Appendix F
Application: Static GPS Control Survey--Coyote Dam, Russian River, CA (Sacramento District)

This appendix provides an example of a static GPS surveys performed on a Corps civil works project performed during 1989. This survey was performed prior to full operational capability of the GPS satellite constellation; thus, observation windows had to be observed in order to obtain four or more satellites. The procedures and standards that were used for performing, reducing, and adjusting these early GPS surveys have not significantly changed, other than the more user-friendly field data collection devices and significantly updated Windows-based baseline reduction and adjustment software. Baseline reduction and adjustment software techniques shown on these 1989 surveys are still representative of the current reductions and analyses performed today--only the output formats have changes.

F-1. Planning Phase

The GPS survey was planned for 25 April 1989 in the vicinity of Coyote Dam on the East Fork of the Russian River, near Ukiah, California.

a. A diagram of the project area is shown in Figure F-1. Three fixed control points were connected--Calpella 1949, Perry 1949, and Ukiah Airport 1949.

b. Four Trimble 4000 SL GPS carrier phase tracking receivers were used for the survey--with one person per receiver. In actuality, because the personnel were inexperienced in conducting a GPS survey, a fifth person was also used. The fifth person was used as a "runner" who can be called upon during the survey to aid in smoothing out any complications (e.g., aiding in overall communication and coordination, parts retrieval in case of breakdown, bad power source, blown fuse, misplaced equipment, forgotten measurement device or power cord, as well as any other possible complication). Communication between personnel was by two-way radio. Care was taken in choosing and operating the two-way radio near the GPS survey so that the radio transmitter and receiver chosen, when in operation, would not interfere with the GPS receiver.

c. Prior to data collection, the stations were inspected and found to be acceptable (easy accessibility, no obstruction or possible multipath sources, and at least 20 degree satellite visibility above the horizon).

d. April 25, 1989 corresponds to Julian calendar day 115. Calpella, Perry, and Ukiah Airport were stations with established horizontal control. Pier 1 and Pier 2 were stations requiring horizontal coordinates accurate to 1:10,000 (refer to Figure F-2). Therefore, the following station conventions for Session 1 of the survey were:

Pier 1 - Station 20011151
Pier 2 - Station 20021151
Calpella - Station 20131151
Ukiah Airport - Station 20141151

It is important to note that this station convention was used for this survey because the Trimble receiver only allowed numeric input of station names. Newer receivers allow alphanumeric inputs for station names, which provides more flexibility in station naming.

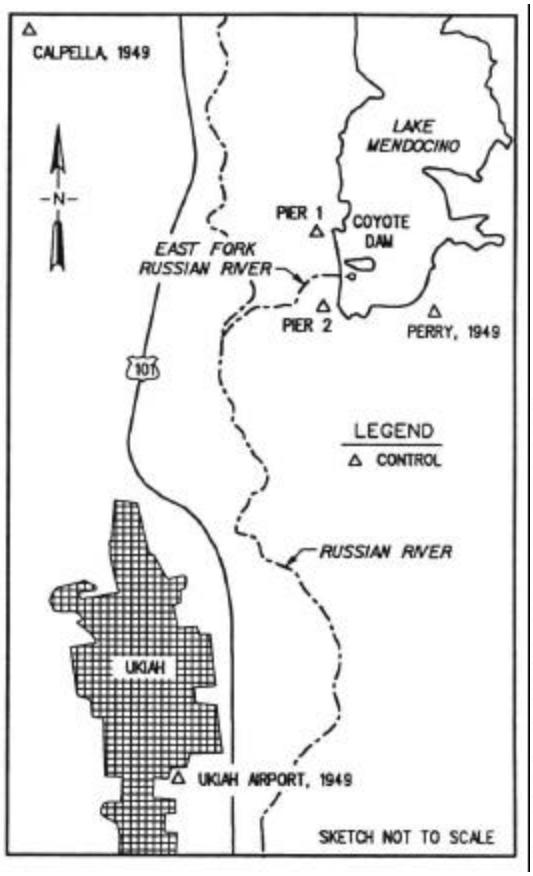


Figure F-1. Ukiah Project Area

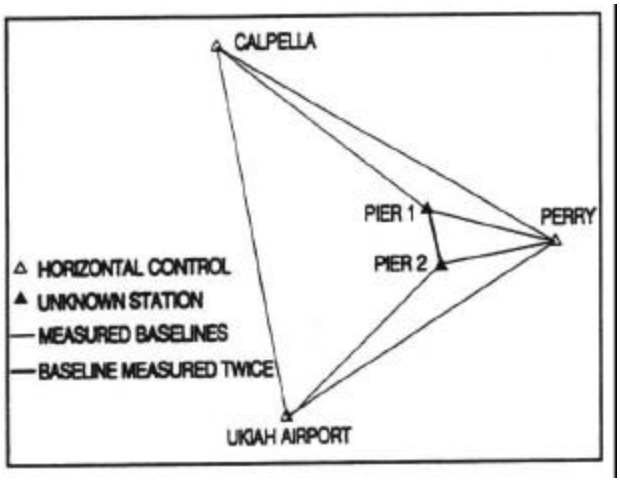


Figure F-2. GPS Project Diagram (Ukiah)

e. A satellite visibility plan (a software package that produces a hard copy listing of satellite constellations and time availability based on ephemerides) was run for the project location. The satellite visibility was run with the most up-to-date ephemeris for the period of observation, using four-satellite visibility, and with a cut-off elevation angle of 20 deg. An up-to-date ephemeris was used to ensure the satellite visibility formulated was the most accurate. A minimum of 4 visible satellites was specified in order to formulate accurate three-dimensional solutions. A cut-off elevation of 20 deg was chosen in order to minimize any diffusion or dispersion of the signal by the atmosphere which in turn may cause errors in the solution as the satellites pass near the horizon. The satellite visibility plan produced for the Ukiah project is shown below.

All-In-View PDOP for UKIAH

Date : 25 Feb 1990 Time : 4:00 -> 4:00
Latitude : 39° 12' 30" N Longitude : 123° 10' 30" W
Cut-off Elevation : 20 Zone : - 7:00

	Time	Time		PDOP	
Satellite Constellation	Rise	Set	dT	Rise	Set
6 9 11 13	21:55	22:03	0:08	4.9	5.0
6 9 11 12 13	22:02	22:33	0:30	3.8	3.6
6 9 11 12 13 19	22:32	23:18	0:45	3.2	3.3
3 6 9 11 12 13 19	23:17	23:48	0:30	2.9	3.0
3 9 11 12 13 19	23:47	1:08	1:20	4.2	4.2
3 11 12 13 19	1:07	1:22	0:15	4.9	5.0
3 12 13 19	1:22	2:20	0:58	22.7	31.6

The portion of the satellite visibility where the PDOP is near 5.0 m/m or below are times when the satellite geometry is conducive for conduct of a survey. A PDOP near or below 5.0 m/m does not guarantee a successful survey but it does indicate good satellite geometry during that moment of the survey--see Chapter 5 for further information on PDOP.

f. From the satellite visibility plan, it was decided to conduct three sessions during the survey. Travel between survey sites, time to set up and take down the equipment before and after the survey, receiver warm up time, time of survey (at least an hour allotment for survey data collection, but more than an hour if at all possible), and possible time loss due to unforeseeable problems or complications were taken into account before deciding on a specific session schedule. The final survey session schedule is shown in the chart below:

Final Survey Session Schedule

Session	Start Time	Stop Time
1	21:55	22:55
2	23:38	00:38
3	01:23	02:20

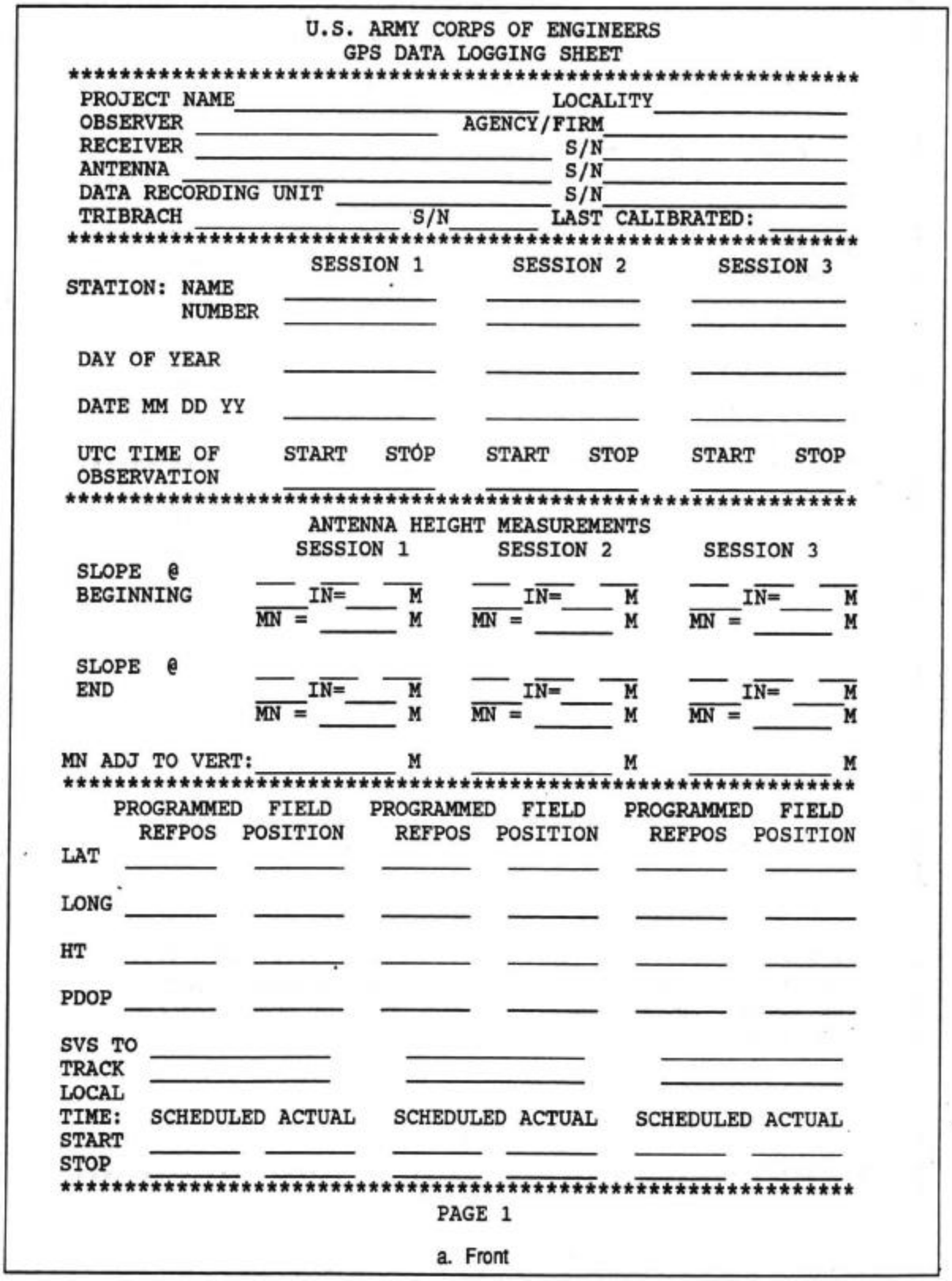
It was further decided which stations would be occupied during each session. Station occupation was designed to minimize travel time and to add to the overall efficiency of the survey. The station occupation schedule was planned as shown in the following chart:

Station Occupation Schedule

Session	Station	Station	Station	Station
1	Calpella	Ukiah Airport	Pier 1	Pier 2
2	Calpella	Perry	Pier 1	Pier 2
3	Ukiah Airport	Perry	Pier 1	Pier 2

g. A GPS Station Observation Log is generally filled out prior to conduct of the survey. An example of a GPS Station Observation Log is shown in Figure F-3. The GPS Station Observation Log must be filled out for each of the station occupied in order to have a written record of the actual survey and as an aid for the personnel occupying each of the station.

h. Portions of the GPS Station Observation Log were filled out prior to data collection. These portions included the station name, start date, GPS 8 character ID for each session, project name, project location, observer name, approximate receiver position (latitude, longitude, and elevation), session scheduled start and stop times, and requisite tracking equipment information. In this case, six GPS Station Observation Logs were filled out, one each for: Calpella (Sessions 1 & 2), Ukiah Airport (Session 3), Ukiah Airport (Session 1), Perry (Sessions 1 & 2), Pier 1 (Sessions 1, 2, and 3), and Pier 2 (Sessions 1, 2, and 3). An example of a GPS Station Observation Log for Station "Pier 2" is shown in Figure F-4.



U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

PROJECT NAME _____ LOCALITY _____
OBSERVER _____ AGENCY/FIRM _____
RECEIVER _____ S/N _____
ANTENNA _____ S/N _____
DATA RECORDING UNIT _____ S/N _____
TRIBRACH _____ S/N _____ LAST CALIBRATED: _____

	SESSION 1	SESSION 2	SESSION 3
STATION: NAME			
NUMBER			
DAY OF YEAR			
DATE MM DD YY			
UTC TIME OF OBSERVATION	START STOP	START STOP	START STOP

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	___ ___ ___ IN= ___ M MN = ___ M	___ ___ ___ IN= ___ M MN = ___ M	___ ___ ___ IN= ___ M MN = ___ M
SLOPE @ END	___ ___ ___ IN= ___ M MN = ___ M	___ ___ ___ IN= ___ M MN = ___ M	___ ___ ___ IN= ___ M MN = ___ M
MN ADJ TO VERT:	___ M	___ M	___ M

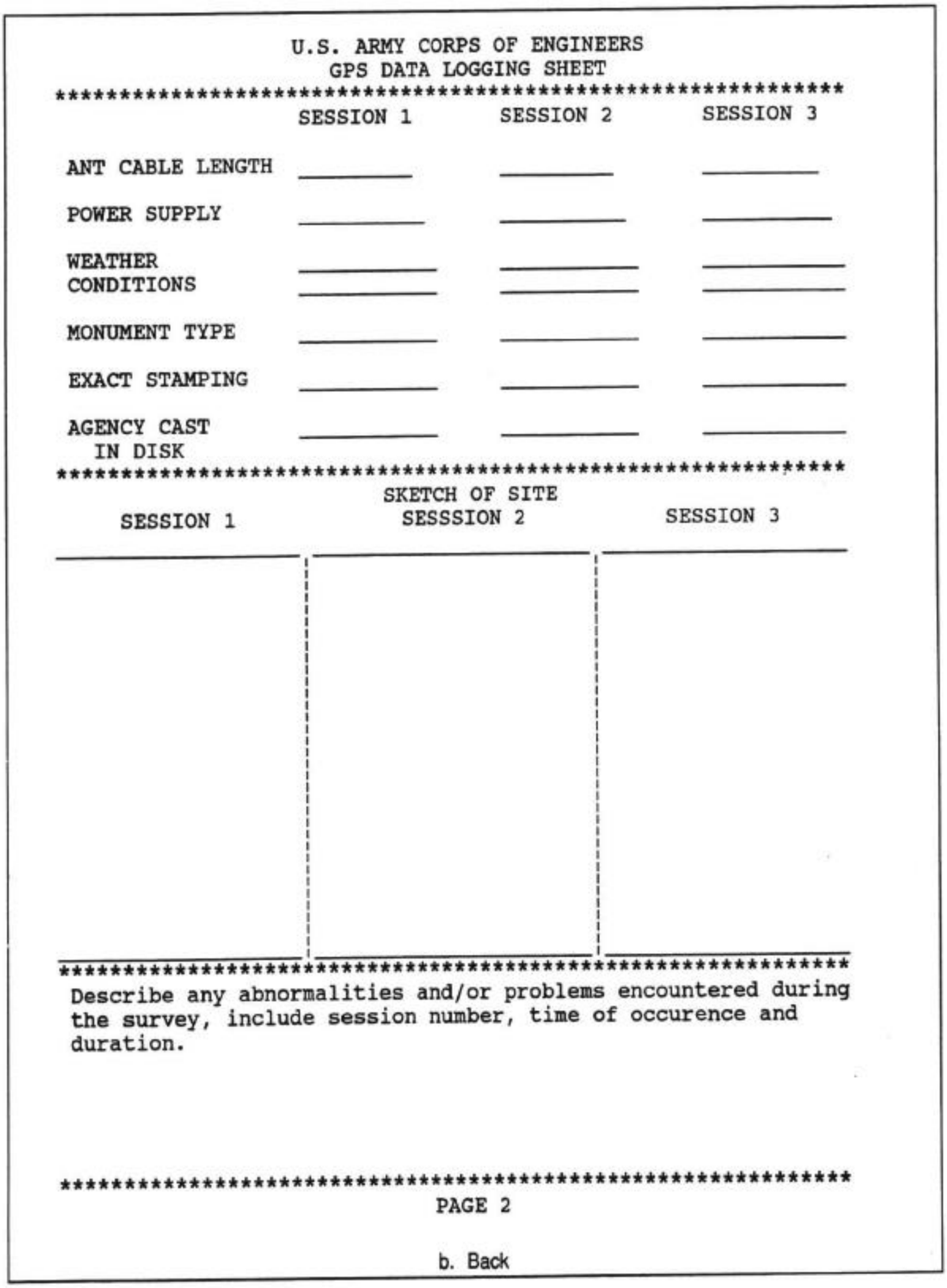
	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT						
LONG						
HT						
PDOP						

