Chapter 1 - Static GPS

Policy Statement
Any survey which incorporates a Static GPS network shall conform to the specifications as defined in this document.

General Statement
The term “Static GPS” mentioned herein is used as a general term, and may also refer to procedures more accurately classified as “Rapid Static GPS”.

Accuracy Standards
The general standard to be applied to most projects is a combined (relative) positional accuracy of **1:10,000** (at a 95% confidence level, or 2 sigma), or a combined distance error of **≤ 0.033 feet** for connection distances shorter than 330 feet. Relative positional accuracy is a measure of the accuracy of point positions in relation to each other, and is not to be confused with the measure of traverse closure expressed as a ratio. This accuracy standard applies to any survey which:

- Locates or establishes land boundaries, rights of way, or centerline alignments
- Establishes control for photogrammetric or topographic surveys
- Establishes first generation control for construction projects

Variations from the above standard are as follows:

- Projects which establish new primary control stations for the OC Survey Geodetic Network shall conform to a minimum combined (relative) positional accuracy of **1:20,000**. In addition, each new control station shall have a computed network accuracy (error ellipse semi-major axis) **≤ 0.033 feet**.
- Projects which incorporate CGPS stations to establish a pair of primary project control points which serve as the project basis of bearings shall conform to a minimum combined (relative) positional accuracy of **1:20,000**. In addition, each of these new control points shall have a computed network accuracy (error ellipse semi-major axis) **≤ 0.033 feet**.
- In some rare instances, a project may require less stringent accuracy standards than those described above. This determination will be made by the Senior Land Surveyor on a project by project basis.

The procedure for determining whether or not these accuracy standards have been met is outlined below in the section entitled *“**Adjustment of the Network.**”*

Legacy Control vs. CGPS
It is the policy of OC Survey that CGPS stations will be used as the primary basis for future control. Legacy control is generally only to be used when tying into or working adjacent to an older project, or where project location prevents selection of CGPS stations in at least three of four geographic quadrants. The decision to hold legacy control over CGPS stations must be

made by the Senior Land Surveyor. In the case of work being conducted by a consultant, the decision will be made by the designated OC Survey Project Manager.

Legacy Control

Advantages:

Orange County has the luxury of access to an extensive network of legacy control stations, on a roughly half-mile grid across most of the County. Most projects can easily be encircled by at least 4 existing stations. As baselines are generally under a mile in length, occupation times can be cut to a minimum. An added bonus is that many of these stations represent a position of record, such as a centerline intersection, so use of the stations may provide essentially "free" boundary points.

Disadvantages:

Each of these stations must be occupied at least twice, adding time to the field survey and complexity to the mission planning. Many of the stations are located in busy street intersections, creating potential safety concerns. Perhaps most importantly, the original survey of these stations was performed over 20 years ago, and with time, subsidence, and shifting tectonic plates, the integrity of this network has degraded and will continue to degrade. Also, over the years, many of the original monuments have been destroyed and replaced by various surveyors. These monuments become R1 (or even R2) status, and the actual positions relative to the published coordinate values may be questionable.

Methodology:

The survey must be constrained to a minimum of 4 legacy control stations, with coordinates based on the same epoch date and published by OC Surveys. The control stations are selected so as to create a polygon which fully encompasses the project area.

While the network *may* be designed and adjusted using only GPS vectors (stand-alone), combining conventional traverse (total station) data with GPS vectors will result in a network with higher relative positional accuracy (and may eliminate the minimum spacing requirements that follow).

