

Chapter 11 Adjustment of GPS Surveys

11-1. General

Differential carrier phase GPS survey observations are adjusted no differently than conventional, terrestrial EDM surveys. Each three-dimensional GPS baseline vector is treated as a separate distance observation and adjusted as part of a trilateration network. A variety of techniques may be used to adjust the observed GPS baselines to fit existing control. Since GPS survey networks often contain redundant observations, they are usually adjusted by some type of rigorous least-squares minimization technique. This chapter describes some of the methods used to perform GPS survey adjustments and provides guidance in evaluating the adequacy and accuracy of the adjustment results.

11-2. Adjustment Considerations

a. This chapter primarily deals with the adjustment of horizontal control established using GPS observations. Although vertical elevations are necessarily carried through the baseline reduction and adjustment process, the relative accuracy of these GPS-derived elevations is normally inadequate for many engineering and construction purposes. Special techniques and constraints are necessary to determine approximate orthometric elevations from relative GPS observations, as were described in Chapter 8.

b. The baseline reduction process (described in Chapter 10) directly provides the raw baseline distances and relative position coordinates that are used in a 3-D GPS network adjustment. In addition, and depending on the vendor's software, each reduced baseline will contain various orientation parameters, covariance matrices, and cofactor and/or correlation statistics that may be used in weighting the final network adjustment. Most least-squares adjustments use the accuracy or correlation statistics from the baseline reductions; however, other weighting methods may be used in a least-squares or approximate adjustment.

c. The adjustment technique employed (and time devoted to it) must be commensurate with the intended accuracy of the survey, as defined by the project's engineering and construction requirements. Care must be taken to prevent the adjustment process from becoming a project in itself.

d. There is no specific requirement that a rigorous least-squares type of adjustment be performed on USACE surveys, whether conventional, GPS, or mixed observations. Traditional approximate adjustment methods may be used in lieu of least-squares, and will provide comparable practical accuracy results.

e. Commercial software packages designed for higher-order geodetic densification surveys often contain a degree of statistical sophistication that is unnecessary for engineering survey control densification. For example, performing repeated Chi-square statistical testing on observed data intended for 1:20,000 base mapping photogrammetric control may be academically precise but, from a practical engineering standpoint, is inappropriate. The distinction between geodetic surveying and engineering surveying must be fully considered when performing GPS survey adjustments and analyzing the results thereof.

f. The advent of GPS surveying technology has provided a cost-effective means of tying previously poorly connected USACE projects to the NGRS, and simultaneously transforming the project to the newly defined NAD 83. In performing (adjusting) these connections, care must be taken not to

distort or warp long-established project construction/boundary reference points. Connections and adjustments to existing control networks, such as the NGRS, must not become independent projects. It is far more important to establish dense and accurate local project control than to consume resources tying into high-order NGRS points miles from the project. Engineering, construction, and property/boundary referencing requires consistent local control with high relative accuracies; accurate connections/references to distant geodetic datums are of secondary importance. (Exceptions might involve projects in support of military operations.)

11-3. GPS Error Measurement Statistics

In order to understand the adjustment results of a GPS survey network (or any network containing GPS, angle, distance, and/or elevation observations), some simple statistical terms should be fully understood. Many of these terms have varying names in different commercial software adjustment packages, as indicated below.

- *Accuracy.* Accuracy is the how well a measurement or a group of measurements are in relation to a "true" or "known" value.
- *Precision.* Precision is how close a group or sample of measurements are to each other or their mean. For example, a low standard deviation indicates high precision. It is important to understand that a survey or group of measurements can have a high precision, but have a low accuracy (i.e. measurements are close together but not close to the known or true value).
- *Standard deviation.* Also termed "standard error." The standard deviation is a range of how close the measured values are from the arithmetic average. A low standard deviation indicates that the observations or measurements are close together. Standard deviation is computed by taking the square root of the variance. *A priori* observation weights are inversely proportional to the estimated variance. A large weight implies a small variance or standard deviation. Deviations can be reported at different confidence levels--e.g., 67%, 95%.
- *A priori weighting.* The initial weighting assigned to an observation. The *a priori* weight is based on past experience of resultant accuracies in network adjustments, or from manufacturer's estimates. For example, past adjustment results from a certain total station indicate it can measure angles to an accuracy of ± 7 arc-seconds ($1-\sigma$). The *a priori* weighting used in subsequent adjustments would be $1/(7^2)$, or 0.02. (Weights are inversely proportional to the variance). Weights from independent observations are usually uncorrelated. However, they may be correlated, as is the case with GPS baseline vector components.
- *Least-squares adjustment.* One of the most widely used methods for adjusting geodetic and photogrammetric surveys. Least-squares adjustments provide a structured approach as opposed to approximate adjustment techniques. The principle of least-squares is simply:

$$\sum [\mathbf{V}^T \mathbf{P} \mathbf{V}] \rightarrow \text{minimum}$$

where \mathbf{V} is the matrix of the residuals (\mathbf{V}^T is the transpose of \mathbf{V})
 \mathbf{P} is the "weight" matrix of the observations

If there are " n " observations, then there will be " n " residuals (v) and the weight matrix will be " $n \times n$ " square, containing variations within, and correlations between, the individual observations.

- *Residual.* Difference between a computed (i.e. adjusted) and observed quantity ... often designated as "(c-o)" for "computed minus observed". The residual for a single observation is symbolized as " v " or, for a group of " n " observations, " \mathbf{V} " is a [$n \times 1$] column matrix. The computed value typically is output from a least-squares adjustment. From this adjusted value the original observation is subtracted to obtain the residual.
- *Standardized or Normalized residual.* Allows for a consistent evaluation of different types of observations (GPS 3-D baseline vectors, angles, EDM distances, elevation differences, etc.) in order to flag potential outlier observations. For each observation, most commercial adjustment software lists the resultant residuals in their original units (meters, degrees, etc.) and then "normalizes" these residuals by multiplying the residual " v " by the square root of the input weight of the observation (or by the adjusted standard error of the observation).

$$\text{Normalized or standardized residual} = v / \sigma = v \cdot \sqrt{w}$$

$$\text{where the "weight" } w = 1/(\sigma^2)$$

Normalized residuals are unitless. Some software (e.g., Trimble Geomatics Office) use normalized residuals to plot histograms that depict the relative magnitude of the distribution of the residuals, from which outlier tests (i.e. Student "t" or "Tau") can be performed.

- *Covariance matrix.* Also termed the "variance-covariance matrix." Usually designated by the term " \mathbf{S} ". The covariance matrix contains variance elements for a three-dimensional vector or observation, such as a GPS baseline. A GPS baseline covariance matrix contains the variances and correlations in all three dimensions. It is typically output from the baseline reduction software and input into a least-squares network adjustment for use in forming *a priori* weight factors. Covariance matrices are also generated for all points and lines in a free or constrained network adjustment. Covariance matrices contain the parameters needed to portray 1-D estimated errors, 2-D error ellipses, or 3-D error ellipsoids, and include the parameters needed to compute related RMS and confidence level statistics.
- *Degrees of Freedom.* Typically designated by the symbol " r ." Simply, the number of redundant observations in an adjustment, which, in turn, is a function of the number of conditions and unknowns in the network.
- *Variance of Unit Weight.* Also termed "reference variance" or "variance factor." Usually designated by the symbol " s_0^2 " and is computed from:

$$s_0^2 = \mathbf{V}^T \mathbf{P} \mathbf{V} / r$$

where r = the degrees of freedom

This statistic is important in evaluating the results of an adjustment. It represents the overall ratio of variance of all the residuals in a network adjustment relative to the *a priori* variance estimate. It is used for testing *a priori* weighting estimates of the observations relative to the actual variations resulting in the least-squares adjustment. Reference variances around 1.0

indicate the observations conformed to the nominal estimated accuracy. Large reference variances typically indicate one or more poor observations in the adjustment.

- *Standard error of unit weight.* The square root of the "Variance of Unit Weight" is termed the "reference standard deviation," "reference factor," or "standard error of unit weight."
- *Chi-square test.* Statistical hypothesis test on the computed reference variance in a network of observations relative to the *a priori* estimate; for a given level of significance (e.g., 95%) and degrees of freedom. Chi-square is computed directly from the residuals and weights in the least-squares adjustment and an assumed *a priori* reference variance. Many commercial software packages use the Tau criterion test, which is derived from a standard Student t-distribution, and is used to test the statistical significance of outliers in the residuals.
- *Error ellipse.* Graphical depiction of a point's geometric accuracy and alignment. Relative accuracy ellipses may also be shown for GPS baseline distances. Error ellipses are normally plotted at the 95% confidence level, meaning a 95% probability exists that the resultant adjusted point falls within the dimensions of the ellipse. Two and three-dimensional ellipsoids of constant probability may be output in an adjustment.
- *Root mean square (RMS).* Also termed "mean square error." In one dimension (e.g., X, Y, or Z) RMS is equivalent to standard deviation. In two dimensions, RMS is a radial measure approximating the probability of an error ellipse. RMS is usually stated at the 95% probability level. RMS may include both random and systematic errors.
- *Free or Minimally Constrained network adjustment.* Also termed "internal adjustment." A free network adjustment normally holds only one point fixed, which allows assessment of all the observations. Distinctions between "free" and "minimally constrained" adjustments are made by some software vendors.
- *Constrained Adjustment.* Also termed "external adjustments." A constrained adjustment holds two or more points, azimuths, scales, etc. fixed and constrains all the observations to these fixed values. Constrained points may be held rigid or may be weighted.

For further information on the principles and theory of least-squares adjustments, and the statistics resulting from these adjustments, consult Leick 1995 or Mikhail 1976. For more practical discussions on these statistical concepts, see Trimble 2001c (*Trimble Geomatics Office--Network Adjustment Software User Guide*).

11-4. Survey Adjustments and Accuracy

GPS-performed surveys are usually adjusted and analyzed relative to their internal consistency and external fit with existing control. The internal consistency adjustment (i.e. free or minimally constrained adjustment) is important from a contract compliance standpoint. A contractor's performance should be evaluated relative to this adjustment. The final, or constrained, adjustment fits the GPS survey to the existing network. This is not always easily accomplished since existing networks often have lower relative accuracies than the GPS observations being fit. Evaluation of a survey's adequacy should not be based solely on the results of a constrained adjustment.

a. General. The accuracy of a survey (whether performed using conventional or GPS methods) is a measure of the difference between observed values and the true values (coordinates, distances, angles,

etc.). Since the true values are rarely known, only estimates of survey accuracy can be made. These estimates may be based on the internal observation closures, such as on a loop traverse, or connections with previously surveyed points assumed to have some degree of reliability. The latter case is typically a traverse (GPS or conventional) between two previously established points, either existing USACE project control or the published NGRS network.

(1) GPS internal accuracies are typically far superior to most previously established control networks. Therefore, determining the accuracy of a GPS survey based on misclosures with external points is not always valid unless statistical accuracy estimates (i.e. station variance-covariance matrices, distance/azimuth relative accuracy estimates, etc.) from the external network's original adjustment are incorporated into the closure analysis for the new GPS work. Such geodetic refinements are usually unwarranted for most USACE work.

(2) Most survey specifications and standards (including USACE) classify accuracy as a function of the resultant relative accuracy between two adjacent points in a network. This resultant accuracy is estimated from the statistics in an adjustment, and is defined by the size of a 2-D or 3-D relative error ellipse formed between the two points. Relative distance, azimuth, or elevation accuracy specifications and classifications are derived from this model, and are expressed either in absolute values (e.g., ± 1.2 cm) or as ratios of the propagated standard errors to the overall length (e.g., 1:20,000).

b. Internal accuracy. A loop traverse originating and ending from a single point will have a misclosure when observations (i.e. EDM traverse angles/distances or GPS baseline vectors) are computed forward around the loop back to the starting point. The forward-computed misclosure provides an estimate of the relative or internal accuracy of the observations in the traverse loop, or more correctly, the internal precision of the survey. This is perhaps the simplest method of evaluating the adequacy of a survey, and most commercial GPS adjustment software contains loop closure checks. These loop point misclosures, either expressed as distances or ratios, are not the same as relative distance accuracy measures.

(1) Internal accuracy estimates made relative to a single fixed point are obtained when so-called free, unconstrained, or minimally constrained adjustments are performed. In the case of a single loop, no redundant observations (or alternate loops) back to the fixed point are available. When a series of GPS baseline loops (or network) are observed, then the various paths back to the single fixed point provide multiple position computations, allowing for a statistical analysis of the internal accuracy of not only the position closure but also the relative accuracies of the individual points in the network (including relative distance and azimuth accuracy estimates between these points). The magnitude of these internal relative accuracy estimates (on a free adjustment) determines the adequacy of the control for subsequent design, construction, and mapping work.

(2) Loop traverses are discouraged for most conventional surveys due to potential systematic distance (scale) or orientation errors that can be carried through the network undetected. FGDC classification standards for geodetic surveys do not allow traverses to start and terminate at a single point. Such procedures are unacceptable for incorporation into the NGRS network; however, due to many factors (primarily economic), loop traverses or open-ended spur lines are commonly employed in densifying project control for engineering and construction projects. Since such control is not intended for inclusion in the NGRS and usually covers limited project ranges, such practices have been acceptable. Loop traverses will also be acceptable for GPS surveys performed in support of similar engineering and construction activities.

c. External accuracy. The coordinates (and reference orientation) of the single fixed starting point will also have some degree of accuracy relative to the network in which it is located, such as the

NGRS, if it was established relative to that system/datum. This "external" accuracy (or inaccuracy) is carried forward in the traverse loop or network; however, any such external variance (if small) is generally not critical to engineering and construction. When a survey is conducted relative to two or more points on an existing reference network, such as USACE project control or the NGRS, misclosures with these fixed control points provide an estimate of the "absolute" accuracy of the survey. This analysis is usually obtained from a final adjustment, such as a fully constrained least-squares minimization technique or by other recognized traverse adjustment methods (Transit, Compass, Crandall, etc.).

d. NGRS versus local project control. Classical geodetic surveying is largely concerned with absolute accuracy, or the best-fitting of intermediate surveys between points on a national network, such as the NGRS. Alternatively, in engineering and construction surveying, and to a major extent in boundary surveying, relative, or local, accuracies are more critical to the project at hand. As was outlined in Chapter 8, the absolute NAD 27 or NAD 83 coordinates (in latitude and longitude) relative to the NGRS datum reference are of less importance; however, accurate relative coordinates over a given project reach (channel, construction site, levee section, etc.) are critical to design and construction. This absolute accuracy estimate assumes that the fixed (existing) control is superior to the survey being performed, and that any position misclosures at connecting points are due to internal observational errors and not the existing control. This has always been a long-established and practical assumption, and has considerable legal basis in property/boundary surveying. New work is rigidly adjusted to existing control regardless of known or unknown deficiencies in the fixed network.

(1) For example, in establishing basic mapping and construction layout control for a military installation, developing a dense and accurate internal (or relative) control network is far more important than the values of these coordinates relative to the NGRS.

(2) On flood control and river and harbor navigation projects, defining channel points must be accurately referenced to nearby shore-based control points. These points, in turn, directly reference boundary/right-of-way points and are also used for dredge/construction control. Absolute coordinates (NGRS/NAD 83) of these construction and/or boundary reference points are of less importance.

(3) Although reference connections with the NGRS are desirable and recommended, and should be performed where feasible and practicable, it is critical that such connections (and subsequent adjustments thereto) do not distort the internal (relative) accuracy of intermediate points from which design, construction, and/or project boundaries are referenced.

(4) Connections and adjustments to distant networks (i.e. NGRS) can result in mixed datums within a project area, especially if not all existing project control has been tied in. This in turn can lead to errors and contract disputes during both design and construction. On existing projects with long-established reference control, connections and adjustments to outside reference datums/networks should be performed with caution. The impacts on legal property and project alignment definitions must also be considered prior to such connections.

(5) On newly authorized projects, or on projects where existing project control has been largely destroyed, reconnection with the NGRS is highly recommended. This will ensure future work will be supported by a reliable and consistent basic network, while minimizing errors associated with mixed datums.

(6) Since the relative positional accuracies of points on the NGRS are known from the NAD 83 readjustment, and GPS baseline vector accuracy estimates are obtained from the individual reductions, variations in misclosures in GPS surveys are not always due totally to errors in the GPS work. Forcing a

GPS traverse/network to rigidly fit the existing (fixed) network usually results in a degradation of the internal accuracy of the GPS survey, as compared with a free (unconstrained) adjustment.

11-5. Free or Minimally Constrained Adjustments

This adjustment is made to determine how well the baseline observations fit or internally close within themselves. This adjustment provides a measure of the internal precision of the survey. If a network of GPS and terrestrial observations is minimally constrained, internal observation errors can be assessed independent of external control points. The minimally constrained adjustment is performed to find and remove poor quality observations (outliers). It also may be used to readjust the *a priori* weights for each observation (or types of observations) should the adjustment results indicate that the estimated weights were inaccurate. The flexibility to perform these adjustments depends on the software used. Other terrestrial EDM distances or angles may also be included in the adjustment.

a. In a simplified example, a conventional EDM traverse that is looped back to the starting point will misclose in both azimuth and position, as shown in Figure 11-1. Classical "approximate" adjustment techniques (e.g., Transit, Compass, Bowditch, Crandall, etc.) will typically assess the azimuth misclosure, proportionately adjust the azimuth misclosure (usually evenly per station), recompute the traverse with the adjusted azimuths, and obtain a position misclosure. This position misclosure (in X and Y) is then distributed among all the points on the traverse using various weighting methods (distance, latitudes, departures, etc.). Final adjusted azimuths and distances are then computed from grid inverses between the adjusted points. The adequacy/accuracy of such a traverse is evaluated based on the azimuth misclosure and position misclosure after azimuth adjustment (usually expressed as a ratio to the overall length of the traverse).

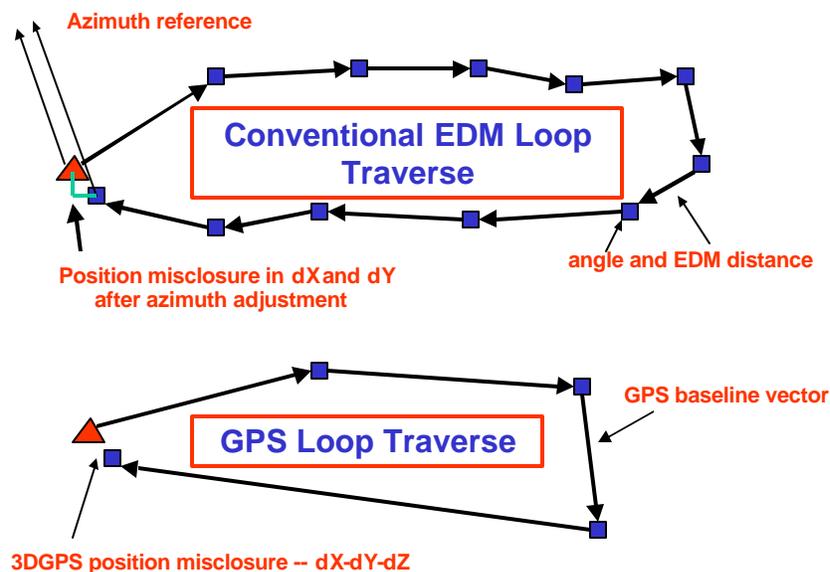


Figure 11-1. Conventional EDM and GPS traverse loops

b. A least-squares adjustment of the same conventional loop traverse will end up adjusting the points similarly to the approximate methods traditionally employed. The only difference is that a least-squares adjustment simultaneously adjusts both observed angles (or directions) and distance measurements. A least-squares adjustment also allows variable weighting to be set for individual angle/distance observations, which is a somewhat more complex process when approximate adjustments are performed. In addition, a least-squares adjustment will yield more definitive statistical results of the internal accuracies of each observation and/or point, rather than just the final closure. This includes estimates of the accuracies of individual station X-Y coordinates, relative azimuth accuracies, and relative distance accuracies.

c. A series of GPS baselines forming a loop off a single point can be adjusted and assessed similarly to a conventional EDM traverse loop described above (Figure 11-1). The baseline vector components may be computed (accumulated) around the loop with a resultant three-dimensional misclosure back at the starting point. These misclosures (in X, Y, and Z) may be adjusted using either approximate or least-squares methods. The method by which the misclosure is distributed among the intermediate points in the traverse is a function of the adjustment weighting technique.