	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
SVS TO TRACK LOCAL TIME: START						
STOP						

PAGE 1

a. Front

Figure F-3 a. Example GPS Station Observation Log (Front)



U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH			
POWER SUPPLY			
WEATHER CONDITIONS			
MONUMENT TYPE			
EXACT STAMPING			
AGENCY CAST IN DISK			

SKETCH OF SITE

SESSION 1 | SESSION 2 | SESSION 3

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurence and duration.

PAGE 2

b. Back

Figure F-3 b. Example GPS Station Observation Log (Back)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

PROJECT NAME COYOTE DAM LOCALITY UKIAH, CA
OBSERVER LARRY LAMB AGENCY/FIRM COE, SACRAMENTO DISTRICT
RECEIVER TRIMBLE 4000 SL S/N 2820A00223
ANTENNA TRIMBLE MICRO SL S/N 2816A00224
DATA RECORDING UNIT RECEIVER S/N 2820A00224
TRIBRACH WILD GDF 22 S/N N/A LAST CALIBRATED: 4/24/89

	SESSION 1	SESSION 2	SESSION 3
STATION: NAME	PIER2	PIER 2	PIER 2
NUMBER	2002	2002	2002
DAY OF YEAR	115	115	115
DATE MM DD YY	4/25/89	4/25/89	4/25/89
UTC TIME OF OBSERVATION START	04:56	06:10	07:55
UTC TIME OF OBSERVATION STOP	05:55	07:38	09:20

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	___ IN= ___ M MN = ___ M	___ IN= ___ M MN = ___ M	___ IN= ___ M MN = ___ M
SLOPE @ END	___ IN= ___ M MN = ___ M	___ IN= ___ M MN = ___ M	___ IN= ___ M MN = ___ M
MN ADJ TO VERT:	___ M	___ M	___ M

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30		39-12-30		39-12-30	
LONG	123-10-30		123-10-30		123-10-30	
HT	244.0		244.0		244.0	
PDOP	3.6		4.8		4.0	
SVS TO	02,03,06,09		02,03,06,09		03,06,09,11	
TRACK	11,12,13,14		11,12,13,14		12,13,14,16	
LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55		23:38		01:20	
STOP	22:55		00:38		02:20	

PAGE 1

a. Front

Figure F-4. GPS Station Observation Log (Pre-Survey)

F-2. Actual Survey Operation

Those portions of the GPS Station Observation Log, which were not filled out during the planning phase of the survey, were filled out during data collection. An example of the GPS Station Observation Log for Station "Pier 2", filled out after data collection, is shown in Figure F-5.

a. Key to proper data collection is correct set up of the equipment (tripod, receiver, and power source) and correct antenna height measurements (height of the antenna above the mark).

b. Figure F-6 shows personnel correctly taking an antenna height measurement over a temporary monument. Figure F-7 illustrates a typical antenna setup with the following equation detailing the antenna height correction.

$$v = sqrt [s^2 - r^2]$$

where

v = corrected vertical height distance of the antenna center above the mark,

s = slope distance measurement derived from the average of several antenna height measurements

r = antenna radius

c. When measuring the antenna height during this survey, the following procedure was followed in order to ensure an accurate reading:

(1) The slope distance from the North point of the antenna to the center of the monument was measured to the nearest millimeter (0.001 m). Measurement was also done in English units (inches) to the nearest 1/32th of an inch. This value then was compared to the metric value measured earlier. This comparison is done to detect blunders.

(2) Similar measurements are also taken from the South point of the antenna to the center of the monument.

(3) The resultant North and South slope distances were averaged.

(4) Example: (Refer to Figure F-5)

- Tripod set up flat on a dock.
- The North side measure up for session 1 = .120m
- The South side measure up for session 1 = .120m
- An extra "Check Measurement" was also taken for the measure up for Session 1 and was found to = 0.394 ft.
- As a check: (0.394 ft.) x (1m / 3.281 ft.) = .120m
- This value was recorded in the GPS Station Observation Log.

d. Each GPS receiver was operated in direct accordance with the manufacturer instructions, procedures, and/or guidance.

e. No problems were encountered during the survey sessions.

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

PROJECT NAME COYOTE DAM LOCALITY UKIAH, CA
OBSERVER LARRY LAMB AGENCY/FIRM COE SACRAMENTO DISTRICT
RECEIVER TRIMBLE 4000SL S/N 2826A00223
ANTENNA TRIMBLE [illegible]0 SL S/N 2816A00224
DATA RECORDING UNIT RECEIVER S/N 2820A00224
TRIBRACH WILD GDF 22 S/N N/A LAST CALIBRATED: 4/24/89

	SESSION 1	SESSION 2	SESSION 3
STATION: NAME	PIER 2	PIER 2	PIER 2
NUMBER	2002	2002	2002
DAY OF YEAR	115	115	115
DATE MM DD YY	4/25/89	4/25/89	4/25/89
UTC TIME OF OBSERVATION	START 04:56 STOP 05:55	START 06:10 STOP 07:38	START 07:55 STOP 09:20

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	0.120 0.120 0.120 4 12/16 IN=0.121 M MN = 0.120 M	0.116 0.116 0.116 4 9/16 IN=0.116 M MN = 0.116 M	0.123 0.124 0.124 4 15/16 IN=0.124 M MN = 0.1238 M
SLOPE @ END	4 11/16 4 12/16 4 11/16 0.120 IN=4 12/16 M MN = 0.120 M	4 9/16 4 10/16 4 9/16 0.116 IN=4 9/16 M MN = 0.116 M	4 13/16 4 14/16 4 14/16 0.123 IN=4 13/16 M MN = 0.1230 M
MN ADJ TO VERT:	0.120 M	0.116 M	0.1234 M

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30	39-12-22.64	39-12-30	39-12-22.48	39-12-30	39-12-22.81
LONG	123-10-30	123-10-33.42	123-10-30	123-10-33.20	123-10-30	123-10-33.62
HT	244.0	210.6	244.0	199.8	244.0	222.8
PDOP	3.6	—	4.8	—	4.0	—
SVS TO TRACK	02,03,06,09 11,12,13,14		02,03,06,09 11,12,13,14		03,06,09,11 12,13,14,16	
LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55	21:56	23:38	23:10	01:20	00:55
STOP	22:55	22:55	00:38	00:38	02:20	02:20

