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 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. While the underlying technique may be similar for most GPS survey adjustment software packages, the user interface, process flow, and default settings will vary from vendor to vendor. The detailed instruction manuals provided by the vendor, along with any sample adjustment projects, should be carefully reviewed and consulted for proper use. Additional technical training courses may be offered by the vendor as well. 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 baseline reduction and adjustment is necessarily a three-dimensional process, the relative accuracy of GPS-derived orthometric heights (elevations) is very much dependant on the existence of an adequate geoid model and its proper use. Special techniques and constraints are necessary to determine approximate orthometric heights 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.

f. The advent of GPS surveying technology has provided a cost-effective means of tying previously poorly connected USACE projects to the NSRS, and simultaneously transforming the project to the currently defined national horizontal and vertical datums. 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 NSRS, 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 NSRS 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 $\pm$ 7 arc-seconds (1-σ). 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:

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

where V is the matrix of the residuals (V^T is the transpose of V)
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 x 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, "V" is a [*n x 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 " Σ". 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 " σ_0^2 " and is computed from:

$$\sigma_0^2 = V^T P V / r$$

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 NSRS 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 NSRS 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 NSRS 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 NSRS, 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 NSRS, 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. NSRS 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 NSRS. 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 83 coordinates (in latitude and longitude) relative to the NSRS 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 NSRS.

(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 (NSRS/NAD 83) of these construction and/or boundary reference points are of less importance.

(3) Although reference connections with the NSRS 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. NSRS) 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 NSRS 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 NSRS 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 network. 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.

e. Further thoughts on NSRS versus local project control. In the past, the extension or “realization” of a given horizontal reference frame depended on the existence of local control monumentation and horizontal coordinate data computed for those local control monuments usually based on conventional traverses measurements (angles and distances measured sequentially with transit and tape, theodolite and EDM, or total station) that connected the local control monumentation to certain published NSRS control points. Due to the nature of error propagation inherent in older conventional traverse methods, the accuracy of the computed coordinates of each point in the traverse is generally degraded the further removed it is from the initial control points. Presently, the quality of our surveying tools and methods (primarily carrier-phase differential GPS) have improved to the point that we now have direct, reliable, precise/repeatable, and very accurate access to established geodetic reference frames (i.e., NAD83, typically to within a few centimeters horizontally) regardless of our proximity to fundamental control monumentation (i.e., published NSRS control points). Because of this, we can now “see” discrepancies between earlier conventionally-derived coordinate data for a given local monument and its “true” coordinate position as derived from carrier-phase differential GPS observation. As was mentioned in Section 9-23-e, localization to any control not included in the NSRS (e.g., legacy Corps baseline monumentation) should be undertaken with great caution and with full attention to detail. Localization to control monuments not included in the NSRS could (if the control monuments are subsequently disturbed or destroyed) result in a survey data set that cannot be reproduced or confidently integrated with other properly acquired data sets. The need to localize to control that is not part of the NSRS should be addressed on a case by case basis.

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).

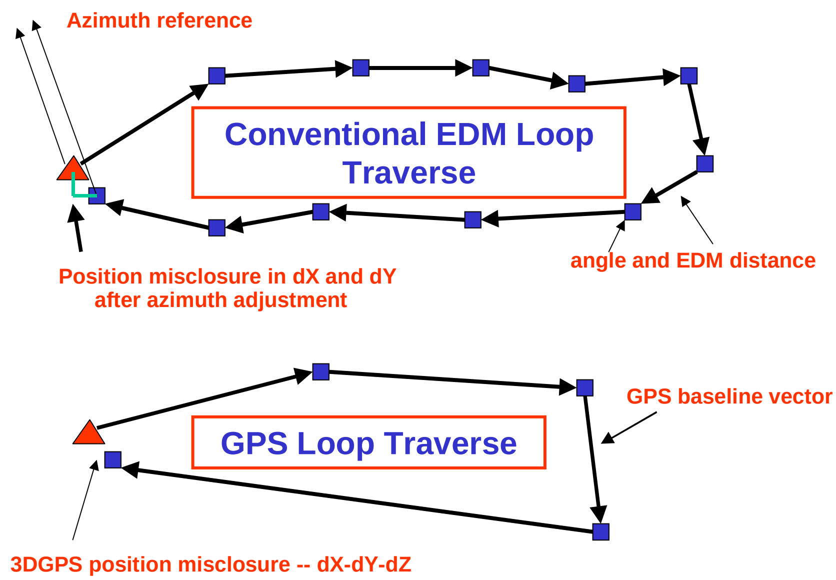

Figure 11-1. Conventional EDM and GPS traverse loops

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 NSRS (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.