(1) In the case of a simple EDM traverse adjustment, the observed distances (or position corrections) are weighted as a function of the segment length and the overall traverse length (Compass Rule), or to the overall sum of the latitudes/departures (Transit Rule). Two-dimensional EDM distance observations are not dependent on their direction; that is, a distance's X- and Y-components are uncorrelated.

(2) GPS baseline vector components (in X, Y, and Z) are correlated due to the geometry of the satellite solution; that is, the direction of the baseline vector is significant. Since the satellite geometry is continuously changing, remeasured baselines will have different correlations between the vector components. Such data are passed down from the baseline reduction software for use in the adjustment.

d. The magnitude of the misclosure (i.e. loop closure) of the GPS baseline vectors at the initial point provides an estimate of the internal precision or geometric consistency of the loop (survey). When this misclosure is divided by the overall length of the baselines, an internal relative accuracy estimate results. For example, if the position misclosure of a GPS loop is 0.08 m and the length of the loop is 8,000 m, then the loop closure is $0.08/8,000$ or 1 part in 100,000 (1:100,000). This misclosure ratio should not be less than the relative distance accuracy classification intended for the survey.

e. When an adjustment is performed, the individual corrections/adjustments made to each baseline--the residual errors--provide an accuracy assessment for each baseline segment. A least-squares adjustment can additionally provide relative distance accuracy estimates for each line, based on standard error propagations between adjusted points. This relative distance accuracy estimate is most critical to USACE engineering and construction work, and represents the primary basis for assessing the acceptability of a survey.

11-6. Fully Constrained Adjustments

The internal "free" geometric adjustment provides adjusted positions relative to a single, often arbitrary, fixed point. Most surveys (conventional or GPS) are connected between existing stations on some predefined reference network or datum. These fixed stations may be existing project control points (on NAD 27--SPCS 27) or stations on the NGRS (NAD 83). In OCONUS locales, other local or regional reference systems may be used. A constrained adjustment is the process used to best fit the survey observations to the established reference system.

a. A simple conventional EDM traverse (Figure 11-2) between two fixed stations best illustrates the process by which comparable GPS baseline vectors are adjusted. The misclosure in azimuth and position between the two fixed end points may be adjusted by any type of approximate or least-squares adjustment method. Unlike a loop traverse, however, the azimuth and position misclosures are not wholly dependent on the internal errors in the traverse--the fixed points and their azimuth references are not absolute, but contain relative inaccuracies with respect to one another.

b. A GPS survey between the same two fixed points also contains a 3-D position misclosure. Due to positional uncertainties in the two fixed network points, this misclosure may (and usually does) far exceed the internal accuracy of the raw GPS observations. As with a conventional EDM traverse, the 3-D misclosures may be approximately adjusted by proportionately distributing them over the intermediate points. A least-squares adjustment will also accomplish the same thing.

c. If the GPS survey is looped back to the initial point, the free adjustment misclosure at the initial point may be compared with the apparent position misclosure with the other fixed point. In Figure 11-2, the free adjustment loop misclosure is 0.2 ft or 1:100,000, whereas the 2-ft misclosure relative to the two network control points is only 1:5,000. Thus, the internal relative accuracy of the GPS survey is on the order of 1 part in 100,000 (based on the misclosure); if the GPS baseline observations are constrained to fit the existing control, the 2-ft external misclosure must be distributed amongst the individual baselines to force a fit between the two end points.

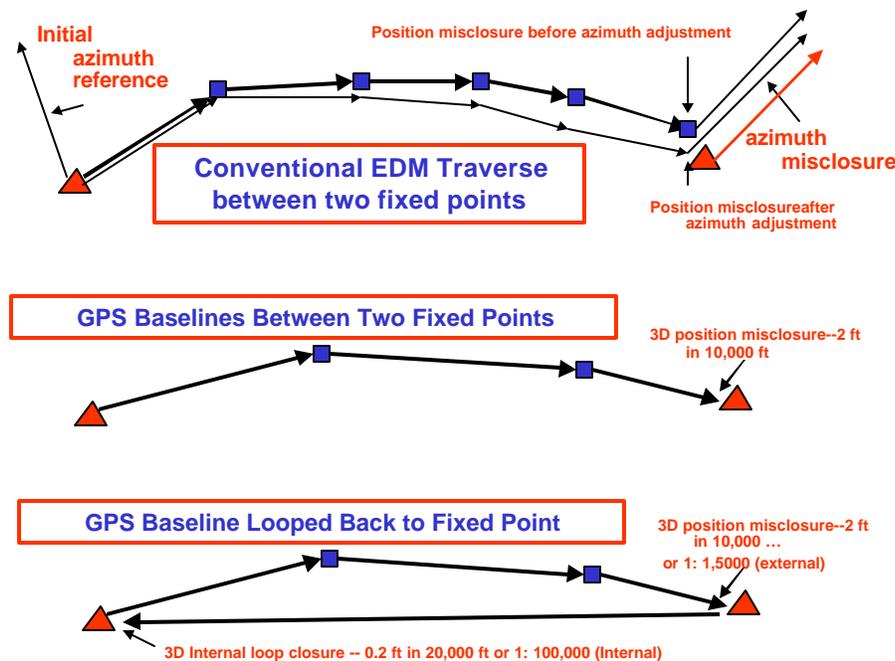


Figure 11-2. Constrained adjustments between two fixed points

(1) After a constrained adjustment, the absolute position misclosure of 2 ft causes the relative distance accuracies between individual points to degrade. They will be somewhat better than 1:5,000 but far less than 1:100,000. The statistical results from a constrained least-squares adjustment will provide estimates of the relative accuracies between individual points on the traverse.

(2) This example also illustrates the advantages of measuring the baseline between fixed network points when performing GPS surveys, especially when weak control is suspected (as in this example).

(3) Also illustrated is the need for making additional ties to the existing network. In this example, one of the two fixed network points may have been poorly controlled when it was originally established, or the two points may have been established from independent networks (i.e. were never connected). A third or even fourth fixed point would be beneficial in resolving such a case.

d. If the intent of the survey shown in Figure 11-2 was to establish 1:20,000 relative accuracy control, connecting between these two points obviously will not provide that accuracy given the amount of adjustment that must be applied to force a fit. For example, if one of the individual baseline vectors was measured at 600 m and the constrained adjustment applied a 0.09 m correction in this sector, the relative accuracy of this segment would be roughly 1:6,666. This distortion would not be acceptable for subsequent design/construction work performed in this area.

e. Most GPS survey networks are more complex than the simple traverse example in Figure 11-2. They may consist of multiple loops and may connect with any number of control points on the existing network. In addition, conventional EDM, angles, and differential leveling measurements may be included with the GPS baselines, resulting in a complex network with many adjustment conditions.

11-7. Partially Constrained Adjustments

In the previous example of the simple GPS traverse, holding the two network points rigidly fixed caused an adverse degradation in the GPS survey, based on the differences between the free (loop) adjustment and the fully constrained adjustment. An alternative is to perform a semi-constrained (or partially constrained) adjustment of the net. In a partially constrained adjustment, the two network points are not rigidly fixed but only partially fixed in position. The degree to which the existing network points are constrained may be based on their estimated relative accuracies or, if available, their original adjustment positional accuracies (covariance matrices). Partially constrained adjustments are not practicable using approximate adjustment techniques; only least-squares will suffice.

a. For example, if the relative distance accuracy between the two fixed network points in Figure 11-2 is approximately 1:10,000, this can be equated to a positional uncertainty between them. Depending on the type and capabilities of the least-squares adjustment software, the higher accuracy GPS baseline observations can be "best fit" between the two end points such that the end points of the GPS network are not rigidly constrained to the two original control points but will end up falling near them.

b. Some (but not all) commercial adjustment software will allow relative weighting of the fixed points to provide a partially constrained adjustment. Any number of fixed points can be connected to, and these points may be given partial constraints in the adjustment. Fixed control points are partially constrained by setting the standard error to varying amounts. A large standard error (i.e. low relative weight) would be set for uncertain accuracy points. A small standard error would be set for high accuracy points, such as a published NGRS point or First-Order level line benchmark. To effectively fix a rigid point in a network, its standard error can be set extremely low--e.g., ± 0.01 mm.

c. Performing partially constrained adjustments (as opposed to a fully constrained adjustment) takes advantage of the inherent higher accuracy GPS data relative to the existing network control, which is traditionally weak on many USACE project areas. Less warping of the GPS data (due to poor existing networks) will then occur.

d. A partial constraint also lessens the need for performing numerous trial-and-error constrained adjustments in attempts to locate the poor external control points that are causing high residuals. Fewer ties to the existing network need be made if the purpose of such ties was to find a best fit on a fully constrained adjustment.

e. When connections are made to the NAD 83 or NAVD 88, relative accuracy estimates of NGRS stations can be obtained from the NGS. Depending on the type of adjustment software used, these partial constraints may be in the form of variance-covariance matrices, error ellipses, or circular accuracy estimates.

11-8. Rigorous Least-Squares Adjustments of GPS Surveys

Adjustment of survey networks containing GPS baselines and/or conventional observations is typically a trial-and-error process for both the free (minimally constrained) and fully constrained adjustments. A generalized flow for performing the adjustment is shown in Figure 11-3. Once the baselines have been reduced and meet acceptable criteria, then the "free" or "minimally constrained" adjustment is performed, holding one point fixed. Individual network observations may be reweighted during this phase. The next step is to include all the fixed-point constraints in a network and perform the "fully constrained" adjustment. These "fixed" points may be partially or fully constrained, depending on their estimated accuracy. Adjustments are performed on the project's horizontal and vertical datums. This requires transforms from the satellite-based WGS 84 earth-centered, earth-fixed, geocentric coordinates. Typically, transforms are performed from WGS 84 to NAD 83 or NAD 27 horizontal systems, and to a local vertical network that may be based on NGVD 29, NAVD 88, or some other local vertical datum. Geoid models may also be added to the adjustment. Performing these accurate datum transforms is critical. Final adjusted coordinates are output, along with relative accuracies.

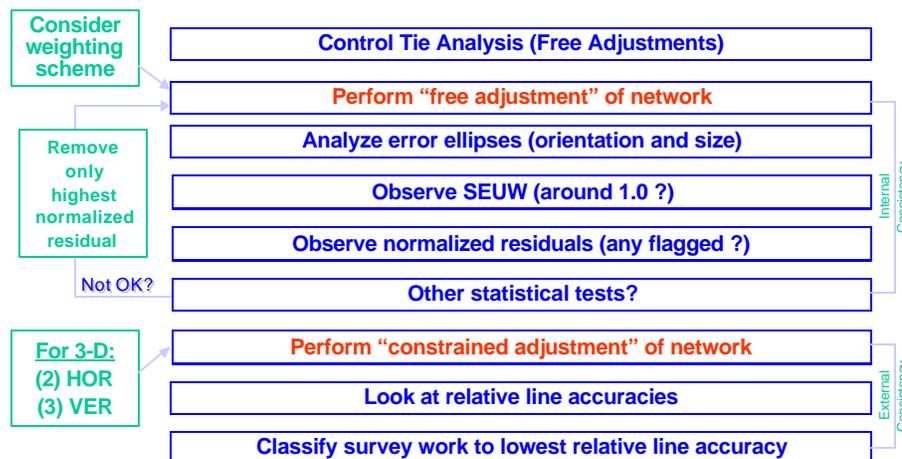


Figure 11-3. Sequential flow of a GPS network adjustment

The following is a summary of a network adjustment sequence recommended by NGS for surveys that are connected to the NGRS:

- A minimally constrained 3-D adjustment is done initially as a tool to validate the data, check for blunders and systematic errors, and to look at the internal consistency of the network.
- A 3-D horizontal constrained adjustment is performed holding all previously published horizontal control points fixed and one height constraint. If the fit is poor, then a readjustment is considered. All previous observations determining the readjusted stations are considered in the adjustment.
- A fully constrained vertical adjustment is done to determine the orthometric heights. All previously published benchmark elevations are held fixed along with one horizontal position in a 3-D adjustment. Geoid heights are predicted using the latest model.
- A final free adjustment to obtain final accuracy estimates using the rescaled variance factor from the fully constrained adjustment.

The last step is usually not applicable to Corps projects since few points are established for incorporation in the national network. The above sequence used by NGS differs somewhat with adjustment techniques recommended by other commercial software vendors. For example, some recommend that the constrained adjustment be performed by sequentially adding fixed control points. Other variations also exist. For most engineering and construction work, many of the sophisticated adjustment procedures and techniques are not relevant to the project accuracy requirements.

11-9. Network Adjustment Software Used in Corps

A number of commercial and government least-squares adjustment software packages are available that will adjust GPS networks using standard desktop or laptop computers. Those commonly used by USACE Commands include the following:

- "ADJUST," an adjustment program distributed by the National Geodetic Survey.
- "Ashtech Solutions," distributed by Thales Navigation LTD.
- "GeoLab," distributed by Microsearch, Inc.
- "GPSurvey," distributed by Trimble Navigation LTD.
- "GrafNav/GrafNet," distributed by Waypoint Consulting Inc.
- "SKI Pro," distributed by Leica Geosystems, Inc.
- "STAR*NET, STAR*NET PRO, and STAR*LEV," distributed by Starplus Software, Inc.
- "Trimble Geomatics Office (TGO)," distributed by Trimble Navigation LTD.

The above software packages have varying applications in USACE. Some are more applicable to traditional static or kinematic GPS surveys and others allow incorporation of terrestrial observations and GPS observations. Some are designed to support airborne GPS (ABGPS) control where velocity and inertial measurement units (IMU) are included. USACE commands selecting network adjustment

software need to evaluate many factors, including cost, which varies if mixed terrestrial and GPS adjustments are opted and baseline reduction is included. As a result, costs can vary widely--from \$1,000 to over \$15,000. Complexity of the software is also a consideration. Some software is designed to support high-order geodetic network adjustments and may be overly complex for engineering and construction surveys. In general, all these packages perform a standard least-squares adjustment; however, adjustment algorithms, weighting strategies, and statistical terminology can vary among vendors. As a result, identical input data may yield slightly different results when run through different adjustment software. In general, using baseline reduction and adjustment software developed by the same GPS receiver/data collector manufacturer is the best approach if a District has identical receivers; however, there are exceptions. To help in evaluating adjustment software, sample adjustment output from some vendors are given throughout this chapter and in various appendices attached to this manual. Many of these examples contain annotations explaining input and output parameters specific to the software. Trade publications (e.g., "*Point of Beginning--POB*") periodically publish comparisons between different adjustment software systems. These comparisons can also be of value in evaluating which adjustment software best meets an application.

11-10. Network Adjustment Criteria

When a least-squares adjustment is performed on a network of GPS observations, most adjustment software will provide the adjusted 2-D or 3-D coordinate data, positional accuracy estimates of adjusted points, covariance matrix (error ellipse) data for the adjusted coordinates, and related baseline covariance data between adjusted points (i.e. relative line distance and azimuth accuracy estimates). Analyzing these various statistics is not always simple. These statistics are also easily misinterpreted given the varied weighting and confidence interval options. Arbitrary rejection and readjustment in order to obtain a best fit (or best statistics) must be avoided. The original data reject criteria must be established and justified in a final report document. Recommended criteria that should be followed are summarized in Table 11-1 and more fully explained in subsequent sections of this chapter.

Table 11-1. Free and Constrained Least-Squares Network Adjustment Criteria

Criterion	
Evaluation statistic on free/unconstrained adjustment	relative distance accuracies
Error ellipse size	95%
Reject Criteria:	
Statistic	normalized residual
Standard	± 3 times standard error of unit weight
Optimum/Nominal Weighting:	± 2 cm + 2 ppm
Optimum Variance of Unit Weight (Free Adjustment)	between 0.5 and 1.5
Allowable Variance of Unit Weight (Free Adjustment)	between 2.0 and 10
Allowable Variance of Unit Weight (Constrained Adjustment)	no specific criteria

11-11. Baseline Weights--Covariance Matrix

Baseline reduction vector component error statistics are usually carried down into the least-squares adjustment and used for relative weighting of the observations. Relative GPS baseline standard errors can be obtained from the baseline reduction output and in some software can be directly input into the adjustment. These standard errors, along with their correlations, are given for each vector component (in geocentric ΔX , ΔY , and ΔZ). They are converted to relative weights in the adjustment. A typical baseline vector and covariance matrix input (from GrafNet) is shown below:

SESSION NAME	VECTOR(m)			----- Covariance (m) [unscaled] -----		
	DX/DY/DZ			standard deviations in (parens)		
2 to 7 (1)	22054.8259	2.9600e-005		(0.0054)		
	-11419.0806	5.0662e-005		1.1843e-004	(0.0109)	
	-4620.2154	-3.8191e-005		-8.5945e-005	7.7102e-005	(0.0088)

The above baseline contains the 3-D geocentric coordinate vectors, along with the covariance matrix variance (standard deviation) and correlation values. These values are then used as input and weighting in the subsequent adjustment. The default *a priori* standard errors in an adjustment package have been found to be reasonable in standard USACE work where extremely long baselines are not involved. Use of these optimum values is recommended for the first adjustment iteration. If the network also contains terrestrial observations (differential leveling, total station, etc.) then each of these observations must be properly weighted. Most software provides recommended guidance for weighting conventional leveling, angle, and distance observations. For many lower-order engineering surveys, least-squares adjustments can be performed without all the covariance and correlation statistics from the GPS baseline reduction. The following is a listing of default Standard errors (i.e. weights) for GPS and terrestrial observations used by Star*Net 6.0, a comprehensive adjustment program that handles mixed observations. These standard errors can be easily modified to reflect local conditions or experience. Star*Net recommends scaling GPS vectors by 8.0, to reflect over-optimistic weighting from baseline reduction software. For this sample project, the geoid height (-31.2000 m) was assumed constant over the entire area. Alternatively, a geoid model could have been input.