PAGE 1

a. Front

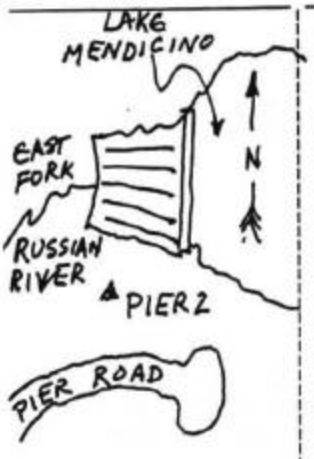
Figure F-5a. GPS Observation Log (Post-Survey)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	100 ft	100 ft	35 ft
POWER SUPPLY	12 V DC	12 V DC	12 V DC
WEATHER CONDITIONS	CLEAR, COOL 45°	CLEAR, COOL 40°	CLEAR, COOL 40°
MONUMENT TYPE	"C" (SET IN PIER)	← SAME	← SAME
EXACT STAMPING	PIER 2 1953	← "	← "
AGENCY CAST IN DISK	COE	← "	← "

SKETCH OF SITE

SESSION 1



SESSION 2: ← SAME

SESSION 3: ← SAME

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

THE ANTENNA WAS MOUNTED DIRECTLY OVER PIER 2 WITH NO TRIPOD USED. ANTENNA HEIGHT WAS MEASURED VERTICALLY FROM GROUND PLANE TO BRASS DISK.

PAGE 2

b. Back

Figure F-5b. GPS Observation Log (Post-Survey)

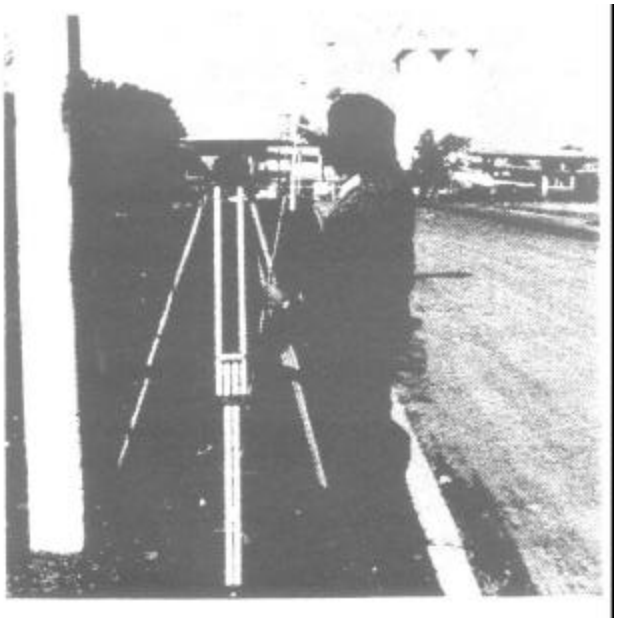


Figure F-6. Antenna Height Measurement

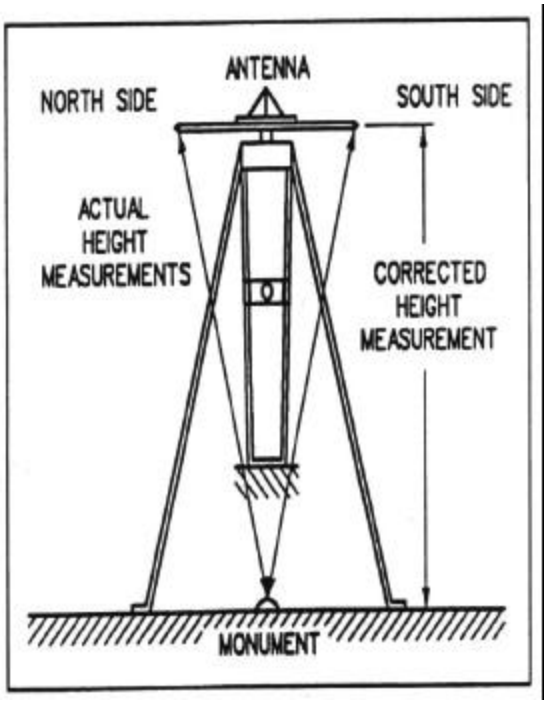


Figure F-7. Diagram of Antenna Setup

F-3. Post-Processing Observation Data

All recorded observation data were downloaded from the receivers to 5.25" floppy discs. The downloading procedures detailed in the manufacturer's operating manuals were strictly adhered to.

a. Once the observation data was downloaded, preprocessing of data was performed. Preprocessing of data included checking the station names, antenna heights, latitude and longitude of the points, elevation of the points, as well as applying any required corrections. In general, most GPS processing software requires the antenna slope height be corrected to vertical at some point in the survey, usually during the preprocessing phase (consult receiver/software manufacturer guidelines for specifics).

b. The data for the Ukiah project was post-processed using Trimble software TRIMVEC Version 88.028--GPS Relative Positioning Solution), but in general, all post-processing software produces similar results. The observation data was processed in accordance with manufacturer guidelines (see Chapter 10 for further discussion on GPS baseline post-processing).

(1) An examination of the results reveals the following, which are produced in one form or another in other manufacturer's solution file formats:

a--Listing of the filename
b--Types of solutions (single, double, or triple difference)
c--Satellite availability during the survey for each station occupied
d--Ephemeris file used for solution formulation
e--Type of satellite selection (manual or automatic)
f--Elevation mask
g--Minimum number of satellites used
h--Meteorological data (pressure, temperature, humidity)
i--Session time (date, time)
j--Data logging time (start, stop)
k--Station information: Location (latitude, longitude); Receiver serial number used; Antenna serial number used; ID number; Antenna height
l--RMS
m--Solution files: dx, dy, dz between station; Slope distance between station; dlatitude, dlongitude between station; Distance between station; dheight
n--Epoch intervals
o--Number of epochs

(2) The triple difference, double difference float, and double difference fix Trimble solutions of the baseline reductions for baseline 2014--2002 were computed. The fixed solution is shown in Figures F-8a through F-8d--annotated with the above conventions (a through o) provided as an explanation. A summary of all solutions is shown in Figure F-8e. The baseline formulations are reproduced from the Trimble Navigation TRIMVEC solution file.

c. In general, all GPS manufacturer data reduction software programs produce a summary of results once data has been reduced and a baseline formulated.

d. Although the Trimble summary solution file does specify that the integers were found, the RMS is OK, and FIXED solution is recommended, an analysis of the output prior to this conclusion in accordance with Chapter 10 would have revealed the following:

(1) With a baseline distance of 7000 m for the formulated baseline (baseline 1402) and from Table 10-2 (Fixed Solution Acceptance Criteria), the RMS must be less than (0.02+(0.004*d)). Using the formula (0.02+(0.004/d)) from Table 10-2 with a distance (d) equal to 7 km, the equation is (0.02 + (0.004*7)) and the RMS is approximately equal to 0.048. Therefore, the RMS is acceptable.

(2) With a baseline distance of 7000 m for the formulated baseline (baseline 1402) and from Table 10-3, the variance ratio must be more than 1.5. The fixed solution factor from the summary solution file is 18.9. Therefore, the fixed solution quality factor is acceptable.

(3) From Table 10-3, with a baseline length of 7 km for baseline 1402 (between 0 - 20 km), an acceptable RMS (small), an acceptable variance ratio (large), and an integer solution, the fixed solution should be acceptable.

e. All other formulated baselines for this survey were found to be acceptable.

