following an adjustment), the Trimble Geomatics Office software creates a new report. It stores the new report in the ...\Netadj folder, and moves the current report to the ...\Netadj-old folder. If you leave the Network Adjustment report open between each adjustment, your HTML viewer updates the display with the new report.*

Tip – You can select outlier observations in the Survey view from the Network Adjustment report. To do this, select the outlier Observation ID from the Network Adjustment report (to select multiple observations, use Ctrl). The current selection in the Survey view is replaced by the new selection.

Project Details

The Project Details section at the top of the report contains relevant project information.

The fields are shown below. These reflect the project properties as defined in the *Project Properties* dialog:

- Project – name of project.
- User Name
- Date & Time – when the report was created.
- Coordinate System
- Zone – If a calibration site is selected, the zone is displayed as the site name.
- Project Datum
- Vertical Datum
- Geoid Model – This reads Not Selected if no geoid model is selected.
- Coordinate Units
- Distance Units
- Height Units

The report includes hyperlinks for navigating to all sections, and a Project Details hyperlink for returning to the Adjustment Header.

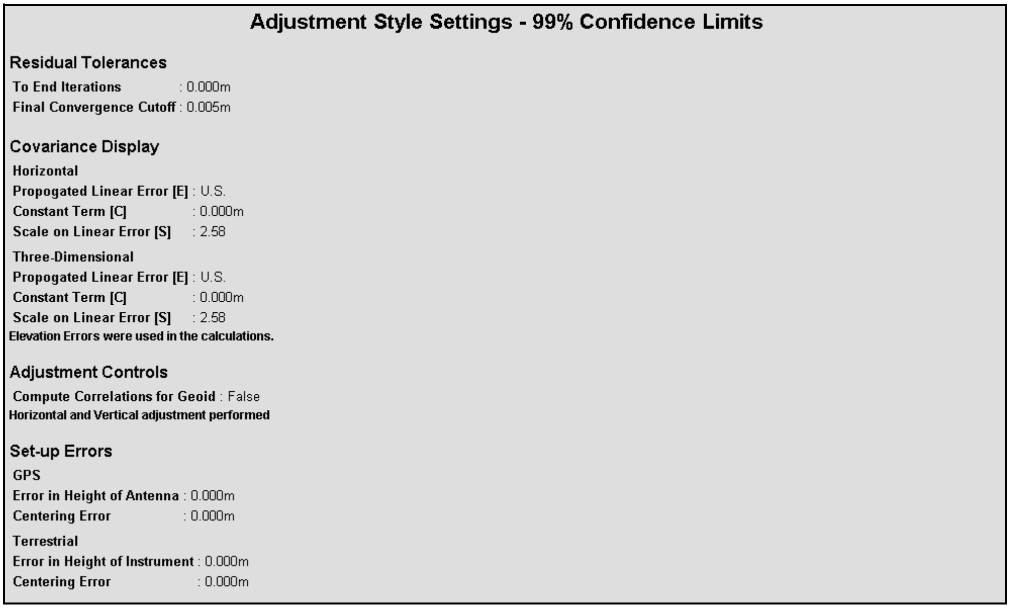
Adjustment Style Settings

The Adjustment Style Settings section summarizes the adjustment settings made before the adjustment.

To view it:

- In the report Contents, click Adjustment Style Settings.

Figure 3.1 shows an example of the Adjustment Style Settings section.



Adjustment Style Settings - 99% Confidence Limits

Residual Tolerances

To End Iterations : 0.000m
Final Convergence Cutoff : 0.005m

Covariance Display

Horizontal
Propogated Linear Error [E] : U.S.
Constant Term [C] : 0.000m
Scale on Linear Error [S] : 2.58

Three-Dimensional
Propogated Linear Error [E] : U.S.
Constant Term [C] : 0.000m
Scale on Linear Error [S] : 2.58
Elevation Errors were used in the calculations.

Adjustment Controls

Compute Correlations for Geoid : False
Horizontal and Vertical adjustment performed

Set-up Errors

GPS
Error in Height of Antenna : 0.000m
Centering Error : 0.000m

Terrestrial
Error in Height of Instrument : 0.000m
Centering Error : 0.000m

Figure 3.1 Adjustment Style Settings section

Table 3.1 describes the Adjustment Style Settings fields.

Table 3.1 Adjustment Style Settings fields

Field	Meaning
Residual Tolerances	
To End Iterations	This value is the residual tolerance used to determine if adjustment iterations should continue or stop. After each adjustment iteration, an observation residual is computed using two different methods. The difference between the two computations is compared to the To End Iterations tolerance. If the difference is less than or equal to the tolerance, then the adjustment is completed.
Final Convergence Cutoff	The final convergence cutoff tolerance is used for the final iteration of the network adjustment. The software uses this value to determine if the network adjustment is successful when the final iteration does not pass the To End Iterations tolerance.
Covariance Display	
Propagated Linear Error [E]	This value defines the horizontal (two-dimensional) or three-dimensional propagated linear error. For more information on propagated linear error, refer to the Help.
Constant Linear Term [C]	The Constant Linear Term is a way of apportioning some error to a ***constant*** component, leaving the remaining to be apportioned to a proportional term. For example, if a distance-measuring instrument is consistently measuring 15 mm short +/– a PPM term, then C would be 15 mm, which leaves the rest to be correctly related to the length of the baseline. This term must range from 0.0 m (0.0 US ft) to 0.1 m (0.3 US ft).
Scalar on Linear Error [S]	Use this list to define the horizontal (two-dimensional) or three-dimensional scalar for scaling precision to the desired level of confidence. For scaling relative covariance matrices, the propagated linear error is squared. For more information on Scalar on Linear Error, refer to the Help.

Table 3.1 Adjustment Style Settings fields (Continued)

Field	Meaning
Adjustment Controls	
Compute Correlations for Geoid	When using geoid observations in an adjustment, you must hold vertical coordinates fixed so that an overdetermined solution can exist, and a geoid residual can be calculated for that point. When this *Compute Correlations for Geoid* check box is selected, geoid residuals are also calculated for points with unconstrained vertical coordinates, using geoid model correlations between the points.
Setup Errors	
Error in Height of Antenna	Antenna height error[1]
GPS Centering Error	Plumbing (centering) error[1]
Error in Height of Instrument	Instrument height error[1]
Terrestrial Centering Error	Plumbing (centering) error[1]

[1]Used in the adjustment

Statistical Summary

The Statistical Summary section is an important tool for analyzing the adjustment. Typically, you will go directly to the *Statistical Summary* to analyze your results when performing a minimally constrained adjustment. The Chi-square test is a key indicator of how well your observations fit together. The network reference factor is a key indicator of how well the observation errors are estimated.

To view the *Statistical Summary* section:

- From the *Contents* section of the report, click Statistical Summary.

The *Statistical Summary* appears, as shown in Figure 3.2.

Statistical Summary

Successful Adjustment in 3 iteration(s)

Network Reference Factor : 0.95
Chi Square Test (α=95%) : PASS
Degrees of Freedom : 27.00

GPS Observation Statistics

Reference Factor : 0.94
Redundancy Number (r) : 16.46

Individual GPS Observation Statistics

Observation ID	Reference Factor	Redundancy Number
B1	1.56	1.93
B2	0.20	1.94
B3	1.02	1.35
B4	0.69	2.34
B5	1.02	2.25
B6	1.51	1.02
B7	0.72	1.16
B8	0.26	2.39
B9	0.93	2.08

Figure 3.2 Sample Statistical Summary (truncated)

The *Individual GPS Observation Statistics* section includes statistics for every GPS observation used in the adjustment.

Figure 3.3 continues the example of the Statistical Summary.

Terrestrial Observation Statistics

Reference Factor : 0.99

Redundancy Number (r) : 9.00

Horizontal Angles: Reference Factor: 0.03 **(r):** 1.08

Ellipsoid Distances: Reference Factor: 0.25 **(r):** 4.92

ΔElevations: Reference Factor: 0.19 **(r):** 3.00

Geoid Model Statistics

Reference Factor : 0.84

Redundancy Number (r) : 1.54

Weighting Strategies

GPS Observations

User-defined Scalar Applied to All Observations

Scalar : 34.65

Terrestrial Observations

Alternative Scalar Applied to All Observations

Scalar : 0.19

Geoid Observations

Alternative Scalar Applied to All Observations

Scalar : 7.11

Back to top

Figure 3.3 Sample Statistical Summary (continued / truncated)

The content of the *GPS*, *Terrestrial*, and *Geoid Observations* sections of the *Weighting Strategies* section varies depending on the types of observations included in the adjustment. The *Geoid Observations* heading and fields are available in the report once they are loaded. If the Weighting Strategies' scalar type is set to *Variance Groups*, the *GPS Observations* fields reflect the results for the *Variance Groups* included in the project.

Table 3.2 clarifies these differences and describes the *Statistical Summary* fields.

Table 3.2 Statistical Summary Fields

Field	Meaning
Number of Iterations	The number of adjustment iterations required for successful adjustment convergence.
Network Reference Factor	How well the residuals from all observations in the network adjustment compared to the pre-adjustment estimated errors of the observations. A value of 1.00 indicates your estimated errors are matching your residuals. A value greater than 1.00 indicates your estimated errors are underestimated.
Chi-Square Test	The quickest check of how well the adjusted network fits together. When performing a successful least-squares adjustment, mathematical closure of the network is one important factor. Consider the *Chi-Square Test* as the best indicator of mathematical closure. The test results are an evaluation of the *Network Reference Factor* (NRF), Global Degrees of Freedom (GDOF), and the level of significance. If the NRF is close to 1.0, the GDOF is acceptable and the network observations are fitting together well (mathematically), the *Chi-Square Test* passes. Failure is the result of improper a priori weighting or a blunder, or both. The Chi-square test can pass if the large setup errors are included in the adjustment.
Degrees of Freedom	The amount of redundancy in the network. It indicates the number of independent observations included in the adjustment that were used to over-determine your solutions. Larger numbers of independent observations will allow for better analysis and more confidence in your results. Smaller numbers of independent observations are less desirable.

Table 3.2 Statistical Summary Fields (Continued)

Field	Meaning
GPS / Terrestrial Observation or Geoid Model Statistics	
Reference Factor	How well the residuals from a type of observation (GPS, terrestrial, or geoid) in the network adjustment compare to the pre-adjustment estimated errors of those same observations. A value of 1.00 indicates your estimated errors are matching your residuals. A value greater than 1.00 indicates your estimated errors are underestimated.
Redundancy Number	The degrees of freedom of a type of observation (GPS, terrestrial, or geoid) and how much the observation contributes to the overall network redundancy. By scanning through the Individual Observation Statistics, you can identify those observations that lack redundancy.
Variance Group Statistics	
Reference Factor	How well the residuals from the observations in a variance group of the network adjustment compare to the pre-adjustment estimated errors of those same observations. A value of 1.00 indicates your estimated errors are matching your residuals. A value greater than 1.00 indicates your estimated errors are underestimated.
Redundancy Number	The amount of redundancy of a variance group and how much the group contributes to the overall network redundancy.
Individual GPS Observation Statistics	
Observation ID	Project record number assigned to the observation.
Reference Factor	Use the Reference Factor (RF) to determine how much the observation contributes to the Network RF. This indicates how well the residuals from a single GPS observation in the network adjustment compare to the pre-adjustment estimated errors for that same observation.

Table 3.2 Statistical Summary Fields (Continued)

Field	Meaning
Redundancy Number	Use the Individual Redundancy Number to evaluate how much redundancy each GPS observation contributes to the Global Degrees of Freedom. Consider the following: All numbers should be greater than 0.00 and less than or equal to 3.00. Each observation contributes three components (azimuth, distance and delta height) to the network, thus limiting the degrees of freedom to 3. As the redundancy number approaches 3.00, the observation progressively contributes more redundancy. A redundancy number of 0.00 suggests the observation is not connected with any other observation. In surveying terms, this condition is called a sideshot. If the sideshot was not intentional, check why the observation does not contribute to the overall redundancy.
Weighting Strategies	
Observation Type	The title for a type of observation (GPS, terrestrial, or geoid). The report updates to reflect the types of observations and variance groups currently loaded in the adjustment.
Scalar type and method of applying the scalar	Updates to reflect the current *Weighting Strategies* dialog settings for a type of observation. Possible values for the Apply scalars to method are all observations, each observation, or variance groups. Possible values for scalar type are default, alternative, or user-defined.
Scalar	The scalar value used in the current adjustment. If the default scalar type is used, the value will always be 1.00. If the alternative scalar type is used, the value is the previous adjustment reference factor multiplied by the previous adjustment scalar. If the user-defined scalar type is used, the value reflects the scalar entered in the *Scalar Value* field of the *Weighting Strategies* dialog. If Variance Groups is selected as the Apply scalar to method, the *Scalar* field is updated to reflect the weighting strategies for a variance group.

Adjusted Coordinates

The Adjusted Coordinates section offers a quick check for the following statistics:

- adjustment datum used
- number of points
- number of points constrained and which components of the constrained points are held fixed
- univariate sigma scalar used
- coordinate values of constrained points
- a posteriori (estimated) errors of each point in the adjustment
- coordinate deltas

Use the hyperlinks to navigate to different areas of the report to view a summary or table for points from the last iteration of the adjustment. The Adjusted Coordinates section is divided into four sections:

- Point Summary
- Grid Coordinates
- Geodetic Coordinates
- Coordinate Deltas

The header section contains relevant point information, as shown in Figure 3.4.

Adjusted Coordinates

Adjustment performed in NAD 1983 (Conus)

Number of Points	: 5
Number of Constrained Points	: 3
Elevation Only	: 2
Horizontal and Elevation Only	: 1

Figure 3.4 Adjusted Coordinates section

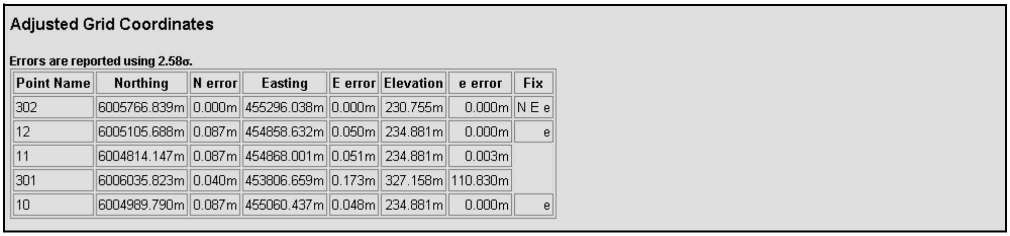
Adjusted Grid Coordinates

This section shows the adjusted grid coordinates of each point in the last adjustment. The coordinates include the a posteriori errors multiplied by the univariate sigma scalar associated with each coordinate component.

To view the Adjusted Grid Coordinates section:

- From report *Contents*, click Adjusted Coordinates – Grid.

  The Adjusted Grid Coordinates section appears, as shown in Figure 3.5.



Adjusted Grid Coordinates

Errors are reported using 2.58σ.

Point Name	Northing	N error	Easting	E error	Elevation	e error	Fix
302	6005766.839m	0.000m	455296.038m	0.000m	230.755m	0.000m	N E e
12	6005105.688m	0.087m	454858.632m	0.050m	234.881m	0.000m	e
11	6004814.147m	0.087m	454868.001m	0.051m	234.881m	0.003m	
301	6006035.823m	0.040m	453806.659m	0.173m	327.158m	110.830m	
10	6004989.790m	0.087m	455060.437m	0.048m	234.881m	0.000m	e

Figure 3.5 Sample Adjusted Grid Coordinates section

***Note –** The Adjusted Grid Coordinates are always shown in the coordinate system selected in the Project Properties dialog, even when performing an adjustment using WGS-84 as the adjustment.*

Table 3.3 describes the data fields in the Adjusted Grid Coordinates section.

Table 3.3 Adjusted Grid Coordinates

Field	Meaning
Point Name	Name of the point.
Northing	Northing coordinate of the point on the projection selected for the project.
N error	Amount of Northing error, in project units.
Easting	Easting coordinate of the point on the mapping projection selected for the project.
E error	Amount of Easting error, in project units.

Table 3.3 Adjusted Grid Coordinates (Continued)

Field	Meaning
Elevation	Elevation of the point above or below mean sea level or the defined vertical reference. N/A appears in this field when the elevation is not applicable (geoid observations not loaded).
e error	Amount of elevation error, in project units. N/A appears in this field when the elevation is not applicable.
Fix	Constrained points in the adjustment and the constrained coordinate component. Constraining coordinate components include: horizontal only (2D) vertical only – Height (h) or Elevation (e) horizontal and vertical. All constrained coordinate components will have a posteriori errors of 0.000. If no value is available for the elevation, then the elevation errors are displayed as N/A. Possible values include: *N E* for the Horizontal 2D *e* for Elevation *h* for Height (Ellipsoid)

Adjusted Geodetic Coordinates

This table shows the adjusted geodetic coordinates of each point in the last adjustment. The coordinates include the a posteriori errors multiplied by the univariate sigma scalar associated with each coordinate component. The errors are shown in linear units based on the project units.

To view the Adjusted Geodetic Coordinates section:

- From the report *Contents*, click Adjusted Coordinates – Geodetic.

The Adjusted Geodetic Coordinates section appears, as shown in Figure 3.6.

Adjusted Geodetic Coordinates

Errors are reported using 2.58σ.

Point Name	Latitude	N error	Longitude	E error	Height	h error	Fix
302	36°05'29.65812"S	0.000m	146°30'12.31797"E	0.000m	238.877m	16.855m	Lat Long e
12	36°05'51.04326"S	0.087m	146°29'54.69069"E	0.050m	249.718m	12.805m	e
11	36°06'00.50694"S	0.087m	146°29'55.00524"E	0.051m	240.530m	12.194m	
301	36°05'20.67718"S	0.040m	146°29'12.81757"E	0.173m	337.589m	109.441m	
10	36°05'54.83850"S	0.087m	146°30'02.73725"E	0.048m	248.073m	12.448m	e

Figure 3.6 Sample Adjusted Geodetic Coordinates section

Table 3.4 describes the data fields in the Adjusted Geodetic Coordinates section.