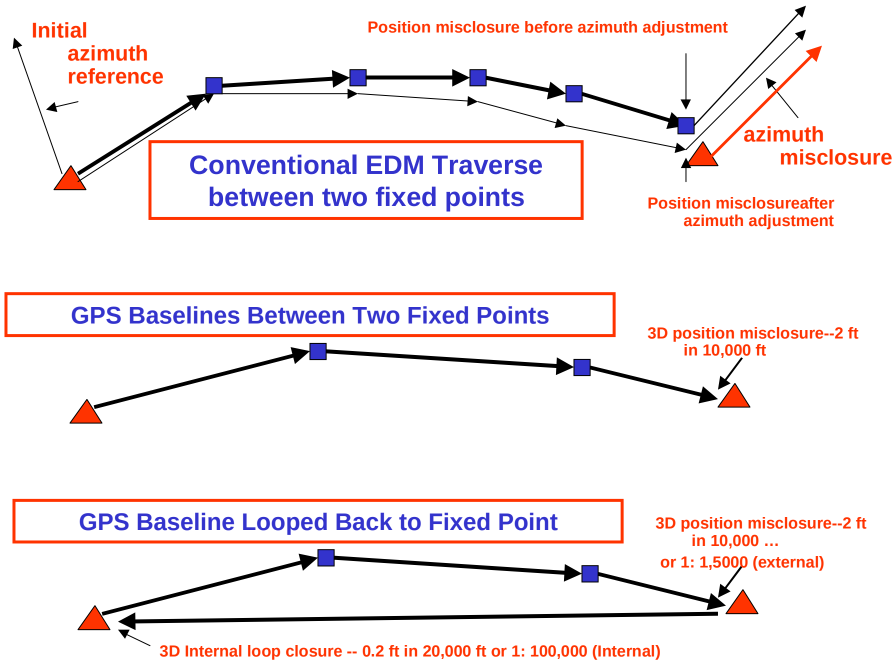

Figure 11-2. Constrained adjustments between two fixed points

(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 NSRS 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 NSRS 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.

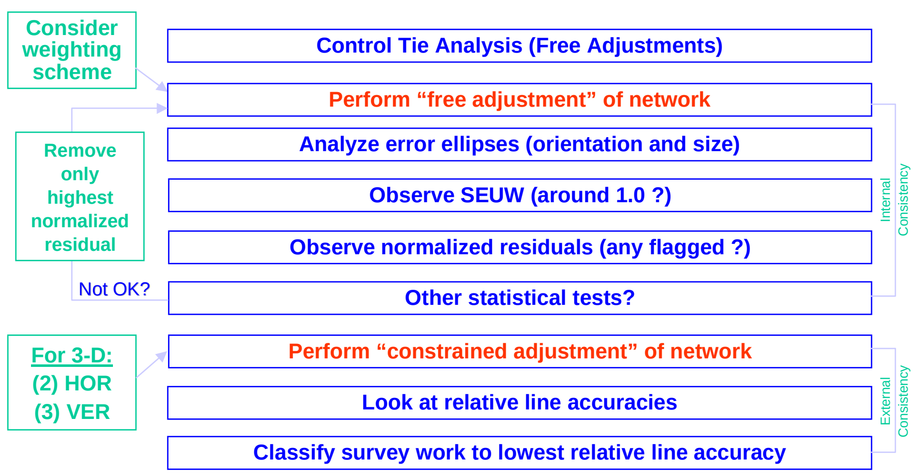

Figure 11-3. Sequential flow of a GPS network adjustment

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

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 USACE. 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 bests 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 Adj.)	no specific criteria

11-11. <u>Baseline Weights--Covariance Matrix</u>. 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 brackets

AA5493 to OFFSET (1)  -4345.9720     8.1161e-007   (0.0009)
                         911.4010    -1.5108e-007    1.5096e-006 (0.0012)
                        3410.0230     7.4691e-007   -1.1100e-006  3.1877e-006 (0.0018)
```

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 scaling and estimated centering error

```
GPS Vector Standard Error Factors   : 8.0000
GPS Vector Centering (Meters)       : 0.00200
GPS Vector Transformations          : Solve for Scale and Rotations

                 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 ± 50 cm + 50 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.

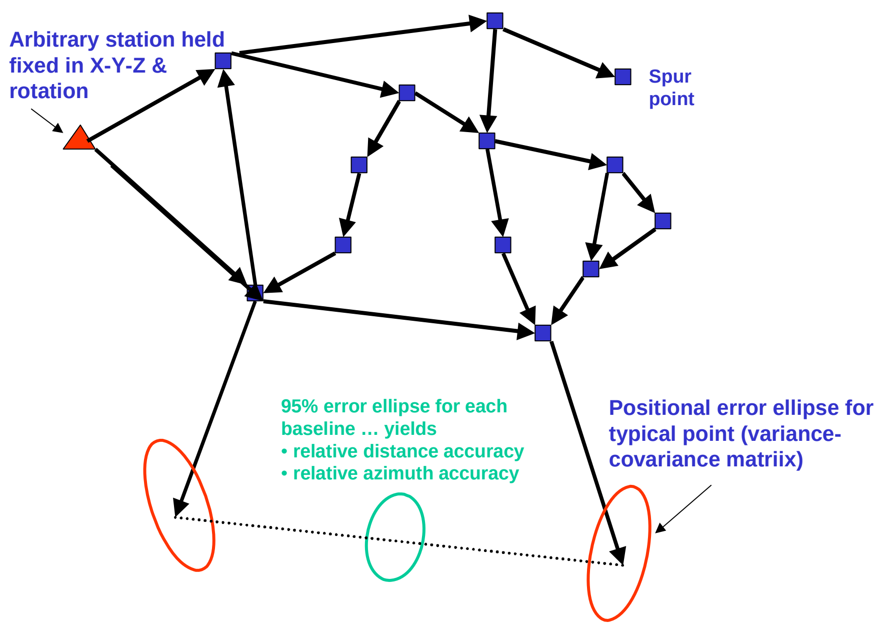

Figure 11-4. Free adjustment of a complex GPS network

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 --    -- RN --    -- RH --    - PPM -    DIST - STD -
                             (m)         (m)         (m)                 (km)   (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)-- ν/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. <u>Outlier Tests and Reject Criteria</u>. 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.