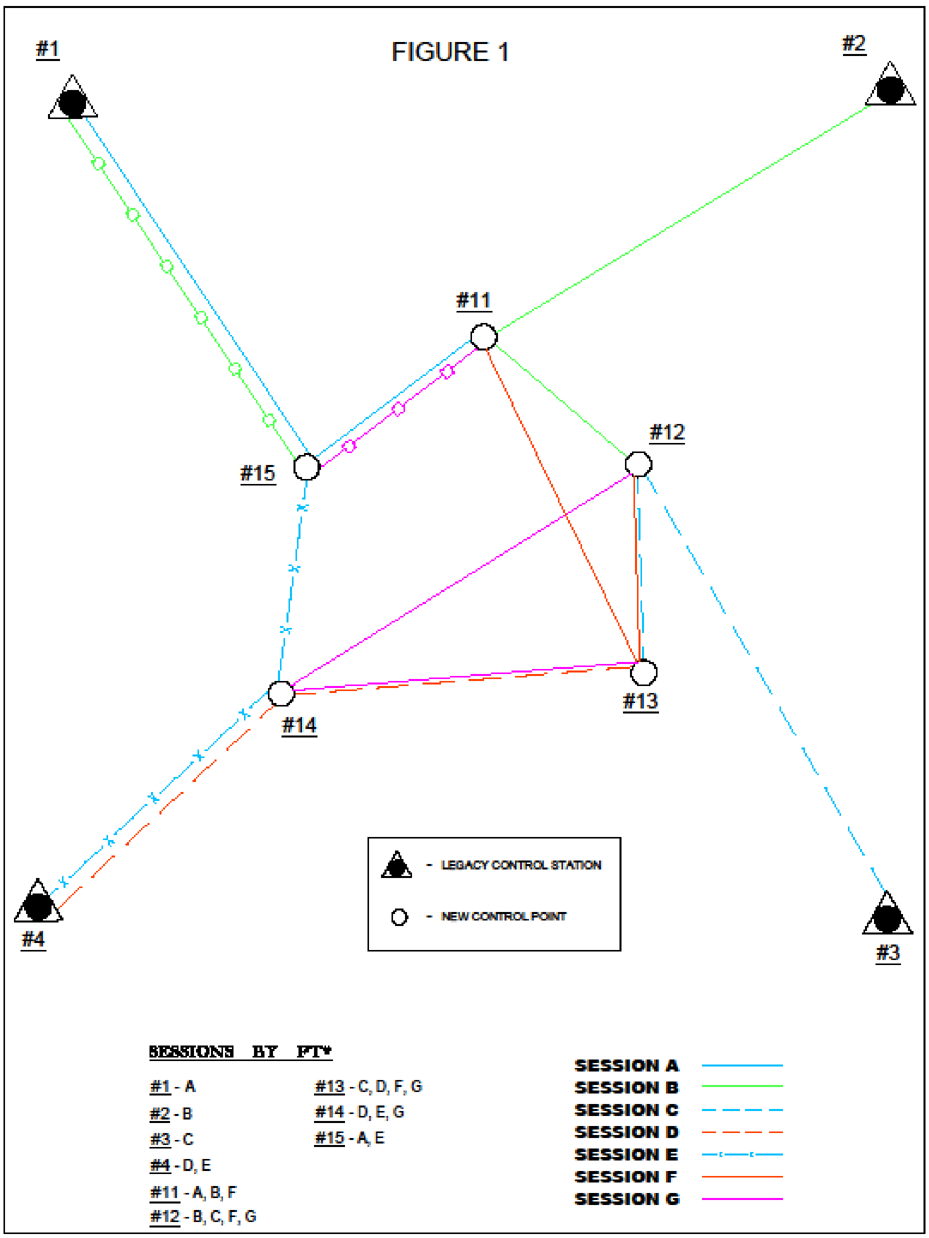
The minimum allowable spacing for points in stand-alone networks shall be dictated by the following criteria:

- Trimble R10 receivers, rated for static surveys at 3mm + 0.5 ppm at 68% confidence level (1 sigma): a minimum spacing of **300 feet** when tied to legacy control, at an average distance of 4,000 feet (see the formula shown in "***Appendix A, Section 1***")
- Minimum spacing for GPS receivers with static survey ratings different from those listed above can be computed using the formula shown in "***Appendix A, Section 1***"

Sessions should be planned with the intention of occupying each new control point at least twice and each existing control point at least once, while observing all *desired* baselines at least once. Careful planning yields increased efficiency and assurance that all *desired* baselines are observed.

Figure 1 represents an example of a static network with the following parameters:

- 4 existing legacy control stations
- 5 new control stations to be tied in
- 3 GPS receivers
- Total of 7 occupation sessions
- 2 non-trivial baselines measured per session (only baselines shown in Figure 1 are to be processed)
- 15 minute sessions with approximate 15 minute move times
- All desired non-trivial baselines are captured in approximately 4 hours



CGPS

Advantages:
The use of CGPS stations offers the luxury of 3 to 4 essentially "free" receivers, operating continuously. This saves time in the field and reduces the complexity of mission planning.