Table 3.4 Adjusted Geodetic Coordinates

Column	Meaning
Point Name	Name of the point.
Latitude	Angular value of the North/South coordinate component.
N error	North/South coordinate component error in the project units.
Longitude	Angular value of the East/West coordinate component point.
E error	East/West coordinate component error in the project units.
Height	Height above or below the ellipsoid in the project units.
h error	Height error, in the project units.
Fix	Constrained points in the adjustment and the constrained coordinate component. Constraining coordinate components include: horizontal only (2D) vertical only – Height (h) or Elevation (e) horizontal and vertical All constrained coordinate components will have a posteriori errors of 0.000. Possible values include: *Lat Long* for the Horizontal 2D *e* for Elevation *h* for Height (Ellipsoid)

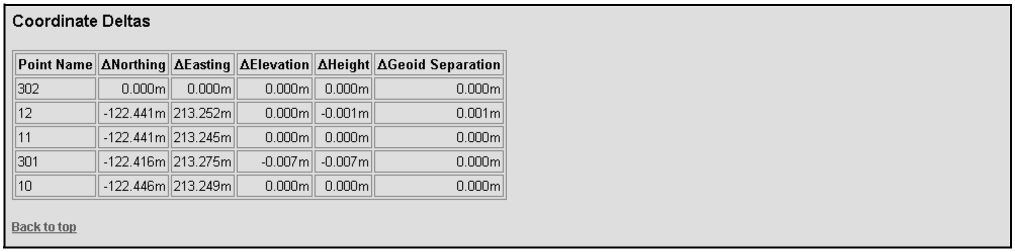
Coordinate Deltas

The Coordinate Deltas section provides a quick check of the difference in a point’s coordinates from the last adjustment to the current adjustment. The deltas are shown in linear units based on the project units set in the project properties.

The Coordinate Deltas section is most useful during a fully constrained adjustment, when you are evaluating changes in unfixed coordinates after new constraints have been added to the adjustment. To view the Coordinate Deltas section:

- From the report *Contents*, click Adjusted Coordinates – Deltas.

  The Coordinate Deltas section appears, as shown in Figure 3.7.



Coordinate Deltas

Point Name	ΔNorthing	ΔEasting	ΔElevation	ΔHeight	ΔGeoid Separation
302	0.000m	0.000m	0.000m	0.000m	0.000m
12	-122.441m	213.252m	0.000m	-0.001m	0.001m
11	-122.441m	213.245m	0.000m	0.000m	0.000m
301	-122.416m	213.275m	-0.007m	-0.007m	0.000m
10	-122.446m	213.249m	0.000m	0.000m	0.000m

Back to top

Figure 3.7 Sample Coordinate Deltas section

Table 3.5 describes the data fields in the *Coordinate Deltas* section.

Table 3.5 Coordinate Deltas

Column	Meaning
Point Name	Name of the point.
Δ *Northing*	Amount of change in the *Northing* component of the point.
Δ *Easting*	Amount of change in the *Easting* component of the point.
Δ *Elevation*	Amount of change in the *Elevation* component of the point.
Δ *Height*	Amount of change in the *Height* component of the point, if applicable.
Δ *Geoid Separation*	Amount of change in the *Geoid Separation* of the point, if applicable.

Control Coordinate Comparisons

The Control Coordinate Comparisons section summarizes the difference between the unconstrained coordinates and the adjusted values of the control points. This section only appears if it is selected in the *Network Adjustment Report Setup* dialog.

Control Coordinate Comparisons

Values shown are control coord minus adjusted coord.

Point Name	ΔNorthing	ΔEasting	ΔElevation	ΔHeight
302	-122.452m	213.268m	0.000m	N/A

Back to top

Figure 3.8 Sample Control Coordinate Comparisons section

Adjusted Observations

The Adjusted Observations section of the report contains a summary of the observation type used in the adjustment, the associated transformation parameters from each *Transformation* Group, and a list of all the observations (GPS, terrestrial, and geoid) and their estimated errors.

Use these statistics to review the following observation information:

- adjustment datum
- transformation parameters with their associated error estimates (fully constrained adjustment)
- the number of observations of that section’s type, and the number of those observations that are outliers
- Critical Tau value used in the adjustment
- observations with their associated a posteriori (estimated) errors, residuals, and standardized residuals
- observation flagged as outliers

To navigate to the Adjusted Observations section of the report:

- From the report *Contents*, click Adjusted Observations.

  The *Adjusted Observations* summary appears, as shown in Figure 3.9.

Adjusted Observations

Adjustment performed in NAD 1983 (Conus)

GPS Observations

GPS Transformation Group: <GPS Default>
Deflection in Longitude : -3°46'04.5995" **(2.58σ)** : 3°52'26.1876"
Deflection in Latitude : -1°31'54.1474" **(2.58σ)** : 2°07'46.6726"
Network Scale : 0.99999172 **(2.58σ)** : 0.00011248

Number of Observations : 9
Number of Outliers : 1

Observation Adjustment (Critical Tau = 3.02). Any outliers are in red.

Obs. ID	From Pt.	To Pt.		Observation	A-posteriori Error (2.58σ)	Residual	Stand. Residual
B6	302	301	Az.	280°31'47.9997"	0°00'02.9526"	0°00'01.8111"	3.32
			ΔHt.	-6.571m	0.078m	0.036m	0.82
			Dist.	1514.040m	0.014m	0.005m	2.10
B1	302	12	Az.	213°46'50.5964"	0°00'06.3297"	-0°00'09.3464"	-2.46
			ΔHt.	-0.532m	0.080m	-0.012m	-0.37
			Dist.	793.036m	0.029m	0.034m	1.70
B3	12	301	Az.	311°46'40.0703"	0°00'03.6837"	-0°00'00.8461"	-0.51
			ΔHt.	-6.035m	0.064m	-0.001m	-0.06
			Dist.	1404.732m	0.023m	-0.016m	-1.71

Figure 3.9 Sample Adjusted Observations section (truncated)

***Note –** The sample shows information for the GPS Observation. Table 3.6 lists the fields for GPS, terrestrial, and geoid observations.*

Use the observation list to:

- Verify the number of observations used in the adjustment.
- Evaluate the a posteriori errors of each component of the observations.
- Identify those observations exceeding the Critical Tau defined for the network (outliers). Suspect observations are highlighted in red to help identify outliers.

- Identify any unexpected transformation and large error estimates in parameters.

Table 3.6 describes the adjusted observation fields.

Table 3.6 Adjusted Observations Fields

Field	Meaning
Adjustment performed in <datum>	Adjustment datum selected prior to beginning the network adjustment
Observation Type	Title of the observation type with the associated statistics below it
Number of Observations	Total number of adjusted observations
Number of Outliers	Number of outliers (observations with large standardized residuals)
Observation Adjustment (Critical Tau)	Critical Tau value computed in the adjustment
GPS Observations	
Observation ID	Project record number assigned to observation. If the observation has an outlier, you can click on the observation ID to select the outlier observation in the Survey view.
*From Poin*t	Point used to propagate coordinates from
To Point	Point used to propagate coordinates to
Observations	Adjusted observation components (modeled onto the adjustment ellipsoid)
A Posteriori Error (sigma)	A posteriori estimate of each observation multiplied by the sigma value listed in the column heading
Residual	Observation residual (adjustment)
Std. Residual	Standardized residual for each observation component

Table 3.6 Adjusted Observations Fields (Continued)

Field	Meaning
Terrestrial Observations	
Observation ID	Project record number assigned to observation
Backsight Point	Name of backsight point
Instrument Point	Name of instrument point
Foresight Point	Name of foresight point
Observations	Adjusted observation components (reduced to the ellipsoid)
A Posteriori Error (sigma)	A posteriori error of each observation multiplied by the sigma value listed in the column heading
Residual	Observation residual (adjustment)
Std. Residual	Standardized residual for each observation component
Geoid Observations	
Observation ID	Project record number assigned to observation
Point Name	Name of point used to generate the geoid separation
Separation	Adjusted values of the geoid separation
A posteriori Error (sigma)	A posteriori estimate of each geoid separation multiplied by the sigma value listed in the column heading
Residual	Observation residual (adjustment)
Standardized Residual	Standardized residual for the geoid separation
Unused Observations	
Observation ID	Project record number assigned to observation
Observation	Unused observation

Table 3.6 Adjusted Observations Fields (Continued)

Field	Meaning
Level Observations	
Observation ID	Project record number assigned to observation
Backsight Point	Name of backsight point
Instrument Point	Name of instrument point
Foresight Point	Name of foresight point
Observations	Adjusted delta elevation
A Posteriori Error (sigma)	A posteriori error of each observation multiplied by the sigma value listed in the column heading
Residual	Observation residual (adjustment)
Std. Residual	Standardized residual for each observation component
Azimuth Observations	
Observation ID	Project record number assigned to observation
Backsight Point	Name of backsight point
Instrument Point	Name of instrument point
Foresight Point	Name of foresight point
Observations	Azimuth observations
A Posteriori Error (sigma)	A posteriori error of each observation multiplied by the sigma value listed in the column heading
Residual	Observation residual (adjustment)
Std. Residual	Standardized residual for each observation component

Histograms of Standardized Residuals

The Histograms provide graphical views of the:

- frequency distribution of the standardized residuals
- observation outliers
- normal distribution curve
- critical tau values.

To view the Histograms section:

- From the report *Contents*, click Histograms of Standardized Residuals.

  The Histograms appear as shown in Figure 3.10.

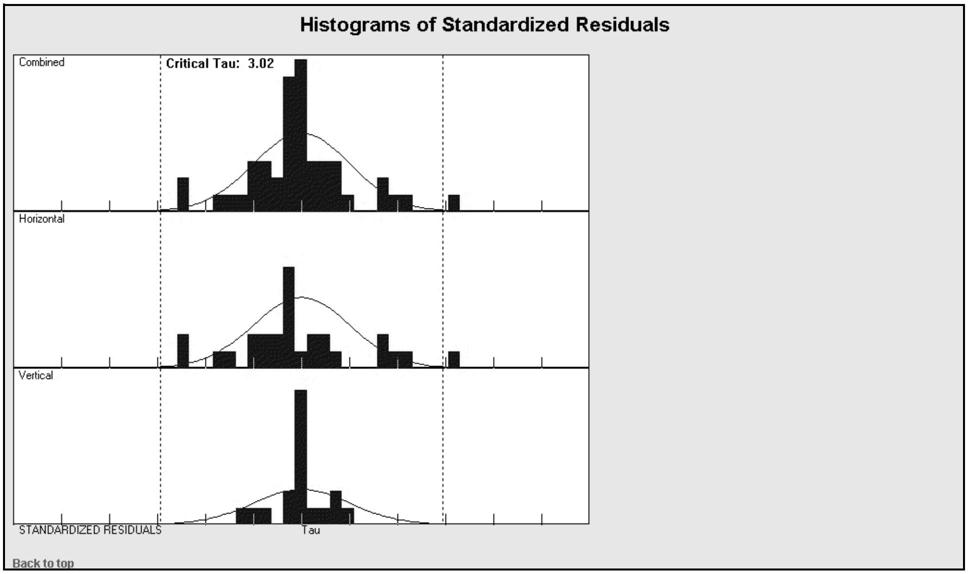


Figure 3.10 Sample Histogram of Standardized Residuals

The Trimble Geomatics Office software generates three histograms:

- Combined – residual plot for both the horizontal and vertical observations
- Horizontal – residual plot for the horizontal component of the observations
- Vertical – residual plot for the vertical component of the observations

The Histograms show the frequency distribution of the observations standardized residuals from the most recent adjustment. The Observations section of the report lists the standardized residuals (Std. Residual) associated with the histograms.

Consider the following when viewing the histograms:

- The central vertical line is the zero residual. Because the residuals are normally distributed, the smallest residuals are clustered around the center and show the highest frequency of the plotted residuals. The larger residuals are placed further from the zero line and the frequency diminishes.
- If the adjustment residuals are randomly distributed, the frequency distribution plot approximates the normal distribution curve. The curve is superimposed over the residuals plot.
- The vertical lines to the left and right of the zero line indicate the Critical Tau value. Residuals outside these lines are considered outliers.
- The bar scale represents the sigma value. The sigma values match the standardized residual values in the Observations section.

Point Error Ellipses

The Point Error Ellipses section provides a graphical view of the magnitude and direction of the point errors—both horizontal and vertical.

To view the Point Error Ellipses:

- From the report Contents, click Point Error Ellipses.

  The error ellipse for each point appears, as shown in Figure 3.11.

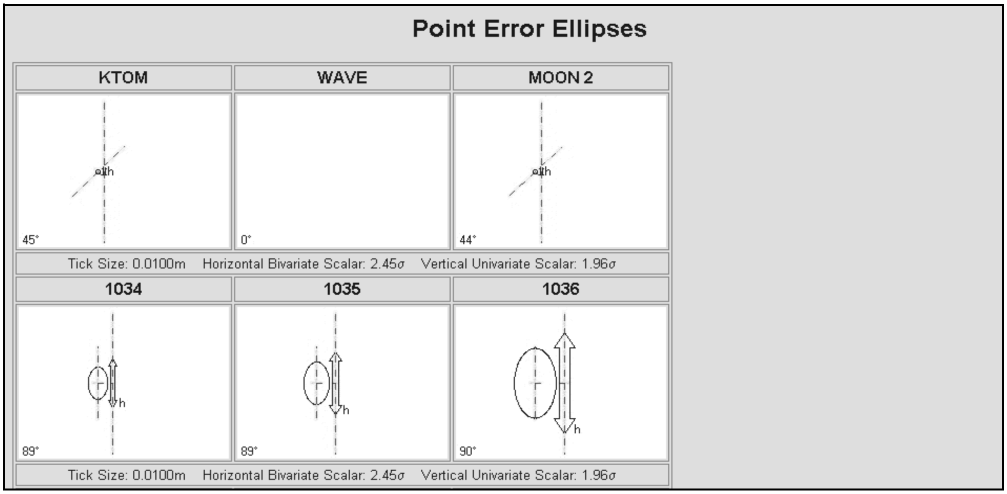


Figure 3.11 Sample Point Error Ellipses

The height error bars are drawn in black, closest to each ellipse. Elevation error bars are drawn in blue, farthest from each ellipse.

The *Point Error Ellipses* graphically show:

- the adjusted point’s horizontal coordinate a posteriori errors

Consider these guidelines when viewing the error ellipses:

- The top of each plot is oriented to north.
- Arrows to the right of the ellipse represent the a posteriori errors for the heights and elevations.

- The bar scales running through the ellipse and arrow indicate the magnitude of the errors.
- The bar scale tick size is displayed in the project units along with the bivariate scalar.
- The orientation of the semi-major axis (axis indicating the direction of the largest error) is shown to the lower-left of the ellipse. This angle is measured counter-clockwise from the positive x axis.
- The standard errors for the horizontal and vertical coordinates are multiplied by the bivariate and univariate sigma scalars, respectively.

Covariant Terms

The Covariant Terms section provides a list of the relative precisions of the lines between point pairs. This list is useful in determining the relative error for any pair of points in the network.

You can display the Covariant Terms in two views:

- All possible lines – Azimuth, Delta Ellipsoid Height, Delta Elevation and Distance with associated errors and precisions between every point pairs in the network
- Observed lines – Azimuth, Delta Ellipsoid Height, Delta Elevation and Distance with associated errors and precisions for all observed lines only

To view the Covariant Terms:

- From the report Contents, click Covariant Terms.

The Covariant Terms section appears, as shown in Figure 3.12.

Covariant Terms

Adjustment performed in WGS-84

From Point	To Point		Components	A-posteriori Error (1.96σ)	Horiz. Precision (Ratio)	3D Precision (Ratio)
WAVE	MOON 2	**Az.**	208°35'46.1525"	0°00'00.4640"	1:28222	1:28222
		ΔHt.	-2.716m	0.005m		
		ΔElev.	-2.685m	0.308m		
		Dist.	962.405m	0.034m		
WAVE	N 245	**Az.**	99°25'53.3390"	0°00'01.0325"	1:28210	1:28210
		ΔHt.	3.832m	0.009m		
		ΔElev.	3.797m	0.200m		
		Dist.	852.578m	0.030m		

Figure 3.12 Sample Covariant Terms section (truncated)

***Note –** For information about how to set the method for displaying Covariant Terms, see Selecting and Editing the Adjustment Styles, page 17.*

Table 3.7 describes the data fields.

Table 3.7 Covariant Terms Fields

Field	Meaning
From Point	Point used to propagate coordinates from.
To Point	Point used to propagate coordinates to.
Components	The azimuth, delta height, and distance between the points.
A-posteriori Error	A posteriori estimated error for the indicated components.
Horz. Precision (Ratio)	The two-dimensional precision of the distance between two points in terms of proportional errors, expressed in units of PPM or Ratio. No value is displayed if *None* is selected in the adjustment style.
3D Precision (Ratio)	The three-dimensional precision in terms of proportional errors. For three-dimensional precision, the indicated distance is the slope distance between points. No value is displayed if *None* is selected in the adjustment style.

Subnetwork Reporting

A survey can consist of subnetworks and this is reflected in the Network Adjustment report. The software generates information associated with each subnetwork and includes the following information in the report:

- Statistical Summary
- Adjusted Coordinates
- Adjusted Observations

Use this information to evaluate each subnetwork's statistics. Compare the subnetwork statistics to the overall network statistics to help identify a source of error.

APPENDIX

A

A Guide to Least-Squares Adjustments

In this chapter:

- Introduction
- The purpose of a least-squares adjustment
- The least-squares criterion
- Error types
- Precision versus accuracy
- Setup errors
- Least-squares statistics
- Variance groups
- Network adjustment procedures

Introduction

This appendix introduces the primary concepts of least-squares adjustments of survey networks. This information will help you to use the Trimble Geomatics Office software to produce professional results from network adjustments. The least-squares terminology used in the *Adjustment* menu and dialogs is defined and explained using as few mathematical terms as possible.