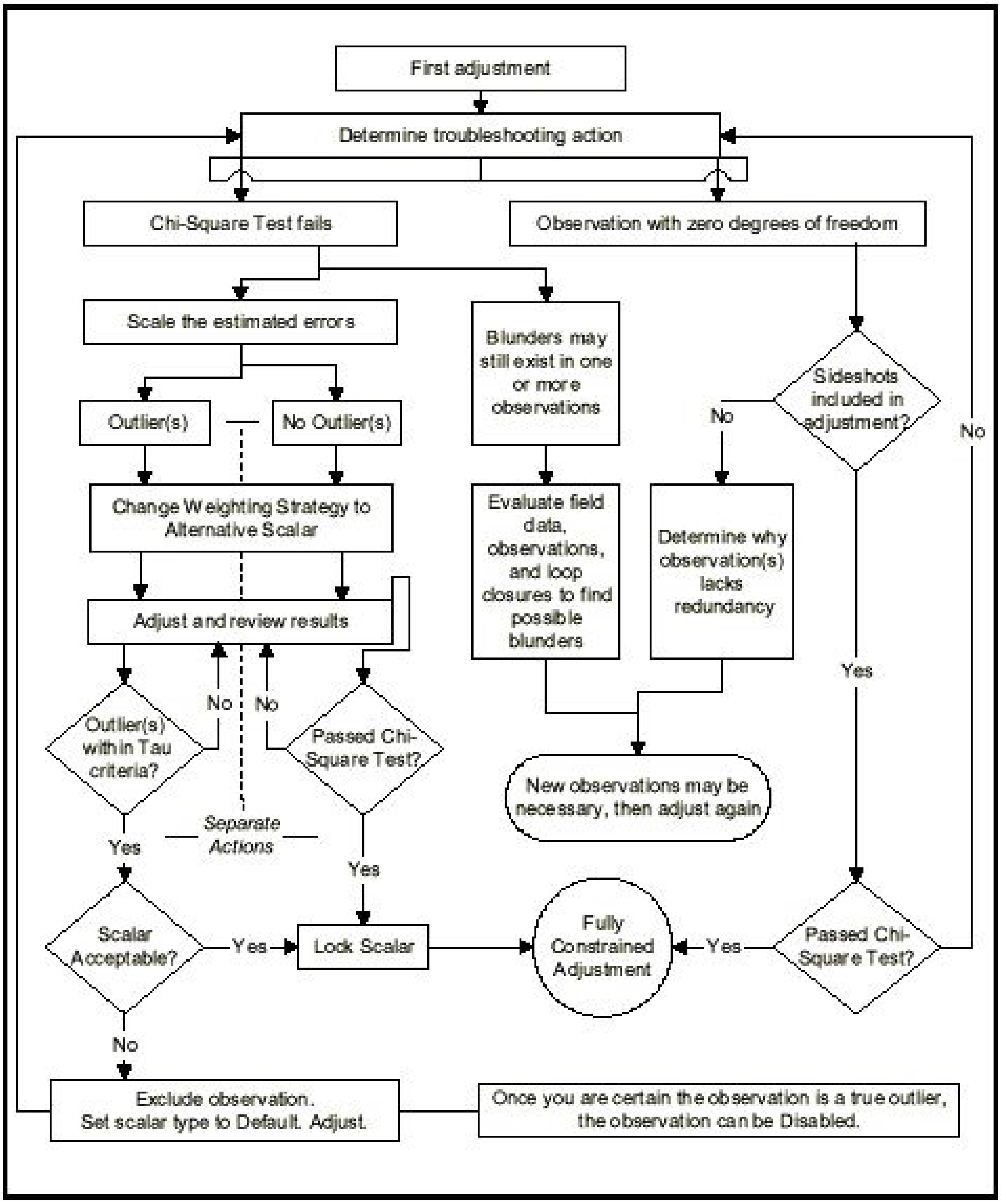

Figure 11-5. Use of outlier test statistics in performing a network adjustment (Trimble Navigation LTD)

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.