Project Option Settings (from STAR*NET 6.0 Demonstration Program)

```

STAR*NET Run Mode           : Adjust with Error Propagation
Type of Adjustment          : 3D
Project Units                : Meters; DMS
Coordinate System           : Mercator NAD83; AZ Central 0202
Geoid Height                 : -31.2000 (Default, Meters)
Longitude Sign Convention    : Positive West
Input/Output Coordinate Order : North-East
Angle Data Station Order    : At-From-To
Distance/Vertical Data Type : Slope/Zenith
Convergence Limit; Max Iterations : 0.001000; 10
Default Coefficient of Refraction : 0.070000
Create Coordinate File       : Yes
Create Geodetic Position File : Yes
Create Ground Scale Coordinate File : No
Create Dump File            : No
GPS Vector Standard Error Factors : 8.0000
GPS Vector Centering (Meters) : 0.00200
GPS Vector Transformations   : Solve for Scale and Rotations
  
```

GPS Vector scaling and
estimated centering error

Instrument Standard Error Settings

```

Project Default Instrument
Distances (Constant)       : 0.007500 Meters
Distances (PPM)            : 2.000000
Angles                      : 0.500000 Seconds
Directions                  : 1.000000 Seconds
Azimuths & Bearings         : 1.000000 Seconds
Zeniths                     : 3.000000 Seconds
Elevation Differences (Constant) : 0.010000 Meters
Elevation Differences (PPM)  : 0.000000
Differential Levels         : 0.002403 Meters / Km
Centering Error Instrument   : 0.002000 Meters
Centering Error Target       : 0.002000 Meters
Centering Error Vertical     : 0.000000 Meters
  
```

Terrestrial Observation Weighting

a. *Variance factor.* The adequacy of the initial network *a priori* weighting described above is indicated by the variance of unit weight, which equals the square of the standard error of unit weight. The variance of unit weight should range between 0.5 and 1.5 (or the standard error of unit weight should range between 0.7 and 1.2), with an optimum value of 1.0 signifying realistic weighting of the GPS input observations. A large unit variance (say 5.0) indicates the initial GPS standard errors were too optimistic (low) or, more likely, some poor observations are present. A low unit variance (say 0.1) indicates the results from the adjustment were better than the assumed GPS baseline precisions used. This unit variance test is, however, generally valid only when a statistically significant number of observations are involved. This is a function of the number of "degrees of freedom" shown on the adjustment. To evaluate the adequacy of the unit weight, a test such as Chi-square is performed. Failure of such a test indicates the variance factor statistic may not be statistically valid, including any rejections made using this value.

b. *Changing weight factors.* In performing a free adjustment, the input (*a priori*) standard errors can easily be "juggled" in order to obtain a variance of unit weight near 1.0. This trial-and-error method is generally not a good practice--especially if observational blunders are present. If the input weights are changed, they should not be modified beyond reasonable levels (e.g., do not input a GPS standard error of

$\pm 50 \text{ cm} + 50 \text{ ppm}$ in order to get a good unit variance). If input standard errors are modified, these modifications should be the same for all lines, not just selected ones. Any such modifications of *a priori* standard errors must be justified and explained in the adjustment report.

c. Rescaling the variance of unit weight. Some software allows rescaling of the entire network with the initial variance of unit weight, with a new resultant 1.0 variance factor. Changing the magnitude of the input standard errors/weights will not change the adjusted position or residual results in a free adjustment provided all weight changes are made equally--i.e. the entire project is rescaled. Although the reference variance will change, the resultant precisions (relative line accuracies) will not change. (This is not true in a constrained adjustment.) Therefore, the internal accuracy of a survey can be assessed based on the free adjustment line accuracies regardless of the initial weighting or variance of unit weight.

11-12. Adjustment Output Statistics

Least-squares adjustment software will output various statistics from the free adjustment to assist in detecting blunders and residual outliers in the free adjustment. Most commercial packages will display the normalized residual for each observation (GPS, EDM, angle, elevation, etc.), which is useful in detecting and rejecting residual outliers. The variance of unit weight (or its square root--the Standard Error of Unit Weight) is important in evaluating the overall adequacy of the observed network. The initial variance of unit weight on the first free adjustment is often input to rescale the weighting for a second free adjustment, providing more representative error statistics with a unity variance of unit weight. Other statistics, such as Tau, Chi-square, histograms, etc., are useful in assessing (or statistically testing) outlier data for potential reject. These statistical tests may or may not be significant for lower-order USACE engineering projects, and become totally insignificant if one is not well versed in statistics and adjustment theory. Use of these statistics to reject data (or in reporting results of an adjustment) without a full understanding of their derivation and source within the network adjustment is ill-advised.

11-13. Minimally Constrained Adjustment Considerations

The "free" adjustment is probably the most important phase of reducing and evaluating survey data--especially when redundant observations are involved. When a series of observation loops are formed relative to a fixed point or off another loop, different redundant conditions are formed. These different loops allow forward baseline vector position computations to be made over different paths. From the different routes (loops) formed, different positional closures at a single fixed point result. These variances in position misclosures from the different routes provide additional data for assessing the internal consistency of the network, in addition to checking for blunders in the individual baselines. The number of different paths, or conditions, is partially related to the number of degrees of freedom in the network. Since a "free" adjustment only holds one arbitrary point fixed (in position and orientation), the resultant adjustment will provide a clean analysis of the internal consistency of the observations in the network. Performing a free adjustment on a complex network containing many redundancies is best performed using least-squares methods. An example of such a network is shown in Figure 11-4. Approximate adjustment methods are difficult to evaluate when complex interweaving networks are involved.

a. Redundant baseline observations. Duplicate baseline observations also provide additional redundancy or strength to a line or network since they are observed at two distinct times of varying satellite geometry and conditions. The amount of redundancy required is a function of the accuracy requirements of a particular survey. Redundant baseline results are especially critical in assessing the accuracy of vertical densification surveys.

b. Fixed constraint. In practice, any station on the network can be held fixed for the free adjustment. The selected point is held fixed in all three coordinates, along with the orientation of the three axes and a network scale parameter. Usually one of the higher-order points on the existing network is used.

11-14. Relative Baseline Accuracy Estimates

The accuracy of an observed GPS baseline in a network is influenced by the accuracy of the GPS observation (i.e. baseline covariance matrix) and the accuracy of all other GPS baselines and other conventional survey observations throughout the network. Most commercial software indicates the resultant accuracy of the baseline vectors. This output statistic is called "relative distance accuracies," "output vector residuals," and other terms depending on the software. These relative distance accuracy estimates between points in a network are determined by error propagation of the relative positional standard errors at each end of the line, as shown in Figure 11-4. Relative accuracy estimates may be derived for resultant distances or azimuths between the points. The relative distance accuracy estimates are those typically employed to assess the free and constrained accuracy classifications, typically expressed as a ratio, such as 1:80,000, a standard error statistic, or graphically in error ellipse dimensions. Since each point in the network will have its particular position variances, the relative distance accuracy propagated between any two points will also vary throughout the network. Relative positional and distance accuracy estimates resulting from a free (minimally constrained) adjustment of a GPS network are usually excellent in comparison to conventional surveying methods. Loop misclosure and relative distance accuracies between points will commonly exceed 1:100,000.

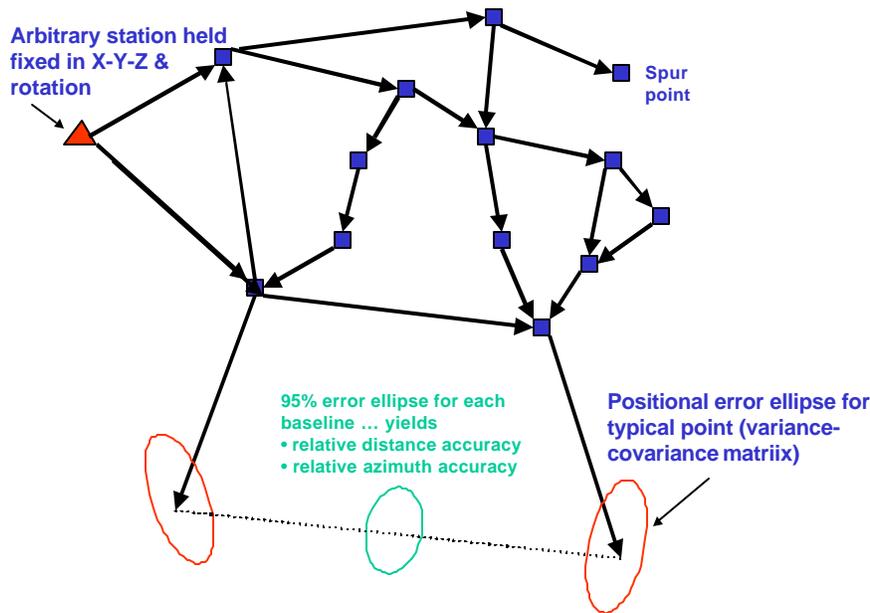


Figure 11-4. Free adjustment of a complex GPS network

a. Residual corrections. Most commercial adjustment software will output the residual corrections to each observed baseline (or actually baseline vector components). These residuals indicate the amount by which each segment was corrected in the adjustment. A least-squares adjustment minimizes the sum of the squares of these baseline residual corrections. When terrestrial survey

observations are included in the network, residual corrections may be in distance or angular units. The following output from GrafNet is typical of most software. For each observed GPS baseline session it lists the residual corrections (RE, RN, RH), a parts per million (PPM) ratio, the baseline distance in km (DIST), and the 1-sigma standard deviation (STD).

```

*****
      OUTPUT VECTOR RESIDUALS (North, East, Height - Local Level)
*****

```

SESSION NAME	-- RE -- (m)	-- RN -- (m)	-- RH -- (m)	- PPM -	DIST - (km)	STD - (m)
2 to 7 (1)	-0.0018	-0.0030	-0.0134	0.547	25.3	0.0150
3 to 7 (1)	0.0000	-0.0027	-0.0040	0.539	8.9	0.0052
6 to 7 (1)	0.0000	0.0022	0.0032	103.562	0.0	0.0047
8 to 3 (1)	0.0000	-0.0040	-0.0060	0.467	15.4	0.0064
8 to 2 (1)	-0.0024	-0.0040	-0.0176	0.572	31.8	0.0172
8 to 6 (1)	-0.0004	0.0012	0.0048	0.727	6.8	0.0061

RMS	0.0012	0.0030	0.0098			

b. Free adjustment assessment criteria. The primary criteria for assessing the adequacy of a particular GPS survey shall be based on the relative distance accuracy results from a minimally constrained free adjustment, not the fully constrained adjustment. This is due to the difficulty in assessing the adequacy of the surrounding network. Should the propagated relative accuracies fall below the specified level, then reobservation would be warranted.

(1) The minimum relative distance accuracy value (i.e. the largest ratio) will govern the relative accuracy of the overall project. This minimum value (from a free adjustment) is then compared with the intended relative accuracy classification of the project to evaluate compliance. However, relative distance accuracy estimates should not be rigidly evaluated over short lines (i.e. less than 500 m).

(2) Depending on the size and complexity of the project, large variances in the propagated relative distance accuracies can result.

c. Constrained adjustment. When a constrained adjustment is subsequently performed, the adequacy of the external fixed stations will have a major impact on the resultant propagated distance accuracies, especially when connections are made to weak control systems. Properly weighted partially constrained adjustments will usually improve the propagated distance accuracies. If the relative distance accuracies significantly degrade on a constrained adjustment (due to the inadequacy of the surrounding network), additional connections to the network may be required to resolve the conflicts. A large variance of unit weight usually results in such cases.

11-15. Normalized or Standardized Residuals

The magnitude of the residual corrections shown in the sample adjustments may be assessed by looking for blunders or outliers; however, this assessment should be performed in conjunction with the related "normalized residual" or "standardized residual" statistic--i.e. $v / \sigma = v \cdot \sqrt{w}$. Most commercial software packages provide this statistic for each observation. This statistic is obtained by multiplying the residual by the square root of the input weight (the inverse of the square of the standard error). If the observations are properly weighted, the "normalized residuals" should be around 1.0. Most adjustment software will flag normalized residuals that exceed selected statistical outlier tests. Such flagged

normalized residuals are candidates for rejection. A rule-of-thumb reject criterion should be set at three times the standard error of unit weight, again provided that the variance of unit weight is within the acceptable range given in Table 11-1 above. All rejected GPS observations must be justified in the adjustment report, which should clearly describe the test used to remove the observation from the file. The following excerpt from a GeoLab output shows the standardized residual (STD RES) in the last column. This value is computed from data in the next to last column--dividing the RESIDUAL by the STD DEV (standard error)-- v / σ .

```

=====
                                gpstrav.iob
Microsearch GeoLab, V2001.9.20.0          WGS 84          UNITS: m,DMS  Page 0006
=====
Residuals (critical value = 1.728):
NOTE: Observation values shown are reduced to mark-to-mark.
                                OBSERVATION RESIDUAL  STD RES
TYPE AT          FROM          TO          STD DEV  STD DEV  PPM
-----
DXCT             Control 1     Point 1     -4996.35800    0.013    1.938

                                0.012    0.006    1.69
=====

```

11-16. Outlier Tests and Reject Criteria

One of the main purposes of the free adjustment is to check for poor observational data. This is accomplished by reviewing the statistics from the adjustment output software. The statistics can be presented in tabular format or graphically, depending on the software. A variety of statistical tests have been developed to evaluate survey data. Most involve some type of outlier test. Most adjustment software will output standardized or normalized residuals for each observation, as defined above. This equalizes all angular and distance observations so relative assessments can be made. Standardized residuals are typically plotted on histograms that provide a graphical assessment of outlying observations--for example, those beyond a "x-sigma" standardized residual distance. The criteria for determining "x-sigma" may be obtained from the Tau Criteria, a statistic derived from a standard Student t-distribution statistic. Thus, for a large data set, "x" will typically be around "3" meaning normalized residuals greater than 3-sigma from the mean are outliers and candidates for reject. Chi-square is another statistical test used to assess the validity of the adjusted/computed variance of unit weight (reference variance), and is especially useful for small data sets, i.e. those with few degrees of freedom. The Marginally Detectable Error (MDE) is a statistic used by NGS in their ADJUST program. The MDE is a measure of how large an error has to be before the standardized residual reaches 3-sigma. The general flow sequence for using these criteria is illustrated in Figure 11-5 below. This figure details the sequential "free" adjustments that may be necessary to isolate observational blunders, using the Chi-square, Tau, and variance statistics. Use of all these statistics requires a full understanding of their underlying concepts--these concepts are well covered in vendor's user manuals and/or "help" files that accompany the software. See also the references in Appendix A.

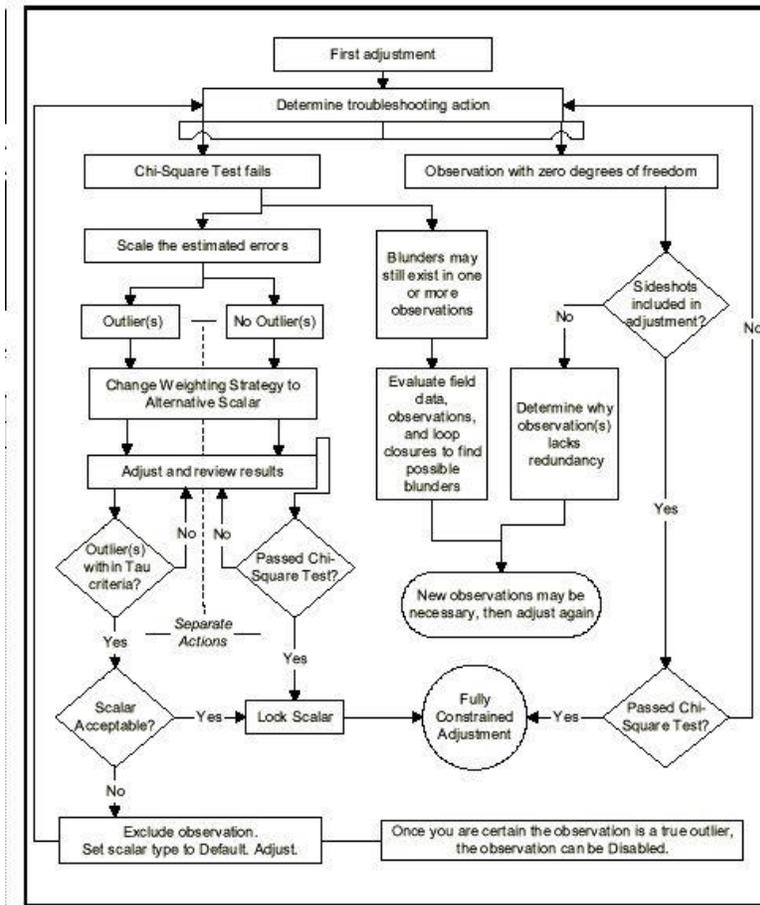


Figure 11-5. Use of outlier test statistics in performing a network adjustment (Trimble Navigation LTD)

The following is a typical statistical summary taken from a GeoLab adjustment. GeoLab uses a "Tau-max" criteria for assessing outlier observations. GeoLab also has options for other statistical outlier tests (e.g., Student t). In this sample, four residuals exceeded the Tau-max 1.7284 limit that was computed for this data set. The Chi-square test on the variance of unit weight allowed for a wide "Pass" range of 0.446 to 20.198. This is due to the relatively small number of observations and degrees of freedom ($r = 3$).

S T A T I S T I C S S U M M A R Y	
Residual Critical Value Type	Tau Max
Residual Critical Value	1.7284
Number of Flagged Residuals	4
Convergence Criterion	0.0010
Final Iteration Counter Value	2
Confidence Level Used	95.0000
Estimated Variance Factor	1.4529
Number of Degrees of Freedom	3

Chi-Square Test on the Variance Factor:

4.6625e-01 < 1.0000 < 2.0198e+01 ?

THE TEST PASSES

NOTE: All confidence regions were computed using the following factors:

Variance factor used	=	1.4529
1-D expansion factor	=	1.9600
2-D expansion factor	=	2.4477

Note that, for relative confidence regions, precisions are computed from the ratio of the major semi-axis and the spatial distance between the two stations.

11-17. Positional Accuracy Statistics and Error Ellipses

2-D error ellipses (or 3-D error ellipsoids) generated from the adjustment variance-covariance matrices for each adjusted point are also useful in depicting the relative positional accuracy--see Figure 11-6. The scale of the ellipse may be varied as a function of the 2-D deviation. In the Corps a 95 % probability ellipse is selected for output since final accuracies are always reported at the 95% confidence level--refer to accuracy reporting standards specified in FGDC 1998a and FGDC 1998b. The size of the error ellipse will give an indication of positional reliability, and the critical relative distance/azimuth accuracy estimate between two adjacent points is a direct function of the size of these positional ellipses.

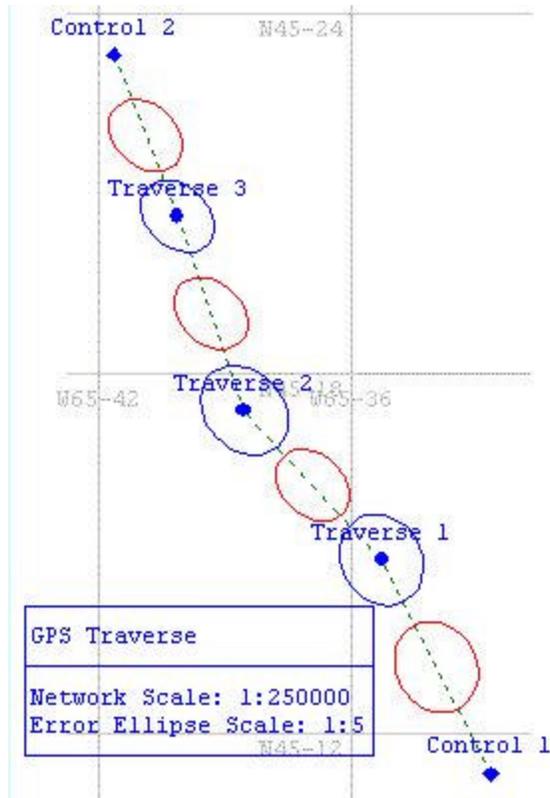


Figure 11-6. Relative accuracy ellipses for points (blue) and baselines (red). Control 1 and Control 2 are fixed points. (Microsearch GeoLab 2001 Adjustment Software)

A typical list of positional accuracies resulting from a least-squares adjustment is shown below. The standard errors are shown for the local coordinate system (E-N-UP) and the 1-sigma covariance matrix is relative to the geocentric (X-Y-Z) coordinate system. From these data the error ellipses shown above are formed.

```

*****
          OUTPUT VARIANCE/COVARIANCE
*****
                                     2
STA_ID   SE/SN/SUP  ----- CX matrix (m )-----
          (95.00 %) (not scaled by confidence level)
          (m)       (ECEF, XYZ cartesian)
2         0.0093   2.7948e-005
          0.0099   3.2261e-005  8.7560e-005
          0.0296  -2.4249e-005 -5.7075e-005  6.1238e-005
  
```

The following adjustment outputs are excerpts taken from Star*Net 6.0. It illustrates error ellipse and line accuracy output data typical of mixed terrestrial and GPS vector observations. Terrestrial observations included EDM, horizontal angles, and vertical angles (zenith distances).