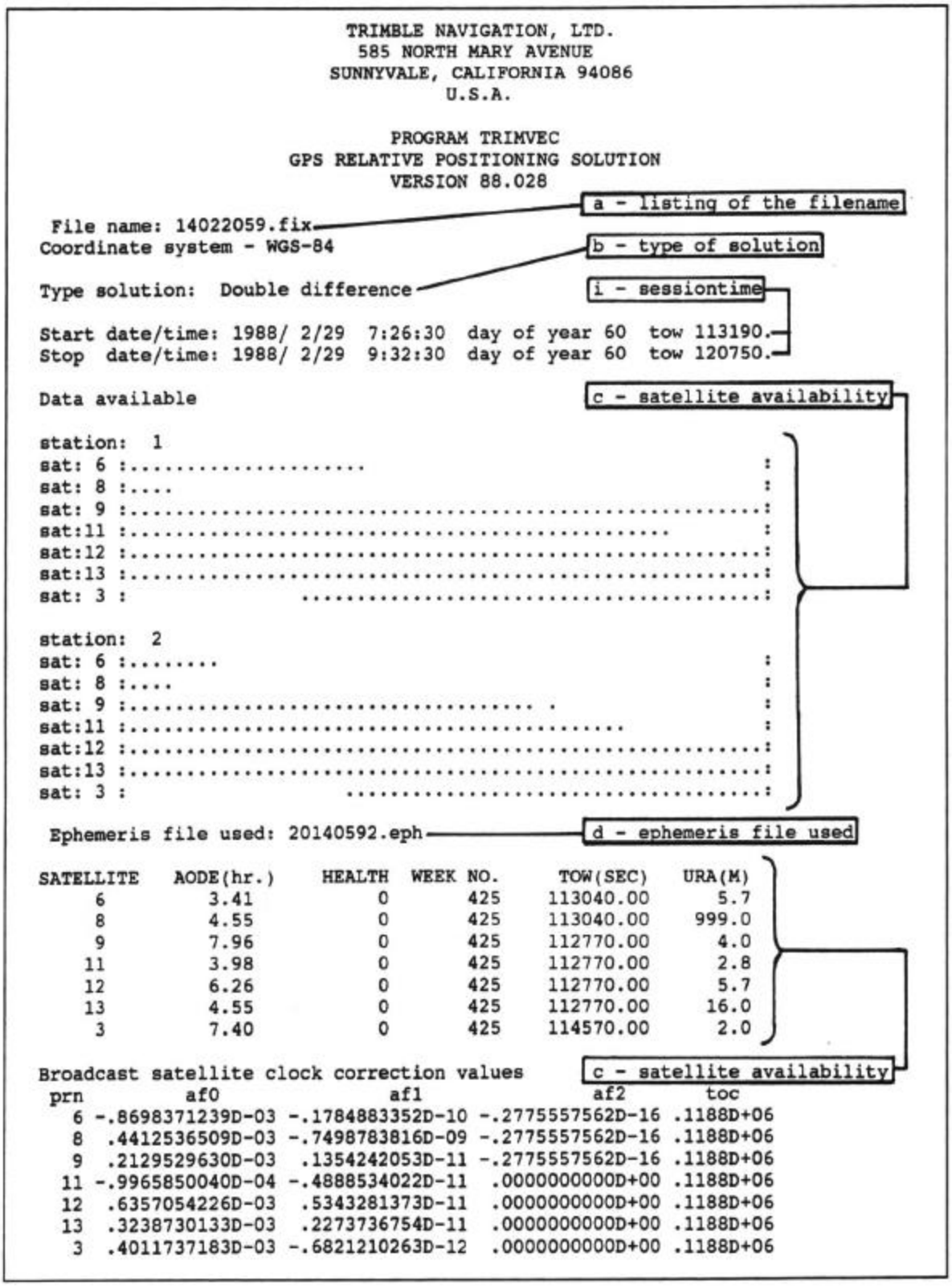


Figure F-8a. TRIMBLE Baseline Solution File (Ukiah Baseline 2014--2002)