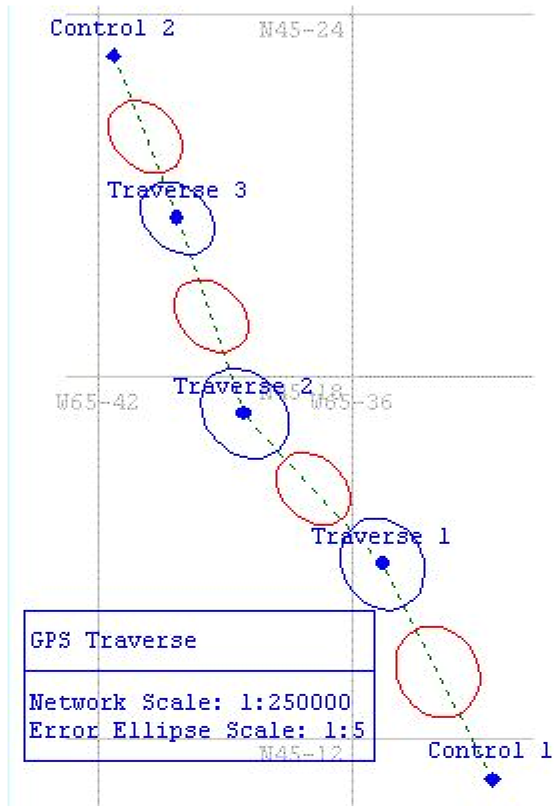

Figure 11-6. Relative accuracy ellipses for points (blue) and baselines (red). Control 1 and Control 2 are fixed points. (Microsearch GeoLab 2001 Adjustment Software)

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

EDM Distance Observations

Adjusted Measured Distance Observations (Meters)

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 To	Component	Adj Value	Residual	StdErr	StdRes
(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 Grnd Dist	95% RelConfidence Azi	 Dist	 PPM
0012	0013	170-36-18.76	10261.4179 10261.6712	0.12	0.0065	0.6324
0012	0016	119-21-46.52	7490.5576 7490.7714	0.13	0.0046	0.6123

Station Coordinate Error Ellipses (Meters)
Confidence Region = 95%

Error ellipse data for adjusted points on network

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)
Confidence Region = 95%

Relative line error ellipse data for adjusted points on network

Stations From	To	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis	Vertical
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 NSRS points to the flood control project area.

OBSERVATION ADJUSTMENT SUMMARY (Observed and Adjusted Parameters)

Network calibration 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          1.00σ = 0.0155 seconds
Deflection in latitude =  +2.4780 seconds    1.00σ = 1.5593 seconds
Deflection in longitude =  +4.3040 seconds   1.00σ = 0.9980 seconds
Network scale = 1.000001515015               1.00σ = 0.000000064660

OBS#  BLK#/  TYPE      BACKSIGHT/      UDVC/    OBSERVED/      1.00σ/     TAU
      REF#             INSTRUMENT/     UDPG/    ADJUSTED/      1.00σ/
                       FORESIGHT       SBNT     RESIDUAL       1.00σ

   1   -**- hgoid                -**-   -**-       -45.2101m   0.0001m    0.49
          1                    A 1001   -**-       -45.2101m   0.0001m
                                 -**-      1     -0.000001m    0.0000m

   2   -**- hgoid                -**-   -**-       -41.3690m   0.0001m    OPEN
          2                   COMERIO   -**-       -41.3690m   0.0001m
                                 -**-      1     +0.000000m    0.0000m

  17      2 gpsaz                -**-   -**-    90°12'28.3727"  0.0356"   0.13
          1                     PUR 3   -**-    90°12'28.3885"  0.0132"
                               A 1001      1       +0.015842"   0.0330"

  18      2 gpsht                -**-   -**-      -131.9826m   0.1479m    0.16
          1                     PUR 3   -**-      -131.9021m   0.0349m
                               A 1001      1     +0.080439m    0.1437m

  19      2 gpsds                -**-   -**-     104825.8866m  0.0594m    0.33
          1                     PUR 3   -**-     104825.9576m  0.0070m
                               A 1001      1     +0.070964m    0.0590m
                 •
                 •
                 •
```

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

```
 224     71 gpsaz                -**-   -**-    92°41'28.2839"  0.0308"   0.37
          1                     PUR 3   -**-    92°41'28.2472"  0.0133"
                                 TATI      1       -0.036688"   0.0277"

 225     71 gpsht                -**-   -**-      -124.3835m   0.1211m    0.04
          1                     PUR 3   -**-      -124.3994m   0.0405m
                                 TATI      1     -0.015882m    0.1141m

 226     71 gpsds                -**-   -**-     104537.6590m  0.0155m    0.41
          1                     PUR 3   -**-     104537.6797m  0.0066m
                                 TATI      1     +0.020775m    0.0141m
```

Tau Test

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 (à = 95%) = PASS
      Degrees of Freedom = 163.00

                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

        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

               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

     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
```

Degrees of Freedom "r"

Reference Factors for Baseline Solutions

Reference Factors for Geoid Model

Weight Assignments for GPS and equipment centering

Sample of Trimble GPSurvey Observation Adjustment Summary (Continued)