Adjusted Measured Geodetic Angle Observations (DMS) Horizontal Angle Observations

At	From	To	Angle	Residual	StdErr	StdRes
0013	0012	0051	67-58-22.13	-0-00-01.37	0.52	2.6
0051	0013	0052	160-18-02.35	0-00-00.65	0.61	1.1

Adjusted Measured Distance Observations (Meters) EDM Distance Observations

From	To	Distance	Residual	StdErr	StdRes
0013	0051	4013.9490	-0.0010	0.0158	0.1
0051	0052	2208.2595	-0.0105	0.0122	0.9

Adjusted Zenith Observations (DMS) Vertical Angle Observations

From	To	Zenith	Residual	StdErr	StdRes
0013	0051	90-04-41.00	-0-00-03.00	3.00	1.0
0051	0052	90-14-28.41	-0-00-04.59	3.00	1.5

Adjusted GPS Vector Observations Sorted by Names (Meters) GPS Vector Observations

From	Component	Adj Value	Residual	StdErr	StdRes
To					
(V1 Day125(1) 14:14	00120013.SSF)				
0012	Delta-N	-10107.7168	0.0011	0.0035	0.3
0013	Delta-E	1770.6887	0.0019	0.0032	0.6
	Delta-U	-27.1137	-0.0018	0.0049	0.4
	Length	10261.6769			

Adjusted Azimuths (DMS) and Horizontal Distances (Meters) Relative accuracies and error ellipse data--for azimuths between points on network

=====
(Relative Confidence of Azimuth is in Seconds)

From	To	Grid Azimuth	Grid Dist	95% RelConfidence		
				Grnd Dist	Azi	Dist
0012	0013	170-36-18.76	10261.4179	0.12	0.0065	0.6324
			10261.6712			
0012	0016	119-21-46.52	7490.5576	0.13	0.0046	0.6123
			7490.7714			

Station Coordinate Error Ellipses (Meters) Error ellipse data for adjusted points on network
Confidence Region = 95%

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Elev
0012	0.000000	0.000000	0-00	0.000000
0013	0.006490	0.006144	170-13	0.000000

Relative Error Ellipses (Meters) Relative line error ellipse data for adjusted points on network
Confidence Region = 95%

Stations	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Vertical
From To				
0012 0013	0.006490	0.006144	170-13	0.000000
0012 0016	0.004786	0.004569	13-12	0.006523

11-18. Sample GPSurvey Network Adjustment--San Juan PR Flood Control Project

The following Trimble GPSurvey adjustment example is taken from GPS control surveys performed on a flood control project near San Juan, PR. This Jacksonville District survey was conducted to extend both horizontal and vertical control from NGRS points to the flood control project area.

Sample of Trimble GPSurvey Observation Adjustment Summary

OBSERVATION ADJUSTMENT SUMMARY (Observed and Adjusted Parameters)

NETWORK = 02097base
 TIME = Wed Jul 24 17:53:49 2002
 OBSERVATION ADJUSTMENT (Tau = 3.61)
 GPS Parameter Group 1 GPS Observations
 Azimuth rotation = -0.1347 seconds
 Deflection in latitude = +2.4780 seconds
 Deflection in longitude = +4.3040 seconds
 Network scale = 1.000001515015

Network calibration parameters

1.00σ = 0.0155 seconds
 1.00σ = 1.5593 seconds
 1.00σ = 0.9980 seconds
 1.00σ = 0.00000064660

OBS#	BLK#/ REF#	TYPE	BACKSIGHT/ INSTRUMENT/ FORESIGHT	UDVC/ UDPG/ SBNT	OBSERVED/ ADJUSTED/ RESIDUAL	1.00σ/ 1.00σ/ 1.00σ	TAU Tau Test
1	***- 1	hgoid	***- A 1001 ***-	***- ***- 1	-45.2101m -45.2101m -0.000001m	0.0001m 0.0001m 0.0000m	0.49
2	***- 2	hgoid	***- COMERIO ***-	***- ***- 1	-41.3690m -41.3690m +0.000000m	0.0001m 0.0001m 0.0000m	OPEN
17	2 1	gpsaz	***- PUR 3 A 1001	***- ***- 1	90°12'28.3727" 90°12'28.3885" +0.015842"	0.0356" 0.0132" 0.0330"	0.13
18	2 1	gpsht	***- PUR 3 A 1001	***- ***- 1	-131.9826m -131.9021m +0.080439m	0.1479m 0.0349m 0.1437m	0.16
19	2 1	gpsds	***- PUR 3 A 1001	***- ***- 1	104825.8866m 104825.9576m +0.070964m	0.0594m 0.0070m 0.0590m	0.33

•
•
• **GPS Azimuth-Height-Distance residuals for each baseline (OBSERVATIONS 20 THRU 223 NOT SHOWN)**

224	71 1	gpsaz	***- PUR 3 TATI	***- ***- 1	92°41'28.2839" 92°41'28.2472" -0.036688"	0.0308" 0.0133" 0.0277"	0.37
225	71 1	gpsht	***- PUR 3 TATI	***- ***- 1	-124.3835m -124.3994m -0.015882m	0.1211m 0.0405m 0.1141m	0.04
226	71 1	gpsds	***- PUR 3 TATI	***- ***- 1	104537.6590m 104537.6797m +0.020775m	0.0155m 0.0066m 0.0141m	0.41

Sample of Trimble GPSurvey Observation Adjustment Summary (Continued)

ADJUSTMENT SUMMARY

NETWORK = 02097base TIME = Wed Jul 24 17:53:48 2002

Network Reference Factor = 1.00
Chi-Square Test ($\hat{\alpha}$ = 95%) = PASS
Degrees of Freedom = 163.00

**Degrees
of
Freedom
"r"**

GPS OBSERVATIONS
Reference Factor = 1.00 r = 163.00

GPS Solution 1 Reference Factor = 1.00 r = 0.00
GPS Solution 2 Reference Factor = 0.75 r = 2.77
GPS Solution 3 Reference Factor = 2.13 r = 1.82
GPS Solution 4 Reference Factor = 1.95 r = 2.68
•
•
GPS Solution 67 Reference Factor = 0.64 r = 2.46
GPS Solution 68 Reference Factor = 0.51 r = 2.61
GPS Solution 69 Reference Factor = 1.91 r = 2.59
GPS Solution 70 Reference Factor = 1.00 r = 0.00
GPS Solution 71 Reference Factor = 1.16 r = 2.51

**Reference Factors for
Baseline Solutions**

GEOID MODEL

Reference Factor = 1.57 r = 0.00

Geoid Heights: Reference Factor = 1.57 r = 0.00
Delta Geoid Heights: Reference Factor = 1.00 r = 0.00

**Reference Factors for
Geoid Model**

WEIGHTING STRATEGIES:

GPS OBSERVATIONS: Scalar Weighting Strategy:
Alternative Scalar Set Applied Globally = 12.88

No summation weighting strategy was used

Station Error Strategy: H.I. error = 0.0051 Tribrach error = 0.0051

**Weight Assignments for
GPS and equipment
centering**

GEOID MODEL: Scalar Weighting Strategy:
Alternative Scalar Set Applied Globally = 0.00

No summation weighting strategy was used

Results of adjusted Geoid model: Noise in vertical GPS observations: 0.01911537

Variance of geoid model: 0.00000001

Further use of correlated Geoid Model not recommended

Sample of Trimble GPSurvey Observation Adjustment Summary (Continued)

NETWORK ADJUSTMENT CONSTRAINTS

NETWORK = 02097base
TIME = Wed Jul 24 17:53:48 2002

Datum = NAD-83
Coordinate System = Geographic
Zone = Global

Network Adjustment Constraints:
3 fixed coordinates in y
3 fixed coordinates in x
3 fixed coordinates in h

**3 Constrained Points
in X-Y-Z**

**1-sigma errors in X, Y,
and height**

POINT	NAME	OLD COORDS	ADJUST	NEW COORDS	1.00σ
1	A 1001				
	LAT=	18° 27' 24.980321"	+0.000000"	18° 27' 24.980321"	0.005905m
	LON=	66° 04' 28.426893"	+0.000000"	66° 04' 28.426893"	0.005750m
	ELL HT=	-42.4781m	+0.0000m	-42.4781m	0.000120m
	ORTHO HT=	2.7320m	+0.0000m	2.7320m	FIXED
	GEOID HT=	-45.2101m	+0.0000m	-45.2101m	0.000120m
2	COMERIO				
	LAT=	18° 14' 08.759650"	+0.000000"	18° 14' 08.759650"	FIXED
	LON=	66° 12' 52.299500"	+0.000000"	66° 12' 52.299500"	FIXED
	ELL HT=	149.1713m	+0.0000m	149.1713m	0.214935m
	ORTHO HT=	190.5403m	+0.0000m	190.5403m	0.214935m
	GEOID HT=	-41.3690m	+0.0000m	-41.3690m	0.000120m
3	DRYDOCK				
	LAT=	18° 26' 47.892303"	+0.000000"	18° 26' 47.892303"	0.006453m
	LON=	66° 05' 28.523900"	+0.000000"	66° 05' 28.523900"	0.006270m
	ELL HT=	-42.8225m	+0.0000m	-42.8224m	0.039711m
	ORTHO HT=	2.1642m	+0.0000m	2.1643m	0.039712m
	GEOID HT=	-44.9867m	+0.0000m	-44.9867m	0.000120m
4	MESAS				
	LAT=	18° 16' 11.084080"	+0.000000"	18° 16' 11.084080"	FIXED
	LON=	66° 03' 12.743070"	+0.000000"	66° 03' 12.743070"	FIXED
	ELL HT=	326.5441m	+0.0001m	326.5442m	0.154736m
	ORTHO HT=	368.7046m	+0.0001m	368.7047m	0.154736m
	GEOID HT=	-42.1605m	+0.0000m	-42.1605m	0.000120m
		•			
		•			
		•			
		•			
13	TATI				
	LAT=	18° 24' 57.790078"	+0.000000"	18° 24' 57.790078"	0.006387m
	LON=	66° 04' 42.999849"	+0.000000"	66° 04' 42.999849"	0.006301m
	ELL HT=	-34.9294m	+0.0000m	-34.9294m	0.040113m
	ORTHO HT=	9.4295m	+0.0000m	9.4296m	0.040113m
	GEOID HT=	-44.3590m	+0.0000m	-44.3590m	0.000120m

Sample of Trimble GPSurvey Observation Adjustment Summary (Continued)

SUMMARY OF BASELINE COVARIANCES

NETWORK = 02097base
TIME = Wed Jul 24 17:53:49 2002

Definition of precision $(E \times S)\hat{y} = C\hat{y} + P\hat{y}$:

Horizontal:

Precision (P) expressed as: ratio
Propagated linear error (E): U.S.
(standard error of adjusted horizontal distance)
Scalar (S) on propagated linear error: 1.0000
Constant error term (C): 0.0000

3-Dimensional:

Precision (P) expressed as: ratio
Propagated linear error (E): U.S.
(standard error of adjusted slope distance)
Scalar (S) on propagated linear error: 1.0000
Constant error term (C): 0.0000
Using orthometric height errors

**Azimuth-Distance-Height
errors for each observed
baseline**

Absolute and ratio

FROM/ TO	AZIMUTH/ DELTA H	1.00σ 1.00σ	DISTANCE/ DELTA h	1.00σ 1.00σ	HOR PREC/ 3-D PREC
A 1001 COMERIO	211°10'02" +191.6495m	0.04" 0.2149m	28603.164m +187.8083m	0.0059m 0.2149m	1: 4837618 1: 4837618
A 1001 DRYDOCK	237°06'49" -0.3443m	0.64" 0.0397m	2099.955m -0.5677m	0.0068m 0.0397m	1: 309088 1: 309088
A 1001 MESAS	173°52'33" +369.0223m	0.06" 0.1547m	20838.212m +365.9727m	0.0059m 0.1547m	1: 3536897 1: 3536897
A 1001 MP 1	203°05'54" +6.2453m	0.51" 0.0254m	2160.316m +5.8614m	0.0056m 0.0254m	1: 382773 1: 382773
	•				
	•				
	•				
	•				
RRS 1 TATI	212°00'38" -8.7112m	0.33" 0.0592m	4586.198m -9.4431m	0.0075m 0.0592m	1: 615545 1: 615545
SJH 44 SJHL 11 RM 1	163°44'08" +1.4034m	0.37" 0.0363m	3556.270m +0.7455m	0.0063m 0.0363m	1: 566242 1: 566242
SJH 44 TATI	139°55'03" +8.9809m	0.18" 0.0401m	6204.046m +8.0800m	0.0051m 0.0401m	1: 1210786 1: 1210786
SJHL 11 RM 1 TATI	113°58'02" +7.5775m	0.49" 0.0387m	3281.605m +7.3344m	0.0074m 0.0387m	1: 444627 1: 444627

Sample of Trimble GPSurvey Observation Adjustment Summary (Continued)

FINAL ADJUSTED COORDINATES AND HEIGHTS

Projection Group: Geographic
 Zone Name: Puerto Rico
 Linear Units: meter
 Angular Units: degrees
 Datum Name: NAD-83

Ortho Hgt = Ellip Hgt + Geoid Undulation (N)

Station	Latitude Northing (Y)	Longitude Easting (X)	Ortho.Hgt(m) Ortho. Hgt(ft)	Ellip. Hgt
A 1001	18°27'24.98033" N 882738.00637	066°04'28.42689" W 780498.87896	2.73200 8.96324	-42.48337
COMERIO	18°14'08.75965" N 802345.96891	066°12'52.29950" W 732089.99908	190.56082 625.22327	149.19186
DRYDOCK	18°26'47.89232" N 878985.77825	066°05'28.52390" W 774720.68565	2.16132 7.08975	-42.82538
MESAS	18°16'11.08408" N 814776.08472	066°03'12.74307" W 787925.49457	368.70346 1209.66679	326.54298
MP 1	18°26'20.34912" N 876213.11755	066°04'57.30844" W 777731.11182	8.59188 28.18954	-36.23434
MP 3	18°26'18.28984" N 876013.28555	066°04'15.21238" W 781784.27695	6.58580 21.60691	-38.22604
PN 007	18°24'00.86849" N 862161.61528	066°03'22.35068" W 786902.04404	13.16149 43.18265	-30.89685
PN 030	18°23'50.41792" N 861089.02683	066°04'58.66515" W 777629.43315	11.87409 38.96153	-32.12466
PUR 3	18°27'46.70249" N 885187.27032	067°04'01.05083" W 436591.08273	133.53638 438.16948	87.35157
RRS 1	18°27'04.27895" N 880663.02269	066°03'20.16586" W 787074.26883	18.86853 61.90391	-26.22228
SJH 44	18°27'32.19208" N 883438.71281	066°06'59.11446" W 765991.82221	1.34960 4.42781	-43.90927
SJHL11RM	18°25'41.15411" N 872243.79347	066°06'25.17479" W 769278.91615	2.09702 6.88033	-42.50505
TATI	18°24'57.79009" N 867887.87460	066°04'42.99983" W 779124.78992	9.42896 30.93844	-34.92999

***** End of Report *****

11-19. Sample Network Adjustment--Virginia Key, FL Disposal Area Site

The following adjustment is an example of a small network adjustment using Waypoint Consulting's GrafNet software. The project is located at Virginia Key, Dade County, Florida. The GPS survey was performed for the Jacksonville District by Sea Systems, Inc. The purpose of the survey was to provide reference horizontal and vertical control for a topographic survey of the Northern Virginia Key Disposal Site, for ultimate use in determining fill capacity for possible use in upcoming construction dredging in Miami Harbor. The reference control will be used to obtain cross-sections at 100-foot intervals across the disposal site. A sketch of the network is shown in Figure 11-7 below.

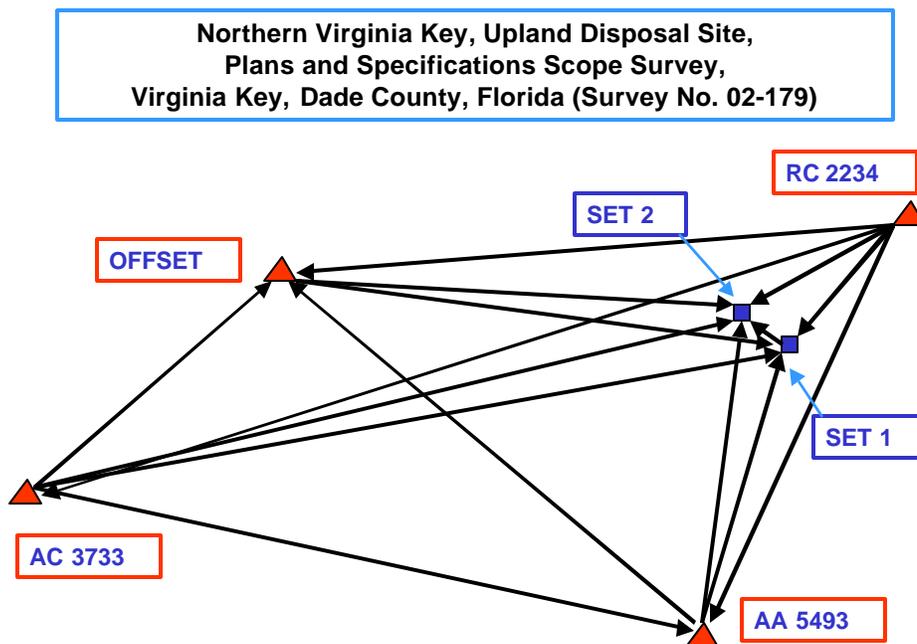


Figure 11-7. Virginia Key Disposal Site Control Network

In the above figure, stations shown in triangles are known points. These known points have either fixed horizontal coordinates or fixed elevations; or both--see INPUT CONTROL block on the following constrained adjustment. Fixed coordinates were given a standard error of ± 5 mm. Point OFFSET is a benchmark with no fixed position. Its elevation was also assigned a standard error of ± 5 mm. The two points to be adjusted are "SET 1" and SET 2." Baseline observations between the points are as indicated. A total of 35 baselines were observed and adjusted, including redundant lines. Baselines were reduced and a free (unconstrained) adjustment was run with no outlier rejects. The following GrafNet constrained adjustment is held to NAVD 88 orthometric elevations at the fixed points. This same network was also adjusted to obtain NGVD 29 elevations but these results are not shown in this example. However, a summary of the NGVD 29 and NAVD 88 adjusted elevations is shown at the end of the adjustment.