For more information about terminology, see the Glossary in this manual and refer to the Help for a bibliography of references.

The Purpose of a Least-Squares Adjustment

The purpose of a least-squares adjustment is to:

- estimate and remove random errors
- provide a single set of coordinates for the points even when there is redundant data.
- detect blunders and large errors
- generate information for analysis, including estimates of precision.

The Least-Squares Criterion

Perform a least-squares adjustment to determine the following:

- There are no blunders and systematic errors in the observations and control points.
- Remaining errors are small, random, and properly distributed.

A least-squares adjustment ensures good positional closures and estimates of errors (repeatability). Thus, it ensures the reliability of your current and future measurements.

The criterion of a least-squares network is stated in two parts:

- The network must close geometrically and mathematically.
- The sums of the squares of the residuals must be a minimum.

Figure A.1 illustrates good network geometry.

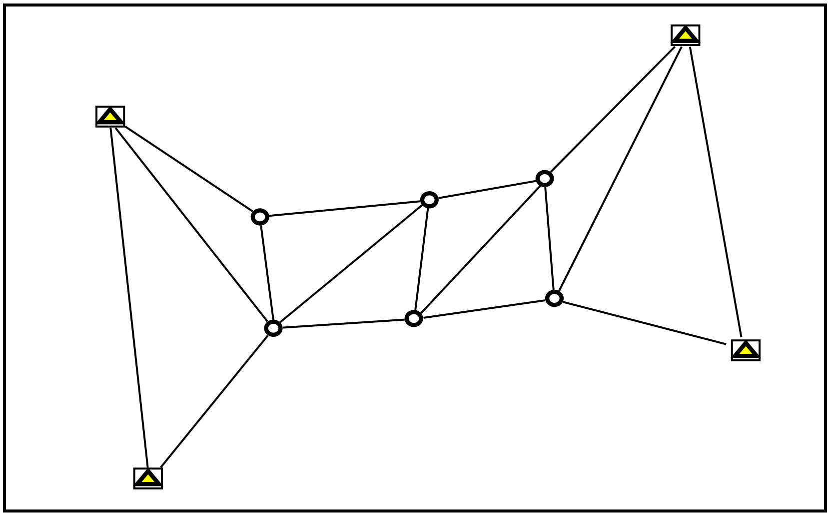


Figure A.1 Network geometry

Good Network Design

Good network design principles are required if your network is to close geometrically. A GPS network design consists of a set of baselines between network points. These baselines have angular and spatial relationships amongst themselves. These relationships provide the network with geometry.

The baselines connecting these points should create closed figures with a minimum number of sides, such as triangles. Triangles will create a rigid network by adding more baselines, thus helping generate redundancy and multiple, evenly distributed baselines to each point.

Note the following about points:

- The points with multiple baselines are networked points using networked observations.
- A point with a single observed baseline (sideshot) to determine its position is considered a *non-networked* point, and adds nothing to the geometry and redundancy of your network.

To maintain good network geometry as the survey progresses, pay attention to the way the network develops. As you exclude (or disable) bad observations from the network, maintain closed geometric figures. In some cases, this might require reobservation of the baseline to replace the observation you removed.

Good Surveying Techniques

The network must be free of large errors that prevent it from closing within mathematical tolerances. Use good surveying techniques:

- Make careful, repeated measurements.
- Maintain your equipment.
- Be aware of the environmental conditions that introduce additional error into your measurements.

Use good surveying techniques to reduce the possibility of large errors, to minimize corrections made to your measurements, and to close the network mathematically. The least-squares adjustment will provide the results necessary to troubleshoot problems.

Error Types

By performing a network adjustment, you can identify gross errors and properly distribute (model) the remaining inherent errors in all measurements. Least squares evaluates the errors associated with a set of measurements. Three common types of errors are:

- mistakes (blunders)
- systematic errors
- random errors.

These errors are described in the following sections.

Mistakes

In many surveying textbooks, mistakes are considered *blunders* and are not typically recognized as errors. However, in the context of this discussion, mistakes are to be considered errors. Unlike other error types—which are associated with equipment—mistakes are caused by inattention or carelessness. Mistakes of this type are usually large and must be corrected or removed before adjusting your network.

Leaving mistakes in the network has an adverse effect on the network adjustment. Some of these mistakes are found before processing your baselines (for example, note-keeping mistakes), or sometimes they are found after the baselines are processed and evaluated with loop closures.

Note – *The recompute function in the Trimble Geomatics Office software is also useful for detecting large errors in the observations. For more information, refer to the Trimble Geomatics Office User Guide.*

If the mistakes are not found before performing an adjustment, the adjustment will assist in detecting and highlighting mistakes.

Examples of common mistakes in GPS surveying include:

- incorrectly measuring the antenna height
- occupying the wrong survey point
- entering the wrong station name
- entering incorrect coordinates.

Systematic Errors

Systematic errors are constant and follow a physical law. They can be mathematically modeled. Note the following:

- Systematic errors for each observation usually have the same size and the same sign (±) under the same conditions, so the errors accumulate as more measurements are made.
- Systematic errors can be introduced with improperly used or maintained survey equipment.

A simple example of this type of error is a cloth measurement tape. After repeated use, the tape will stretch. If you are aware of the magnitude of the tape stretch, then you can account for (or model) the error. For example, if the stretch is 2 cm over 1 m, then by adding 2 cm to every meter measured (or 2% to every measurement), the systematic error is properly modeled.

Like mistakes, these errors must be modeled before completing an adjustment. The Trimble Geomatics Office software allows you to model some of the GPS surveying systematic errors before and during baseline processing. Examples of these errors include:

- antenna phase center variations
- tropospheric noise
- antenna height measurement rods that measure short or long.

Random Errors

All measurement methods have some inherent error. Surveying is no exception. These errors are random, typically small, and mutually compensating. The random errors are revealed as discrepancies through repeated measurements and can never be completely known, only estimated as probable values.

Random errors follow the laws of probability. You can statistically evaluate individual measurements based on a group of measurements:

- The discrepancies between each individual measurement within a group of measurements are typically small, and all measurements are centered on a mean.
- Large errors (blunders) are detected and removed from the data set, along with systematic errors.
- Corrections are distributed throughout the network in the least-squares adjustment using estimates for the random errors.

Examples of random errors in GPS surveying are:

- atmospheric noise in the GPS signal
- interpolation errors in measuring the antenna height
- centering (plumbing) the antenna over the point.

An Example of Errors

The following example graphically represents errors and illustrates how they occur. Figure A.2 illustrates how five people determined the measurement of the arrow to three decimal places (n.nnn) as shown on the right side of the figure.

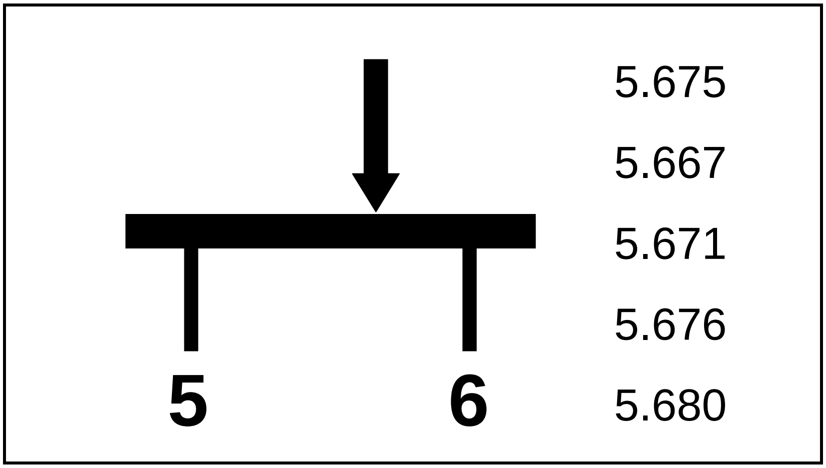


Figure A.2 Errors in measurements

Notice that the measurements (guesses) are fairly consistent, with some small discrepancies. If you take the mean of all the guesses you will see that all are within an *acceptable* error from the mean and that they are random.

But if someone in the group misinterpreted the integer 5 as a 6, then the error would be large and obvious. It would be outside the acceptable error. This can be considered a mistake, removed from the group, and a new mean calculated.

However, if all five people interpreted the integer to be 6 instead of 5, this would represent a systematic error. The correct value could be obtained by subtracting 1 from all the guesses or subtracting 1 from the mean. This would eliminate the systematic error.

Precision versus Accuracy

Precision and accuracy are two words that are often incorrectly used to mean the same thing. However, they do not.

Precision is the nearness of one measurement to another or to the mean value of those measurements, without regard to correctness or truth. In Figure A.3, (a) illustrates the shots on the target are close together and at the same magnitude and direction away from the center (true value).

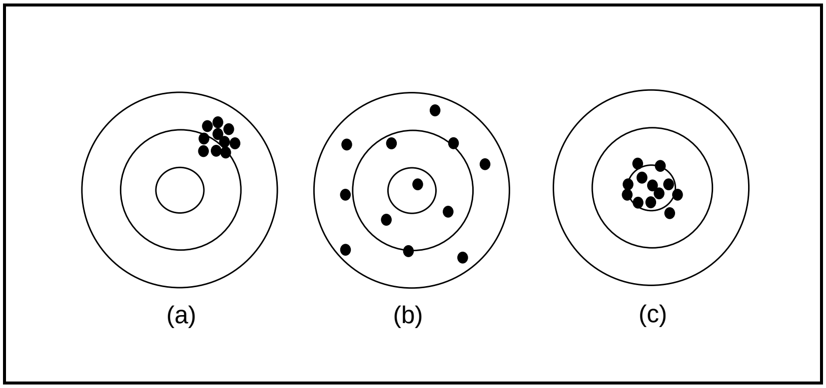


Figure A.3 Precision versus accuracy

In contrast, *accuracy* is the closeness of a measurement to the true (or accepted) value of the quantity being measured. In Figure A.3 (b), the shots are distributed throughout the target, but centered on the bulls-eye (true value).

The ideal results are shown in Figure A.3 (c), which shows a group of very precise shots, accurately centered at the true value.

From a surveying perspective, GPS is a very precise measurement method. If the same equipment and careful measurement techniques are used, GPS will give you consistent repeatability or precision.

The accuracy comes from:

- application of surveying methods, such as the network design (geometry)
- stability and accuracy of the control network
- redundant measurements
- application of precise measurements to network and control coordinates.

Setup Errors

Setup errors are present in every survey, for example: antenna or instrument centering errors (plumbing) and height measurement errors. No matter how carefully you set up your equipment over the survey point and make your height measurements, there will always be some small errors.

The Trimble Geomatics Office software uses your estimates for those errors. Your job is to estimate how large these allowable setup errors are for your surveying methods. Specify these errors in your network adjustment styles. For more information on adjustment styles, see Chapter 2.

Estimating Centering Error

Estimate your centering error based on how well your survey crew:

- maintains or calibrates tribrachs
- centers tribrachs over survey points
- checks circular bubbles on fixed-height rods.

If your crew is using fixed-height tripods, centering errors are reduced, (assuming the bubble level is well adjusted and the tripod carefully leveled). Usually the tribrach centering errors are of the magnitude of 0.0–2 mm.

Estimating Height Measurement Error

For GPS surveying, estimate the antenna height measurement error based on the type of measurement tool used. For example:

- If a crew used a steel tape to measure antenna height, then the allowable error estimates would be slightly larger than if the crew used a height measurement rod. The height measurement rod is a more rigid tool for measuring compared to a flexible steel tape.
- A fixed-height tripod yields a consistent true measurement with minimal error in the antenna height. Little or no error would be applied when using fixed-height tripods.

Usually the height measurement errors are on the magnitude of 0.0–4.0 mm.

An Analogy for Setup Errors

The following example describes an analogy for setup errors. Imagine that you have four bolts cemented in the ground, and you want to fit five boards to the bolts to make a structure as shown in Figure A.4.

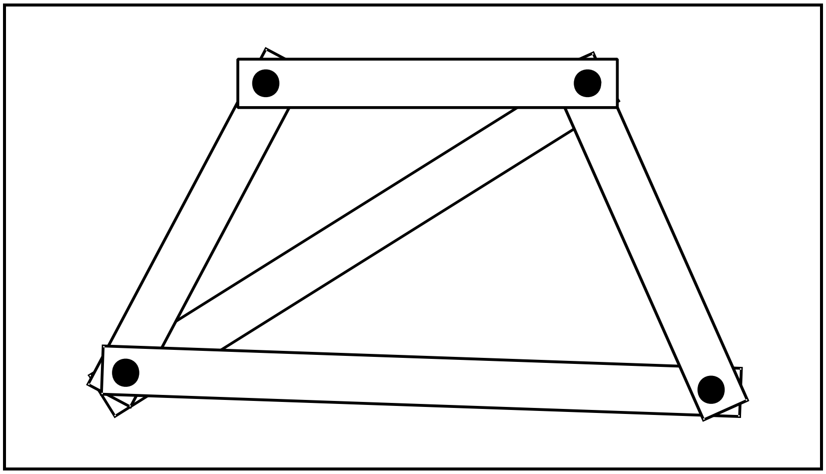


Figure A.4 An analogy for setup errors

You must decide how big to make the holes. You can choose to do one of the following:

- Measure the exact distance between the bolts and then drill holes in the board that are the size of the bolts.
- Measure the distances, but not as accurately, and then drill holes that are slightly larger than the bolts. This allows for more error in the distance measurement between bolts. However, the desired structure may not be achieved if the bolt holes are too big.

If you apply this analogy to GPS surveying, the bolts are survey monuments and the boards are baseline measurements. There are always some errors in the instrument set up (bolt holes). It is assumed that these errors are small. However, they do exist and the Trimble Geomatics Office software allows you to account for them.

You must decide how much error to allow in the setup of the equipment. If you allow for too much setup error, then the network adjustment allows for too much movement or adjustment of the baseline. This produces erroneous results, even though the statistics are acceptable in the output.

In the analogy above, if you allow too much error and drill the bolt holes too large, the structure will look like the planned structure, but it will not be sturdy.

Least-Squares Statistics

When using GPS as a surveying tool, consider the statistics used in least-squares adjustments. In this section, analogies explain terms and concepts; figures and tables illustrate some of the basic concepts of least squares.

The Mean

The fundamental principle of least squares is illustrated by an adjustment that is familiar to most surveyors: the determination of the mean of five measured distances to produce one *observed* distance.

The usual procedure is to adopt the mean distance as the most probable value for the distance and then use it for all further coordinate computations. You can use the mean of several measured distances to calculate an observed distance and then use this observed distance for computing coordinates.

Table A.1 shows the mean of five measurements of a distance.

Table A.1 The mean of five measured distances

	Measured distances (in meters)
	99.98
	99.99
	100.00
	100.01
	100.02
Sum of the measurements =	500.00
Number of measured distances =	5
Mean distance = 500.00/5 =	100.00

The Residual

The corrections in least-squares terminology are called *residuals*. For most direct applications of least squares, the two terms—*corrections* and *residuals*—mean the same thing.

A residual is the difference between the adjusted value of an observation (in this case, the mean distance) and an individual measurement of the same observation (each of the five individual measured distances). Another synonym for the residual of an observation would be the *adjustment* of the observation. One of the objectives of least squares is to minimize the sum (of the squares) of these residuals or adjustments.

In the example in Table A.2, the most probable value of 100.00 implies that each of the five distances receives a *correction* which, when added to the individual measurement, results in the *mean distance*.

Subtracting each measured distance from the mean distance makes the direct computation of each *correction*. Table A.2 shows how these corrections are calculated.

Table A.2 The residual

Mean distance		Measured distance		Residuals (correction)
100.00	–	99.98	=	+0.02
100.00	–	99.99	=	+0.01
100.00	–	100.00	=	0.00
100.00	–	100.01	=	–0.01
100.00	–	100.02	=	–0.02

Residuals are one of the fundamental concepts of least squares. To take this concept a step further, look at an example of residuals with GPS surveying. Figure A.5 illustrates three baseline measurements to one station.

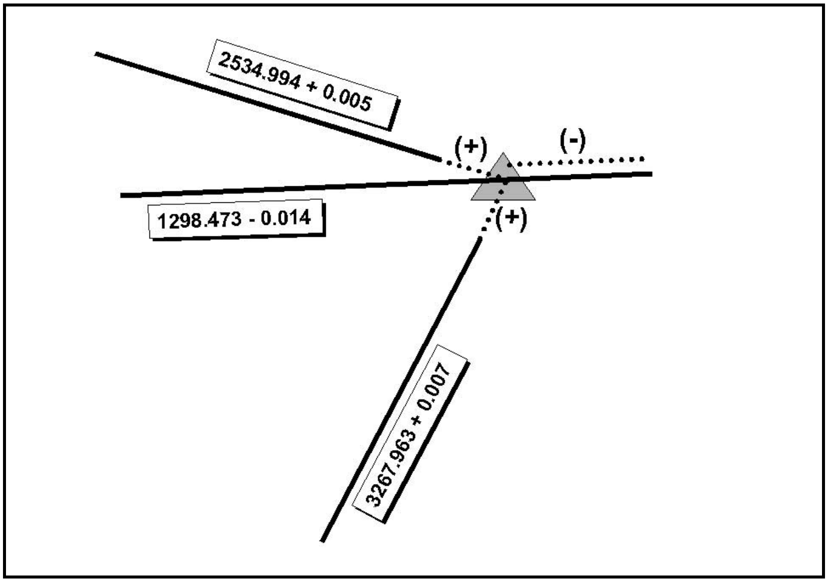


Figure A.5 One-dimensional residuals

To simplify the example, only the distance component of a baseline is used. From these three distance-only measurements, the most probable value is determined and shown as the center of the triangle. The dotted lines represent the residuals or adjustments made to the measurements to achieve the most probable values.

Figure A.5 is a one-dimensional example. GPS surveying works in three dimensions. Adjustment becomes more complicated and requires least-squares adjustments.