NETWORK ADJUSTMENT CONSTRAINTS

3 Constrained Points in X-Y-Z

1-sigma errors in X, Y, and height

```
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

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 x S)ý = Cý + Pý:
   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	211°10'02"	0.04"	28603.164m	0.0059m	1: 4837618
COMERIO	+191.6495m	0.2149m	+187.8083m	0.2149m	1: 4837618
A 1001	237°06'49"	0.64"	2099.955m	0.0068m	1: 309088
DRYDOCK	-0.3443m	0.0397m	-0.5677m	0.0397m	1: 309088
A 1001	173°52'33"	0.06"	20838.212m	0.0059m	1: 3536897
MESAS	+369.0223m	0.1547m	+365.9727m	0.1547m	1: 3536897
A 1001	203°05'54"	0.51"	2160.316m	0.0056m	1: 382773
MP 1	+6.2453m	0.0254m	+5.8614m	0.0254m	1: 382773
	•				
	•				
	•				
	•				
RRS 1	212°00'38"	0.33"	4586.198m	0.0075m	1: 615545
TATI	-8.7112m	0.0592m	-9.4431m	0.0592m	1: 615545
SJH 44	163°44'08"	0.37"	3556.270m	0.0063m	1: 566242
SJHL 11 RM 1	+1.4034m	0.0363m	+0.7455m	0.0363m	1: 566242
SJH 44	139°55'03"	0.18"	6204.046m	0.0051m	1: 1210786
TATI	+8.9809m	0.0401m	+8.0800m	0.0401m	1: 1210786
SJHL 11 RM 1	113°58'02"	0.49"	3281.605m	0.0074m	1: 444627
TATI	+7.5775m	0.0387m	+7.3344m	0.0387m	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	066°04'28.42689" W	2.73200	-42.48337
	882738.00637	780498.87896	8.96324	
COMERIO	18°14'08.75965" N	066°12'52.29950" W	190.56082	149.19186
	802345.96891	732089.99908	625.22327	
DRYDOCK	18°26'47.89232" N	066°05'28.52390" W	2.16132	-42.82538
	878985.77825	774720.68565	7.08975	
MESAS	18°16'11.08408" N	066°03'12.74307" W	368.70346	326.54298
	814776.08472	787925.49457	1209.66679	
MP 1	18°26'20.34912" N	066°04'57.30844" W	8.59188	-36.23434
	876213.11755	777731.11182	28.18954	
MP 3	18°26'18.28984" N	066°04'15.21238" W	6.58580	-38.22604
	876013.28555	781784.27695	21.60691	
PN 007	18°24'00.86849" N	066°03'22.35068" W	13.16149	-30.89685
	862161.61528	786902.04404	43.18265	
PN 030	18°23'50.41792" N	066°04'58.66515" W	11.87409	-32.12466
	861089.02683	777629.43315	38.96153	
PUR 3	18°27'46.70249" N	067°04'01.05083" W	133.53638	87.35157
	885187.27032	436591.08273	438.16948	
RRS 1	18°27'04.27895" N	066°03'20.16586" W	18.86853	-26.22228
	880663.02269	787074.26883	61.90391	
SJH 44	18°27'32.19208" N	066°06'59.11446" W	1.34960	-43.90927
	883438.71281	765991.82221	4.42781	
SJHL11RM	18°25'41.15411" N	066°06'25.17479" W	2.09702	-42.50505
	872243.79347	769278.91615	6.88033	
TATI	18°24'57.79009" N	066°04'42.99983" W	9.42896	-34.92999
	867887.87460	779124.78992	30.93844	

***** 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.

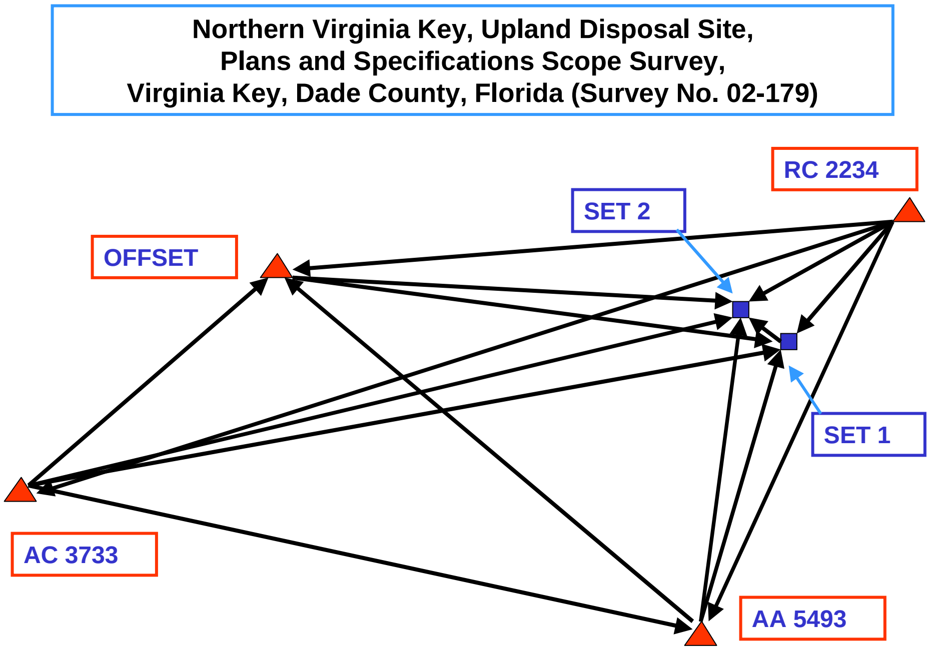

Figure 11-7. Virginia Key Disposal Site Control Network

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)

******************************************************
    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
```