Virginia Key, FL Constrained Network Adjustment

```
*****
* NETWORK - WEIGHTED GPS NETWORK ADJUSTMENT *
*
* (c) Copyright Waypoint Consulting Inc., (2000) *
*
* VERSION: 6.03 *
*
* FILE: C:\02179A\02179A.net
*****
```

DATE(m/d/y): Thur. 10/03/02 TIME: 13:27:09

```
DATUM:          'NAD83'
GRID:           Grid: US State Plane, FL East
SCALE_FACTOR:  57.6315
CONFIDENCE LEVEL: 95.00 % (Scale factor is 2.4479)
```

Fixed X-Y-Z Points:
AA5493
AC2234
AC3733
Fixed in Z only: OFFSET

```
*****
INPUT CONTROL/CHECK POINTS
*****
```

STA_ID	TYPE	-- LATITUDE --	-- LONGITUDE --	ELLHGT -	HZ-SD	V-SD
AA5493	GCP-3D	25 43 35.37003	-80 09 15.51953	-24.944	0.00500	0.00500
AC2234	GCP-3D	25 45 56.06211	-80 08 02.49717	-23.521	0.00500	0.00500
AC3733	GCP-3D	25 44 26.83627	-80 13 10.56329	-24.315	0.00500	0.00500
OFFSET	GCP-VT			-20.733		0.00500

5 mm standard errors

```
*****
INPUT VECTORS
*****
```

35 observed baseline input vectors & covariance matrices

SESSION NAME	VECTOR(m)	----- Covariance (m) [unscaled] -----
	DX/DY/DZ	standard deviations in brackets
AA5493 to OFFSET (1)	-4345.9720 911.4010 3410.0230	8.1161e-007 (0.0009) -1.5108e-007 1.5096e-006 (0.0012) 7.4691e-007 -1.1100e-006 3.1877e-006 (0.0018)
AA5493 to OFFSET (2)	-4345.9790 911.3820 3410.0200	9.4716e-007 (0.0010) -1.3388e-006 6.5898e-006 (0.0026) 6.3886e-007 -2.1769e-006 1.6410e-006 (0.0013)
AA5493 to OFFSET (3)	-4345.9750 911.3960 3410.0190	8.8808e-007 (0.0009) -7.9258e-007 3.2975e-006 (0.0018) 4.7680e-008 -3.0244e-007 8.9945e-007 (0.0009)
AA5493 to SET1 (1)	527.3470 1463.4770 2804.1390	2.5454e-007 (0.0005) -1.3575e-007 1.5997e-006 (0.0013) 1.5573e-008 -6.5468e-007 6.0109e-007 (0.0008)
AA5493 to SET1 (2)	527.3460 1463.4670 2804.1500	9.6956e-007 (0.0010) -1.0256e-006 4.0156e-006 (0.0020) 5.8803e-007 -1.8213e-006 1.1555e-006 (0.0011)
AA5493 to SET1 (3)	527.3410 1463.4740 2804.1560	6.7566e-007 (0.0008) -8.9273e-007 2.8178e-006 (0.0017) 3.4075e-007 -9.6947e-007 8.4725e-007 (0.0009)

Virginia Key, FL Constrained Network Adjustment (Continued)

AA5493 to SET2 (1)	183.4260	2.7612e-007	(0.0005)				
	1518.1400	-1.2588e-007	1.6500e-006	(0.0013)			
	3037.5440	2.3001e-009	-6.8352e-007	6.7586e-007	(0.0008)		
AA5493 to SET2 (2)	183.4290	6.8405e-007	(0.0008)				
	1518.1260	-5.4212e-007	4.3782e-006	(0.0021)			
	3037.5590	1.6255e-007	-6.6215e-007	7.2271e-007	(0.0009)		
AA5493 to SET2 (3)	183.4240	6.8019e-007	(0.0008)				
	1518.1320	-4.8324e-007	3.7894e-006	(0.0019)			
	3037.5660	1.7634e-007	-4.6283e-007	7.3229e-007	(0.0009)		
AC2234 to AA5493 (1)	-1683.4200	8.7470e-007	(0.0009)				
	-2200.0290	-1.4696e-007	1.9535e-006	(0.0014)			
	-3900.3850	-3.9538e-007	-4.1776e-007	2.1921e-006	(0.0015)		
AC2234 to AA5493 (2)	-1683.4430	1.2038e-006	(0.0011)				
	-2200.0120	-9.9266e-007	4.5283e-006	(0.0021)			
	-3900.4030	7.4956e-007	-1.9036e-006	1.3560e-006	(0.0012)		
AC2234 to OFFSET (1)	-6029.4190	1.5439e-004	(0.0124)				
	-1288.7690	1.7075e-005	3.0166e-004	(0.0174)			
	-490.3520	2.6812e-005	-4.7363e-005	3.3521e-005	(0.0058)		
AC2234 to OFFSET (2)	-6029.4140	9.4516e-007	(0.0010)				
	-1288.5960	-8.3686e-007	1.2101e-005	(0.0035)			
	-490.3920	4.5221e-007	-4.1408e-006	2.4716e-006	(0.0016)		
AC2234 to SET1 (1)	-1156.0830	7.1801e-007	(0.0008)				
	-736.5510	-1.2067e-007	1.6032e-006	(0.0013)			
	-1096.2420	-3.2557e-007	-3.3912e-007	1.7975e-006	(0.0013)		
AC2234 to SET1 (2)	-1156.0990	6.3275e-007	(0.0008)				
	-736.5380	-5.6626e-007	5.9402e-006	(0.0024)			
	-1096.2560	1.4765e-007	-7.1220e-007	6.5753e-007	(0.0008)		
AC2234 to SET2 (1)	-1500.0060	7.2331e-007	(0.0009)				
	-681.8870	-1.2156e-007	1.6151e-006	(0.0013)			
	-862.8380	-3.2796e-007	-3.4163e-007	1.8107e-006	(0.0013)		
AC2234 to SET2 (2)	-1500.0190	6.3474e-007	(0.0008)				
	-681.8700	-5.6714e-007	5.9473e-006	(0.0024)			
	-862.8530	1.4802e-007	-7.1328e-007	6.5867e-007	(0.0008)		
AC3733 to AA5493 (1)	6572.5550	1.2659e-006	(0.0011)				
	439.5040	-1.3419e-006	5.2399e-006	(0.0023)			
	-1426.9770	7.8483e-007	-2.4146e-006	1.5525e-006	(0.0012)		
AC3733 to AA5493 (2)	6572.5490	7.1515e-007	(0.0008)				
	439.5320	-5.4746e-007	4.5827e-006	(0.0021)			
	-1427.0080	1.6796e-007	-5.0904e-007	6.6952e-007	(0.0008)		
AC3733 to AC2234 (1)	8255.9920	1.0793e-006	(0.0010)				
	2639.5390	-1.2860e-006	1.3182e-005	(0.0036)			
	2473.3960	6.4343e-007	-5.0607e-006	3.2850e-006	(0.0018)		

Virginia Key, FL Constrained Network Adjustment (Continued)

AC3733 to OFFSET (1)	2226.5690	6.3259e-007 (0.0008)
	1350.9290	-8.5721e-007 2.8679e-006 (0.0017)
	1983.0120	3.1585e-007 -9.3196e-007 7.7437e-007 (0.0009)
AC3733 to OFFSET (2)	2226.5840	8.1728e-007 (0.0009)
	1350.9190	-1.1227e-006 4.4849e-006 (0.0021)
	1983.0190	5.1104e-007 -1.1740e-006 9.7556e-007 (0.0010)
AC3733 to SET1 (1)	7099.8930	7.8833e-007 (0.0009)
	1902.9860	-5.8486e-007 4.7634e-006 (0.0022)
	1377.1540	1.9193e-007 -5.4995e-007 7.7778e-007 (0.0009)
AC3733 to SET1 (2)	7099.8960	8.5710e-007 (0.0009)
	1903.0120	-1.2296e-006 5.1840e-006 (0.0023)
	1377.1400	4.6990e-007 -1.1777e-006 9.5439e-007 (0.0010)
AC3733 to SET2 (1)	6755.9730	8.3658e-007 (0.0009)
	1957.6580	-5.8188e-007 4.3591e-006 (0.0021)
	1610.5530	2.2816e-007 -5.9007e-007 9.0215e-007 (0.0009)
AC3733 to SET2 (2)	6755.9730	1.2266e-006 (0.0011)
	1957.6830	-1.7619e-006 6.4245e-006 (0.0025)
	1610.5420	7.7503e-007 -1.6224e-006 1.2553e-006 (0.0011)
OFFSET to SET1 (1)	4873.3100	3.3145e-007 (0.0006)
	552.0730	-1.1994e-007 1.8526e-006 (0.0014)
	-605.8730	-2.0091e-008 -7.7142e-007 8.5374e-007 (0.0009)
OFFSET to SET1 (2)	4873.3150	6.4153e-007 (0.0008)
	552.0630	-5.0275e-007 1.6390e-006 (0.0013)
	-605.8550	1.9615e-007 -3.2252e-007 6.3350e-007 (0.0008)
OFFSET to SET1 (3)	4873.3180	8.7943e-007 (0.0009)
	552.0600	-1.2151e-006 4.7929e-006 (0.0022)
	-605.8460	5.5000e-007 -1.2606e-006 1.0262e-006 (0.0010)
OFFSET to SET2 (1)	4529.3890	3.2547e-007 (0.0006)
	606.7360	-1.1703e-007 1.8219e-006 (0.0013)
	-372.4680	-2.0457e-008 -7.5827e-007 8.3920e-007 (0.0009)
OFFSET to SET2 (2)	4529.3950	6.9596e-007 (0.0008)
	606.7290	-5.1822e-007 1.6025e-006 (0.0013)
	-372.4520	2.2261e-007 -3.7470e-007 7.4870e-007 (0.0009)
OFFSET to SET2 (3)	4529.3970	1.0660e-006 (0.0010)
	606.7290	-1.5254e-006 5.6727e-006 (0.0024)
	-372.4420	6.6847e-007 -1.4856e-006 1.1226e-006 (0.0011)
SET1 to SET2 (1)	-343.9200	5.5512e-007 (0.0007)
	54.6670	-4.3883e-007 3.5448e-006 (0.0019)
	233.4040	1.3188e-007 -5.3718e-007 5.8763e-007 (0.0008)
SET1 to SET2 (2)	-343.9210	5.2863e-007 (0.0007)
	54.6660	-3.9745e-007 1.2402e-006 (0.0011)
	233.4040	1.6649e-007 -2.7847e-007 5.6816e-007 (0.0008)
SET1 to SET2 (3)	-343.9210	2.3912e-007 (0.0005)
	54.6600	-1.1279e-007 1.4035e-006 (0.0012)
	233.4060	3.3420e-009 -5.8588e-007 5.8424e-007 (0.0008)

Virginia Key, FL Constrained Network Adjustment (Continued)

OUTPUT VECTOR RESIDUALS (East, North, Height - Local Level)

35 baseline residuals

SESSION NAME	-- RE -- (m)	-- RN -- (m)	-- RH -- (m)	- PPM -	DIST - (km)	STD - (m)
AA5493 to OFFSET (1)	-0.0013	-0.0110	-0.0074	2.380	5.6	0.0178
AA5493 to OFFSET (2)	0.0089	-0.0007	-0.0219	4.218	5.6	0.0230
AA5493 to OFFSET (3)	0.0025	-0.0055	-0.0096	2.031	5.6	0.0171
AA5493 to SET1 (1)	-0.0066	0.0055	0.0079	3.645	3.2	0.0119
AA5493 to SET1 (2)	-0.0039	-0.0002	-0.0056	2.137	3.2	0.0188
AA5493 to SET1 (3)	-0.0002	-0.0090	-0.0012	2.830	3.2	0.0158
AA5493 to SET2 (1)	-0.0060	0.0052	0.0071	3.136	3.4	0.0122
AA5493 to SET2 (2)	-0.0065	-0.0021	-0.0123	4.134	3.4	0.0183
AA5493 to SET2 (3)	-0.0026	-0.0113	-0.0092	4.365	3.4	0.0173
AC2234 to AA5493 (1)	-0.0074	-0.0026	-0.0119	2.981	4.8	0.0170
AC2234 to AA5493 (2)	0.0123	0.0046	0.0145	4.103	4.8	0.0202
<u>AC2234 to OFFSET (1)</u>	<u>0.0420</u>	<u>0.0358</u>	<u>-0.1446</u>	<u>25.023</u>	<u>6.2</u>	<u>0.1680</u>
AC2234 to OFFSET (2)	0.0075	-0.0019	0.0255	4.315	6.2	0.0299
AC2234 to SET1 (1)	-0.0044	-0.0019	-0.0033	3.307	1.8	0.0154
AC2234 to SET1 (2)	0.0092	0.0040	0.0168	11.121	1.8	0.0204
AC2234 to SET2 (1)	-0.0019	-0.0019	-0.0024	1.945	1.9	0.0155
AC2234 to SET2 (2)	0.0080	0.0034	0.0212	12.298	1.9	0.0204
AC3733 to AA5493 (1)	0.0020	-0.0087	-0.0281	4.382	6.7	0.0216
AC3733 to AA5493 (2)	0.0031	0.0068	0.0111	1.981	6.7	0.0185
AC3733 to AC2234 (1)	-0.0084	0.0034	-0.0083	1.364	9.0	0.0318
AC3733 to OFFSET (1)	0.0104	-0.0004	0.0027	3.283	3.3	0.0157
AC3733 to OFFSET (2)	-0.0027	-0.0014	-0.0115	3.639	3.3	0.0190
AC3733 to SET1 (1)	0.0033	0.0011	-0.0109	1.537	7.5	0.0191
AC3733 to SET1 (2)	-0.0041	0.0028	0.0178	2.465	7.5	0.0201
AC3733 to SET2 (1)	0.0015	0.0025	-0.0013	0.437	7.2	0.0187
AC3733 to SET2 (2)	-0.0028	0.0017	0.0257	3.590	7.2	0.0227
OFFSET to SET1 (1)	0.0040	0.0072	0.0092	2.505	4.9	0.0132
OFFSET to SET1 (2)	0.0008	-0.0044	-0.0082	1.891	4.9	0.0130
OFFSET to SET1 (3)	-0.0017	-0.0109	-0.0153	3.816	4.9	0.0196
OFFSET to SET2 (1)	0.0047	0.0069	0.0085	2.594	4.6	0.0131
OFFSET to SET2 (2)	-0.0001	-0.0040	-0.0056	1.510	4.6	0.0133
OFFSET to SET2 (3)	-0.0020	-0.0129	-0.0103	3.624	4.6	0.0213
SET1 to SET2 (1)	-0.0010	-0.0010	0.0031	8.072	0.4	0.0164
SET1 to SET2 (2)	0.0002	-0.0007	0.0023	5.797	0.4	0.0116
SET1 to SET2 (3)	0.0012	0.0001	-0.0039	9.631	0.4	0.0113

RMS	0.0088	0.0082	0.0275			

\$ - This session is flagged as a 3-sigma outlier

Underlined session AC2234-OFFSET (1) has abnormally large adjustment and deviation ... marginal/suspect

Virginia Key, FL Constrained Network Adjustment (Continued)

CONTROL POINT RESIDUALS (ADJUSTMENT MADE)

STA. NAME	-- RE -- (m)	-- RN -- (m)	-- RH -- (m)
AA5493	-0.0194	-0.0126	-0.0071
AC2234	0.0161	0.0085	0.0048
AC3733	0.0032	0.0041	0.0025
OFFSET			-0.0002

RMS	0.0147	0.0091	0.0044

Note that fixed control points were assigned 5 mm standard error. OFFSET was only held fixed in vertical.

OUTPUT STATION COORDINATES (LAT/LONG/HT)

STA_ID	-- LATITUDE --	-- LONGITUDE --	- ELLHGT -	ORTHOHGT
AA5493	25 43 35.36962	-80 09 15.52023	-24.9511	0.7156
AC2234	25 45 56.06239	-80 08 02.49659	-23.5162	2.1831
AC3733	25 44 26.83640	-80 13 10.56317	-24.3125	1.0849
OFFSET	25 45 38.32461	-80 11 43.58762	-20.7332	4.7284
SET1	25 45 16.52663	-80 08 47.89629	-24.6836	0.9756
SET2	25 45 24.94919	-80 08 59.71990	-24.7666	0.8763

NAVD 88 ortho heights

OUTPUT STATION COORDINATES (ECEF)

STA_ID	---- X ---- (m)	---- Y ---- (m)	---- Z ---- (m)
AA5493	983140.1505	-5664838.2823	2751785.2653
AC2234	984823.5795	-5662638.2615	2755685.6579
AC3733	976567.5973	-5665277.8079	2753212.2624
OFFSET	978794.1770	-5663926.8797	2755195.2752
SET1	983667.4918	-5663374.8111	2754589.4127
SET2	983323.5714	-5663320.1475	2754822.8171

ECEF geocentric coordinates

Virginia Key, FL Constrained Network Adjustment (Continued)

OUTPUT VARIANCE/COVARIANCE

```

STA_ID      SE/SN/SUP  ----- CX matrix (m2)-----
            (95.00 %) (not scaled by confidence level)
            (m)      (ECEF, XYZ cartesian)
AA5493      0.0077  9.9663e-006
            0.0077  -4.0723e-007  1.2020e-005
            0.0086  2.4550e-007 -6.6579e-007  1.0018e-005

AC2234      0.0080  1.0688e-005
            0.0081  -4.6222e-007  1.4580e-005
            0.0094  2.5833e-007 -1.1509e-006  1.1165e-005

AC3733      0.0079  1.0634e-005
            0.0079  -1.0831e-006  1.5026e-005
            0.0096  5.6622e-007 -1.2673e-006  1.0700e-005

OFFSET      0.0082  1.1484e-005
            0.0085  -5.7821e-007  1.3011e-005
            0.0087  3.3286e-007  2.4449e-007  1.1682e-005

SET1        0.0080  1.1088e-005
            0.0082  -1.5090e-006  1.7694e-005
            0.0105  5.1383e-007 -1.9026e-006  1.1568e-005

SET2        0.0081  1.1180e-005
            0.0084  -1.4287e-006  1.8188e-005
            0.0105  4.4044e-007 -1.6083e-006  1.1714e-005
    
```

**95% adjusted position
standard errors
&
covariance matrices for
4 fixed points and 2
new points**

**Used to develop
relative line accuracies
and error ellipses**

VARIANCE FACTOR = 1.0609

Note: Values < 1.0 indicate statistics are pessimistic, while values > 1.0 indicate optimistic statistics. Entering this value as the network adjustment scale factor will bring variance factor to one.

**Variance
Factor
close to
1.0 ...
good**

```

Project:    02179A Virginia Key Survey 2002-179
Program:    GrafNet Version 6.03b
Source:     Network Adjustment
CoordType:  U.S. State Plane for FL East (901)
Units(h,v): U.S. Survey Feet, U.S. Survey Feet
Geoid:     Geoid99-ContUS.wpg
Datum:     NAD83(90)/NAVD88/NGVD29
    
```

**Summary of
Adjustment
Results
NAD 83 (90)
&
NAVD 88 and
NGVD 29
adjustments**

NAME	EASTING(X)	NORTHING(Y)	HEIGHT(88)	HEIGHT(29)
AA5493(BRUCE 2)	934579.734	507176.193	2.348	3.880
AC2234(BASE USE)	941164.684	521424.341	7.162	8.709
AC3733(LIZ)	913053.811	512239.973	3.559	5.106
OFFSET(from AC2164)	920962.902	519505.389	15.513	17.058
SET1(MH 61)	937039.950	517405.598	3.201	4.743
SET2(MH 62)	935953.420	518248.986	2.875	4.417

NOTES: AC2164 OFFSET is a temporary bench mark and is reported here for informational purposes only.

11-20. Sample Network Adjustment--Everglades National Park Modified Water Deliveries

The following project example is typical of a small network where accurate vertical control is densified using GPS methods. Given the small and critical elevation gradients in an area such as the Everglades, redundant GPS observations and good geoid model adjustments are essential. The adjustment technique is similar to that performed in the above paragraph. However, in this example, a variety of existing control is constrained in the adjustment. In the network sketch in Figure 11-8 below, only AC4421 is held fixed in X-Y-Z. AC4743 and C546 are held fixed only in elevation, and AC4450 is held in X-Y coordinates only. AC0511 is set as a "check point" in the adjustment. Since the final adjusted values did not agree with published values, its check point setting proved correct. The only point without existing coordinate values is OSC 1. A ± 5 mm standard deviation was set for all constrained coordinates. 30 baselines were observed over all possible 15 lines. Resultant elevation accuracy from this adjustment scheme was about ± 1 centimeter (95%)--excellent results.