The Sum of the Squares of the Residuals Must be a Minimum

One of the criteria of a least-squares adjustment is that the sum of the squares of the residuals must be a minimum**.**

You have determined a mean for your measurements. Now, you must determine if the sum of the squares of the measurement residuals is a minimum. Table A.3 shows the sum of the squares of the residuals associated with the measurements from Table A.2.

Table A.3 Sum of the squares of the residuals

Residuals	Squares of the residuals (v^2)
+ 0.02	0.0004
+ 0.01	0.0001
0.00	0.0000
– 0.01	0.0001
– 0.02	0.0004
	Sum = 0.0010

The sum of the squares of the residuals is determined to be 0.0010 by using the adjusted or most probable value of 100.00. Any value for the adjusted (most probable) distance other than 100.00 would result in different residuals, and the sum of the squares of the new residuals would be greater than 0.0010.

For example, if you arbitrarily used the adjusted distance of 99.99, you will find that after determining the new residuals, the sum of the squares of the residuals is 0.0015, showing that 0.0010 is the best answer. In this way, least squares satisfies the concept that the mean of the five measured distances is the best value for the unknown true distance.

Normal Distribution

For any given set of measurements, there is a set of corresponding residuals. The residuals can be plotted as a function of frequency—how many times each residual occurs. Figure A.6 illustrates this plot, called a histogram. The histogram shows a plot of the residuals for the measured distance (in Table A.2, page 138) using more than five measurements.

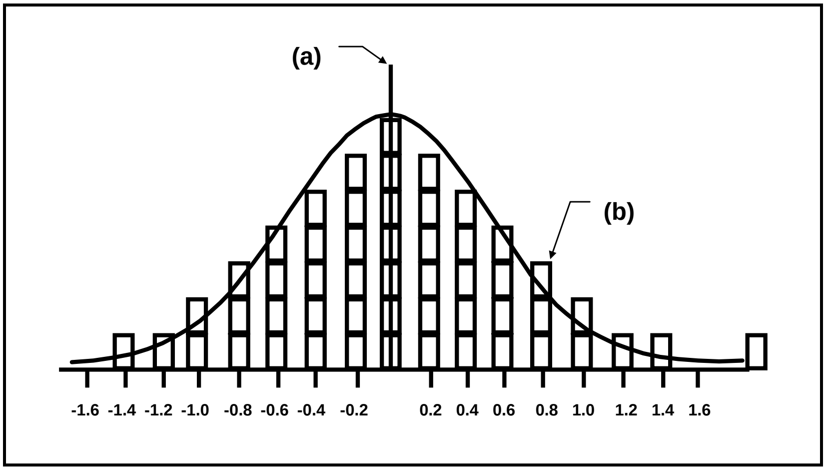


Figure A.6 Normal distribution

In this histogram:

- The line (a) represents the mean of the residuals.
- Each square (b) represents a residual.

Closer examination of the histogram shows that most of the residuals occur near the mean. As residuals get further away from the mean, their frequency gets lower. As a data set becomes infinitely large, it will exhibit the classical behavior of a ***normal*** distribution. Note that in Figure A.6, the normal distribution resembles a bell-shaped curve.

In statistics, normal distribution means that:

- small errors are more common than large errors
- very large random errors seldom occur

- both positive and negative errors have the same probability and frequency of occurrence

In most cases, there is not an infinite number of measurements to evaluate. However, if the errors in your measurements fit the pattern of a bell-shaped curve, you will have the same confidence that you would with an infinite set of measurements. From this information, you can determine that:

- the mean value is the most probable value
- the variation from the mean gives some clue to the uncertainty of the value

Standard Error

The mean of a set of measurements is a familiar concept, but the standard error may not be. The concept of standard error is crucial to understanding least-squares adjustments and analysis of results.

The *standard error* is an estimate of the mean uncertainty of a set of measurements. In the example above, the standard error of a set of measurements illustrates how much error (plus or minus) is in the calculated mean distance.

Equation A-1 shows the formula for the standard error of the mean of a set of measurements:

$$\sigma_m = \sqrt{\frac{\Sigma v^2}{n(n-1)}} \qquad \text{(A-1)}$$

where:

σ_m = standard error of the mean

Σv^2 = sum of the squares of the residuals

n = number of measurements

(n – 1) = degrees of freedom

The formula uses some of the values described in the previous sections, along with the concept of degrees of freedom. For more information, see Degrees of Freedom, page 154.

When you calculate a mean, there is an associated standard error. Continuing with the example, the mean distance is 100.00 ±0.0071 m (where the standard error is ±0.0071). An acceptable distance is anywhere between 99.9929 and 100.0071. The units of the standard error are the same as the units of the measured quantity. The common symbol for standard error is sigma (σ).

The standard error is a useful statistical parameter because it defines the degree of confidence of the results.

- A 1-sigma error, which is the degree of confidence calculated above, corresponds to 68% confidence.
- This 1-sigma error equates to saying 68% of all measurements made under the same conditions will be within the stated standard error of the mean.
- Continuing with the example, repeated measurements of the distance might indicate that 68% of those distances would be somewhere between 99.9929 and 100.0071.

When surveying, you need a high level of confidence in your results. Errors for most surveys are often reported at 95% confidence or 1.96-sigma. The Trimble Geomatics Office software allows you to display the desired confidence level when choosing the adjustment style. For more information on adjustment styles, see Chapter 2.

Note – *Consult your project specifications for the required confidence levels for your reported results.*

You determine 95% confidence in your results by applying a scalar to the standard error (sigma).

- We can calculate a 95% level of confidence by multiplying 0.0071 m by 1.960, which now sets our error statement at 0.0139.

- The Trimble Geomatics Office software handles all of the values and computations after you have configured your adjustment. At 95%, your mean distance is now 100.00 ± 0.014 m.
- This means that if you measured the distance 100 times, 95 of those measurements will fall within 14 mm of the mean.

The standard error can be defined for a set of observations because it is a function of the square of the residuals. Because one of the main objectives of least squares is to minimize the residuals, it follows that the standard error will also be minimized.

Figure A.7 illustrates the normal distribution of the residuals in the example, along with the standard errors at 1-sigma (68%) and 1.96-sigma (95%).

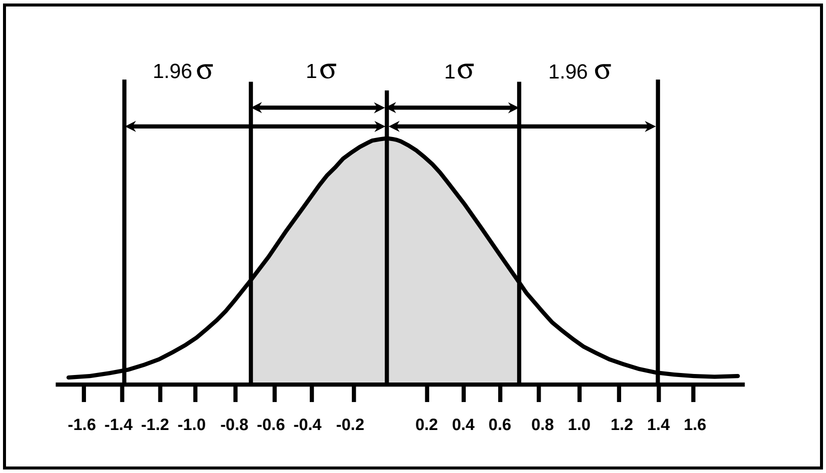


Figure A.7 Standard error

A Priori Errors (Pre-Adjustment Errors)

Every adjustment requires an initial a priori error estimate for each observation used in the adjustment. For GPS measurements, the observation error estimates come from the baseline processor in the form of a ***covariance matrix***.

This discussion avoids a detailed description of the error matrix. Basically, the reason for the matrix is that GPS measurements are three-dimensional, and the matrix consists of the errors of the three components of the baseline.

Figure A.8 shows a sample report for the following information:

- baseline components
- errors in each component
- covariance matrix a posteriori errors from baseline processing, which are a priori errors for the adjustment

The adjustment uses the error estimates from the processor associated with the dx (ΔX), dy (ΔY), and dz (ΔZ) components for the first run through the adjustment.

Baseline Components (meters):	dx	–7.274	dy	81.883	dz	84.825
Standard Deviations (meters):		0.000392		0.000648		0.000883
	dn	107.199	de	–49.608	du	–0.571
		0.000561		0.000352		0.000956
					dn	–0.570
						0.000956
A posteriori Covariance Matrix	1.539165E-007					
	1.168243E-007		4.202073E-007			
	–1.185407E-007		–3.448070E-007		7.789994E-007	

Figure A.8 A priori errors

Weighted Measurements

This section introduces the concept of weighted measurements. There is no need to use weights in a network if all measurements are of:

- the same type (for example, all FastStatic observations)
- equal reliability.

Typically, the above situation is rare. Use weights for your measurements when there are several types of measurements (for example, FastStatic, and kinematic), and when the measurements have different levels of precision and reliability. Some reasons for different results for levels of precision and reliability may be:

- using differing methods of measurement
- observing for longer periods of time (or collecting differing numbers of observations)
- using instruments of differing orders of precision
- taking measurements over lines of differing lengths
- using different satellite constellations.

The more-reliable measurements in a network should receive smaller corrections in the adjustment than the less-reliable measurements. Weighting the measurements achieves this goal. The more-reliable measurements are assigned larger weights in the adjustment than the less-reliable measurements. The general theory is easy to apply.

Every measurement has a standard error. To compute the weight for each measurement from the standard error:

- Determine the variance of the measurement. The variance is the standard error squared (σ^2).
- Invert the variance to determine the weight associated with the measurement ($1/\sigma^2$).

By inverting the variance, a smaller variance will become a larger number, thus a higher weight. A larger variance becomes a smaller number, thus a lower weight.

To fully understand weighted measurement, remember the following rules:

- Observations with small standard errors (small variance) get large weights, and observations with large standard errors (large variance) get small weights.
- Observations with large weights get small residuals (corrections), and observations with small weights get large residuals (corrections).

After weights are computed for each observation, the least-squares criteria are revised to the following:

- The network must close mathematically and geometrically.
- The sum of the weighted squares of the residuals must be a minimum.

To explain weighted measurements and why they are important, consider the following example—a triangle where all the angles were measured. Figure A.9 illustrates how weighted measurements work.

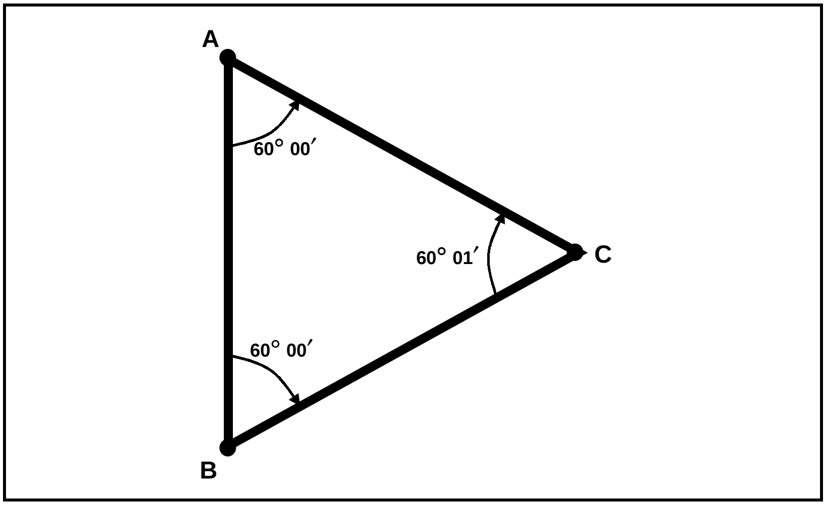


Figure A.9 Weighted measurements

Figure A.9 shows the following:

- Two of the observed angles measured as 60^{o} 00' and the third measured as 60^{o} 01'.
- The sum of the three angles equals 180^{o} 01', producing a 1-minute arc of misclosure in the observed angles of the triangle.

To properly adjust the observations, apply a correction to each of the observed angles.

Table A.4 shows two ways of applying the correction or adjustment based on how the measurements are weighted.

Table A.4 Two ways of weighting and adjusting measurements

Angle	Observed	Standard Error	Weight	Adjustment
First Adjustment				
ABC	60^{o} 00’	1"	1.00	-00^{o} 00' 20"
CAB	60^{o} 00’	1"	1.00	-00^{o} 00' 20"
BCA	60^{o} 01’	1"	1.00	-00^{o} 00' 20"
Second Adjustment				
ABC	60^{o} 00’	2"	0.25	-00^{o} 00' 40"
CAB	60^{o} 00’	1"	1.00	-00^{o} 00' 10"
BCA	60^{o} 01’	1"	1.00	-00^{o} 00' 10"

In the first adjustment, all three angles have been equally weighted with a standard error of 1 second. When applying equal weights to all measurements, you are indicating that all observations were measured with the same equipment and quality (standard error). If this is true, then this weighting is acceptable.

Consider a second adjustment in which the quality of the of the measurements is not the same and the standard errors are different.

Looking at the second adjustment:

- The standard error for each of the observed angles is based on multiple measurements of the angles at ABC, CAB, and BCA (mean observed angle shown).
- The angle at ABC is found to have twice the error as the other two angles, resulting in a weight four times smaller.
- By applying the weights, the corrections for the observations change to reflect the quality of the observations.

The results of the first adjustment show that all three angles receive equal adjustments of 20 seconds, while the second adjustment shows that the angle with the higher standard error receives 40 seconds adjustment, with each of the other two receiving only 10 seconds.

In the second adjustment, the errors are properly distributed, based on the quality of the observations. This explains why weighted measurements are important and also why least-squares adjustments are used to produce quality survey results. In some cases the weights and errors of each observation will be different, as in this case. But in some cases the weights and errors of each observation will be the same. With GPS surveying, allowing a least-squares adjustment to distribute the weights and errors is the most reliable method. Now, you are confident that the network is truly closed mathematically, and you have minimized the sum of the weighted squares of the residuals.

Standardized Residuals

Up to this point, simple examples were used to explain residuals, standard error and weights, and other least-squares statistics. The previous examples used a single unit of measure—linear or angular. Surveying measurements use a combination of linear and angular units requiring more complicated examples.

In the example in Standard Error, page 142, the residuals and standard error were calculated for a distance (measure in linear units). In the example in Weighted Measurements, page 146, angles, measured in angular units, were used to show the concept of weights.

Residuals for these measurements are produced in both meters (linear) and degrees (angular), complicating the ability to compare residuals directly. Because least squares deals with different types of observations, there is a need to directly compare residuals of different units.

The Trimble Geomatics Office software uses *standardized (unitless) residuals* rather than residuals of differing units, allowing you to directly compare quantities of different units.

Note – *The observations in the adjustment are now represented as azimuth, distance, and delta height. In the section, A Priori Errors (Pre-Adjustment Errors), page 144, the observations (baselines) were represented as dx, dy, and dz. Once in the adjustment, the observations (along with associated errors) are transformed to a local geodetic horizon, displaying the observations in more familiar terms.*

Each observed baseline includes an azimuth (angular), distance (linear), and difference in ellipsoid height (linear). Without producing standardized residuals, the residuals of the azimuth cannot be directly compared to the residuals of the distance and delta height. With unitless (standardized) residuals, you have the ability to properly analyze the errors in observations.

The process of producing standardized residuals from residuals of differing units is simple.

- A residual is calculated for every observation (or in the case of a GPS measurement, the components of the baseline).
- For each observation residual, a standard error is calculated as part of the adjustment.
- The standardized residual is computed by dividing the residual of an observation by the standard error (σ) of that residual.

Table A.5 illustrates the process for a GPS baseline. Since the standardized residuals from each component have the same units, the resulting quotient is unitless.

Table A.5 Comparing standardized residuals

Observation	Residual	Standard error of the residual	Standardized residual[1]
Azimuth	+0.0806"	0.1032"	0.78
Distance	–0.0353 m	0.0488 m	0.72
Δ Ellipsoid height	–0.0284 m	0.0364 m	0.78

[1] Standardized residuals = residual / standard error of the residual

Compare each component (observation) of the baseline to each other. The residuals are difficult to compare directly, but in the standardized residual column you can make a straightforward comparison of the magnitude of the error in each observation component.

Histogram of Standardized Residuals and Tau Criterion

Use standardized residuals to evaluate your adjustment. The Trimble Geomatics Office software generates a histogram of the standardized residuals, and derives a normal distribution from the data set.

View this histogram as a relative plot of estimated errors. As previously discussed, large errors occur less frequently than small errors, and the probability and frequency of a positive or negative error are the same.

Figure A.10 shows a plot of standardized residuals with a normal distribution curve.

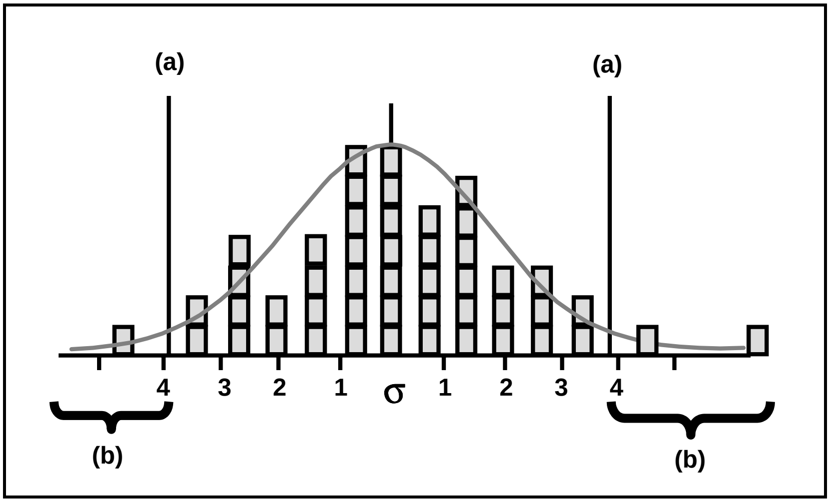


Figure A.10 Histogram of standardized residuals and critical tau

In Figure A.10, two additional items are added to the histogram:

- The letters (a) represent the critical tau values (explained below).
- The letters (b) indicate outliers.