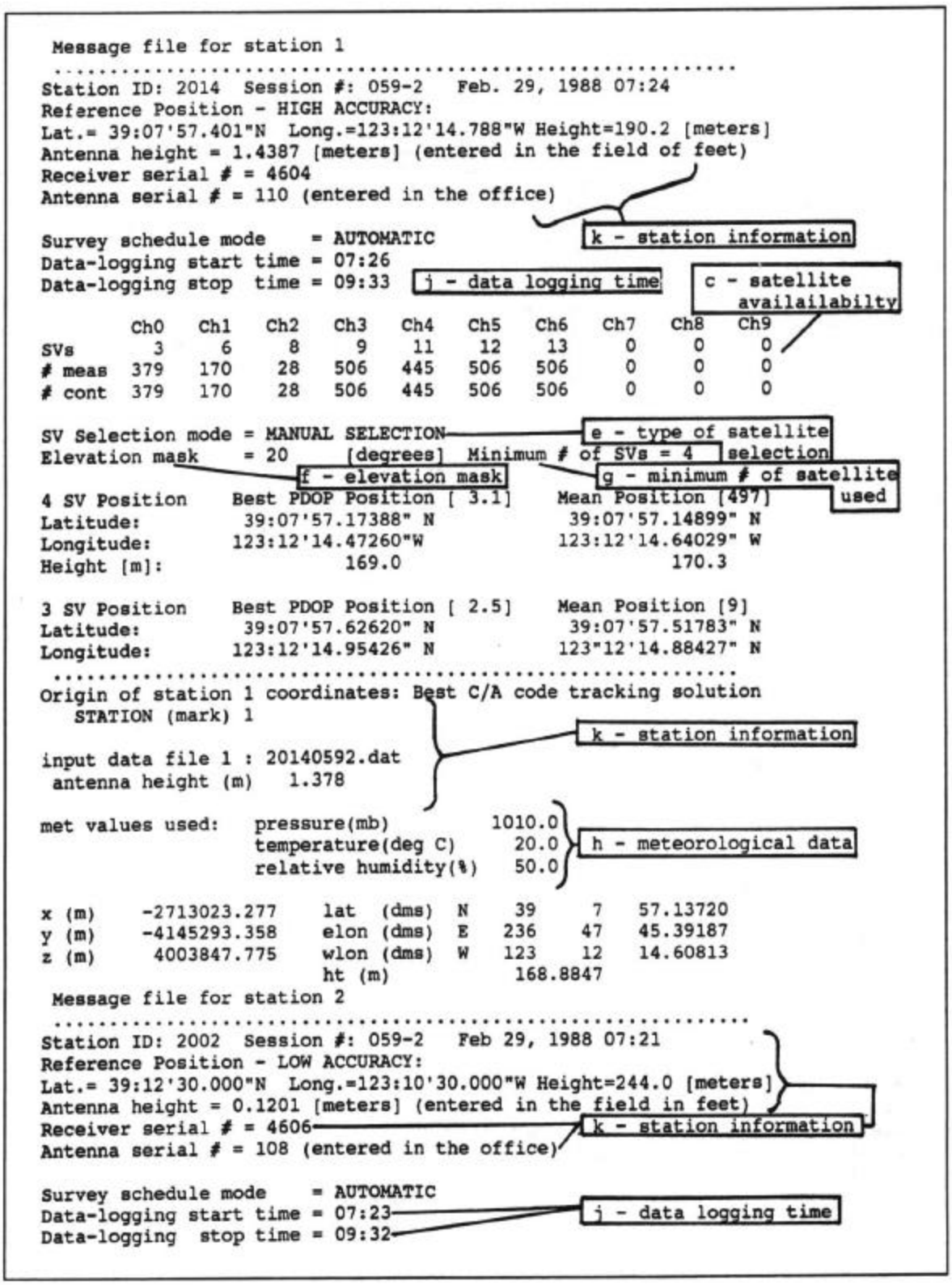
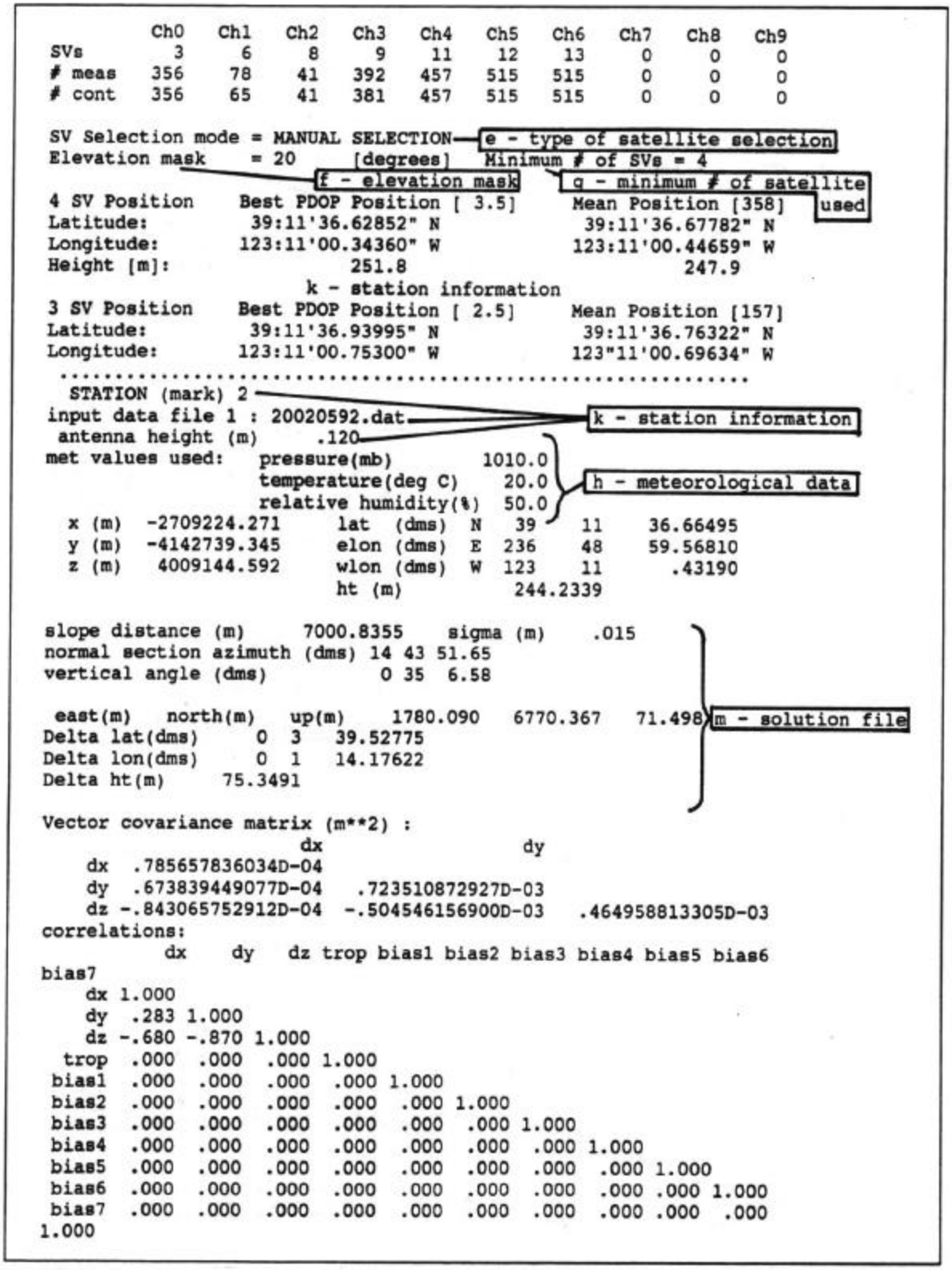
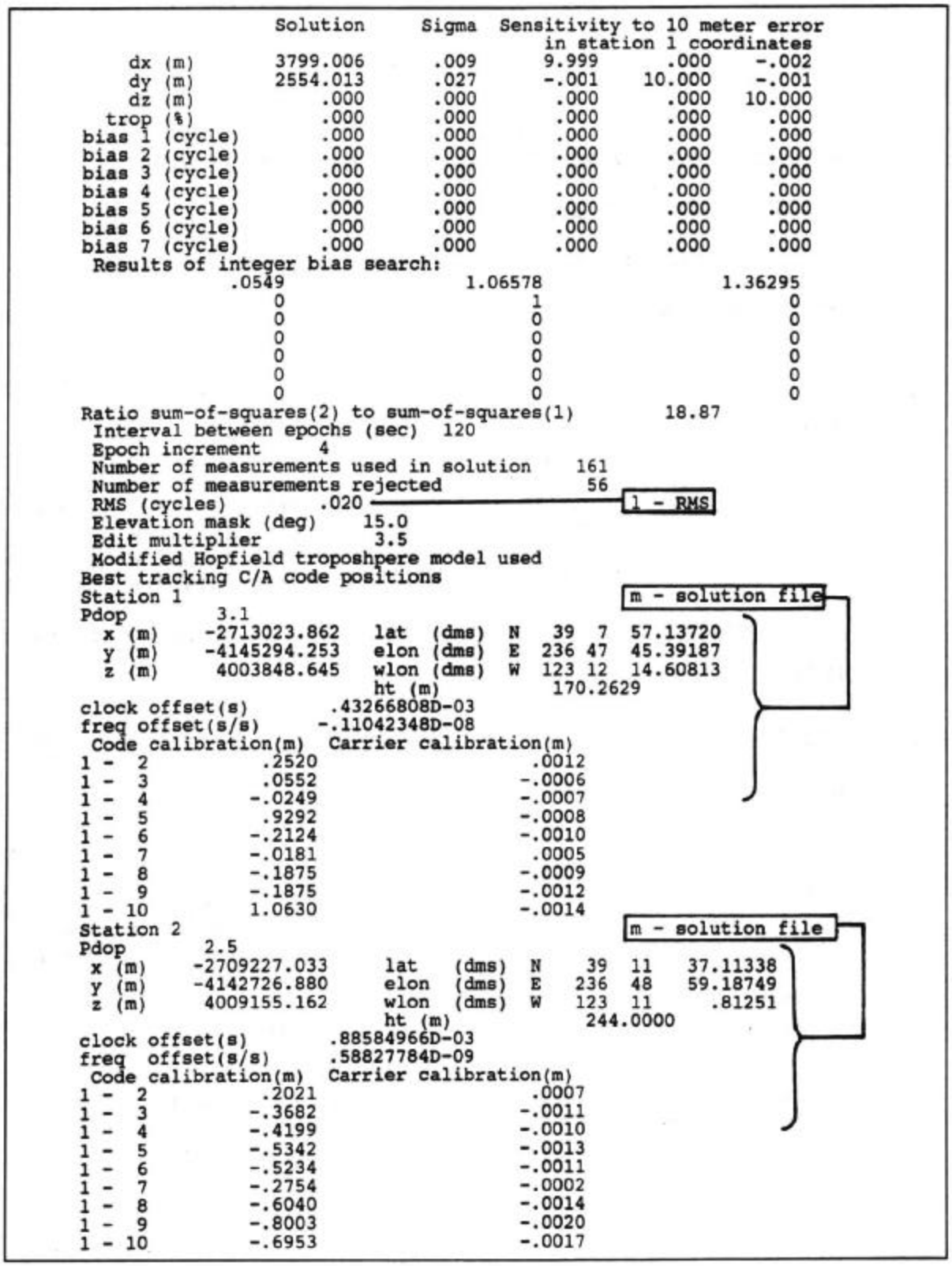