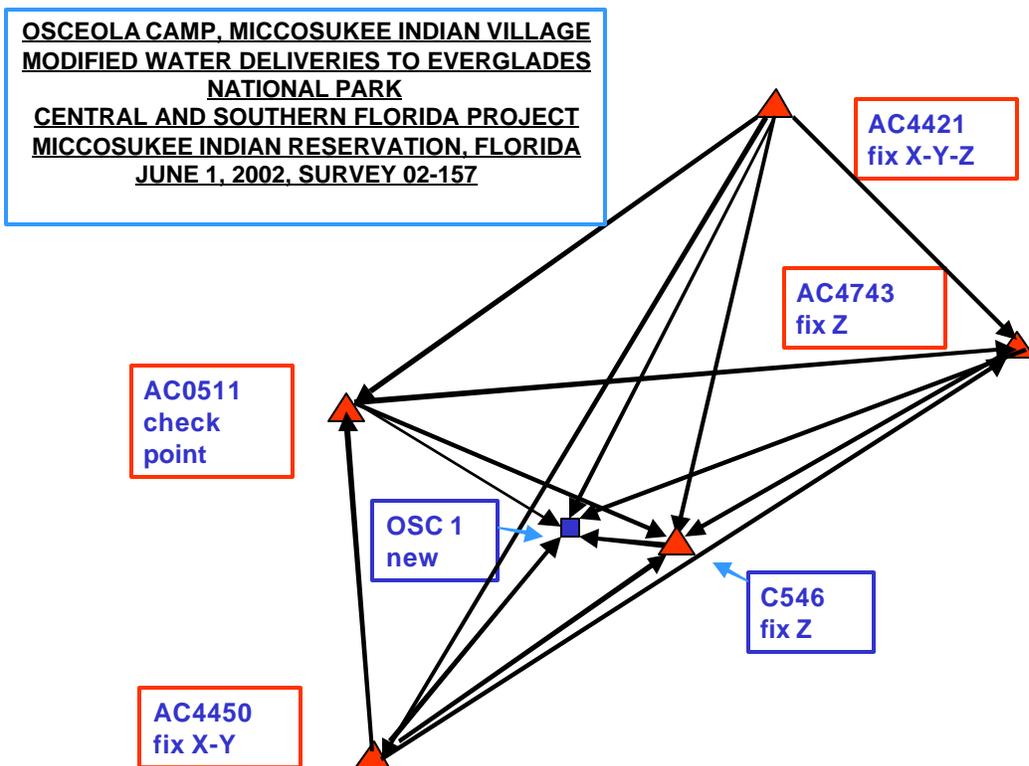


Figure 11-8. Osceola Camp GPS network control scheme

Horizontal coordinates were adjusted relative to NAD 83 (1990). The constrained elevation adjustment used the GEOID 99 model and elevations were adjusted relative to the NAVD 88 datum. A separate adjustment (not shown) was made to determine elevations relative to NGVD 29. Adjusted elevations in both NAVD 88 and NGVD 29 are listed at the end of the following adjustment output. The field survey was performed by Sea Systems, Inc. and adjusted by the Jacksonville District.

Everglades National Park--Osceola Camp GPS Adjustment

```
*****  
* NETWORK - WEIGHTED GPS NETWORK ADJUSTMENT *  
* * * * *  
* (c) Copyright Waypoint Consulting Inc., (2000) *  
* * * * *  
* VERSION: 6.03 *  
* * * * *  
* FILE: C:\02157A\01257A.net *  
*****
```

DATE(m/d/y): Wed. 8/07/02 TIME: 14:56:44

```
*****  
DATUM: 'NAD83'  
GRID: Grid: US State Plane, FL East (901)  
SCALE_FACTOR: 32.5131  
CONFIDENCE LEVEL: 95.00 % (Scale factor is 2.4479)  
*****
```

[Fixed X-Y-Z Points:](#)
[AC4421](#)
[Fixed X-Y Points:](#)
[AC4450](#)
[Fixed Z Points:](#)
[AC4743](#)
[C546](#)
[Check Point: AC0511](#)
[New Point: OSC 1](#)

```
*****  
INPUT CONTROL/CHECK POINTS  
*****
```

STA_ID	TYPE	-- LATITUDE --	-- LONGITUDE --	ELLHGT -	HZ-SD	V-SD
AC0511	CHK-3D	25 45 43.46685	-80 41 35.17195	-20.816		
AC4421	GCP-3D	25 51 44.92959	-80 37 19.81874	-19.325	0.00500	0.00500
AC4450	GCP-HZ	25 42 11.38117	-80 40 18.10062		0.00500	
AC4743	GCP-VT			-22.007		0.00500
C546	GCP-VT			-21.843		0.00500

```
*****  
INPUT VECTORS  
*****
```

30 observed baseline input vectors & covariance matrices

SESSION NAME	VECTOR(m)	----- Covariance (m) [unscaled] -----
	DX/DY/DZ	standard deviations in brackets
AC0511 to AC4450 (1)	2578.6070 -2448.8320 -5879.2220	2.0675e-007 (0.0005) -9.9567e-008 1.1169e-006 (0.0011) 5.8886e-008 -3.8150e-007 4.5670e-007 (0.0007)
AC0511 to AC4450 (2)	2578.5950 -2448.8200 -5879.2160	5.7093e-007 (0.0008) -2.3657e-007 2.1838e-006 (0.0015) -3.1864e-009 -8.7442e-007 1.1279e-006 (0.0011)
AC0511 to AC4743 (1)	11409.6470 1856.3890 -54.2970	3.1346e-007 (0.0006) -1.6648e-007 1.6595e-006 (0.0013) 9.6551e-008 -5.5090e-007 6.5289e-007 (0.0008)
AC0511 to AC4743 (2)	11409.6400 1856.4020 -54.2970	6.5983e-007 (0.0008) -2.7220e-007 2.5029e-006 (0.0016) -4.5299e-009 -1.0087e-006 1.3303e-006 (0.0012)
AC0511 to C546 (1)	6402.6260 1029.4410 -50.5110	3.1519e-007 (0.0006) -1.8154e-007 1.6328e-006 (0.0013) 1.0456e-007 -5.2772e-007 6.3081e-007 (0.0008)

Everglades National Park--Osceola Camp GPS Adjustment (Continued)

AC0511 to C546 (2)	6402.6260	5.3039e-007	(0.0007)
	1029.4530	-2.1387e-007	2.0364e-006 (0.0014)
	-50.5120	-7.1812e-009	-8.1844e-007 1.0774e-006 (0.0010)
AC0511 to OSCI (1)	2826.3730	3.7274e-007	(0.0006)
	404.6930	-2.6391e-007	2.0154e-006 (0.0014)
	-124.1030	1.3580e-007	-6.6592e-007 6.5855e-007 (0.0008)
AC0511 to OSCI (2)	2826.3650	8.4775e-007	(0.0009)
	404.6950	-2.8715e-007	1.4421e-006 (0.0012)
	-124.1140	4.2744e-007	-9.1936e-007 3.2470e-006 (0.0018)
AC4421 to AC0511 (1)	-6232.2220	9.2131e-007	(0.0010)
	-5932.4830	5.4026e-007	1.2058e-005 (0.0035)
	-10014.2210	-2.7845e-007	-3.4691e-006 1.9579e-006 (0.0014)
AC4421 to AC0511 (2)	-6232.2330	7.5210e-007	(0.0009)
	-5932.4600	-3.8308e-007	2.9070e-006 (0.0017)
	-10014.2290	2.0782e-007	-1.6442e-006 3.1353e-006 (0.0018)
AC4421 to AC4450 (1)	-3653.6150	1.1259e-006	(0.0011)
	-8381.3130	-5.9188e-007	9.2928e-006 (0.0030)
	-15893.4400	2.7188e-007	-3.3162e-006 2.2906e-006 (0.0015)
AC4421 to AC4450 (2)	-3653.6400	1.0867e-006	(0.0010)
	-8381.2780	-5.7658e-007	3.6854e-006 (0.0019)
	-15893.4530	4.6676e-007	-1.9728e-006 3.1363e-006 (0.0018)
AC4421 to AC4743 (1)	5177.4260	8.6219e-007	(0.0009)
	-4076.0780	-7.9451e-007	5.2706e-006 (0.0023)
	-10068.5230	3.3408e-007	-1.8431e-006 1.4359e-006 (0.0012)
AC4421 to AC4743 (2)	5177.4070	7.8702e-007	(0.0009)
	-4076.0560	-4.5627e-007	2.7180e-006 (0.0016)
	-10068.5270	6.1596e-008	-1.0694e-006 1.2751e-006 (0.0011)
AC4421 to C546 (1)	170.4060	9.4167e-007	(0.0010)
	-4903.0240	-6.7498e-008	9.8157e-006 (0.0031)
	-10064.7380	1.1574e-007	-3.1915e-006 1.8121e-006 (0.0013)
AC4421 to C546 (2)	170.3920	5.5963e-007	(0.0007)
	-4903.0050	-2.5663e-007	2.3604e-006 (0.0015)
	-10064.7420	2.1925e-008	-9.4061e-007 1.0812e-006 (0.0010)
AC4421 to OSCI (1)	-3405.8410	8.5957e-007	(0.0009)
	-5527.7820	4.5942e-007	1.1213e-005 (0.0033)
	-10138.3240	-2.5094e-007	-3.2530e-006 1.8422e-006 (0.0014)
AC4421 to OSCI (2)	-3405.8610	8.3149e-007	(0.0009)
	-5527.7630	-4.1256e-007	4.0949e-006 (0.0020)
	-10138.3360	8.6963e-008	-1.5747e-006 1.4468e-006 (0.0012)
AC4450 to AC4743 (1)	8831.0450	6.3641e-007	(0.0008)
	4305.2230	-2.6640e-007	2.5327e-006 (0.0016)
	5824.9200	4.1565e-009	-1.0129e-006 1.2527e-006 (0.0011)

Everglades National Park--Osceola Camp GPS Adjustment (Continued)

AC4450 to AC4743 (2)	8831.0390	3.1074e-007	(0.0006)			
	4305.2200	-1.6068e-007	1.6600e-006	(0.0013)		
	5824.9260	9.2403e-008	-5.4809e-007	6.4638e-007	(0.0008)	
AC4450 to C546 (1)	3824.0170	3.3440e-007	(0.0006)			
	3478.2730	-1.8974e-007	1.7443e-006	(0.0013)		
	5828.7110	1.0963e-007	-5.6357e-007	6.6786e-007	(0.0008)	
AC4450 to C546 (2)	3824.0240	6.3212e-007	(0.0008)			
	3478.2790	-4.0326e-007	2.3609e-006	(0.0015)		
	5828.7040	7.6899e-008	-9.2258e-007	9.8419e-007	(0.0010)	
AC4450 to OSCI (1)	247.7780	6.6765e-007	(0.0008)			
	2853.5060	-3.3646e-007	3.2715e-006	(0.0018)		
	5755.1150	7.2410e-008	-1.2595e-006	1.1570e-006	(0.0011)	
AC4450 to OSCI (2)	247.7700	4.3775e-007	(0.0007)			
	2853.5220	-3.0438e-007	2.3932e-006	(0.0015)		
	5755.1210	1.5746e-007	-7.8969e-007	7.7406e-007	(0.0009)	
AC4743 to C546 (1)	-5007.0180	5.6984e-007	(0.0008)			
	-826.9480	-3.2246e-007	2.0020e-006	(0.0014)		
	3.7850	4.1288e-008	-7.8730e-007	9.4577e-007	(0.0010)	
AC4743 to C546 (2)	-5007.0200	2.9664e-007	(0.0005)			
	-826.9520	-1.7240e-007	1.5355e-006	(0.0012)		
	3.7880	9.8675e-008	-4.9653e-007	5.9224e-007	(0.0008)	
AC4743 to OSCI (1)	-8583.2680	2.2110e-006	(0.0015)			
	-1451.7250	-1.3886e-006	2.9021e-006	(0.0017)		
	-69.8050	2.2770e-007	-6.6224e-007	1.1514e-006	(0.0011)	
AC4743 to OSCI (2)	-8583.2680	4.8045e-007	(0.0007)			
	-1451.7040	-3.4129e-007	2.6017e-006	(0.0016)		
	-69.8030	1.7535e-007	-8.5930e-007	8.4823e-007	(0.0009)	
C546 to OSCI (1)	-3576.2450	3.8622e-007	(0.0006)			
	-624.7600	-2.7415e-007	2.0848e-006	(0.0014)		
	-73.5840	1.4094e-007	-6.8895e-007	6.8216e-007	(0.0008)	
C546 to OSCI (2)	-3576.2530	1.3190e-006	(0.0011)			
	-624.7670	-8.8551e-007	1.9994e-006	(0.0014)		
	-73.5870	1.8526e-007	-4.8323e-007	7.1551e-007	(0.0008)	

Everglades National Park--Osceola Camp GPS Adjustment (Continued)

```

*****
      OUTPUT VECTOR RESIDUALS (East, North, Height - Local Level)
*****
SESSION NAME      -- RE --      -- RN --      -- RH --      - PPM -      DIST - STD -
                   (m)         (m)         (m)         (m)         (km)  (m)
AC0511 to AC4450 (1)  -0.0027    0.0033    -0.0053     0.994     6.9  0.0076
AC0511 to AC4450 (2)   0.0072   -0.0081     0.0045     1.707     6.9  0.0112
AC0511 to AC4743 (1)  -0.0015    0.0024    -0.0093     0.841    11.6  0.0092
AC0511 to AC4743 (2)   0.0033   -0.0036     0.0033     0.512    11.6  0.0121
AC0511 to C546 (1)    -0.0004    0.0016    -0.0078     1.229     6.5  0.0092
AC0511 to C546 (2)    -0.0023   -0.0026     0.0033     0.744     6.5  0.0109
AC0511 to OSCI (1)     0.0011   -0.0010     0.0061     2.202     2.9  0.0100
AC0511 to OSCI (2)     0.0087    0.0075     0.0138     6.288     2.9  0.0134
AC4421 to AC0511 (1)  -0.0025    0.0036    -0.0199     1.541    13.2  0.0220
AC4421 to AC0511 (2)   0.0046    0.0001     0.0056     0.553    13.2  0.0149
AC4421 to AC4450 (1)  -0.0055    0.0033    -0.0248     1.395    18.3  0.0203
AC4421 to AC4450 (2)   0.0135   -0.0018     0.0157     1.131    18.3  0.0160
AC4421 to AC4743 (1)  -0.0075    0.0037    -0.0129     1.280    12.0  0.0157
AC4421 to AC4743 (2)   0.0076   -0.0035     0.0111     1.160    12.0  0.0125
AC4421 to C546 (1)    -0.0078    0.0030    -0.0094     1.118    11.2  0.0202
AC4421 to C546 (2)     0.0030   -0.0026     0.0113     1.068    11.2  0.0114
AC4421 to OSCI (1)    -0.0105   -0.0003    -0.0078     1.091    12.0  0.0213
AC4421 to OSCI (2)     0.0061    0.0009     0.0172     1.517    12.0  0.0144
AC4450 to AC4743 (1)  -0.0040    0.0031    -0.0007     0.452    11.4  0.0120
AC4450 to AC4743 (2)   0.0024   -0.0014    -0.0051     0.509    11.4  0.0092
AC4450 to C546 (1)     0.0043   -0.0018    -0.0022     0.658     7.8  0.0094
AC4450 to C546 (2)    -0.0036    0.0024     0.0052     0.868     7.8  0.0114
AC4450 to OSCI (1)    -0.0049    0.0083    -0.0055     1.723     6.4  0.0129
AC4450 to OSCI (2)     0.0004   -0.0045     0.0073     1.343     6.4  0.0108
AC4743 to C546 (1)    -0.0019    0.0003     0.0015     0.476     5.1  0.0107
AC4743 to C546 (2)     0.0007   -0.0008    -0.0031     0.645     5.1  0.0089
AC4743 to OSCI (1)     0.0014    0.0085    -0.0117     1.668     8.7  0.0143
AC4743 to OSCI (2)    -0.0020   -0.0023     0.0061     0.785     8.7  0.0113
C546 to OSCI (1)      -0.0044   -0.0041    -0.0014     1.709     3.6  0.0101
C546 to OSCI (2)       0.0046    0.0010    -0.0052     1.925     3.6  0.0115

```

30 baseline residuals

RMS 0.0053 0.0038 0.0099
\$ - This session is flagged as a 3-sigma outlier

```

*****
      CHECK POINT RESIDUALS (East, North, Height - Local Level)
*****

```

```

STA. NAME      -- RE --      -- RN --      -- RH --
                (m)         (m)         (m)
AC0511          0.1149    0.0706    0.0205
-----
RMS             0.1149    0.0706    0.0205

```

AC0511 Check Point ... note large residuals relative to published X-Y coordinates

```

*****
      CONTROL POINT RESIDUALS (ADJUSTMENT MADE)
*****

```

```

STA. NAME      -- RE --      -- RN --      -- RH --
                (m)         (m)         (m)
AC4421         -0.0022   -0.0003    0.0023
AC4450          0.0022    0.0003
AC4743                          0.0013
C546                          -0.0037
-----
RMS             0.0022    0.0003    0.0026

```

Note that only AC4421 was fixed in X-Y-Z. AC4450 in X-Y. AC4743 & C546 in Z only.