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

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   8.1161e-007 (0.0009)
                         911.4010   -1.5108e-007 1.5096e-006 (0.0012)
                        3410.0230   7.4691e-007 -1.1100e-006 3.1877e-006 (0.0018)

AA5493 to OFFSET (2)   -4345.9790   9.4716e-007 (0.0010)
                         911.3820   -1.3388e-006 6.5898e-006 (0.0026)
                        3410.0200   6.3886e-007 -2.1769e-006 1.6410e-006 (0.0013)

AA5493 to OFFSET (3)   -4345.9750   8.8808e-007 (0.0009)
                         911.3960   -7.9258e-007 3.2975e-006 (0.0018)
                        3410.0190   4.7680e-008 -3.0244e-007 8.9945e-007 (0.0009)

AA5493 to SET1 (1)       527.3470   2.5454e-007 (0.0005)
                        1463.4770   -1.3575e-007 1.5997e-006 (0.0013)
                        2804.1390   1.5573e-008 -6.5468e-007 6.0109e-007 (0.0008)

AA5493 to SET1 (2)       527.3460   9.6956e-007 (0.0010)
                        1463.4670   -1.0256e-006 4.0156e-006 (0.0020)
                        2804.1500   5.8803e-007 -1.8213e-006 1.1555e-006 (0.0011)

AA5493 to SET1 (3)       527.3410   6.7566e-007 (0.0008)
                        1463.4740   -8.9273e-007 2.8178e-006 (0.0017)
                        2804.1560   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)
```

```
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
AC2234 to OFFSET (1)	0.0420	0.0358	-0.1446	25.023	6.2	0.1680
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 --     -- RN --     -- RH --
                 (m)          (m)          (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 ----    ---- Y ----    ---- Z ----
                   (m)            (m)            (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 (m 2 )-----------
            (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
**********************************************************************
```

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

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

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

11-20. <u>Sample Network Adjustment--Everglades National Park Modified Water Deliveries</u>. 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.

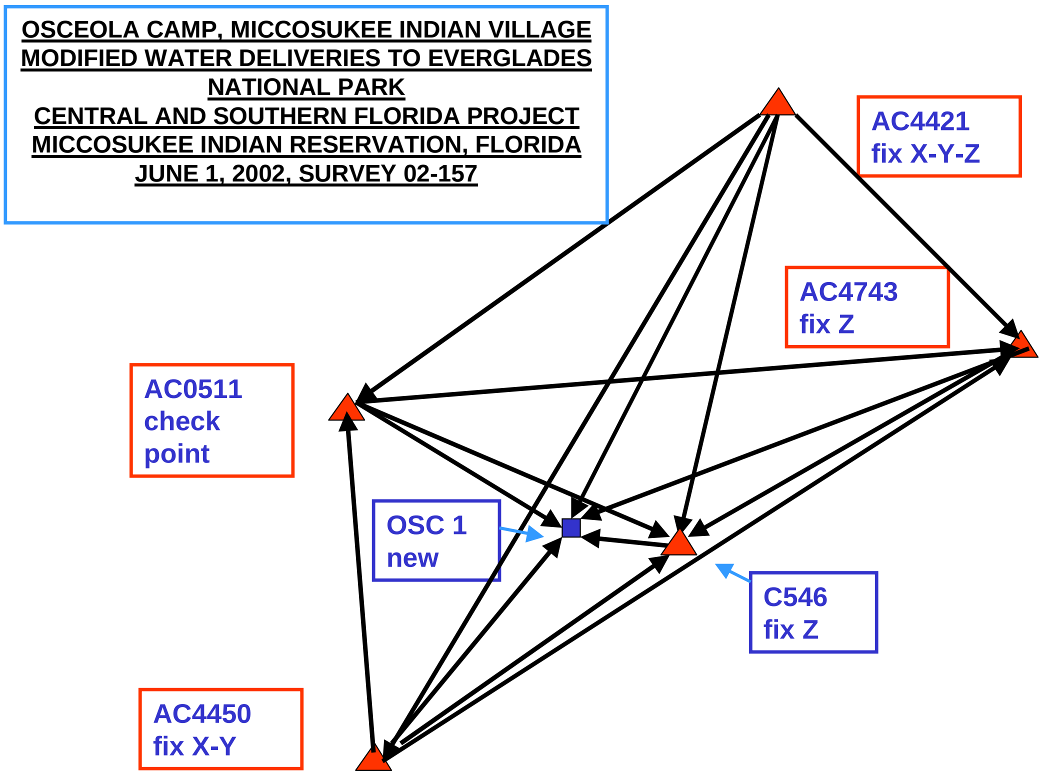

Figure 11-8. Osceola Camp GPS network control scheme

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.