At this point in the adjustment:

- Blunders are eliminated from the adjustment.
- The systematic errors are modeled.
- The plot of the residuals shows only random errors.

There is always a possibility of a large random error—an error in an observation that is not consistent with the rest of the errors. Do not be alarmed by the presence of high standardized residuals. It now becomes a matter of what is acceptable and what is not. A limit on the magnitude of the standardized residual must be determined.

The *Tau Criterion* is useful for determining the limit. This test is also useful for smaller data sets and when a normal distribution is not statistically valid. (For information on the Tau Criterion, refer to the bibliography [Pope] in Help.) Consider the following:

- The Tau Criterion uses an internalized *Student distribution* (a distribution model for small data sets), which becomes identical to the normal distribution as the degrees of freedom increase.
- From the adjustment, a critical tau (τ) value is computed from a Student distribution, using an algorithm based upon the size (number of observations), degrees of freedom, and desired confidence level for a given data set. In Figure A.10, the critical tau values are shown as two vertical lines—one to the left and one to the right of the zero centerline at about 3.90σ.
- Compare the standardized residual to the critical tau to determine if it fits with the rest of the data set. If it exceeds the critical tau, then it is possibly an outlier. The outliers are shown at the left and right of each critical tau line in Figure A.10.
- The Tau Criterion flags the observations that do not statistically fit well with the rest of the data set and are candidates for removal from the network. If an observation is flagged as an outlier, there is a statistical basis for its removal. If you choose to *not* remove the observation from the adjustment, then you must justify why the observation should be retained.

For more information about removing outliers, see Minimally Constrained or Free Adjustment, page 168.

Degrees of Freedom

In the Trimble Geomatics Office software, *degrees of freedom* is defined as the number of independent observations beyond the minimum required to uniquely define the unknown quantities. Figure A.11 presents an example of this concept.

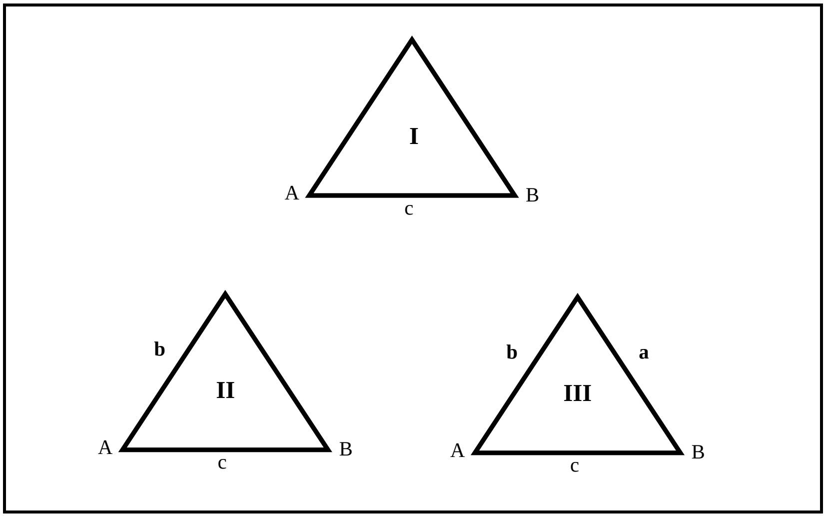


Figure A.11 Degrees of freedom

Figure A.11 shows a simple triangular computation. To uniquely define (solve for) a triangle, one known (observed) side and any two other known angles or sides are required. Consider the following:

- In Figure A.11 (I), two observed angles and the side (distance) between the two angles are known. This is the minimum you need to solve a triangle, so we have *zero degrees of freedom*.
- As in Figure A.11 (II), if you measure one of the other sides of the triangle, you increase to *one degree of freedom*.
- Then, as in Figure A.11 (III), if you measure the third side of the triangle, you have *two degrees of freedom*.

The strength of and confidence in the solution increases as the degrees of freedom increase. In a least-squares adjustment, try to maximize the degrees of freedom to help detect blunders and to correctly distribute the error in the measurements. This is also called *adding redundancy* to the network or observations.

One key aspect to degrees of freedom is the requirement to use *independent* observations:

- In Figure A.11, all angle and distance observations were measured independently.
- If we were to compute the angle at C and add that to our survey as an observation, the angle at C is not independent of the other measurements. The solution for C is dependent on the observed angles and distances.
- There are no independent errors in the angle at C, and adding the computed angle skews the statistical results, thus creating a false sense of confidence.

In the formula for standard error (page 143), the degrees of freedom ($n - 1$) are in the denominator. So as you erroneously increase $n - 1$, you determine the square root of a smaller number and the standard error becomes smaller and smaller. If you falsely add distance observations of 100.00 to the example (starting in section A.7.1), then recompute the standard error, you will see how it decreases—incorrectly indicating better results.

In GPS surveying, a *session* is defined as static collection of simultaneous data with two or more receivers. When surveying with GPS, pay attention to independent and dependent observations. The number of independent observations in a GPS survey session equals $n - 1$, with n representing the number of receivers used in the session.

Reference Factor (Standard Error of Unit Weight)

The *reference factor* is another indicator for testing the quality of measurements and isolating suspect measurements. Reference factor is defined as a measure of the magnitude of observational *residuals* in an adjusted network as compared to estimated preadjustment observational errors. It is also called the *standard error of unit weight*.

A network adjustment makes small corrections (residuals) to the observations to make them *fit* well with each other. You must determine if these corrections are acceptable and reasonable.

If observational errors have been accurately estimated, you can expect that, on average, the residual received by each observation will be about the same size as its estimated error. In any adjustment, some observations will receive corrections smaller than their estimated errors, and some will receive larger. It can be demonstrated mathematically that if the estimated errors for an observation have been accurately estimated, the reference factor will be about 1.00.

Figure A.12 shows a graphical representation of the reference factor on individual observations.

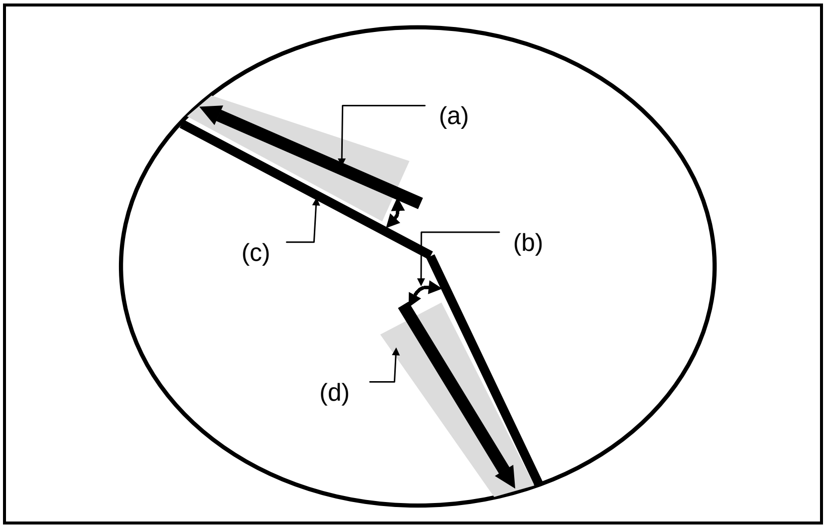


Figure A.12 Reference factor

In Figure A.12, the letters represent the following:

(a) = the observed value

(b) = residual or correction

(c) = adjusted value

(d) = a priori estimated error

A reference factor is computed for each observation and for the entire network. Use the network reference factor to determine if the errors are properly estimated for the entire network. For this discussion, it is simply stated as the overall amount of adjustment in the network, compared to the overall amount of estimated error in the network.

The reference factor is about 1.00 when the amount of the adjustment to the observations equals the estimated errors of those observations. With this information, you can determine the following:

- If the reference factor is less than 1.00, then the errors have been overestimated, and the network exceeds the precision estimated for it.
- If the reference factor is greater than 1.00, it indicates that, for a variety of reasons, one or more (or all) of the estimated errors have been underestimated.

In either case, more reasonable error estimates must be determined.

***Note –** An inflated reference factor can also indicate a blunder.*

At this point, you must investigate why the reference factor does not equal 1.00. In the case where the reference factor is greater than 1.00, do the following:

- Remove all outliers or statistically justify them.
- Begin applying a *scalar* to your estimated errors to bring them in line with the residuals of the observations.

The concept of scalars is important when producing proper statistics in your adjustment and is discussed in Scaling Your Estimated Errors, page 158, and also in Chapter 2.

Chi-Square Test

Another test of the integrity of your adjusted network is an overall test of the adjustment statistics. This test is based upon the following:

- sum of the weighted squares of the residuals
- degrees of freedom
- critical probability of 95% (in the Trimble Geomatics Office software)

In some cases, the estimated errors are considered valid even though the reference factor exceeds 1.0. This is true when the network adjustment passes the *Chi-square* probability test.

The purpose of the test is to accept or reject the hypothesis that the predicted errors have been accurately estimated. The Trimble Geomatics Office software computes the probability percentage (*level of significance)* for the adjusted network. If this is greater than or equal to 95%, the reference factor passes the Chi-square test.

Failure of the Chi-square test indicates that you should do one of the following:

- Revise some or all of the predicted errors of the observations.
- Reject and possibly reobserve some or all of the observations.
- Use a combination of both of the above.

Scaling Your Estimated Errors

When performing an adjustment, it is possible that the reference factor exceeds 1.00 and the Chi-square test fails. These results indicate that the estimated observational errors are underestimated and do not match the amount of adjustment made to the observations.

When processing GPS baselines, there are limited data from which to calculate good error estimates. This could easily give rise to a reference factor (RF) > 1.

To better model the network errors, apply a *scalar* to the estimated errors. In the alternative scaling example below, if after the first adjustment the reference factor is 1.72 and the Chi-square test fails, this indicates that the errors are underestimated. Increase the estimated error by some scalar to properly model the network error. There are two considerations:

- Determine what value to use as the scalar.
- Determine the best estimate of the error in the network.

For both considerations, the answer is the *reference factor (RF)*. In the Trimble Geomatics Office software, using the RF as the scalar for the next adjustment is called *alternative scaling*. This is an iterative process. Three strategies for applying a scalar to the estimated errors are as follows:

1. Apply a scalar to each observation. This equates to using the individual observation RF as the scalar that is applied to *each* estimated error in the next iteration of the adjustment.
2. Apply the network reference factor globally to each observation's estimated errors: *All Observations*. This is the strategy used in the alternative scaling example below.
3. Apply a scalar to the *Variance Groups*. For more information, see Variance Groups, page 165.

Alternative scaling example

As an example, consider that the default scalar strategy is used during the first adjustment of a network. The default scalar value is always 1.0. The estimated errors are used at their face value to produce the reference factor of 1.72.

***Note –** To simplify this example, there are no outliers in the adjustment.*

Using the alternative scalar strategy for the second adjustment automatically multiplies the first scalar value (1.0) by the current adjustment RF value (1.72), making the new scalar 1.72. During the second adjustment the new, scaled estimated errors are applied and the new RF is closer to 1.0.

If the reference factor is still greater than 1.0 (in this case, 1.50), then a new scalar is calculated by multiplying the latest reference factor (1.50) by the previous scalar (1.72) to produce a scalar ($1.00 \times 1.72 \times 1.50 = 2.58$) for the third adjustment. This process is continued until the reference factor approaches 1.0 and the Chi-square test passes.

Tip – This process can be performed automatically using the Automatic Scalar Type option.

The observation error estimates may be approaching their *true* value when:

- The reference factor approaches 1.0.
- The histogram represents a bell-shaped curve.

Note – *If the histogram appears as a narrow spike, then a lot of observations have had their error estimates over-inflated by the scaling. This is due to the presence of a bad observation. When the combined histogram appears to be normally distributed with no outliers, you can be confident that the overall weighting strategy is being applied correctly.*

You now will have confidence in your results—both statistically and geometrically. When globally scaling, you improve the confidence of your error modeling and statistics without drastically changing your observations. This insures that the appropriate adjustments are made where needed in the network, and you are seeing a true representation of the errors in your final results.

Some analysis of the magnitude of the initial RF must be made when using a scalar. If the RF is a high, you will begin scaling the estimated errors by a large amount, then with subsequent iterations, the scalar will increase at a considerable rate. This is not a good practice. If the RF is high (inflated), it usually indicates a blunder still exists in the observations. The blunder must be removed from the adjustment before you can proceed with using a scalar.

Tip – RTK and kinematic baselines produce a priori errors that are not as well defined as those for static baselines. You should be more concerned about static baselines with a large RF than about RTK and kinematic baselines with a large RF.

When performing an adjustment, consider the following guidelines:

- In a proper adjustment, you are evaluating and applying a scalar only to random errors. All other errors are removed or modeled.
- Observations with large random errors are flagged as outliers, and in most cases must be removed from the adjustment.

Note – *Scale the estimated errors of the outliers using alternative scaling before excluding them from the adjustment. In some cases, scaling the estimated errors will allow the bad observation to fall within the critical tau value.*

For more information about outlier analysis and removal, see Minimally Constrained or Free Adjustment, page 168.

A Posteriori Errors (Post-Adjustment Errors)

An iteration of the adjustment produces *a posteriori errors* (post-adjustment errors) for the adjusted observations and position. The errors provide:

- a measure of the quality of observations and resulting positions based on network adjustment residuals
- information used to determine if further adjustment is needed.

The a posteriori errors for the adjusted observations are a product of the reference factor (scalar) multiplied by the a priori standard errors.

The calculation for the a posteriori error is straightforward and includes many of the topics covered in this appendix. Formula A-2 (a posteriori errors for observations) illustrates how the parts of the network adjustment work together to produce the final postadjustment estimated error:

$$[(\text{a priori error matrix}) \times \text{scalar}] + (\text{setup errors})^2 \tag{A-2}$$

Note – *For a well-conditioned network, the setup errors (even when correctly modeled) can easily be the dominant term in the a posteriori calculation. Always use reasonable setup error estimates.*

Tip – To get a true representation of your observation errors, do not apply setup errors to your first adjustment iteration. Then apply your reasonable setup error estimates to subsequent adjustment iterations.

Coordinate Error Ellipses

The error ellipse is a useful expression of coordinate error propagation. For any given control point, the error ellipse is computed directly from the point's a posteriori errors in easting or longitude, northing or latitude, and from the ellipse rotation.

Figure A.13 shows the construction of the coordinate error ellipse.

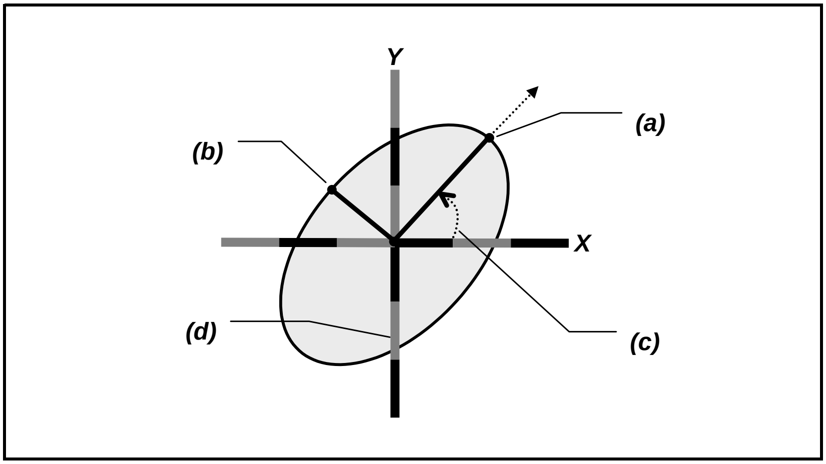


Figure A.13 Construction of the coordinate error ellipse

A coordinate error ellipse is a graphical representation of the magnitude and direction of the error of our adjusted points. The Trimble Geomatics Office software determines and plots information as listed below:

- (a) represents the magnitude (size) of the maximum error at the point, plotted along the long (semi-major) axis of the ellipse.
- (b) represents the magnitude of the minimum error at the point, plotted along the short (semi-minor) axis, perpendicular to the long axis.
- (c) represents the rotation (slant) of the long axis at the station, calculated from the positive X-axis of ellipse.
- (d) represents the scale of the ellipse using each alternating colored bar tick and a tick size (value) associated with each tick.

Ideally, a precise and well-conditioned network will have all ellipses nearly circular and as small as possible. This cannot always be achieved. Consider the following when examining ellipses:

- For GPS surveying, circular ellipses are often seen, due to the setup error dominance described on page 161.

- When ellipses are long and narrow, the direction of greatest estimated error is found in the direction of the slant of the ellipse. This direction is also the path of least resistance for the point to move along during the adjustment.
- When the slant direction for the ellipses is common throughout or in one portion of the network, this indicates a weakness in the configuration of the network in that direction. Such a weakness may be unavoidable. The weakness might be alleviated by additional direct measurements between control points in the quadrants of the network to which the ellipses point.

In a well-conditioned survey network, it is common to find elongated ellipses, but the orientation of the elongations appear to be random, indicating that no inherent structural weakness affects the survey.

Variance Groups

With surveys, there are often varying groups of measurements used in a single network. The measurements can differ in several ways, including:

- the method of collection – GPS and terrestrial observations
- the type of measurements

The adjustment must have a way of accounting for the differing errors associated with these measurements. In the Trimble Geomatics Office software, *variance groups* provide the ability to separate these measurements.

It is easy to see that the more precise the surveying methods, the smaller the measurement errors. The following example uses conventional surveying to explain why measurements are divided into variance groups.

Variance Groups for Conventional Surveying

As an example of variance groups for conventional surveying, consider the following. During a traverse to establish horizontal and vertical control on six points, the following methods were used to establish the vertical control on the points:

- Trigonometric elevations (from vertical angles) with a 10" theodolite were used to establish the difference in elevation between three of the points.
- A level with micrometer was used for determining the difference in elevation of the other three points.