Disadvantages:
CGPS stations are often located miles from the project site and thus require longer occupation times. However, option "B" presented below introduces methodology which mitigates the need for longer occupations.

Methodology:
The survey must be tied to (but not necessarily constrained to) a minimum of 3 CGPS stations. The CGPS stations shall be selected so as to create a polygon which fully encompasses the project area.

While the network *may* be designed and adjusted using only GPS vectors (stand-alone), combining conventional traverse (total station) data with GPS vectors will result in a network with higher relative positional accuracy (and may eliminate the minimum spacing requirements that follow). The minimum allowable spacing for networks tied to CGPS stations in stand-alone networks shall be dictated by the following criteria (based on the Trimble R10 receiver specifications shown above and the formula shown in "***Appendix A, Section 1***"):

- a minimum spacing of **500 feet** when tied to CGPS stations at an average distance of 32,000 feet
- a minimum spacing of **300 feet** when tied to primary project control (see option "B", Figure 3b and Figure 3c below) at an average distance of 4,000 feet

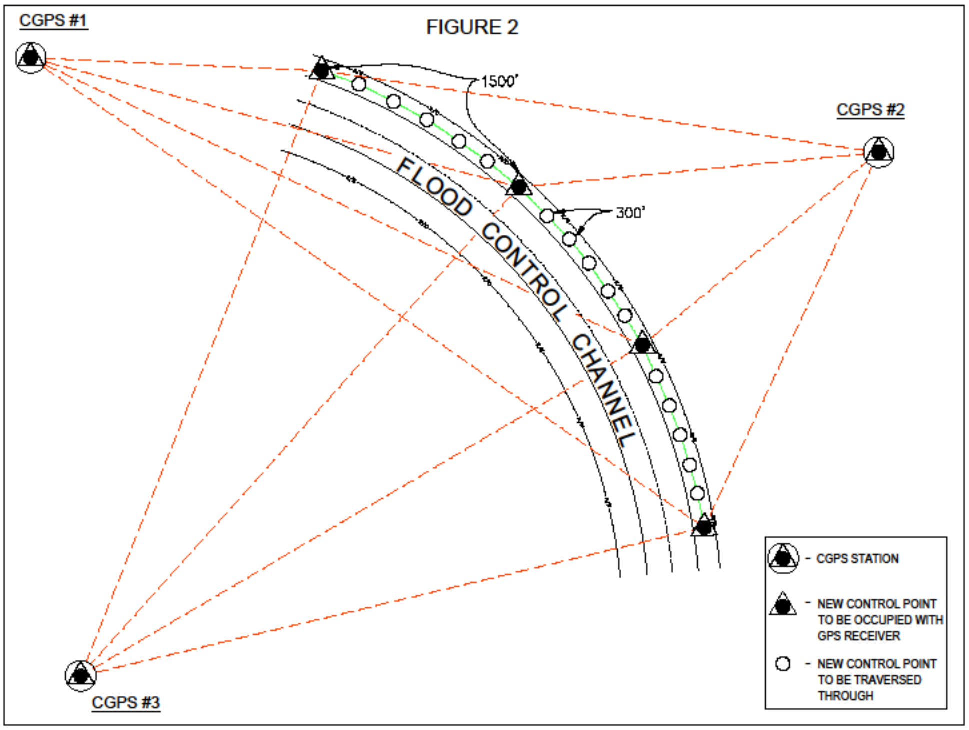
Occupation sessions should be planned with the intention of measuring all desired baselines at least once, while occupying each control point at least twice. Careful planning yields increased efficiency and assurance that all desired baselines are measured.