```
**************************************************
* 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)

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

Fixed X-Y-Z Points:
AC4421
Fixed X-Y Points:
AC4450
Fixed Z Points:
AC4743
C546
Check Point: AC0511
New Point: OSC 1

```
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  2.0675e-007 (0.0005)
                      -2448.8320  -9.9567e-008 1.1169e-006 (0.0011)
                      -5879.2220  5.8886e-008 -3.8150e-007 4.5670e-007 (0.0007)

AC0511 to AC4450 (2)   2578.5950  5.7093e-007 (0.0008)
                      -2448.8200  -2.3657e-007 2.1838e-006 (0.0015)
                      -5879.2160  -3.1864e-009 -8.7442e-007 1.1279e-006 (0.0011)

AC0511 to AC4743 (1)  11409.6470  3.1346e-007 (0.0006)
                       1856.3890  -1.6648e-007 1.6595e-006 (0.0013)
                        -54.2970  9.6551e-008 -5.5090e-007 6.5289e-007 (0.0008)

AC0511 to AC4743 (2)  11409.6400  6.5983e-007 (0.0008)
                       1856.4020  -2.7220e-007 2.5029e-006 (0.0016)
                        -54.2970  -4.5299e-009 -1.0087e-006 1.3303e-006 (0.0012)

AC0511 to C546 (1)     6402.6260  3.1519e-007 (0.0006)
                       1029.4410  -1.8154e-007 1.6328e-006 (0.0013)
                        -50.5110  1.0456e-007 -5.2772e-007 6.3081e-007 (0.0008)
```

```
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)

30 baseline residuals

```
***************************************************************
    OUTPUT VECTOR RESIDUALS (East, North, Height - Local Level)
***************************************************************
SESSION NAME              -- RE --    -- RN --    -- RH --     - PPM -    DIST - STD -
                            (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
                      --------------------------------
            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
****************************************************************
                                                 2
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


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.
```

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

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 ΔX_i, ΔY_i, ΔZ_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:

$$dx = X_F + \Sigma \Delta X_i - X_E$$

$$dy = Y_F + \Sigma \Delta Y_i - Y_E$$

$$dz = Z_F + \Sigma \Delta Z_i - Z_E \qquad \text{(Eq 11-1)}$$

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 ΔX_i, ΔY_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 (δx_i, δy_i, δz_i) to each baseline vector component may be computed using either the Compass Rule:

$$\delta x_i = - dx \; [\, l_i \,/\, L \,] \qquad \text{(Eq 11-2)}$$

$$\delta y_i = - dy \; [\, l_i \,/\, L \,]$$

$$\delta z_i = - dz \; [\, l_i \,/\, L \,]$$

or the Transit Rule:

$$\delta x_i = - dx \; [\, \Delta x_i \,/\, \Sigma \Delta x_i \,] \qquad \text{(Eq 11-3)}$$

$$\delta y_i = - dy \; [\, \Delta y_i \,/\, \Sigma \Delta y_i \,]$$

$$\delta z_i = - dz \; [\, \Delta z_i \,/\, \Sigma \Delta z_i \,]$$

(4) The adjusted vector components are computed from:

$$\Delta X_i^a = \Delta X_i^a + \delta x_i^a \qquad \text{(Eq 11-4)}$$

$$\Delta Y_i^a = \Delta Y_i^a + \delta y_i^a$$

$$\Delta Z_i^a = \Delta Z_i^a + \delta z_i^a$$

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

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

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

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

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):

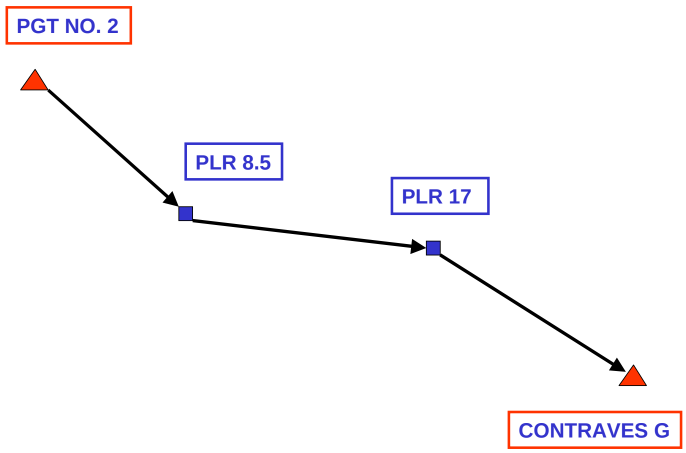

Figure 11-9. US Army Yuma Proving Ground GPS Traverse Sketch

PGT NO 2	CONTRAVES G
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):

(-)2205949.0762	X_F	(-) 4884126.7921	Y_F	3447135.1550	Z_F
+3777.9104	ΔXa	(-) 6006.8201	ΔYa	(-)6231.5468	ΔZa
+7859.4707	ΔXb	(-) 3319.1092	ΔYb	+ 400.1902	ΔZb
+5886.8716	ΔXc	(-) 4288.9638	ΔYc	(-)2350.2230	ΔZc
-(-)2188424.3707	X_E	-(-) 4897740.6844	Y_E	- 3438952.8159	Z_E
dx = (-) 0.4528		dy = (-) 1.0008		dz = + 0.7595	

(3) Linear 3-D Misclosure:

= (0.45282 + 1.00082 + 0.75952) ½ = 1.335 m or 1 part in 25,638.2/1.335 = 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	la/L = 0.368
l_b	= 8 540.955	lb/L = 0.333
l_c	= 7 653.366	lc/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	0.1354	0.2992	(-) 0.2271
	(+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	Za	
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,

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

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

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:

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

δx = - (-) 0.4528 / 3 = + 0.1509
δy = - (-) 1.0008 / 3 = + 0.3336
δz = - (-) 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.

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

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:

$$R_N = (a^2) / [a^2 \cos^2 \Phi + b^2 \sin^2 \Phi]^{½} \qquad \text{(Eq 11-7)}$$

$$\text{or } R_N = (a) / [1 - e^2 \sin^2 \Phi]^{½} \qquad \text{(Eq 11-8)}$$

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:

$$\lambda = \arc\tan (Y/X) \qquad \text{(Eq 11-9)}$$

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

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

where

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

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

$$r = [p^2 + Z^2]^{½}$$

Directly solving for Φ and h:

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

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

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

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

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:

Φ_N = 35 deg 27' 15.217"

λ_W = 94 deg 49' 38.107" then λ = 360 deg - λ_W = 265.1727481 deg h = 100 m (N = 0 assumed)

(2) Given constants (WGS 84):

a = 6,378,137 m b = a(1 - f) = 6,356,752.314
f = 1/298.257223563 e^2 = f(2 - f) = 6.694380 x 10^{-3}

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

Inversing the above X, Y, Z geocentric coordinates:

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

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

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

then Φ = 35.45422693 deg = 35 deg 27' 15.217"

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

then λ_W = 360 deg - λ = 94 deg 49' 38.107"

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

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

then h = 99.999 = 100 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.

Φ_N = 35 deg 27' 15.217" λ_W = 94 deg 49' 38.107" h or H = 100 m

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

a = 6,378,206.4 b = 6,356,583.8 f = 1/294.978698 e^2 = 0.006768658
(NAD 27/Clarke 1866 Spheroid)

$R_N = (a) / [1 - e^2 \sin^2 \Phi]^{½} = 6392\ 765.205$ m
then
$X = (R_N + h) \cos \Phi \cos \lambda = (-)\ 438\ 220.073$ m
$Y = (R_N + h) \cos \Phi \cos \lambda = (-)\ 5189\ 023.612$ m
$Z = ((b^2 / a^2) R_N + h) \sin \Phi = +\ 3733\ 466.852$ 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. Note that all control, including site recon sketches and station visibility diagrams, should ordinarily be documented/archived using the new standardized Corps of Engineers U-Smart form (the form and user guide can be accessed at the following site: http://www.agc.army.mil/ndsp/index.html).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.

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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 Bevill 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
```