Figure F-8b. TRIMBLE Baseline Solution File (Ukiah Baseline 2014--2002)




```
          Ch0   Ch1   Ch2   Ch3   Ch4   Ch5   Ch6   Ch7   Ch8   Ch9
SVs         3     6     8     9    11    12    13     0     0     0
# meas    356    78    41   392   457   515   515     0     0     0
# cont    356    65    41   381   457   515   515     0     0     0

SV Selection mode = MANUAL SELECTION
Elevation mask    = 20      [degrees]   Minimum # of SVs = 4

4 SV Position     Best PDOP Position [ 3.5]      Mean Position [358]
Latitude:          39:11'36.62852" N              39:11'36.67782" N
Longitude:        123:11'00.34360" W             123:11'00.44659" W
Height [m]:              251.8                          247.9

3 SV Position     Best PDOP Position [ 2.5]      Mean Position [157]
Latitude:          39:11'36.93995" N              39:11'36.76322" N
Longitude:        123:11'00.75300" W             123"11'00.69634" W
 ..........................................................
  STATION (mark) 2
input data file 1 : 20020592.dat
 antenna height (m)      .120
met values used:    pressure(mb)          1010.0
                    temperature(deg C)      20.0
                    relative humidity(%)    50.0
  x (m)   -2709224.271      lat  (dms)  N   39    11     36.66495
  y (m)   -4142739.345      elon (dms)  E  236    48     59.56810
  z (m)    4009144.592      wlon (dms)  W  123    11       .43190
                            ht (m)           244.2339

slope distance (m)      7000.8355     sigma (m)     .015
normal section azimuth (dms) 14 43 51.65
vertical angle (dms)          0 35  6.58

 east(m)   north(m)   up(m)     1780.090    6770.367    71.498
Delta lat(dms)      0  3   39.52775
Delta lon(dms)      0  1   14.17622
Delta ht(m)      75.3491

Vector covariance matrix (m**2) :
                        dx                    dy
    dx   .785657836034D-04
    dy   .673839449077D-04    .723510872927D-03
    dz  -.843065752912D-04   -.504546156900D-03    .464958813305D-03
correlations:
          dx    dy    dz trop bias1 bias2 bias3 bias4 bias5 bias6
bias7
    dx 1.000
    dy  .283 1.000
    dz -.680 -.870 1.000
  trop  .000  .000  .000 1.000
 bias1  .000  .000  .000  .000 1.000
 bias2  .000  .000  .000  .000  .000 1.000
 bias3  .000  .000  .000  .000  .000  .000 1.000
 bias4  .000  .000  .000  .000  .000  .000  .000 1.000
 bias5  .000  .000  .000  .000  .000  .000  .000  .000 1.000
 bias6  .000  .000  .000  .000  .000  .000  .000  .000 .000 1.000
 bias7  .000  .000  .000  .000  .000  .000  .000  .000 .000  .000
1.000
```

Figure F-8c. TRIMBLE Baseline Solution File (Ukiah Baseline 2014--2002)



```
                    Solution      Sigma  Sensitivity to 10 meter error
                                         in station 1 coordinates
     dx (m)        3799.006       .009      9.999       .000     -.002
     dy (m)        2554.013       .027      -.001     10.000     -.001
     dz (m)            .000       .000       .000       .000    10.000
   trop (%)            .000       .000       .000       .000      .000
bias 1 (cycle)         .000       .000       .000       .000      .000
bias 2 (cycle)         .000       .000       .000       .000      .000
bias 3 (cycle)         .000       .000       .000       .000      .000
bias 4 (cycle)         .000       .000       .000       .000      .000
bias 5 (cycle)         .000       .000       .000       .000      .000
bias 6 (cycle)         .000       .000       .000       .000      .000
bias 7 (cycle)         .000       .000       .000       .000      .000
 Results of integer bias search:
              .0549                    1.06578                  1.36295
                 0                          1                        0
                 0                          0                        0
                 0                          0                        0
                 0                          0                        0
                 0                          0                        0
                 0                          0                        0
Ratio sum-of-squares(2) to sum-of-squares(1)          18.87
 Interval between epochs (sec)  120
 Epoch increment     4
 Number of measurements used in solution     161
 Number of measurements rejected              56
 RMS (cycles)          .020 ---------------------- 1 - RMS
 Elevation mask (deg)    15.0
 Edit multiplier          3.5
 Modified Hopfield troposhpere model used
Best tracking C/A code positions
Station 1                                                  m - solution file
Pdop        3.1
  x (m)    -2713023.862   lat  (dms)  N   39  7  57.13720
  y (m)    -4145294.253   elon (dms)  E  236 47  45.39187
  z (m)     4003848.645   wlon (dms)  W  123 12  14.60813
                          ht (m)          170.2629
clock offset(s)        .43266808D-03
freq offset(s/s)      -.11042348D-08
 Code calibration(m)  Carrier calibration(m)
1 -  2          .2520                    .0012
1 -  3          .0552                   -.0006
1 -  4         -.0249                   -.0007
1 -  5          .9292                   -.0008
1 -  6         -.2124                   -.0010
1 -  7         -.0181                    .0005
1 -  8         -.1875                   -.0009
1 -  9         -.1875                   -.0012
1 - 10         1.0630                   -.0014
Station 2                                                  m - solution file
Pdop        2.5
 x (m)    -2709227.033     lat  (dms)  N    39  11   37.11338
 y (m)    -4142726.880     elon (dms)  E   236  48   59.18749
 z (m)     4009155.162     wlon (dms)  W   123  11     .81251
                           ht (m)          244.0000
clock offset(s)        .88584966D-03
freq  offset(s/s)      .58827784D-09
 Code calibration(m)  Carrier calibration(m)
1 -  2          .2021                    .0007
1 -  3         -.3682                   -.0011
1 -  4         -.4199                   -.0010
1 -  5         -.5342                   -.0013
1 -  6         -.5234                   -.0011
1 -  7         -.2754                   -.0002
1 -  8         -.6040                   -.0014
1 -  9         -.8003                   -.0020
1 - 10         -.6953                   -.0017
```

Figure F-8d. TRIMBLE Baseline Solution File (Ukiah Baseline 2014--2002)

```
------------------------------------------------------------------
TRIMVEC GPS RELATIVE POSITIONING SOLUTION SUMMARY: VERSION 88.028

SOLUTION OUTPUT FILE: a:14022059.fix

STATION 1:  Station ID: 2014  Session No.: 059-2  Feb 29,1988
07:24
Data-logging start time = 07:26    Data-logging stop time = 09:33

STATION 2:  Station ID: 2002  Session #: 059-2  Feb 29,1988 07:21
Data-logging start time = 07:23    Data-logging stop time = 09:32

STATION COORDINATES:

Sta      Ant (m)      Latitude            Longitude        Hgt (m)
 1         1.378   39:07'57.13720" N  123:12'14.60813" W  168.885
 2 [TRP]   0.120   39:11'36.66538" N  123:11'00.43314" W  244.226
 2 [FLT]   0.120   39:11'36.66472" N  123:11'00.43068" W  244.249
 2 [FIX]   0.120   39:11'36.66495" N  123:11'00.43190" W  244.234

Origin of station 1 coordinates : Best C/A code tracking solution

 SOLUTION SUMMARY:

Solution      dx (m)        dy (m)     dz(m)      dh (m)      RDOP
TRIPLE      3798.989      2554.042   5296.822    75.341      n/a
FLOAT       3799.022      2553.984   5296.821    75.365      n/a
FIXED       3799.006      2554.013   5296.817    75.349      n/a
FLT-FIX        0.016        -0.029      0.004     0.016

Solution Slope (m)  sig  Epochs/Rejected  Epoch int     Epoch inc
TRIPLE   7000.8406 [0.032]  168/  1       150 (secs)    5 (epochs)
FLOAT    7000.8363 [0.036]  167/ 50       120 (secs)    4 (epochs)
FIXED    7000.8355 [0.015]  161/ 56       120 (secs)    4 (epochs)

Fixed solution quality factor:   18.9
Fixed solution rms:            0.020 (cycles)
Maximum float - fixed delta:     2.0 (cm)

Integers found, RMS is OK, FIXED solution recommended.
------------------------------------------------------------------
```

Figure F-8e. TRIMBLE Baseline Solution Summary File (Ukiah Baseline 2014--2002)

F-4. Loop Closure

An approximate loop closure was done by following the procedures detailed in Chapter 10.