Two of the possible methods for designing and processing a network tied to CGPS stations are detailed below:

A. Processing each new control point independently against the CGPS stations: One advantage to this method is that almost no mission planning is needed, and the survey can be performed with just one receiver. Data can be collected by one person (two if working within an active roadway), freeing other crew members to simultaneously perform additional tasks (running levels, etc.). One disadvantage of this method is that baselines are only being measured and processed from the CGPS stations; baselines from point to point within the project become trivial baselines. Without the addition of conventional traverse data, resultant relative positional accuracy may not meet standards as defined by this document. Another disadvantage is that because the CGPS stations are located so far apart, occupation times are increased dramatically.

Figure 2 represents an example of a static network with the following parameters:

- 3 CGPS control stations
- 4 new control points to be tied in
- 1 receiver used
- Total of 8 sessions (two sessions per point)
- 30 minute sessions with approximate 15 minute move times
- All desired baselines are captured in approximately 6 hours.



B. **Establish 2 primary project control points relative to the CGPS stations; establish secondary control points relative to these primary control points:** This option employs three or more receivers and requires more personnel and more complex mission planning than Option "A" above, but will result in a network with a higher relative positional accuracy. The primary project control points are tied to CGPS stations with 2 independent occupations of ≥ 1 hour, with a minimum time differential (time of day) of 2 hours. These points are held to higher network and relative positional accuracy standards (**0.033 feet and 1:20,000, spaced a minimum of 1000 feet apart, as explained above**) and will become the project "basis of bearings". The secondary control points are tied to the primary control with occupation sessions of 10-15 minutes.

Figure 3-A and ***Figure 3-B*** represent an example of a static network with the following parameters:

- 3 CGPS control stations
- 2 new primary control points to be tied in
- 5 new secondary control points to be tied in
- 3 receivers used
- The first session lasts approximately 110 minutes, during which baselines are measured from the CGPS stations to each of the two primary control points. During this 110 minute session, a third receiver occupies each of the secondary control points for 10 minutes each.
- The next session is 15 minutes long, and measures the baseline between the two primary control points while the third receiver is moving.
- The final session is 110 minutes long and repeats the process from the first session and provides a second occupation of each secondary control point.
- 2 non-trivial baselines measured per session; 1 non-trivial baseline measured during the move session (only baselines shown in Figure 3a and 3b are to be processed).
- All desired baselines are captured in approximately 4 hours.