The measurements using the level are more precise (smaller standard errors) than the trigonometric elevations. You do not want the same amount of adjustment (more correctly, *weight*) applied to the differential leveling as is applied to the trig elevations.

By dividing the two groups of measurements into variance groups and using variance group weighting strategy:

- the adjustment will apply different scalars to each group, based on the group's estimated errors.
- separate reference factors and degrees of freedom are generated for each group, allowing analysis of each group's quality of fit. This prevents the large errors (hence large adjustments) of the weaker measurements from being smeared (spread) across the entire network.
- the large errors stay with the weak measurements, and the small errors stay with the stronger measurements.

Variance Groups for GPS Surveying

For GPS surveying, divide the different types of GPS observations into separate groups based on different observation methods and solution type. Consider the following:

- The occupation times of the methods are key factors in the processor's ability to properly model the error in the baseline.
- Occupation times decrease from static to FastStatic, and become very short with the kinematic methods.
- More error is usually associated with kinematic surveys due to use of a range pole when occupying the points.

You might prefer to separate longer baselines from the shorter baselines. The two types of baseline solutions can have varying errors due to:

- using the precise ephemeris for long baselines, and not using it with short baselines in baseline processing
- the effects of the atmosphere over long lines (iono free versus L1 fixed).

Another factor is the different types of baseline solutions. You may consider separating the baseline iono free solutions from the L1-fixed baseline solutions.

For more information on baseline processing, refer to the *Trimble Geomatics Office Software – WAVE Baseline Processing User Guide.*

Network Adjustment Procedures

The network adjustment occurs in two major steps.

The first step is the *minimally constrained* or *free adjustment*, which acts as a quality control check of your observations.

Use it to:

- check the internal consistency of the network.
- detect blunders or ill-fitting observations.
- obtain accurate observation error estimates.

The second step is the *fully constrained adjustment.*

Use it to:

- reference the network to existing control (datum).
- verify existing control.
- produce network transformation parameters (optional).
- obtain accurate coordinate error estimates.

Both steps are required to obtain a complete adjustment and to provide confidence in your results. The adjustment definitions and procedures are discussed in the follow sections.

Minimally Constrained or Free Adjustment

A minimally constrained adjustment is an adjustment with only one control point held fixed in the survey network. Holding one control point fixed *shifts* observations to the correct location within the chosen datum. Not fixing a control point forces the software to perform a *free adjustment*. A free adjustment is accomplished by minimizing the size of the coordinate shift throughout the network. This equates to a mean coordinate shift of 0 (zero) in all dimensions.

A minimally constrained or free adjustment acts as one quality control check on the network. This adjustment helps to identify bad observations in the network. If an observation does not fit with the rest of the observations, it is highlighted as an *outlier.* The minimally constrained or free adjustment also checks how well the observations hold together as a cohesive unit.

Note – *Perform a minimally constrained adjustment of GPS observations using WGS-84 as the adjustment datum. Since all GPS observations are made on the WGS-84 datum, the adjustment of the observations should be tied closely to the WGS-84 datum.*

The minimally constrained adjustment is an iterative process:

- Perform an adjustment to check the observations for internal consistency and estimates errors for all observations. If bad observations are found, they appear as outliers in a histogram of standardized residuals.
- Remove these observations (one at a time, starting with the largest) so that the statistics of the network are not skewed.
- Perform the adjustment again; errors are estimated again.

In the subsequent adjustments, the estimated error may be rescaled to produce more realistic error estimates.

Repeat the process until the results meet the following conditions:

- All outliers have been removed from the network.
- Observations have the most accurate error estimates possible.

- Observations are adjusted such that they fit together well.

During the iteration process, two least-squares statistics are used to gauge progress:

- Reference factor – The reference factor shows how well the observations, along with their respective error estimates, are working together. Once the reference factor approaches 1.00, the errors in the observations are properly estimated and all observations have received their appropriate adjustments.
- Chi-square test – Typically when the reference factor approaches 1.00, the Chi-square test of network error estimates, degrees of freedom, and level of confidence will pass. As long as realistic setup errors were used in the adjustment, you can be confident that the network observations are working together and that there are no large errors remaining in the network.

Once the minimally constrained adjustment is complete, move on to the fully constrained adjustment to *fit* the observations to the local control datum.

Fully Constrained Adjustment

The fully constrained adjustment transforms the network of observations to the control points in the network. Once the network is fixed to those control points, adjusted coordinates (based on the project datum) for all other points in the network can be determined. Use this step to check that the existing control fits together well.

The minimally constrained adjustment showed that the observations fit together and a fairly rigid network is defined. It is assumed that if any large errors are present in the fully constrained adjustment, the source is nonhomogeneous control points (values). Any ill-fitting control points should not be fixed (constrained).

When designing the network, it is good practice to use a minimum of three horizontal control points and four vertical control points because:

- Two horizontal and three vertical control points are required to define transformation parameters.
- The additional horizontal and vertical control points can be used to check the consistency of the adjustment and defined transformation parameters.

Adding additional control points builds more confidence in the calculated parameters.

In the fully constrained adjustment, begin fixing the control values to determine how well the rigid network of observations fit the control. Essentially, the adjustment determines if the network of observations fit the network of fixed control points given some error estimate. These error estimates are the error estimates along with the applied scalar and setup errors. The transformation parameters are then calculated to allow the observations to fit to the control.

Note – *If the measurements are made on the WGS-84 datum. You must provide control values (points) in your local datum that allow the adjustment to solve for the change in datum using calculated transformation parameters.*

Transformation Analogy

This analogy will help you to understand the definition of the transformation parameters in a fully constrained adjustment.
A simple transformation involves three parameters: *rotation*, *scale*, and *deflection*.

Defining the rotation

The *rotation* of the network (datum) can be defined by fixing two horizontal control points:

- Imagine the network as lines and named points on a piece of *rubberized* paper. The paper is rubberized to allow for any stretching or contracting (scaling) that might occur.
- Imagine a defined network of named control points marked on a wall.
- Use a tack to fix a point on the paper to the first control point with the same name on the wall.
- Let the paper hang freely. It will orient itself in an unpredictable direction.
- Now tack (fix) a second point on the paper to a point with the same name on the wall. The sheet of paper is rotated slightly to make the two points line up.

  This is the measure of the rotation needed to fix the two networks together, allowing the observations to fit to the control values. The rotation is calculated but not checked.
- Tack a third point on the paper to the wall to check the rotation. You can determine how far the tack is from a point on the wall with the same name.
- If the tack is close to point on the wall (no large errors are seen), you are confident the rotation is defined correctly. This check is the same on all the parameters defined during the fully constrained adjustment.

Defining the scale

The *scale* of the network can be calculated by fixing one vertical point in addition to the two horizontal points. This concept gets a little more complicated. Continue with the above example:

- Imagine the piece of paper and the wall as curved surfaces, because you know the earth and the models used for coordinate computations are not flat.
- As you fix your first vertical control point, the paper is, perhaps, 10 cm from the wall. (The paper could also be 10 cm below the surface of the wall.) This is the difference between the two ellipsoids that define your datum.
- As you move the paper away from the wall, still holding the horizontal points, the ***horizontal*** distances between the points will become larger (and shorter if the paper is moved below the surface of the wall).
- The difference, or ratio, between two distances is defined as the scale factor. The definition is checked with additional horizontal and vertical control points.

Defining the deflection

As you fix additional vertical control points in the network, you define the network *deflection* (of the vertical). The deflection is the angular difference between the ellipsoid surface of one datum (WGS-84) and the ellipsoid surface of another datum (local). Continue with the above example:

- Now picture the wall as not only curved, but also an inclined surface. This inclination is the difference between the two ellipsoid surfaces.
- Model this inclination by fixing additional vertical control points. As you fix vertical points on the paper, the relationship to the incline of the wall is defined. The measurement of that inclination is the deflection (of the vertical) of your network.

By fixing two vertical points, the deflection in one direction is defined.

By fixing three points, the deflections in all three directions are defined. Adding more points allows you to check your definition of the vertical.

The transformation parameters are defined, allowing you to generate coordinates of the adjusted points in your local datum. The fully constrained adjustment is complete.

Glossary

This section explains some of the terms used in this manual.

1-sigma One standard error from the mean.

a posteriori errors The a priori errors multiplied by the standard error of unit weight (reference factor) resulting from a network adjustment.

a priori errors Errors estimated for observations prior to a network adjustment.

AASHTO American Association of State Highway and Transportation Officials

accuracy The closeness of a measurement to the actual (true) value of the quantity being measured.

adjusted values Values derived from observed data (measurement) by applying a process of eliminating errors in that data in a network adjustment.

adjustment The process of determining and applying corrections to observations for the purpose of reducing errors in a network adjustment.

adjustment convergence When the network adjustment has met the defined residual tolerance or last ditch residual tolerance within a defined number of iterations.

adjustment datum The datum used in the current network adjustment iteration. The Trimble Geomatics Office software lets you select either the project datum or WGS-84.

adjustment styles Trimble default and user-defined settings for a network adjustment.

algebraic sign The sign (+ or –) associated with a value which designates it as a positive or negative number.

algorithm A set of rules for solving a problem in a finite number of steps.

almanac Data transmitted by a GPS satellite that includes orbit information on all the satellites, clock correction, and atmospheric delay parameters. The almanac facilitates rapid SV acquisition. The orbit information is a subset of the ephemeris data with reduced precision.

ambiguity The unknown integer number of cycles of the reconstructed carrier phase contained in an unbroken set of measurements. The receiver counts the radio waves (from the satellite as they pass the antenna) to a high degree of accuracy. However, it has no information on the number of waves to the satellite at the time it started counting. This unknown number of wavelengths between the satellite and the antenna is the ambiguity. Also known as integer ambiguity or integer bias.

annotation A piece of text that describes another database record. To select and edit annotations, use the *Properties* window. An annotation is live—any fields are re-expanded whenever the parent entity changes.

antenna height

The height of a GPS antenna phase center above the point being observed.

The uncorrected antenna height is measured from the observed point to a designated point on the antenna, then corrected to the true vertical manually or automatically in the software.

antenna phase correction

The phase center for a GPS antenna is neither a physical nor a stable point. The phase center for a GPS antenna changes with respect to the changing direction of the signal from a satellite. Most of the phase center variation depends on satellite elevation. Modeling this variation in antenna phase center location allows a variety of antenna types to be used in a single survey. Antenna phase center corrections are not as critical when two of the same antenna are used since common errors cancel out.

Anti-Spoofing (AS)

A feature that allows the U.S. Department of Defense to transmit an encrypted Y-code in place of P-code. Y-code is intended to be useful only to authorized (primarily military) users. AS is used to deny the full precision of GPS to civilian users.

APC

Antenna Phase Center

The electronic center of the antenna. It often does not correspond to the physical center of the antenna. The radio signal is measured at the APC.

In the *Properties* window the height of a point may be the elevation of the APC. If the height is specified as APC, it is the height of the APC—not the ground height.

autonomous positioning
A mode of operation in which a GPS receiver computes position fixes in real time from satellite data alone, without reference to data supplied by a base station. Autonomous positioning is the least precise positioning procedure a GPS receiver can perform, yielding position fixes that are precise to ±100 meters horizontal RMS when Selective Availability is in effect, and to ±10–20 meters when it is not. Also known as absolute positioning and point positioning.

azimuth
A surveying observation used to measure the angle formed by a horizontal baseline and geodetic north. When applied to GPS observations, it refers to a normal section azimuth.

base station
An antenna and receiver set up on a known location. It is used for real-time kinematic (RTK) or differential surveys. Data can be recorded at the base station for later postprocessing. A Trimble base station consists of a receiver in Base Station mode used with the Trimble Reference Station (TRS™) software or the Universal Reference Station (URS™) software.

In GPS surveying practice, you observe and compute baselines (that is, the position of one receiver relative to another). The base station acts as the position from which all other unknown positions are derived.

baseline
The position of a point relative to another point. In GPS surveying, this is the position of one receiver relative to another. When the data from these two receivers is combined, the result is a baseline comprising a three-dimensional vector between the two stations.

baseline processor A computer program that computes baseline solutions from satellite measurements. It may run as a postprocessor on a personal computer, or as a real-time processor in a receiver. WAVE (Weighted Ambiguity Vector Estimator) is Trimble's baseline processor.

baud A unit of data transfer speed (from one binary digital device to another) used when describing serial communications.

bivariate Mathematical function describing the behavior of two-dimensional random errors in error ellipses for:

northing/easting

latitude/longitude

X/Y

CAD styles CAD styles define the appearance of points, lines, arcs, curves, text, and annotations in a project. A style, for example, can be made up of a symbol, line type, color, or font. Style definitions are stored in a project.

To have styles available for a number of projects, define the styles in a template project.

calibrated site A site definition uses an existing coordinate system definition plus correction transformation. This makes the best fit for GPS data in a specific area (or site). The extra correction transformations are required because a coordinate system is designed to apply over a very large area. It does not allow for variations in the local coordinates.

You need to have new work fit with the existing control, so the extra correction transformations will correct for these local variations. Extra corrections are only valid over a limited area. This explains the ‘site’ terminology.

The Trimble Geomatics Office software can compute the extra transformations required to fit to local control and save these definitions in the coordinate system database.

calibration coordinates
WGS-84 coordinates (latitude/longitude/ellipsoid height) generated from a minimally constrained network adjustment of your GPS observation, then saved for later use in a GPS site calibration.

The calibration coordinates are used as the GPS observed coordinates that are associated with the grid coordinates of a particular point when performing a calibration.

Cartesian coordinates
See Earth-Centered-Earth-Fixed Cartesian coordinates.

chi-square test
An overall statistical test of the network adjustment. It is a test of the sum of the weight squares of the residuals, the number of degrees of freedom and a critical probability of 95 percent or greater.

The purpose of this test is to reject or to accept the hypothesis that the predicted errors have been accurately estimated.

clock offset
The constant difference in the time reading between two clocks. In GPS, usually refers to offset between SV clocks and the clock in the user's receiver.

closure
Agreement between measured and known parts of a network.

CMR
Compact Measurement Record

A satellite measurement message that is broadcast by the base receiver and used by real-time kinematic (RTK) surveys to calculate an accurate baseline vector from the base to the rover.

Coarse Acquisition (C/A) code A pseudorandom noise (PRN) code modulated onto an L1 signal. This code helps the receiver compute the distance from the satellite.

code The GPS code is a pseudorandom noise (PRN) code that is modulated onto the GPS carrier signals.

The C/A code is unclassified and is available for use by civilian applications.

The P code is also known and unclassified, but may be encrypted for national defense purposes.

Code measurements are the basis of GPS navigation and positioning. Code also is used in conjunction with carrier phase measurements to obtain more accurate survey quality baseline solutions.

component One of the three surveying observations used to define a three-dimensional baseline between two control points. The same baseline can be defined by azimuth, delta height, and distance (in ellipsoid coordinates); by delta X, delta Y, and delta Z (in Earth Centered Cartesian coordinates); and by delta north, delta east, and delta up (in local plane coordinates).

constellation A specific set of satellites used in calculating positions: three satellites for 2D fixes, four satellites for 3D fixes.

All satellites visible to a GPS receiver at one time. The optimum constellation is the constellation with the lowest PDOP. See also PDOP.

constrained To hold (fix) a quantity (observation and coordinate) as true in a network adjustment.

constraint External limitations imposed upon the adjustable quantities (observations and coordinates) in a network adjustment.

control point A monumented point to which coordinates have been, or are in the process of being, assigned by the use of surveying observations.

conventional observation An observation in the field obtained using a total station or theodolite.

coordinate system A set of transformations that allow GPS positions (in the WGS-84 ellipsoid) to be transformed to projection coordinates with elevations above the Geoid.

It consists of a datum transformation, a geoid model allocation, and a coordinate projection definition.

The datum transformation is defined in the coordinate system database. It includes the definition of the datum on which the coordinate projection is based.

An existing geoid model can be assigned to the coordinate system, but it is also possible to specify a constant geoidal separation rather than using a geoid model. Use the Trimble Coordinate System Manager utility to define geoid models in the coordinate system database.

You can allocate some coordinate projection types to a coordinate system (for example, Transverse Mercator or Lambert One Parallel). Different countries and regions use different projection types to achieve optimum results (that is, minimum distortion) in the projection coordinates. The coordinate projection methods project latitude and longitude values on the appropriate datum to Cartesian coordinate values. The elevations for the projection coordinates are achieved using the geoid model assigned to the coordinate system.

The Trimble Coordinate System Manager utility lets you view, edit, and add to the coordinate system definitions supplied with the Trimble Geomatics Office software.

correlated Said of two or more observations (or derived quantities) which have at least one common source of error.

covariance A measure of the correlation of errors between two observations or derived quantities. Also refers to an off-diagonal term (that is, not a variance) in a variance-covariance matrix.

covariance matrix A matrix that defines the variance and covariance of an observation. The elements of the diagonal are the variance and all elements on either side of the diagonal are the covariance.

covariant values As used by the Trimble Geomatics Office software, this is the publication of the propagated (computed) a posteriori errors in azimuth, distance, and height between pairs of control points resulting from a network adjustment. The term covariant indicates that this computation involves the use of covariant terms in the variance-covariance matrix of adjusted control points.

current view You can open more than one view onto the database using the *Window* / *New Window* command. Each of these views can have different view settings. The current view is the view that has focus and this is identified by the use of the active title bar.

cycle slip An interruption in a receiver's lock onto a satellite's radio signals. A cycle slip requires the re-estimation of integer ambiguity terms during baseline processing.

data logging The process of recording satellite data in a file stored in the receiver, on a data collector running the Trimble Survey Controller software, or on a survey data card.

data message A message, included in the GPS signal, that reports on the location and health of the satellites as well as any clock correction. It includes information about the health of other satellites as well as their approximate position.

datum A mathematical model of the earth designed to fit part or all of the geoid. It is defined by the relationship between an ellipsoid and a point on the topographic surface established as the origin of the datum. It is usually referred to as a geodetic datum.