Everglades National Park--Osceola Camp GPS Adjustment (Continued)

OUTPUT STATION COORDINATES (LAT/LONG/HT)

STA_ID	--	LATITUDE	--	LONGITUDE	--	ELLHGT	-	ORTHOHGT
AC0511	25	45	43.46914	-80	41	35.16782	-20.7955	3.4857
AC4421	25	51	44.92958	-80	37	19.81882	-19.3227	5.1525
AC4450	25	42	11.38118	-80	40	18.10054	-20.4271	3.8297
AC4743	25	45	41.52892	-80	34	40.34114	-22.0057	2.4627
C546	25	45	41.66302	-80	37	42.45544	-21.8467	2.5379
OSCI	25	45	39.01186	-80	39	52.72863	-22.1036	2.2219

OUTPUT STATION COORDINATES (GRID)

STA_ID	-	EASTING	-	NORTHING	-	ELLHGT	-	ORTHOHGT
		(m)		(m)		(m)		(m)
AC0511	230785.8193	158293.4066	-20.7955	3.4857				
AC4421	237869.1636	169434.8382	-19.3227	5.1525				
AC4450	232949.5269	151772.2488	-20.4271	3.8297				
AC4743	242345.1457	158265.6645	-22.0057	2.4627				
C546	237270.4892	158254.5151	-21.8467	2.5379				
OSCI	233640.6253	158163.2008	-22.1036	2.2219				

OUTPUT STATION COORDINATES (ECEF)

STA_ID	----	X	----	Y	----	Z	----
		(m)		(m)		(m)	
AC0511	929550.8543	-5672146.7997	2755337.8280				
AC4421	935783.0819	-5666214.3355	2765352.0545				
AC4450	932129.4576	-5674595.6260	2749458.6067				
AC4743	940960.4983	-5670290.4017	2755283.5292				
C546	935953.4786	-5671117.3512	2755287.3151				
OSCI	932377.2294	-5671742.1124	2755213.7268				

OUTPUT VARIANCE/COVARIANCE

STA_ID	SE/SN/SUP	CX matrix (m)-----			
	(95.00 %)	(not scaled by confidence level)			
	(m)	(ECEF, XYZ cartesian)			
AC0511	0.0093	1.4361e-005			
	0.0094	-1.9537e-007	1.7159e-005		
	0.0103	-2.3383e-010	-1.1162e-006	1.5425e-005	
AC4421	0.0089	1.3301e-005			
	0.0090	6.4995e-008	1.3740e-005		
	0.0091	-8.5067e-008	-9.1607e-008	1.3432e-005	

Everglades National Park--Osceola Camp GPS Adjustment (Continued)

```

AC4450      0.0089  1.3402e-005
            0.0090  -5.5987e-007  1.7644e-005
            0.0106  2.2196e-007  -2.0083e-006  1.4373e-005

AC4743      0.0093  1.4464e-005
            0.0094  2.7930e-007  1.2905e-005
            0.0086  -2.7758e-007  1.0199e-006  1.4280e-005

C546        0.0093  1.4373e-005
            0.0094  3.2785e-007  1.2859e-005
            0.0086  -2.8629e-007  9.9338e-007  1.4100e-005

OSCI        0.0094  1.4906e-005
            0.0095  -6.0164e-007  1.8449e-005
            0.0107  1.3502e-007  -1.3032e-006  1.5374e-005
    
```

VARIANCE FACTOR = 1.0042

Note: Values < 1.0 indicate statistics are pessimistic, while values > 1.0 indicate optimistic statistics. Entering this value as the network adjustment scale factor will bring variance factor to one.

```

Project:    02157A: Survey 02-157 MODIFIED WATER DELIVERIES-OSCEOLA
            CAMP-C&SF
Program:    GrafNet Version 6.03b
Source:     Network Adjustment
CoordType:  U.S. State Plane for FL East (901)
Units(h,v): U.S. Survey Feet
Geoid:      Geoid99-ContUS.wpg
Datum:      NAD83(90)/NAVD88/NGVD29
    
```

NAME	PID	EASTING	NORTHING	88 HGT	29 HGT
N 237	AC0511	-----	-----	11.436	12.969
BUZZARD	AC4421	780409.081	555887.465	16.905	18.433
TROOPER	AC4450	764268.573	497939.453	12.565	14.096
G 237 RESET	AC4743	795094.032	519243.268	8.080	9.615
C 546	AJ7754	778444.930	519206.688	8.326	9.855
OSC1	-----	766535.951	518907.101	7.290	8.821

**Summary of
Adjustment
Results
NAD 83 (90)
&
NAVD 88 and
NGVD 29
adjustments**

NOTES:

1. Published vertical value for AJ7754 is a preliminary CERP line adjusted value.
2. Horizontal values observed for AC0511 did not match published values, nor did they fit with observations made for Survey 01-198. Data will be incorporated into the L-67 Network Surveys and re-evaluated.
3. See "02157A88.net" and "02157A29.net" for more network adjustment information.

11-21. Approximate Adjustments of GPS Networks

Simply constructed GPS networks used for establishing lower-order USACE control can be effectively adjusted using approximate adjustment techniques, or adjustments that approximate the more rigorous least-squares solution. Although least-squares solutions may be theoretically superior to approximate methods, the resultant differences between the adjustments are generally not significant from a practical engineering standpoint.

a. Given the high cost of commercial geodetic adjustment software, coupled with the adjustment complexity of these packages, approximate adjustment methods are allowed for in-house and contracted surveys.

b. In practice, any complex GPS survey network may be adjusted by approximate methods. If the main loop/line closures are good, redundant ties to other fixed network points may be used as checks rather than being rigidly adjusted.

c. In some cases it is not cost-effective to perform detailed and time-consuming least-squares adjustments on GPS project control surveys requiring only 1:5,000 or 1:10,000 engineering /construction /boundary location accuracy. If internal loop closures are averaging over 1:200,000, then selecting any simple series of connecting baselines for an approximate adjustment will yield adequate resultant positional and relative distance accuracies for the given project requirements. If a given loop/baseline series of say five points miscloses by 0.01 ft over 1,000 m (1:100,000), a case can be made for not even making any adjustment if a relative accuracy of only 1:5,000 is required between points.

d. Any recognized approximate adjustment method may be used to distribute baseline vector misclosures. The method used will depend on the magnitude of the misclosure to be adjusted and the desired accuracy of the survey. These include the following:

(1) Simple proportionate distribution of loop/line position misclosures among the new station coordinates.

(2) Compass Rule.

(3) Transit Rule.

(4) Crandall Method.

(5) No adjustment. Use raw observations if misclosures are negligible.

e. Approximate adjustments are performed using the 3-D earth-centered X-Y-Z coordinates. The X-Y-Z coordinates for the fixed points are computed using the transform algorithms shown in the following paragraph or obtained from the baseline reduction software. Coordinates of intermediate stations are determined by using the baseline vector component differences (ΔX , ΔY , ΔZ), which are obtained directly from the baseline reductions. These differences are then accumulated (summed) forward around a loop or traverse connection, resulting in 3-D position coordinate misclosures at the loop nodes and/or tie points. These misclosures are then adjusted by any of the above methods. GPS vector weighting is accomplished within the particular adjustment method used; there is no need to incorporate the standard errors from the baseline reductions into the adjustment. Internal survey adequacy and acceptance are based on the relative closure ratios (e.g., 1:10,000), as in conventional traversing criteria (see FGCC 1984). Final local datum coordinates are then transformed back from the X-Y-Z coordinates.

f. Given a loop of baseline vectors between two fixed points (or one point looped back on itself), the following algorithms may be used to adjust the observed baseline vector components and compute the adjusted station geocentric coordinates.

(1) Given: Observed baseline vector components $\Delta X_i, \Delta Y_i, \Delta Z_i$ for each baseline " *i* " (total of *n* baselines in the loop/traverse). The three-dimensional length of each baseline is " *l_i* " and the total length of the loop/traverse is " *L*."

(2) The misclosures (dx, dy, and dz) in all three coordinates are computed from:

$$\begin{aligned} dx &= X_F + \sum \Delta X_i - X_E \\ dy &= Y_F + \sum \Delta Y_i - Y_E \\ dz &= Z_F + \sum \Delta Z_i - Z_E \end{aligned} \tag{Eq 11-1}$$

Where $X_F, Y_F,$ and Z_F are the fixed coordinates of the starting point, $X_E, Y_E,$ and Z_E are the coordinates of the end point of the loop/traverse, and $\Delta X_i, \Delta Y_i,$ and ΔZ_i are summed from $i = 1$ to n . (These misclosures would also be used to assess the internal accuracy of the work.)

(3) Adjustments ($\delta x_i, \delta y_i, \delta z_i$) to each baseline vector component may be computed using either the Compass Rule:

$$\begin{aligned} \delta x_i &= -dx [l_i / L] \\ \delta y_i &= -dy [l_i / L] \\ \delta z_i &= -dz [l_i / L] \end{aligned} \tag{Eq 11-2}$$

or the Transit Rule:

$$\begin{aligned} \delta x_i &= -dx [\Delta x_i / \sum \Delta x_i] \\ \delta y_i &= -dy [\Delta y_i / \sum \Delta y_i] \\ \delta z_i &= -dz [\Delta z_i / \sum \Delta z_i] \end{aligned} \tag{Eq 11-3}$$

(4) The adjusted vector components are computed from:

$$\begin{aligned} \Delta X_i^a &= \Delta X_i + \delta x_i^a \\ \Delta Y_i^a &= \Delta Y_i + \delta y_i^a \\ \Delta Z_i^a &= \Delta Z_i + \delta z_i^a \end{aligned} \tag{Eq 11-4}$$

(5) The final geocentric coordinates are then computed by summing the adjusted vector components from Equation 11-4 above:

$$X_i^a = X_F + x_i \Sigma \Delta x_i^a \quad (\text{Eq 11-5})$$

$$Y_i^a = Y_F + y_i \Sigma \Delta y_i^a$$

$$Z_i^a = Z_F + z_i \Sigma \Delta z_i^a$$

g. Example of an approximate GPS survey adjustment:

(1) Fixed control points from the US Army Yuma Proving Ground GPS Survey (May 1990) (see Figure 11-9):

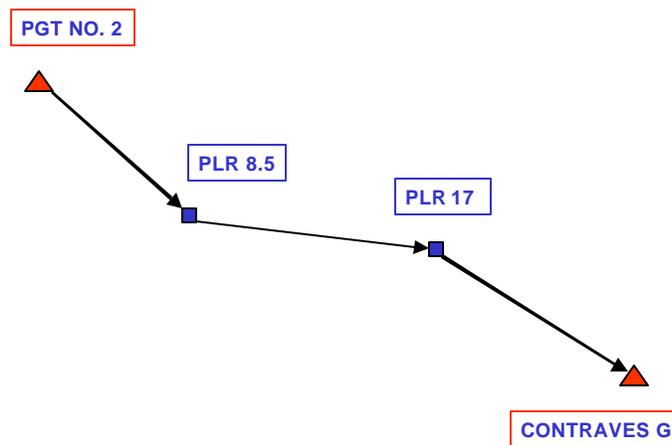


Figure 11-9. US Army Yuma Proving Ground GPS Traverse Sketch

<u>PGT NO 2</u>	<u>CONTRAVES G</u>
$X_F = (-) 2205\ 949.0762$	$X_E = (-) 2188\ 424.3707$
$Y_F = (-) 4884\ 126.7921$	$Y_E = (-) 4897\ 740.6844$
$Z_F = + 3447\ 135.1550$	$Z_E = + 3438\ 952.8159$

(XYZ geocentric coordinates were computed from GP-XYZ transform using Equations 11-6 and 11-7 below).

l_a, l_b, l_c = observed GPS baseline vectors (from baseline reductions) and PLR 8.5 and PLR 17 are the points to be adjusted.

(2) Misclosures in X, Y, and Z (computed from Equation 11-1):

(-)2205 949.0762	X _F	(-) 4884 126.7921	Y _F	3447 135.1550	Z _F
+3 777.9104	ΔX _a	(-) 6 006.8201	ΔY _a	(-)6 231.5468	ΔZ _a
+7 859.4707	ΔX _b	(-) 3 319.1092	ΔY _b	+ 400.1902	ΔZ _b
+5 886.8716	ΔX _c	(-) 4 288.9638	ΔY _c	(-)2 350.2230	ΔZ _c
(-)2188 424.3707	X _E	(-) 4897 740.6844	Y _E	- 3438952.8159	Z _E
<hr/>		<hr/>		<hr/>	
dx = <u>(-) 0.4528</u>		dy = <u>(-) 1.0008</u>		dz = + 0.7595	

(3) Linear 3-D Misclosure:

$$= (0.45282 + 1.00082 + 0.75952)^{1/2} = \underline{1.335 \text{ m}} \text{ or 1 part in } 25,638.2/1.335 = \underline{1:19,200}$$

(Note: This is a constrained misclosure check, not free)

(4) Compass rule adjustment:

(a) Compass Rule misclosure distribution:

l _a	= 9 443.869	l _a /L = 0.368
l _b	= 8 540.955	l _b /L = 0.333
l _c	= 7 653.366	l _c /L = 0.299
L	=25,638.190	Σ = 1.000

(b) Compass Rule adjustment to GPS vector components using Equation 11-2:

Vector	δx	δy	δz
A	0.1666	0.3683	(-) 0.2795
B	0.1508	0.3333	(-) 0.2529
C	<u>0.1354</u>	<u>0.2992</u>	<u>(-) 0.2271</u>
	(+0.4528)	(+1.0008)	((-) 0.7595) Check

(c) Adjusted baseline vectors (from Equation 11-4):

Vector	ΔX ^a	ΔY ^a	ΔZ ^a
A	3778.0770	(-)6006.4518	(-)6231.8263
B	7859.6215	(-)3318.7759	399.9373
C	5887.0070	(-)4288.6646	(-)2350.4501

(d) Final adjusted coordinates (Equation 11-5):

Point	X ^a	Y ^a	Z ^a
PGT No. 2	(-) 2205 949.0762	(-) 4884 126.7921	+ 3447 135.1550
PLR 8.5	(-) 2202 170.9992	(-) 4890 133.2439	+ 3440 903.3287
PLR 17	(-) 2194 311.3777	(-) 4893 452.0198	+ 3441 303.2660
Contraves G	(-) 2188 424.3707	(-) 4897 740.6844	+ 3438 952.8159 (Check)

(e) Adjusted geocentric coordinates are transformed to Φ, λ, h , using Equations 11-9 through 11-13 in the following section. Geographic coordinates may then be converted to local SPCS (either NAD 83 or NAD 27) project control using USACE program CORPSCON.

(5) Transit rule adjustment.

(a) Distribution of GPS vector misclosures using Equation 11-3:

$$\Sigma \Delta x_i = 3777.9104 + 7859.4707 + 5886.8716 = 17,524.2527$$

Similarly,

$$\Sigma \Delta y_i = 13,614.8931 \quad \text{and} \quad \Sigma \Delta z_i = 8,981.9600$$

$$\delta x_i = -dx \left[\Delta x_i / \Sigma \Delta x_i \right] = -(-) [0.4538/17,524.2527] \Delta x_i = +2.584 \times 10^{-5} \Delta x_i$$

Similarly,

$$\delta y_i = +7.351 \times 10^{-5} \Delta y_i \quad \text{and} \quad \delta z_i = (-) 8.456 \times 10^{-5} \Delta z_i$$

(b) Adjustments to baseline vector components using Transit Rule (Equation 11-3):

Vector	δx	δy	δz
A	0.0976	0.4415	(-) 0.5269
B	0.2031	0.2440	(-) 0.0338
C	0.1521	0.3153	(-) 0.1987
(check)	(0.4528)	(1.0008)	(- 0.7595)

(c) Adjusted baseline vectors (from Equation 11-4):

Vector	ΔX^a	ΔY^a	ΔZ^a
A	3 778.0080	(-)6 006.3786	(-)6 232.0737
B	7 859.6738	(-)3 318.8652	+ 400.1564
C	5 887.0237	(-)4 288.6485	(-)2 350.4217

(d) Final adjusted coordinates (computed from Equation 11-5):

Point	X^a	Y^a	Z^a
PGT No. 2	(-) 2 205 949.0762	(-) 4884 126.7921	+3447 135.1550
PLR 8.5	(-) 2 202 171.0682	(-) 4890 133.1707	+3440 903.0813
PLR 17	(-) 2 194 311.3944	(-) 4893 452.0359	+3441 303.2377
Contraves G	(-) 2 188 424.3707	(-) 4897 740.6844	+3438 952.8160

(6) Proportionate distribution adjustment method:

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(a) Vector misclosures are simply distributed proportionately over each of the three GPS baselines in the traverse:

$$\delta x = - (-) 0.4528 / 3 = + 0.1509$$

$$\delta y = - (-) 1.0008 / 3 = + 0.3336$$

$$\delta z = - (-) 0.7595 / 3 = (-) 0.2532$$

Vector	ΔX^a	ΔY^a	ΔZ^a
A	3778.0613	(-) 6006.4865	(-) 6231.8000
B	7859.6216	(-) 3318.7756	+ 399.9370
C	5887.0225	(-) 4288.6302	(-) 2350.4762

(b) Final adjusted coordinates:

Point	X^a	Y^a	Z^a
PLR 8.5	(-) 2202 171.0149	(-) 4890 133.2786	+3440 903.3550
PLR 17	(-) 2194 311.3933	(-) 4893 452.0542	+3441 303.2920

Note: Relatively large horizontal (2-D) misclosure (1:23,340) may be due to existing control inadequacies, not poor GPS baseline observations.

(c) Variances between adjusted coordinates yield relative accuracies well in excess of 1:20,000; thus, if project control requirements are only 1:10,000, then any of the three adjustment methods may be used. The recommended method is the Compass Rule. Fixed coordinates of PGT No. 2 and CONTRAVES G can be on any reference ellipsoid--NAD 27 or NAD 83.

11-22. Geocentric Coordinate Conversions

The following algorithms for transforming between geocentric and geographic coordinates can be performed in the field on a hand-held calculator.

a. Geodetic to Cartesian coordinate conversion. Given geodetic coordinates on NAD 83 (in Φ , λ , H) or NAD 27, the geocentric Cartesian coordinates (X, Y, and Z) on the WGS 84, GRS 80, or Clarke 1866 ellipsoid are converted directly by the following formulas.

$$\begin{aligned} X &= (R_N + h) \cos \Phi \cos \lambda \\ Y &= (R_N + h) \cos \Phi \sin \lambda \\ Z &= ((b^2/a^2) R_N + h) \sin \Phi \end{aligned} \quad (\text{Eq 11-6})$$

where

Φ = latitude in degrees

λ = 360 degrees - λ_w (for CONUS west longitudes)

h = the ellipsoidal elevation. If only the orthometric elevation H is known, then that value may be used.

R_N = the normal radius of curvature

R_N can be computed from either of the following formulas:

$$R_N = (a^2) / [a^2 \cos^2 \Phi + b^2 \sin^2 \Phi]^{1/2} \quad (\text{Eq 11-7})$$

$$\text{or } R_N = (a) / [1 - e^2 \sin^2 \Phi]^{1/2} \quad (\text{Eq 11-8})$$

and

a (GRS 80) = 6,378,137.0 m (semimajor axis)
a (WGS 84) = 6,378,137.0 m
a (NAD 27) = 6,378,206.4 m

b (GRS 80) = 6,356,752.314 1403 m (semiminor axis)
b (WGS 84) = 6,356,752.314 m
b (NAD 27) = 6,356,583.8 m

f (GRS 80) = 1/298.257 222 100 88 (flattening)
f (WGS 84) = 1/298.257 223 563
f (NAD 27) = 1/294.978 698

e^2 (GRS 80) = 0.006 694 380 222 90 (eccentricity squared)
 e^2 (WGS 84) = 0.006 694 379 9910
 e^2 (NAD 27) = 0.006 768 658

NAD 27 = Clarke Spheroid of 1866
GRS 80 \approx NAD 83 reference ellipsoid

also

$$b = a(1 - f)$$

$$e^2 = f(2 - f) = (a^2 - b^2) / a^2$$

$$e^2 = (a^2 - b^2) / b^2$$

b. Cartesian to geodetic coordinate conversion. In the reverse case, given GRS 80 X, Y, Z coordinates, the conversion to NAD 83 geodetic coordinates (Φ , λ , H) is performed using the following noniterative method:

$$\lambda = \arctan(Y/X) \quad (\text{Eq 11-9})$$

The latitude " Φ " and height "h" are computed using the following sequence. The initial reduced latitude β_0 is first computed:

$$\beta_0 = [Z/p] [(1 - f) + (e^2 a / r)] \quad (\text{Eq 11-10})$$

where

$$p = [X^2 + Y^2]^{1/2}$$

$$e^2 = 2f - f^2$$

$$r = [p^2 + Z^2]^{1/2}$$

Directly solving for Φ and h:

$$\tan \Phi = [Z(1 - f) + e^2 a \sin^3 \beta_0] / [(1 - f)(p - a e^2 \cos^3 \beta_0)] \quad (\text{Eq 11-11})$$

$$h^2 = (p - a \cos \beta)^2 + (Z - b \sin \beta)^2 \quad (\text{Eq 11-12})$$

where the final reduced latitude " β " is computed from:

$$\tan \beta = (1 - f) \tan \Phi \quad (\text{Eq 11-13})$$

c. Transforms between other OCONUS datums may be performed by changing the ellipsoidal parameters "a," "b," and "f" to that datum's reference ellipsoid.

d. Example geocentric-geographic coordinate transform

Geographic to geocentric (Φ, λ, h to X, Y, Z) transform:

(1) Given any point:

$$\Phi_N = 35 \text{ deg } 27' 15.217''$$

$$\lambda_W = 94 \text{ deg } 49' 38.107'' \quad \text{then } \lambda = 360 \text{ deg} - \lambda_W = 265.1727481 \text{ deg}$$

$$h = 100 \text{ m} \quad (N = 0 \text{ assumed})$$

(2) Given constants (WGS 84):

$$\begin{aligned} a &= 6,378,137 \text{ m} & b &= a(1 - f) = 6,356,752.314 \\ f &= 1/298.257223563 & e^2 &= f(2 - f) = 6.694380 \times 10^{-3} \end{aligned}$$

e. Geocentric (X, Y, Z) to geographic (Φ, λ, H) transform.