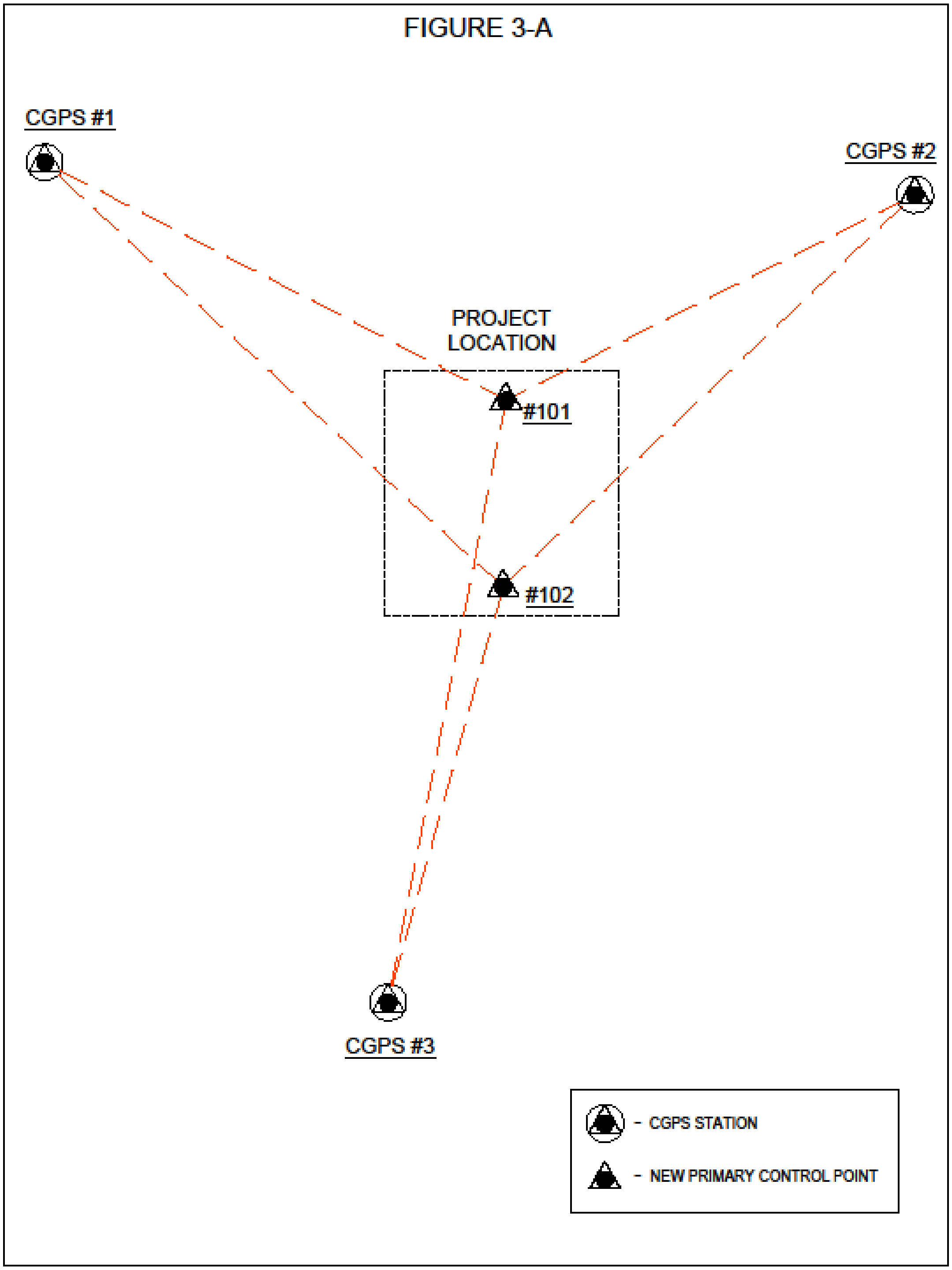


FIGURE 3-A
CGPS #1
CGPS #2
PROJECT
LOCATION
#101
#102
CGPS #3
- CGPS STATION
- NEW PRIMARY CONTROL POINT

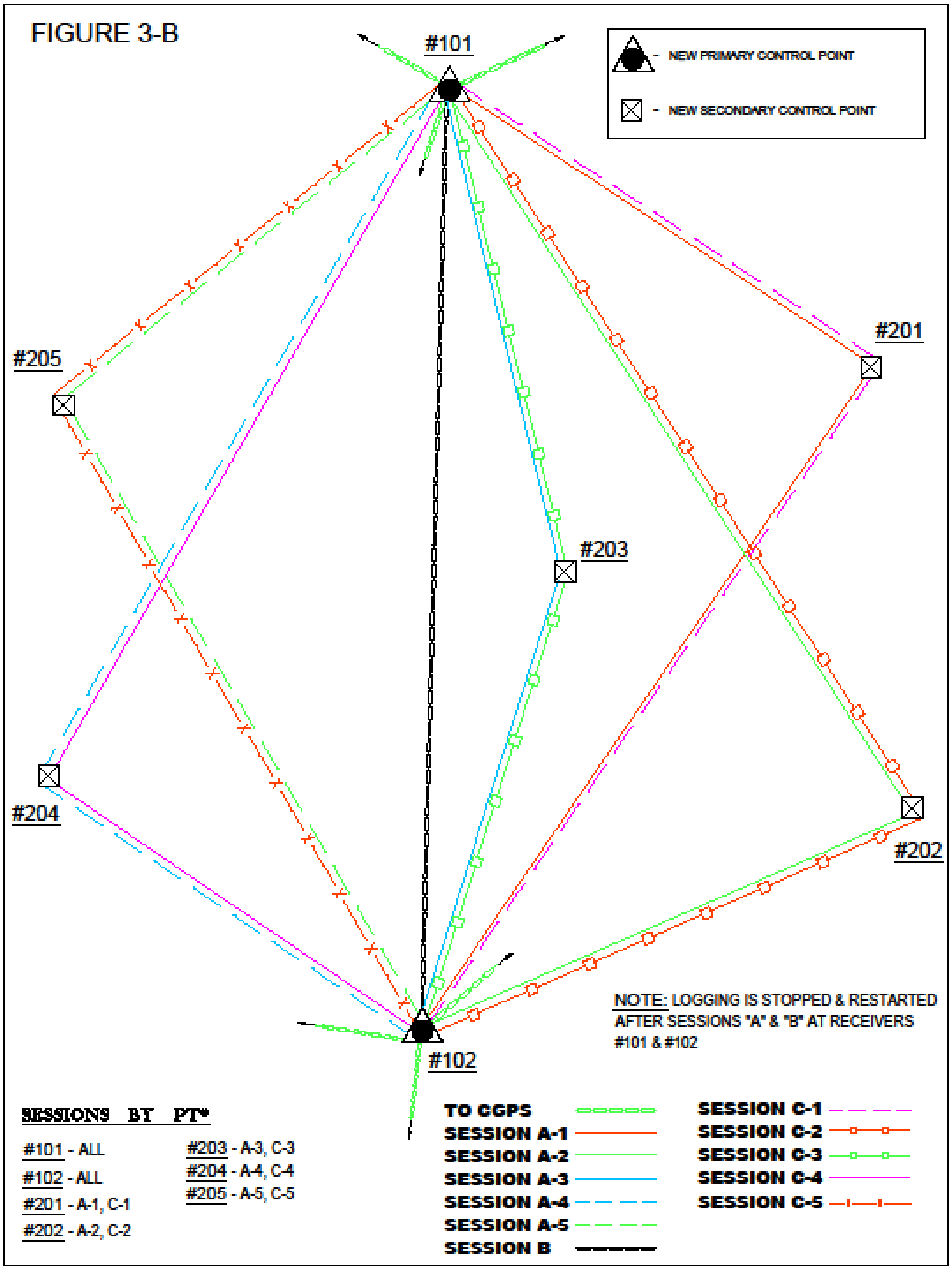


FIGURE 3-B
NEW PRIMARY CONTROL POINT
NEW SECONDARY CONTROL POINT
#101
#201
#205
#203
#204
#202
#102
NOTE: LOGGING IS STOPPED & RESTARTED AFTER SESSIONS "A" & "B" AT RECEIVERS #101 & #102
SESSIONS BY PT*
#101 - ALL
#102 - ALL
#201 - A-1, C-1
#202 - A-2, C-2
#203 - A-3, C-3
#204 - A-4, C-4
#205 - A-5, C-5
TO CGPS
SESSION A-1
SESSION A-2
SESSION A-3
SESSION A-4
SESSION A-5
SESSION B
SESSION C-1
SESSION C-2
SESSION C-3
SESSION C-4
SESSION C-5

Additional Field Procedures

- Conditions which may generate multipath or obstruct view of the satellites, such as overhead power lines, nearby trees, or adjacent buildings, should be avoided.
- Each existing control point shall be occupied at least once and each new control point shall be occupied at least twice (regardless of whether or not conventional traversing is incorporated into the survey), said occupations having a minimum time differential (time of day) of 1 hour. This time differential should be extended to 2 hours when establishing new primary control points.
- GPS receivers shall be mounted on either a tripod/tribrach configuration, or a fixed height or locking-pin rod. This rod shall have three support legs and a center leg which freely turns 360 degrees. A standard layout rod with supporting bipod shall NOT be used for any static GPS occupations.
- Receiver HI is measured two times, one measurement in feet and one in meters, and a unit conversion applied to verify the HI ***before*** the receiver is moved.
- Receivers remaining in place for consecutive sessions shall be re-levelled and re-centered between each session. HI measurements are repeated as well.
- Data is logged with an elevation mask of 10 degrees, but processed with a mask of 15 degrees.
- Data is logged at an interval of 15 seconds.
- While the receiver is logging data, a full description of the physical monument is recorded and a digital image is captured.
- Occupation session data is recorded on the relevant setup sheet (***Static GPS Set-Up Sheet – Loop Network*** or ***Static GPS Set-Up Sheet – Hub Network***). A separate set-up sheet is used for each receiver.
- Considerable care should be given to point naming conventions. Each time a point is occupied, it is to be given the ***same*** name. There is no need to use A, B, C etc. for subsequent occupations of the same point.