The size and shape of an ellipsoid, and the location of the center of the ellipsoid with respect to the center of the earth, usually define world geodetic datums.

datum defect Unknown discrepancies between two sets of coordinates which can only be rectified by the use of a datum transformation as part of a network adjustment.

datum transformation Defines the transformation that is used to transform the coordinates of a point defined in one datum to coordinates in a different datum.

There are a number of different datum transformation methods supported by the Trimble Geomatics Office software:

Seven-Parameter

Three-Parameter (also referred to as Molodensky)

Multiple Regression

Datum Grid

Datum transformations usually convert data collected in the WGS-84 datum (by GPS methods) onto datums used for surveying and mapping purposes in individual regions and countries.

de-correlate	To remove the covariances between observations. This may be done through elaborate orthogonal transformations, or by computing separate horizontal and vertical adjustments.
deflection of the vertical	The angular difference between the upward direction of the plumb line (vertical) and the perpendicular (normal) to the ellipsoid.
degrees of freedom	A measure of the redundancy in a network.
delta elevation	The difference in elevation between two points.
delta height	The vertical component in the Trimble Geomatics Office software's expression of GPS baselines. It is the difference in height or change of height.
delta N, delta E, delta U	Coordinate differences expressed in a Local Geodetic Horizon coordinate system.
delta X, delta Y, delta Z	Coordinate differences expressed in a Cartesian coordinate system.
differential positioning	The precise measurement of the relative position of two receivers that are tracking the same satellites simultaneously.
DOP	Dilution of Precision An indicator of the quality of a GPS position. It takes account of each satellite’s location relative to the other satellites in the constellation, and their geometry in relation to the GPS receiver. A low DOP value indicates a higher probability of accuracy.

Standard DOPs for GPS applications are:

PDOP Position (three coordinates)

HDOP Horizontal (two horizontal coordinates)

RDOP

VDOP Vertical (height only)

TDOP Time (clock offset only)

Doppler shift The apparent change in frequency of a signal caused by the relative motion of satellites and the receiver.

double differencing An arithmetic method of differencing carrier phases simultaneously measured by two receivers tracking the same satellites. This method removes the satellite and receiver clock errors.

DTM Digital Terrain Model

An electronic representation of terrain in three-dimensions.

dual-frequency A type of receiver that uses both L1 and L2 signals from GPS satellites. A dual-frequency receiver can compute more precise position fixes over longer distances and under more adverse conditions because it compensates for ionospheric delays.

Earth-Centered-Earth-Fixed (ECEF) A Cartesian coordinate system used by the WGS-84 reference frame. In this coordinate system, the center of the system is at the earth's center of mass. The z axis is coincident with the mean rotational axis of the earth and the x axis passes through 0° N and 0° E. The y axis is perpendicular to the plane of the x and z axes.

easting Eastward reading of grid values. Left to right on a grid (X-axis).

elevation

The height above mean sea level or the vertical distance above the geoid. Elevation is sometimes referred to as the orthometric height.

elevation mask

An angle which is normally set to 13 degrees. If you track satellites from above this angle, you usually avoid interference caused by buildings, trees, and multipath errors.

Trimble recommends that you do not track satellites from below 13 degrees.

ellipsoid

A mathematical model of the earth formed by rotating an ellipse around its minor axis. For ellipsoids that model the earth, the minor axis is the polar axis, and the major axis is the equatorial axis.

You define an ellipsoid by specifying the lengths of both axes, or by specifying the length of the major axis and the flattening.

Two quantities define an ellipsoid; these are usually given as the length of the semi-major axis, a, and the flattening,

$$f = \frac{(a - b)}{a}$$

where b is the length of the semi-minor axis.

ellipsoid distance

As used in the Trimble Geomatics Office software, it is the length of the normal section between two points.

Ellipsoid distance is not the same as the geodesic distance.

ellipsoid height

The distance, measured along the normal, from the surface of the ellipsoid to a point.

entities

Primary graphical elements that you can view and select from the graphics window.

Entities available in the Trimble Geomatics Office software are points, lines, arcs, curves, text, and annotations.

ephemeris

A set of data that describes the position of a celestial object as a function of time. Each GPS satellite periodically transmits a broadcast ephemeris describing its predicted positions through the near future, uploaded by the Control Segment. Postprocessing programs can also use a precise ephemeris that describes the exact positions of a satellite in the past.

epoch

The measurement interval of a GPS receiver. The epoch varies according to the survey type:

For real-time surveys it is set at one second. For postprocessed surveys it can be set to a rate of between one second and one minute

epoch interval

The measurement interval used by a GPS receiver; also called a cycle.

error

The difference between the measured value of a quantity and its true value. Surveying errors are generally divided into three categories: blunders, systematic errors, and random errors. Least squares analysis is used to detect and eliminate blunders and systematic errors, and least squares adjustment is used to measure and properly distribute random error.

error ellipse

A coordinate error ellipse is a graphical representation of the magnitude and direction of the error of network adjusted points.

events A record of the occurrence of an event, such as the closing of a photogrammetric camera's shutter. A GPS receiver can log an event mark containing the time of the event and an alphanumeric comment entered through the keypad to describe the event. An event can be triggered through the keypad or by an electrical signal input on one of the receiver's ports.

FastStatic A method of GPS surveying using occupations of up to 20 minutes to collect GPS raw data, then postprocessing to achieve sub-centimeter precisions. Typically the occupation times vary based on the number of satellites (SVs) in view:

4 SVs take 20 minutes*

5 SVs take 15 minutes*

6 or more SVs take 8 minutes*

(*collected at a 15 second epoch rate)

Feature and Attribute Library (*.fcl) file A text file that contains the definitions of feature codes, attributes, CAD styles, and control codes.

feature codes Descriptive words or abbreviations that describe the features you see.

field codes Special instructions that tell the Trimble Geomatics Office software to insert information into reports, files, and annotations.

Field codes are used to handle the transfer of database data in ASCII import/export/report operations.

final solution
When postprocessing is used to generate GPS vectors, particularly for static solutions, the baseline processor steps through different solutions using a variety of processing techniques and combinations of GPS measurements. In general each subsequent solution is better than the previous one. The final solution provides the best estimate of the GPS vector between two points.

fixed
See constrained.

fixed coordinates
Point coordinates that do not move when performing a network adjustment.

fixed solution
A solution obtained when the baseline processor is able to resolve the integer ambiguity search with enough confidence to select one set of integers over another. It is called a fixed solution because the ambiguities are all fixed from their estimated float values to their proper integer values.

flattening
A mathematical expression of the relative lengths of the major and minor axes of an ellipsoid.

flattening inverse
An expression of the flattening that is easier to read and edit.

float solution
A solution obtained when the baseline processor is unable to resolve the integer ambiguity search with enough confidence to select one set of integers over another. It is called a float solution because the ambiguity includes a fractional part and is non-integer.

free adjustment
Performing a network adjustment in which no point (coordinate) is constrained. The network adjustment uses inner constraints.

frequency distribution
The size and spread of residuals in a data set. Graphically shown in histograms.

fully constrained A network adjustment in which all points in the network which are part of a larger control network are held fixed to their published coordinate values. Used to merge smaller with larger control networks and old to newer networks.

GDOP Geometric Dilution of Precision

The relationship between errors in user position and time, and errors in satellite range. See also DOP.

geodetic azimuth The angle between the geodetic meridian and the tangent to the geodesic line of the observer, measured in the plane perpendicular to the ellipsoid normal of the observer. Clockwise from north.

geodetic datum A mathematical model designed to fit part or all of the geoid. It is defined by the relationship between an ellipsoid and a point on the topographic surface established as the origin of a datum.The size and shape of an ellipsoid and the location of the center of the ellipsoid with respect to the center of the earth define world geodetic datums.

Various datums have been established to suit particular regions. For example, European maps are often based on the European datum of 1950 (ED-50). Maps of the United States are often based on the North American Datum of 1927 or 1983 (NAD-27, NAD-83). All GPS coordinates are based on the WGS-84 datum surface.

geographic (geodetic) coordinates Latitude, longitude, and ellipsoid height.

geoid

The surface of gravitational equipotential that closely approximates mean sea level. It is not a uniform mathematical shape, but is an irregular figure with an overall shape similar to an ellipsoid.

Generally, the elevations of points are measured with reference to the geoid. However, points fixed by GPS methods have heights established in the WGS-84 datum (a mathematical figure).

The relationship between the WGS-84 datum and the geoid must be determined by observation, as there is no single mathematical definition that can describe the relationship. You must use conventional survey methods to observe the elevation above the geoid, then compare the results with the height above the WGS-84 ellipsoid at the same point.

By gathering a large number of observations of the separation between the geoid and the WGS-84 datum (geoidal separation), grid files of the separation values can be established. This allows the interpolation of the geoidal separation at intermediate positions. Files containing these grids of geoidal separations are referred to as geoid models. Given a WGS-84 position that falls within the extents of a geoid model, the model can return the interpolated geoidal separation at this position.

geoid model

A mathematical representation of the geoid for a specific area, or for the whole earth. The software uses the geoid model to generate geoid separations for your points in the network.

geoid observation A geoid separation, with its associated error, extracted from a geoid model. The Trimble Geomatics Office software network adjustment treats them as in the same way as any observation with an associated error. As the adjustment progresses the observations will become adjusted geoid observations.

geoid separation The distance between the ellipsoid and geoid at a given point.

geomatics The design, collection, storage, analysis, display, and retrieval of spatial information. The collection of spatial information can be from a variety of sources, including GPS and terrestrial methods. Geomatics integrates traditional surveying with new technology-driven approaches, making geomatics useful for a vast number of applications.

GPS Global Positioning System

GPS is based on a constellation of 24 satellites orbiting the earth at a very high altitude.

GPS baseline A three-dimensional measurement between a pair of stations for which simultaneous GPS data has been collected and processed with differencing techniques.

Represented as delta X, delta Y, and delta Z; or azimuth, distance, and delta height.

GPS observations A GPS baseline with its associated errors. As the adjustment progresses the observations become adjusted GPS observations.

GPS raw data The data collected by a GPS receiver for the purpose of processing at a later time. It can be in the form of a .dat file (Trimble raw data file format) or a RINEX file.

GPS time	A measure of time used by the NAVSTAR GPS system. GPS time is based on Universal Time Coordinated (UTC) but does not add periodic *leap seconds* to correct for changes in the earth's period of rotation.
grid	A two-dimensional horizontal rectangular coordinate system, such as a map projection.
grid conversion	The conversion between geographic and map projection coordinates.
grid distance	The distance between two points that is expressed in mapping projection coordinates.
ground distance	The distance (horizontal distance with curvature applied) between two ground points.
HDOP	Horizontal Dilution of Precision
height measurement rod	A measuring tool supplied with an external GPS antenna and used for measuring the height of the antenna above a point.
HI	Height of instrument. Synonymous with antenna heights for GPS.
histogram	A graphical display of the size and distribution of residuals in a network adjustment.
horizontal control point	A point with horizontal coordinate accuracy only. The elevation or ellipsoid height is of a lower order of accuracy or is unknown.
horizontal distance	The distance between two points, computed horizontally from the elevation of either point.
horizontal position	A point with horizontal coordinates only.

independent Subnetworks, observations, and control points not connected by geometry or errors. This term is the opposite of correlated.

inner constraint A network adjustment computed without fixing any point coordinates. The Trimble Geomatics Office software uses the centroid of the network as an inner constraint.

integer ambiguity The whole number of cycles in a carrier phase pseudorange between the GPS satellite and the GPS receiver.

integer search GPS baseline processing, whether real-time or postprocessed, requires fixed integer solutions for the best possible results. The software which processes the GPS measurements used to derive a baseline does an integer search to obtain a fixed integer solution. The search involves trying various combinations of integer values and selecting the best results.

iono free Ionospheric free solution (IonoFree)

A solution that uses a combination of GPS measurements to model and remove the effects of the ionosphere on the GPS signals. This solution is often used for high-order control surveying, particularly when observing long baselines.

ionosphere The band of charged particles 80 to 120 miles above the earth's surface. It affects the accuracy of GPS measurements if you measure long baselines using single-frequency receivers.

ionospheric modeling The time delay caused by the ionosphere varies with respect to the frequency of the GPS signals and affects both the L1 and L2 signals differently. When dual frequency receivers are used the carrier phase observations for both frequencies can be used to model and eliminate most of the ionospheric effects. When dual frequency measurements are not available an ionospheric model broadcast by the GPS satellites can be used to reduce ionospheric affects. The use of the broadcast model, however, is not as effective as the use of dual frequency measurements.

iteration A complete set of adjustment computations that includes the formation of the observation equations, normal equations, coordinate adjustments, and computation of residuals.

kinematic surveying A method of GPS surveying using short Stop and Go occupations, while maintaining lock on at least four satellites. Can be done in real time or postprocessed to centimeter precisions.

known point initialization Known point is used in conjunction with kinematic initialization. If two known points are available, the baseline processor can calculate an inverse between the two points and derive an initialization vector. This initialization vector, with known baseline components, is used to help solve for the integer ambiguity. If the processor is able to successfully resolve this ambiguity a fixed integer solution is possible, yielding the best solutions for kinematic surveys.

L1 The primary L-band carrier used by GPS satellites to transmit satellite data. Its frequency is 1575.42 MHz. It is modulated by C/A code, P code, and a Navigation Message.

L2 — The secondary L-band carrier used by GPS satellites to transmit satellite data. Its frequency is 1227.6 MHz. It is modulated by P code and a Navigation Message.

label — Information that you can assign to points in the project. They appear beside points helping you locate them easily. Labels are visible in Survey view and Plan view.

You can use the Trimble Geomatics Office software's predefined label definition to label points (for example, with their names, feature codes, and elevations).

Labels use the same font and size as the ToolTips in your Microsoft Windows Appearance settings.

To assign labels to points in the database, use *View / Point Labels*.

layers — A place to store data that has been grouped together.

Organizing data into layers in this way makes it easier to manage. You can have any number of layers in a project. To assign or reassign an entity to a layer, use the *Properties* window. A layer name can have up to 100 alphanumeric characters.

least squares — A mathematical method for the adjustment of observations, based on the theory of probability. In this adjustment method, the sum of the squares of all the weighted residuals is minimized.

level observation — A level observation is an observation in the field using a digital level.

level of confidence — A measure of the confidence in our results, expressed in a percentage or sigma.

level of significance

An expression of probability. A one-sigma (standard) error is said to have a level of significance of 68 percent. For one-dimensional errors, a 95 percent level of significance is expressed by 1.96 sigma, and a 99 percent level of significance is expressed by 2.576 sigma.

local ellipsoid

The ellipsoid specified by a coordinate system. The WGS-84 coordinates are first transformed onto this ellipsoid, then converted to grid coordinates.

local geodetic coordinates

The latitude, longitude, and height of a point. The coordinates are expressed in terms of the local ellipsoid.

local geodetic horizon

At any point, a plane at the ellipsoid height of a given point which is parallel to the tangent plane to the ellipsoid at that point. Coordinate values for the local geodetic horizon are expressed as North, East, and Up. The LGH is used for rotating EC Cartesian Coordinate differences, before modeling a baseline on the ellipsoid. Azimuth values computed from LGH components must be corrected for skew normals as part of modeling on the ellipsoid.

loop closure

Loop closures provide an indication as to the amount of error in a set of observations within a network.

A loop closure is calculated by selecting a point from which one or more observations were taken, adding one of those observations to the point's coordinates, and calculating coordinates of the second point based on that observation. This process is repeated one or more times around a loop, finally ending at the original starting point. If there were no errors in the observations, the final calculated coordinate would be exactly the same as the original starting coordinate. By subtracting the calculated coordinate from the original coordinate a misclosure is determined. Dividing this error by the length of the line allows the error to be expressed in parts per million.

This technique can also be used between two different points when both points are known with a high degree of accuracy. This is also known as a traverse closure.

major axis See ellipsoid.

mapping angle The angle between grid north on a mapping projection and the meridian of longitude at a given point. Also know as convergence.

mapping projection A rigorous mathematical expression of the curved surface of the ellipsoid on a rectangular coordinate grid.

mean sea level The mean height of the surface of the ocean for all stages of the tide. Used as a reference for elevations.

minimally constrained A network adjustment in which only enough constraints to define the coordinate system are employed. Used to measure internal consistency in observations.

minor axis See ellipsoid.

modeling Expressing an observation and its related errors mathematically and geometrically on some defined coordinate system, such as an ellipsoid.

multipath Interference (similar to *ghosts* on a television screen) that occurs when GPS signals arrive at an antenna after traveling different paths. The signal traveling the longer path yields a larger pseudorange estimate and increases the error. Multiple paths may arise from reflections from structures near the antenna.

narrow-lane A linear combination of L1 and L2 carrier phase observations (L1 + L2) that is useful for canceling out ionospheric effects in collected baseline data. The effective wavelength of the narrow-lane is 10.7 cm.

NAVDATA NAVDATA is the 1500-bit navigation message broadcast by each satellite. This message contains system time, clock correction parameters, ionospheric delay model parameters, and details of the satellite's ephemeris and health. The information is used to process GPS signals to obtain user position and velocity.

network A set of baselines. See also subnetwork.

network adjustment Solution of simultaneous equations designed to achieve closure in a survey network by minimizing the sum of the weighted squares of the residuals of the observations.

The adjustment technique employed by the Trimble Geomatics Office software is sometimes called variation of coordinates, and at other times the method of indirect observations.

network status An indication that a particular observation will be included in the adjustment.

Network means that it is included in the adjustment

Non-network means that it is excluded from the adjustment.

NMEA National Marine Electronics Association

The NMEA 0183 Standard defines the interface for marine electronic navigational devices. This standard defines a number of *strings* referred to as NMEA strings that contain navigational details such as positions.