Sample Metadata File for a GPS Survey Observations (Continued)

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.

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.

Sample Metadata File for a GPS Survey Observations (Continued)

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 Bevill 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

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

Sample Metadata File for a GPS Survey Observations (Continued)

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

Sample Metadata File for a GPS Survey Observations (Continued)

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

Distribution_Liability:
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.
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

Sample Metadata File for a GPS Survey Observations (Continued)

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.

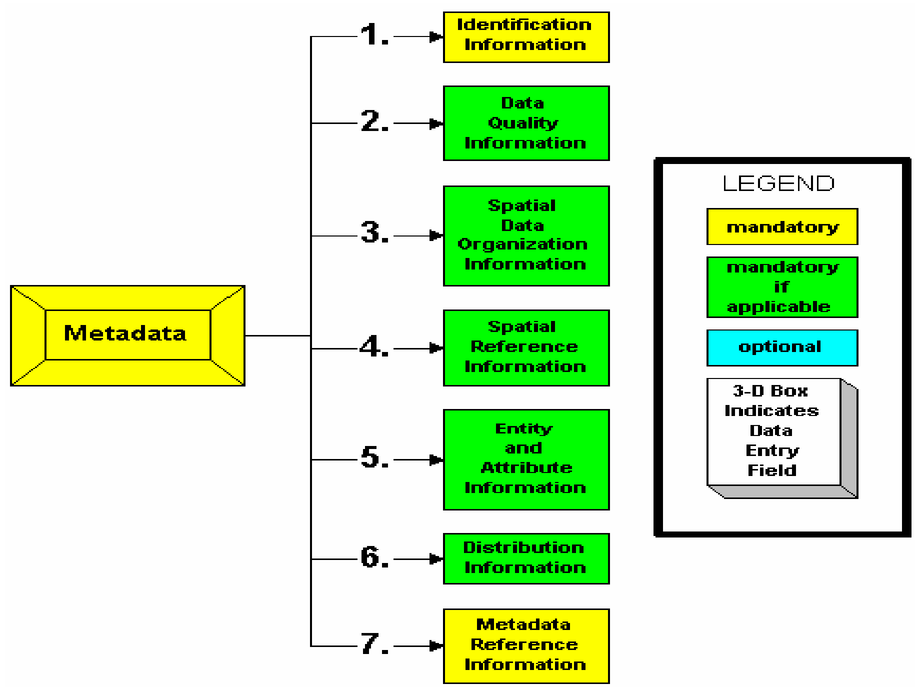

Figure 11-10. General Metadata format indicating sections 2 through 6 are optional

11-25. Mandatory Requirements. The criteria standards in Tables 11-1, 11-2, and 11-3 are considered mandatory.