Inversing the above X, Y, Z geocentric coordinates:

$$p = (X^2 + Y^2)^{1/2} = 5,201,440.106 \quad \text{and} \quad r = (p^2 + Z^2)^{1/2} = 6,371,081.918$$

$$\beta_0 = \tan^{-1} [Z / p] [(1 - f) + (e^2 a / r)] = 35.36295229 \text{ deg}$$

$$\tan \Phi = [Z (1 - f) + e^2 a \sin^3 \beta_0] / [(1 - f) (p - a e^2 \cos^3 \beta_0)] = 0.712088398$$

$$\text{then} \quad \Phi = 35.45422693 \text{ deg} = 35 \text{ deg } 27' 15.217''$$

$$\lambda = \tan^{-1} (Y/X) = 85.17274810 \text{ deg} \text{ or } 265.17274810 \text{ deg}$$

$$\text{then} \quad \lambda_w = 360 \text{ deg} - \lambda = 94 \text{ deg } 49' 38.107''$$

$$\beta = \tan^{-1} [(1 - f) \tan \Phi] = 35.36335663 \text{ deg}$$

$$h^2 = (p - a \cos \beta)^2 + (Z - b \sin \beta)^2 = (81.458)^2 + (58.004)^2$$

$$\text{then} \quad h = 99.999 = 100 \text{ m}$$

f. North American Datum of 1927 (Clarke Spheroid of 1866). Given a point with SPCS/Project coordinates on NAD 27, the point may be converted to X, Y, Z coordinates for use in subsequent adjustments.

$$\Phi_N = 35 \text{ deg } 27' 15.217'' \quad \lambda_w = 94 \text{ deg } 49' 38.107'' \quad h \text{ or } H = 100 \text{ m}$$

(NAD 27 from SPCS X-Y to Φ - λ conversion using USACE program CORPSCON)

$$\begin{aligned} a &= 6,378,206.4 & b &= 6,356,583.8 & f &= 1/294.978698 & e^2 &= 0.006768658 \\ & & & & & & & \text{(NAD 27/Clarke 1866 Spheroid)} \end{aligned}$$

$$\text{then} \quad R_N = (a) / [1 - e^2 \sin^2 \Phi]^{1/2} = 6392 \text{ } 765.205 \text{ m}$$

$$X = (R_N + h) \cos \Phi \cos \lambda = (-) 438 \text{ } 220.073 \text{ m}$$

$$Y = (R_N + h) \cos \Phi \sin \lambda = (-) 5189 \text{ } 023.612 \text{ m}$$

$$Z = ((b^2/a^2) R_N + h) \sin \Phi = + 3733 \text{ } 466.852 \text{ m}$$

These geocentric coordinates (on NAD 27 reference) may be used to adjust subsequent GPS baseline vectors observed on WGS 84.

11-23. Evaluation of Adjustment Results

A survey shall be classified based on its horizontal point closure ratio, as indicated in Table 11-2 or the vertical elevation difference closure standard given in Table 11-3. Other criteria pertaining to the results in free and constrained adjustments were given in Table 11-1.

a. Horizontal control standards. The horizontal point closure is determined by dividing the linear distance misclosure of the survey into the overall circuit length of a traverse, loop, or network line/circuit. When independent directions or angles are observed, as on a conventional survey (i.e. traverse, trilateration, or triangulation), these angular misclosures may optionally be distributed before assessing positional misclosure. In cases where GPS vectors are measured in geocentric coordinates, then the three-dimensional positional misclosure is assessed.

Table 11-2. USACE Point Closure Standards for Horizontal Control Surveys

USACE Classification	Point Closure Standard (Ratio)
Second Order Class I	1:50,000
Second Order Class II	1:20,000
Third Order Class I	1:10,000
Third Order Class II	1: 5,000
4th Order - Construction Layout	1: 2,500 - 1:20:000

Table 11-3. USACE Point Closure Standards for Vertical Control Surveys

USACE Classification	Point Closure Standard (Millimeters)
Second Order Class I	6 mm $K^{1/2}$
Second Order Class II	8 mm $K^{1/2}$
Third Order	12 mm $K^{1/2}$
4th Order - Construction Layout	24 mm $K^{1/2}$

(K is distance in kilometers)

(1) Approximate surveying. Approximate surveying work should be classified based on the survey's estimated or observed positional errors. This would include absolute GPS and some differential GPS techniques with positional accuracies ranging from 10 to 150 feet (95 %). There is no order classification for such approximate work.

(2) Higher-order surveys. Requirements for relative line accuracies exceeding 1:50,000 are rare for most USACE applications. Surveys requiring accuracies of First-Order (1:100,000) or better should be performed using FGCS standards and specifications, and must be adjusted by the National Geodetic Survey (NGS).

(3) Construction layout or grade control (Fourth-Order). This classification is intended to cover temporary control used for alignment, grading, and measurement of various types of construction, and some local site plan topographic mapping or photo mapping control work. Accuracy standards will vary with the type of construction. Lower accuracies (1:2,500 - 1:5,000) are acceptable for earthwork, dredging, embankment, beach fill, levee alignment stakeout and grading, and some site plan, curb and gutter, utility building foundation, sidewalk, and small roadway stakeout. Moderate accuracies (1:5,000) are used in most pipeline, sewer, culvert, catch basin, and manhole stakeout, and for general residential building foundation and footing construction, major highway pavement, and concrete runway stakeout work. Somewhat higher accuracies (1:10,000 - 1:20,000) are used for aligning longer bridge spans, tunnels, and large commercial structures. For extensive bridge or tunnel projects, 1:50,000 or even 1:100,000 relative accuracy alignment work may be required. Vertical grade is usually observed to the nearest 0.005 meter for most construction work, although 0.04-meter accuracy is sufficient for rip rap placement, grading, and small diameter pipe placement. Construction control points are typically marked by semi-permanent or temporary monuments (e.g., plastic hubs, P-K nails, wooden grade stakes). Control may be established by short, nonredundant spur shots, using total stations or GPS, or by single traverse runs between two existing permanent control points. Positional accuracy will be commensurate with, and relative to, that of the existing point(s) from which the new point is established.

b. Vertical control standards. The vertical accuracy of a survey is determined by the elevation misclosure within a level section or level loop. For conventional differential or trigonometric leveling, section or loop misclosures (in millimeters) shall not exceed the limits shown in Table 11-3, where the line or circuit length (K) is measured in kilometers. Fourth-Order accuracies are intended for construction layout grading work. Procedural specifications or restrictions pertaining to vertical control surveying methods or equipment should not be over-restrictive.

11-24. Final Adjustment Reports, Submittals, and Metadata

a. A variety of free and/or constrained adjustment combinations may be specified for a contracted GPS survey. Specific stations to be held fixed may be indicated or a contractor may be instructed to determine the optimum adjustment, including appropriate weighting for constrained points. When fixed stations are to be partially constrained, then appropriate statistical information must be provided--either variance-covariance matrices or relative positional accuracy estimates which may be converted into approximate variance-covariance matrices in the constrained adjustment. All rejected observations will be clearly indicated, along with the criteria/reason used in the rejection.

b. When different combinations of constrained adjustments are performed due to indications of one or more fixed stations causing undue biasing of the data, an analysis shall be made as to a recommended solution that provides the best fit for the network. Any fixed control points that should be readjusted due to anomalies from the adjustment(s) should be clearly indicated in a final analysis recommendation.

c. The final adjusted horizontal and/or vertical coordinate values shall be assigned an accuracy classification based on the adjustment statistical results. This classification shall include both the resultant geodetic/Cartesian coordinates and the baseline differential results. The final adjusted coordinates shall state the 95 percent confidence region of each point and the accuracy in parts per million between all points in the network. The datum and/or SPCS will be clearly identified for all coordinate listings.

d. Final report coordinate listings may be required on hard copy as well as on a specified digital media. It is recommended that a scaled plot be submitted with the adjustment report showing the proper locations and designations of all stations established.

e. Final report format. The following outline is recommended for GPS project submittals involving extensive networks, geoid modeling, and adjustments. Formal reports are usually not required for local topographic site plan or construction stake out surveys where simple GPS "total station" RTK techniques are employed. Typical project reports submitted by A-E contractors are shown in Appendix E and Appendix J. These sample reports include applicable portions of the outline guidance below.

Recommended Outline for Survey Report Submittals

Section 1: General Project Description

-Overview of the project including location, purpose, and parties involved.

Section 2: Background

-Reason for project (more detailed description) and more specific location description including a map. Accuracy and deliverables should be discussed in this section.

Section 3: Project Planning

-How the project was planned including but not limited to: reconnaissance results; PDOP and satellite availability tools used; DGPS method(s) selected; feature and attribute standards selected.

Section 4: Data Collection

-Overview of how data was collected including but not limited to: Equipment used (make and model); data collection method(s) and/or techniques used; control points used (brief history of control, datums, recovery notes); amount of data collected; number of crews and personnel per crew; how long the data collection took; data processing/error checking performed in field.

Section 5: Data Processing

-How was the data processing was performed including but not limited to process followed.

Subsection 5.1: Baseline Processing:

-Software used; baseline processing results (summary); reprocessed baselines and reason for; parameters for baseline processing (elevation mask, type of ephemeris used); summary results or loop closures (if applicable).

Subsection 5.2: Network Adjustments:

-Software used; results of unconstrained adjustment, minimal constrained adjustment (show unconstrained known control compared against published coordinates), and fully constrained adjustment; summary of weights used, general statistics.

Section 6: Project Summary and Conclusion

-This section shall include a narrative of overall results of the processing, products produced, listing of deliverables being submitted, overall accuracy of the data collection (based on results from data processing section), problems encountered during data collection and data processing, recommendations for future data collection efforts of this type or in this area (lessons learned).

Section 7: Output and Reports from Software

-This section shall include the detailed reports and output from software packages used during the data processing. This section might have multiple subsections--e.g., one for each step in the processing that has output that is critical in evaluating results.

f. Metadata submittals. Metadata records should be created for observations and adjustments of project control established by GPS. Corps metadata policy and procedural references are contained in ER 1110-1-8156 (Policies, Guidance, and Requirements for Geospatial Data and Systems) and EM 1110-1-2909 (Geospatial Data and Systems). The following is a sample metadata file developed for a GPS PROSPECT training survey at the Corps Beville Center in Huntsville, AL

Sample Metadata File for a GPS Survey Observations

SurveyIV.met

Identification_Information:

Citation:

Citation_Information:

Originator: Survey IV(comp.)

Publication_Date: Unknown

Publication_Time: Unknown

Title: Field survey to densify geodetic control for civil works plans and specifications for the Tom Bevill Center and adjacent facilities

Edition: FY02

Description:

Abstract:

This data set is the result of a GPS field survey performed to develop geodetic control at specified locations within the vicinity of the Tom Bevill Center, Huntsville, Alabama.

Purpose:

To set control to verify existing map data and to facilitate future civil works projects adjacent to the Tom Bevill Center

Time_Period_of_Content:

Time_Period_Information:

Range_of_Dates/Times:

Beginning_Date: 20020603

Ending_Date: 20020607

Currentness_Reference: Publication Date

Status:

Progress: Complete

Maintenance_and_Update_Frequency: Annually

Spatial_Domain:

Bounding_Coordinates:

West_Bounding_Coordinate: -086.645900

East_Bounding_Coordinate: -086.639310

North_Bounding_Coordinate: +34.732910

South_Bounding_Coordinate: +34.717664

Keywords:

Theme:

Theme_Keyword_Thesaurus: Tri - Service Spatial Data Standard

Theme_Keyword: Geodetic/Cadastral

Place:

Place_Keyword_Thesaurus: Geographic Names Information System

Place_Keyword: Tom Bevill Center

Access_Constraints: None

Use_Constraints:

These data were compiled for government use and represents the results of data collection/processing for a specific U.S. Army Corps of Engineers (USACE) activity. The USACE makes no representation as to the suitability or accuracy of these data for any other purpose and disclaims any liability for errors that the data may contain. As such, it is only valid for its intended use, content, time, and accuracy specifications. While there are not explicit constraints on the use of the data, please exercise appropriate and professional judgment in the use and interpretation of these data.

Sample Metadata File for a GPS Survey Observations (Continued)

Point_of_Contact:

Contact_Information:

Contact_Person_Primary:

Contact_Person: Diane M. Hollingshead

Contact_Organization: U.S. Army Corps of Engineers

Contact_Position: Survey IV Coordinator

Contact_Address:

Address_Type: mailing address

Address:

CEHR-P

P.O. Box 1600

City: Huntsville

State_or_Province: Alabama

Postal_Code: 35807-4301

Contact_Voice_Telephone: 256-895-7449

Native_Data_Set_Environment: ASCII Data

Data Quality Information:

Attribute_Accuracy:

Attribute_Accuracy_Report: Point attributes were supplied by USACE, Survey IV.

Logical_Consistency_Report: None

Completeness_Report: None

Positional_Accuracy:

Horizontal_Positional_Accuracy:

Horizontal_Positional_Accuracy_Report:

Points meet Third Order Class 1 horizontal accuracy as specified in EM1110-1-2909, Change 2, 1 Jul 98; Table 11-5, Design, Construction, Operation & Maintenance of Feature & Topographic Detail Plans.

Vertical_Positional_Accuracy:

Vertical_Positional_Accuracy_Report:

Points meet third order vertical accuracy as specified in EM1110-1-2909, Change 2, 1 Jul 98; Table 11-5, Design, Construction, Operation & Maintenance of Military Feature & Topographic Detail Plans.

Lineage:

Source_Information:

Source_Citation:

Citation_Information:

Originator: Survey IV(comp.)

Publication_Date: Unknown

Publication_Time: Unknown

Title: Field survey to densify geodetic control for civil works plans and specifications for the Tom Beville Center and adjacent facilities

Type_of_Source_Media: paper

Source_Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 20010604

Source_Currentness_Reference: Publication Date

Source_Citation_Abbreviation: None

Source_Contribution: Geodetic Control Points

Sample Metadata File for a GPS Survey Observations (Continued)

Process_Step:
Process_Description:
The data for these points was collected with GPS and
processed/adjusted with Trimble Geomatics Office
software.
Process_Date: 20020606

Spatial Reference Information:

Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 0101
Transverse_Mercator:
Scale_Factor_at_Central_Meridian: 0.9999600000
Longitude_of_Central_Meridian: -085.833333
Latitude_of_Projection_Origin: +30.500000
False_Easting: 656166.667
False_Northing: 0.000
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: .001
Ordinate_Resolution: .001
Planar_Distance_Units: Survey Feet
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000
Denominator_of_Flattening_Ratio: 298.257223563
Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
Altitude_Datum_Name: North American Vertical Datum of 1988
Altitude_Resolution: .01
Altitude_Distance_Units: Meters
Altitude_Encoding_Method: Explicit elevation coordinate included with horizontal
coordinates

Distribution Information:

Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Jim Garster
Contact_Organization: U.S. Army Corps of Engineers
Contact_Position: Survey Engineer
Contact_Address:
Address_Type: mailing and physical address
Address:
ERDC
U.S. Army Topographic Engineering
Center
ERDC-TEC-VA
City: Alexandria
State_or_Province: Virginia
Postal_Code: 22315
Contact_Voice_Telephone: 703-428-6766

Sample Metadata File for a GPS Survey Observations (Continued)

Distribution_Liability:

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Standard_Order_Process:

Non-digital_Form:

For digital or non-digital data, contact Prospect Course Proponent

Fees: No charge

Metadata Reference Information:

Metadata_Date: 20020607

Metadata_Contact:

Contact_Information:

Contact_Person_Primary:

Contact_Person: Fran Woodward

Contact_Organization: U.S. Army Corps of Engineers

Contact_Position: Civil Engineering Technician

Contact_Address:

Address_Type: mailing address

Address:

CESAJ-CO-OM

P. O. Box 4970

City: Jacksonville

State_or_Province: Florida

Postal_Code: 32232-0019

Contact_Voice_Telephone: 904-232-1132

Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata

Metadata_Standard_Version: FGDC-STD-001-1998

Metadata_Time_Convention: Local time

Metadata_Access_Constraints: None

Metadata_Use_Constraints:

These data were compiled for government use and represents the results of data collection/processing for a specific U.S. Army Corps of Engineers (USACE) activity. The USACE makes no representation as to the suitability or accuracy of these data for any other purpose and disclaims any liability for errors that the data may contain. As such, it is only valid for its intended use, content, time, and accuracy specifications. While there are not explicit constraints on the use of the data, please exercise appropriate and professional judgment in the use and interpretation of these data.

Not all metadata fields must be completed for a particular project. Figure 11-10 below shows the required and optional metadata sections. For example, the above sample metadata file used only sections 1, 2, 4, 6, and 7.

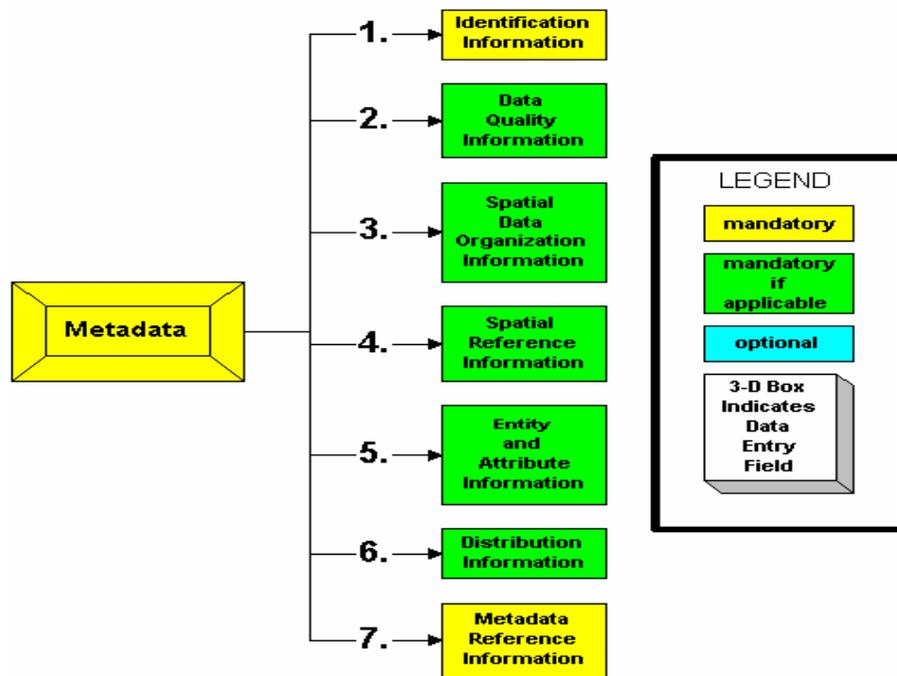


Figure 11-10. General Metadata format indicating sections 2 through 6 are optional

11-25. Mandatory Requirements

The criteria standards in Tables 11-1, 11-2, and 11-3 are considered mandatory.