Most Trimble GPS receivers can output positions as NMEA strings.

normal In geodesy, the straight line perpendicular to the surface of the ellipsoid.

normal distribution curve A graphical illustration of the theoretical distribution of random variables around an expected value according to probability theory. Used with histograms.

northing Northward reading of a grid value.

observation residual The correction applied to an observation, as determined by the adjustment.

observations See surveying observations.

occupation time The amount of time required on a station, or point, to achieve successful process of a GPS baseline. The amount of time will vary depending on the surveying technique, the type of GPS receiver used, and the precision required for the final results. Occupation times can vary from a couple of seconds (kinematic surveys) to several hours (control or deformation surveys that require the highest levels of precision and repeatability).

origin The intersection of axes in a coordinate system. The point of beginning.

orthometric height The distance between a point and the surface of the geoid. It is usually called the elevation.

OTF search method GPS baseline processing, whether real-time or postprocessed, requires fixed integer solutions for the best possible results. (See integer search.)

Historically, this search was done using measurements collected while two or more receivers were stationary on their respective points. Modern receivers and software can use the measurements collected while the roving receiver is moving. Because the receiver is moving, the data is described as collected *On-the-fly* (OTF) and the integer search using this data is an *OTF search*.

outlier An observation which is identified by statistical analysis as having a residual too large for its estimated error. The term derives from the graphical position of an observation in a histogram.

over-determined A network for which more measurements have been made than are necessary to compute the coordinates of the network. Related to redundancy.

P-code The *precise* code transmitted by the GPS satellites. Each satellite has a unique code that is modulated onto both the L1 and L2 carrier waves. The P-code is replaced by a Y-code when Anti-Spoofing is active.

parameter An independent variable in terms of which the coordinates of points on a line or surface are given. See unknowns.

parity A form of error checking used in binary digital data storage and transfer. Options for parity-checking include Even, Odd, or None.

PDOP Position Dilution of Precision

A unitless figure of merit expressing the relationship between the error in user position, and the error in satellite position. Geometrically, PDOP is proportional to 1 divided by the volume of the pyramid formed by lines running from the receiver to four satellites that are observed. Values considered ‘good’ for positioning are small, for example 3. Values greater than 7 are considered poor. Thus, small PDOP is associated with widely separated satellites.

PDOP is related to horizontal and vertical DOP by:

$$\mathrm{PDOP}^2 = \mathrm{HDOP}^2 + \mathrm{VDOP}^2$$

PDOP cutoff A receiver parameter specifying a maximum PDOP value for positioning. When the geometric orientation of the satellites yields a PDOP greater than the mask value, the receiver stops computing position fixes.

PDOP mask The highest PDOP value at which a receiver will compute positions.

phase center See antenna phase correction.

phase center models A model used to apply a correction to a GPS signal based on a specific antenna type. The correction is based on the elevation of the satellite above the horizon and models electrical variations in the antenna phase center location. These models are useful for eliminating errors introduced when identical antennas are not used at both the base and rover points. See also antenna phase correction.

plumbing The act of aligning the antenna or instrument along a vertical line (plumb line) perpendicular to the equipotential surface of earth's gravity field.

point positions See autonomous positioning.

postprocess To process satellite data on a computer after it has been collected.

PPM Parts per million

A standardized representation of a scale error in distance measurements. A 1 PPM error would result in 1 millimeter of measurement error for every 1000 meters of distance traveled.

precise ephemeris See ephemeris.

precision

A measure of how closely random variables tend to cluster around a computed value. High precision implies small residuals. Usually expressed as one part in, or alternatively, as parts per million.

PRN

Pseudorandom number

A sequence of digital 1's and 0's that appear to be randomly distributed like noise, but that can be exactly reproduced. PRN codes have a low autocorrelation value for all delays or lags except when they are exactly coincident.

Each NAVSTAR satellite can be identified by its unique C/A and P pseudorandom noise codes, so the term *PRN* is sometimes used as another name for GPS satellite or SV.

probability

A statistical percentage expressing what portion of a hypothetical number of observations will fall within the defined limits. Sometimes called level of significance.

probable value

The adjusted value for observations and other quantities, assuming that the adjustment has been done correctly. The closest approximation to true value that is possible.

project

The Trimble Geomatics Office software operates on data in projects. You can consider a project to be the workspace you are working in. New projects are always created from existing templates and inherit all the elements of the template. From this point on, all new work is saved only in the new project.

A project contains all of the raw observations, computed points, coordinate system definition, line work, text, and CAD styles.

project datum

The datum associated with a project in the Trimble Geomatics Office software. All local coordinates are displayed using the project datum.

projection Used to create flat maps that represent the surface of the earth or parts of that surface.

propagated error Computed errors derived from estimated observational errors and expressed in terms of coordinate positions. Propagated coordinate errors may, in turn, be propagated into relative errors in azimuth, distance, and delta height between points.

Quality Acceptance test One or more software evaluation tests performed on raw GPS measurement data to determine if the data passes or fails a set of tolerance values that you define. These tests either remove data from further processing or mark data requiring quality improvements.

QC records Quality Control records

QC records contain information about the quality of the measured GPS position. They are stored with the point record.

ratio During initialization, the receiver determines the integer number of wavelengths for each satellite. For a particular set of integers, it works out the probability that it is the correct set.

Ratio is the ratio of the probability of correctness of the currently best set of integers to the probability of correctness of the next-best set. Thus, a high ratio indicates that the best set of integers is much better than any other set. This gives us confidence that it is correct. The ratio must be above 5 for new point and OTF initializations.

RDOP Relative Dilution of Precision

Real-Time kinematic A method of GPS surveying in real-time using short (Stop and Go) occupation, while maintaining lock on at least 4 satellites. This method requires a wireless data link between the base and rover receivers.

rectangular coordinates Coordinates in any system in which the axes of reference intersect at right angles.

reduced column profile An abbreviated version of the normal equations in which the equations are reordered to minimize the computer memory required to store all nonzero elements.

redundancy The amount by which a control network is overdetermined, or has more observations than are needed to strictly compute its parts.

redundancy number A measure of the degrees of freedom in a portion, rather than the entirety, of a control network.

redundant baselines A baseline observed to a point that has already been connected to the network by other observations. A redundant baseline can be either an independent reobservation of a previous measurement, or an observation to a point from another base. It is redundant because it provides more information than is necessary to uniquely determine a point. Redundant observations are very useful, however, in that they provide a check on the quality of previous measurements.

redundant observation A repeated observation, or an observation which contributes to over-determining a network.

reference factor See standard error of unit weight.

reference frame The coordinate system of a datum.

reference station A base station.

reference variance The square of the reference factor.

relative errors Errors and precisions expressed for and between pairs of network-adjusted control points.

residual The correction, or adjustment, of an observation to achieve overall closure in a control network. Also, any difference between an observed quantity and a computed value for that quantity.

RINEX Receiver INdependent EXchange format

A standard GPS raw data file format used to exchange files from multiple receiver manufacturers.

RMS Root Mean Square

RMS expresses the accuracy of point measurement. It is the radius of the error circle within which approximately 70% of position fixes are found. It can be expressed in distance units or in wavelength cycles.

rotated meridian A zone constant for the oblique Mercator mapping projection.

rotation In transformations, an angle through which a coordinate axis is moved around the coordinate system origin.

rover Any mobile GPS receiver and field computer that is collecting data in the field. The position of a roving receiver can be differentially-corrected relative to a stationary base GPS receiver.

RTCM Radio Technical Commission for Maritime Services

A Commission established to define a differential data link for the real-time differential correction of roving GPS receivers. There are two types of RTCM differential correction messages, but all Trimble GPS receivers use the newer Type 2 RTCM protocol.

RTK Real-time kinematic

A type of GPS survey.

satellite geometry Position and movement of GPS satellites during a GPS survey.

scalar In least squares, a value applied to the variances (errors) based on the required level of confidence.

scalar weighting A process of applying a scalar to the estimated errors to achieve proper weighting of the observation. The three types of scalars available in a network adjustment in the Trimble Geomatics Office software are:

Default means that scalar is set to 1.00, initial estimated error remains the same

Alternative means that scalar is set to the Reference Factor of the previous adjustment

User-defined means that you can enter a value for the scalar

The scalar is applied to the observation errors using one of the following methods:

All Observations

Each Observation

Variance Component Groups

scale A multiplier used on coordinate and other linear variables, such as for map projections and transformations.

SDMS Survey Data Management System

A set of format definitions for the storage of survey data. AASHTO maintains this system.

Selective Availability (S/A)	Artificial degradation of the GPS satellite signal by the U.S. Department of Defense. Since 1st May 2000, Selective Availability has been turned off.
semi-major axis	One-half of the major axis.
semi-minor axis	One-half of the minor axis.
session	A period during which one or more GPS receivers log satellite measure data.
set-up error	Errors in tribrach centering or height of instrument at a control point.
sideshot	An observed baseline with no redundancy.
sigma	A mathematical symbol or term for standard error.
single-frequency	A type of receiver that only uses the L1 GPS signal. There is no compensation for ionospheric effects.
site calibration	A process of computing parameters which establishing the relationship between WGS-84 positions (latitude, longitude and ellipsoid height) determined by GPS observations and local known coordinates defined by a map projection and elevations above mean sea level. The parameters are used to generate local grid coordinates from WGS-84 (and vice-versa) real-time in the field when using RTK surveying methods.
skyplot	A polar plot that shows the paths of visible satellites for the time interval selected for the graph. The elevation of the satellite is represented in the radial dimension and the azimuth is shown in the angular dimension. The result depicts the satellite's path as it appears to an observer looking down from a place directly above the survey point.

solution types
A description of both the data and techniques used to obtain baseline solutions from GPS measurements. Typical solution types include descriptions such as code, float, and fixed. These describe techniques used by the baseline processor to obtain a baseline solution. Solution types also may include descriptions such as L1, L2, wide-lane, narrow-lane, or ionospheric free. These describe the way the GPS measurements are combined to achieve particular results. For more information, see the references on GPS processing for a more in depth discussion of these terms and techniques.

slope distance
The distance in the plane parallel to the vertical difference (slope) between the points.

SNR
Signal-to-Noise Ratio

A measure of the strength of a satellite signal. SNR ranges from 0 (no signal) to around 35.

standard error
A statistical estimate of error, according to which 68 percent of an infinite number of observations will theoretically have absolute errors less than or equal to this value.

standard error of unit weight
A measure of the magnitude of observational residuals in an adjusted network as compared to estimated preadjustment observational errors.

State Plane Coordinates
Special definitions of Transverse Mercator and Lambert conformal mapping projections adopted by statute in the USA. There is one set of such zones for NAD-27, and another for NAD-83.

static (surveying)
A method of GPS surveying using long occupations (hours in some cases) to collect GPS raw data, then postprocessing to achieve sub-centimeter precisions.

static network The static network describes the geometry and order in which GPS baselines collected using static and fast static techniques are organized and processed. The baseline processor first examines the project for points with the highest quality coordinates, and then builds the processing network from those points. The result is a set of static baselines that are derived using accurate initial coordinates.

status Every observation and set of keyed-in coordinates for a point has a status field (available in the *Summary* page of the *Properties* window).

The status can be Enabled, Enabled as check, or Disabled:

Enabled observations and coordinates are always used by recomputation in determining the calculated position for the point.

Enabled as check observations and coordinates are only used if there are no Enabled ones

Disabled observations and coordinates are never used.

stochastic model A general reference to the techniques used to estimate errors in a network adjustment.

subnetwork A set of baselines connected together by common control points, and independent of (separate from) any other baselines. As used by the Trimble Geomatics Office software, a network may consist of one or more subnetworks, and any one subnetwork may consist of as few as one baseline and two control points.

Super-trak A Trimble proprietary method of processing the L2 signal when the P-code is encrypted.

surveying observations Measurements made at or between control points using surveying equipment, including GPS receivers and conventional equipment.

SV Satellite Vehicle (or Space Vehicle)

symbols and line types Symbols and line types are maintained using the Trimble Symbol and Line Type Editor utilities. Use these editors to create new symbols and line types as well as to edit existing ones. Symbols are stored in symbol libraries and line types are stored in line type libraries.

The Trimble Geomatics Office software uses the current system symbol and line type libraries. When saving an edited library you can make this the system library (if it is not already the current system library).

systematic errors An error that occurs with the same sign, and often the same magnitude, in a number of related observations.

tau (value) A value computed from an internal frequency distribution based upon the number of observations, degrees of freedom, and a given probability percentage (95%). This value is used to determine if an observation is not fitting with the others in the adjustment. If an observations residual exceeds the tau, it is flagged as an outlier. Known as tau lines in the histogram of standardized residuals, vertical lines left and right of the center vertical line.

tau criterion Allen Pope’s statistical technique for detecting observation outliers. For more information, see Pope (1976).

TDOP Time Dilution of Precision

terrestrial observation A terrestrial observation is an observation in the field using a laser rangefinder or conventional instrument.

TOW
Time of Week

TOW in seconds, from midnight Saturday night/Sunday morning GPS time.

tracking
The process of receiving and recognizing signals from a satellite.

transformation
The rotation, shift, and scaling of a network to move it from one coordinate system to another.

transformation group
A selected group of observations used to compute transformation parameters unique to that group of observations. Typically, the observations within the group are the same type with similar errors and measured using a common method.

transformation parameters
A set of parameters derived for a network adjustment or user-defined, that transform one datum to another. Typically with GPS the parameters are generated to transform WGS-84 to the local datum.

tribrach
Centering device used for mounting GPS antennas and other survey instruments on survey tripods.

tribrach centering errors
The errors associated with centering (plumbing) the tribrach over the observed point. These errors are estimated. The estimate is based on surveying the quality of surveying methods and should be conservative.

tropo correction
Tropospheric correction

The correction applied to a satellite measurement to correct for tropospheric delay.

tropo model

tropospheric model

GPS signals are delayed by the troposphere. The amount of the delay will vary with the temperature, humidity, pressure, height of the station above sea level, and the elevation of the GPS satellites above the horizon. Corrections to the code and phase measurements can be made using a tropo model to account for these delays.

univariate

A mathematical function describing the behavior of one-dimensional random errors, in:

angle

distance

difference in height

elevation

ellipsoid height

URA

User Range Accuracy

A measure of the errors that may be introduced by satellite problems and Selective Availability (S/A) if a particular satellite vehicle (SV) is used. A URA of 32 meters indicates that S/A is enabled. The URA value is set by the Control Segment and is broadcast by the satellites.

unknowns

The computed adjustments to coordinates and transformation parameters. Also used to compute observation residuals.

US National

United States government agency that maintains the national geodetic datum and all geodetic survey control networks within the US and its territories.

US Survey Foot

1200/3937 meter. The official unit of linear measure for NAD-27.

UTC
Universal Time Coordinated

A time standard based on local solar mean time at the Greenwich meridian. See also GPS time.

variance
The square of the standard error.

variance component estimation
A least-squares technique for estimating the relative error of different portions of a network.

variance group
One of the groups of observations for which variance component estimation is being used in a network adjustment.

variance-covariance matrix
The set of numbers expressing the variances and covariances in a group of observations.

VDOP
Vertical Dilution of Precision

vector
A three-dimensional line between two points.

vertical
Similar to the normal, except that it is computed from the tangent plane to the geoid instead of the ellipsoid.

vertical adjustment
A network adjustment of vertical observations and coordinates only.

vertical control point
A point with vertical coordinate accuracy only. The horizontal position is of a lower order of accuracy or is unknown.

WAVE
Weighted Ambiguity Vector Estimator

WAVE is the Trimble baseline processor. It computes GPS vectors from field observations made using static, FastStatic, or kinematic data collection procedures.

weight
The inverse of the variance of an observation.

weighting strategy The collection of values used to augment variance-covariance matrices in the Trimble Geomatics Office software.

weights The set of weights, or the inverse of the variance-covariance matrix of correlated observations.

WGS-84 World Geodetic System (1984)

The mathematical ellipsoid used by GPS since January 1987.

wide-lane A linear combination of L1 and L2 carrier phase observations (L1 – L2). This is useful for its low effective wavelength (86.2 cm) and for finding integer ambiguities on long baselines.

X, Y and Z In the Earth Centered Cartesian system, X refers to the direction of the coordinate axis running from the system origin to the Greenwich Meridian; Y to the axis running from the origin through the 90° east longitude meridian, and Z to the polar ice cap. In rectangular coordinate systems, X refers to the east-west axis, Y to the north-south axis, and Z to the height axis.

Y-code Y-code is an encrypted form of the information contained in the P-code. Satellites transmit Y-code in place of P-code when Anti-Spoofing is in effect.

zenith delay The delay, caused by the troposphere, of a GPS signal observed from a satellite directly overhead. As a satellite approaches the horizon, the signal path through the troposphere becomes longer and the delay increases.

Index

Numerics

A

B

C

D

E

H

I

K

L

M

N

O

P

Q

R

S

T

U

V

W

Reader Comment Form

Trimble Geomatics Office – Network Adjustment User Guide
January 2001 39933-10-ENG Revision A

We appreciate your comments and suggestions for improving this publication.

I use the following Trimble product____

for____

Please circle a response for each of the statements below:

1 = Strongly Agree 2 = Agree 3 = Neutral 4 = Disagree 5 = Strongly Disagree

The manual is well organized.	1	2	3	4	5
I can find the information I want.	1	2	3	4	5
The information in the manual is accurate.	1	2	3	4	5
I can easily understand the instructions.	1	2	3	4	5
The manual contains enough examples.	1	2	3	4	5
The examples are appropriate and helpful.	1	2	3	4	5
The layout and format are attractive and useful.	1	2	3	4	5
The illustrations are clear and helpful.	1	2	3	4	5
The manual is:	too long	just right	too short		

Please answer the following questions:

Which sections do you use the most? ____

What do you like best about the manual? ____

____

What do you like least about the manual? ____

____

Optional

Name ____

Company ____

Address____

____

Telephone______________________________Fax ______________________________

Please mail to the local office listed on the back cover or to Trimble Navigation Limited, Land Survey Division, 645 North Mary Avenue, Post Office Box 3642, Sunnyvale, CA 94088-3642. Alternatively, e-mail your comments and suggestions to ReaderFeedback@trimble.com. All comments and suggestions become the property of Trimble Navigation Limited.