Monumentation

Monuments set as control points during the course of a GPS survey shall meet the following criteria:

- Monuments which fall on concrete curbs or in the surface of concrete paving shall consist of a tag secured in a lead plug or set in epoxy.
- Monuments which fall on asphalt dikes or in the surface of asphalt paving shall consist of a spike or “MAG” nail with a washer.
- Monuments which fall in non-paved areas shall consist of an iron pipe with a tag or disk, or a rebar with an aluminum cap. Rebar must be set a minimum of 3 inches below the ground surface.
- All tags/washers/disks/caps referenced above shall be stamped with the agency name or the license number of the surveyor in responsible charge, and shall also be stamped “CP” or “CONTROL POINT”.
- Tags set in iron pipes shall be of a diameter less than that of the inside diameter of the pipe. Disks affixed to iron pipes shall be of a diameter equal to that of the outside diameter of the pipe.
- Under no circumstances are plastic plugs to be used with iron pipe or rebar.

Adjustment of the Network

All GPS data shall be adjusted by least squares adjustment software, in conformance with ***Chapter 12 – Network Processing***. Note that although a network adjustment *may* be performed using only GPS vectors (stand-alone), combining conventional traverse data with GPS vectors will result in a network with higher relative positional accuracy.

Statistical analysis of the network adjustment shall be performed to ensure that a minimum combined (relative) positional accuracy of **1:10,000** (or **1:20,000** where required above) has been achieved for all connected monument pairs. Although this computation is automatically performed in most network adjustment software, the formula for this computation is shown in "***Appendix A, Section 2.***"

Connections of very short distances often will not meet this **1:10,000** standard. An alternative standard for distances of less than **330 feet** is shown in "***Appendix A, Section 3.***"

In the event one or more pairs of monuments fail to pass these relative positional accuracy criteria, the network adjustment shall be reviewed and a determination made by the Senior Land Surveyor (or Project Manager) as to whether or not additional observations will made in order to improve geometry, increase redundancy, or further isolate errors.

Important Note:
Once a network has been adjusted and coordinates are reported to another entity (e.g.: Boundary Analysis Unit or Mapping Unit), these coordinates shall be deemed final. Should supplemental control or boundary ties be needed, the primary coordinates shall be fixed in subsequent adjustments. Only in the event that erroneous data is discovered will previously reported coordinate values be changed.

Additional Resources:

Chapter 6 of the Caltrans Survey Manual and ***CLSA/CSRC GNSS Surveying Standards and Specifications*** are valuable resources which should be consulted before planning a GPS survey.

Appendix A – Formulas

1. Minimum spacing for new control points to be positioned using static GPS can be computed using the following formula:

   $$D = 10{,}000 \times \sqrt{(2 \times \{ [(1.96)(a)]^2 + [(1.96)(b)]^2 + c^2 \})}$$

   where:

   - D = minimum spacing (in feet) between static occupation stations
   - a = manufacturer's millimeter rating at a 68% confidence level, (converted to feet)
   - b = manufacturer's ppm rating at a 68% confidence level, times the average distance (in feet) from legacy control stations, and divided by 1,000,000
   - c = estimated receiver positioning error (rod plumb or tribrach errors), commonly estimated to be 0.007 feet
   - 1.96 = the multiplier from a 68% confidence level (1 sigma) to a 95% confidence level (2 sigma)

2. All connected monument pairs shall pass the following mathematical test:

   $D \div \sqrt{(x^2 + y^2)} \geq 10{,}000$ (or $\geq$ 20,000 where required above)

   where:

   - D = distance (in feet) between the pair of monuments being examined
   - x = error ellipse semi-major axis for monument #1 (at 95% confidence)
   - y = error ellipse semi-major axis for monument #2 (at 95% confidence)

3. Connections of very short distances often will not meet the **1:10,000** standard defined by the formula in Section 2 above. An alternative standard for distances of less than 330 feet follows:

   $\sqrt{(x^2 + y^2)} \leq 0.033$ **feet**

   where:

   - x = error ellipse semi-major axis for monument #1 (at 95% confidence)
   - y = error ellipse semi-major axis for monument #2 (at 95% confidence)