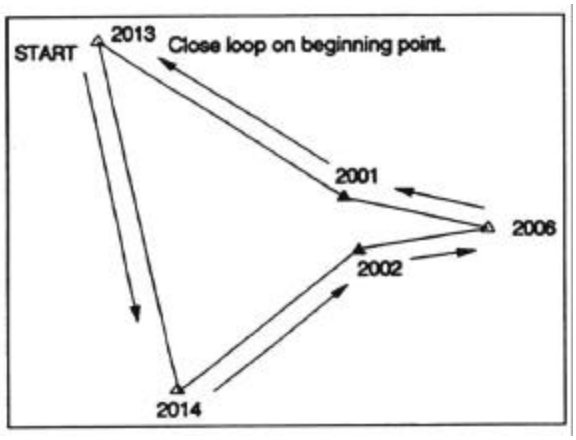


Figure F-9. Loop Closure (Ukiah)

The resulting calculations would proceed as shown in the following computation:

a. Follow Figure F-9, holding 2013 as the starting point.

b. Formulate a table similar to that shown in Chapter 10, where all values are taken from the GPS post-processed baseline formulations:

Baseline	Δ x (m)	Δ y (m)	Δ z (m)	Distance(m)
13142059.FIX 2013 -> 2014	-3367.429	-7891.019	-10410.673	13490.362
14021059.FIX 2014 -> 2002	3799.005	2554.018	5296.798	7000.823
02053056.FIX 2002 -> 2006	953.294	-748.319	-16.709	1212.035
06013056.FIX 2006 -> 2001	-666.617	1441.548	908.280	1829.593
01132059.FIX 2001 -> 2013	-718.244	4683.775	4222.288	6317.297

c. Sum up the Δx, Δy, Δz, and distance components:

$\Sigma\Delta x$ components = $\Delta x(2013\text{->}2014) + \Delta x(2014\text{->}2002) + \Delta x(2002\text{->}2006) + \Delta x(2006\text{->}2001)$
$+ \Delta x(2001\text{->}2013) = -3367.429 + 3799.005 + 953.294 + (-666.617) + (-718.244) = \underline{0.009}$

$\Sigma\Delta y$ components = $\Delta y(2013\text{->}2014) + \Delta y(2014\text{->}2002) + \Delta y(2002\text{->}2006) + \Delta y(2006\text{->}2001)$
$+ \Delta y(2001\text{->}2013) = -7891.019 + 2554.018 + (-748.319) + 1441.548 + 4643.775 = \underline{0.003}$

$\Sigma\Delta z$ components = $\Delta z(2013\text{->}2014) + \Delta z(2014\text{->}2002) + \Delta z(2002\text{->}2006) + \Delta z(2006\text{->}2001)$
$+ \Delta z(2001\text{->}2013) = -10410.673 + 5296.798 + (-16.709) + 908.280 + 4222.288 = \underline{-0.016}$

ΣDistances = (2013->2014) + (2014->2002) + (2002-2006) + (2006->2001) + (2001->2013)
= 13490.362 + 7000.823 + 1212.035 + 1829.593 + 6317.297 = 29850.110

d. From Equation (10-1):

$m = \text{sqrt} [0.009^2 + 0.003^2 + (-0.016)^2] = 0.018601075$ or 0.0186

Therefore, misclosure is approximately 0.0186 in 29850.110 m, or 1 part in 1,600,000.

F-5. Final Adjustment

The program used for final adjustment of the Ukiah survey was the GEOLAB program (Version 1.82--1987). For an in depth technical discussion on GEOLAB, refer to the literature accompanying the GEOLAB software package. The following discussion on the GEOLAB adjustment of the Ukiah survey highlights some of the criteria used in the adjustment of a horizontal survey.

a. The input data file for a GEOLAB adjustment is called an "IOB" file. An IOB file can be created using a text editor program or with a GEOLAB option called "GPS Environment." An IOB file is specific to the GEOLAB adjustment software and may or may not be required by other least-square adjustment software (refer to Chapter 11 or the owner's manual). The GEOLAB Environment option takes GPS baseline solution files developed by most GPS manufacturers and automatically sets up an IOB file for adjustment.

b. The IOB input file generally consists of the following information:

(1) Top Line. Title Record - usually a project name and an adjustment number.

(2) Second Line. Options Record - this record specifies which GEOLAB options are to be activated for processing.

(3) Third Line. Ellipsoid Specification Record - Prints ellipsoid parameters chosen in the Options Record or as chosen by the user.

(4) Station Information Section. All stations must have their coordinates defined here. The coordinates must be given as ellipsoidal latitude, longitude, and orthometric height, or as Cartesian coordinates. In this section, stations are either held fixed or are to be adjusted. If stations are not held fixed, estimated coordinates are input.

(5) Auxiliary Parameter Definition Record. The auxiliary parameter group definition record is optional, but can be used if GEOLAB is to solve for various scale, orientation, translation, or constant parameters. In the sample GEOLAB input, enough vertical and horizontal control is held fixed to solve for SCALE and ROTATION. Rotation is about the Cartesian X-axis, Y-axis, and Z-axis.

(6) Observation Records Section. In the example GEOLAB input file, only GPS observations are entered. Each baseline is entered separately with the station name and Cartesian coordinate differences between the stations, which is the computed baseline. These can also be entered as $\Delta x=0$, $\Delta y=0$, $\Delta z=0$, for station 1 and the 3 D baseline for station 2. For example, baseline 1 would be entered as:

STATION		Δx	Δy	Δz
92	2001	0.000	0.000	0.000
92	2006	-666.617	1441.548	908.280

The correlation matrix elements from the baseline solution are also entered and the last line of the observation record is the standard deviation for Δx, Δy, and Δz.

c. Figure F-10 depicts GEOLAB input with annotations using the above convention.

d. Once an IOB file containing parameters necessary to perform an adjustment has been completed, the adjustment can begin. The first step is to select the baselines needed for the adjustment. The baselines chosen must have been processed adequately, as detailed in Chapter 10, or as recommended by the GPS manufacturer.

e. The example IOB file shown in Figure F-10 was adjusted as shown in Figure F-11.

f. For the first adjustment (Figure F-11), one point was held fixed in 3D, producing a free adjustment). A free adjustment checks the internal consistency of a GPS survey--refer to Chapter 11 for further details.

g. A second adjustment (not shown) can be done to check the existing network if these control points are directly tied together with GPS baselines. To do this with GEOLAB, the user must set up an IOB file with only the fixed control and the respective baselines connecting them. Hold fixed all control except one point, then perform the adjustment. Next, fix that control point and free one of the others, and keep repeating this procedure until all control points have been allowed to be checked against it's true position. If the position of one control point is "bad", that point can generally be omitted from the subsequent constrained adjustment or allowed to adjust with the other points.

h. A final constrained adjustment (Figure F-12) should hold fixed all good horizontal and vertical control. Adjust and check the output as detailed in Chapter 11.

F-6. Check of the Final Adjustment

After each adjustment was run, the 2-D and 1-D station (absolute) error ellipse for each adjusted point was reviewed (for further discussion on error ellipses and adjustments, refer to Chapter 11). These are listed as major semi-axis, minor semi-axis, major azimuth, and vertical. The sizes of the error ellipses listed in this portion of the GEOLAB adjustment are an indication of the internal consistency of the GPS survey. The smaller the size of the ellipse, the better the survey. The size of the ellipse will also generally become larger as the project size increases. In the constrained adjustment shown, the major semi-axis and minor semi-axis are of the mm level (0.0066 and 0.0048 mm for 2001 and 0.0062 and 0.0044 mm, respectively) - which is acceptable.

a. The 2-D and 1-D relative error ellipses and line accuracies (i.e. precision) between survey points were checked. These are listed as major semi-axis, minor semi-axis, major azimuth, vertical, spatial distance, and precision (as shown on labeled page 16 of the free adjustment and page 17 of the constrained adjustment). When checking these values, one should remember they are relative values. The relativity of points used in the adjustment can sometimes produce deceptive values, higher major semi-axis and minor semi-axis values: this may occur between points that are close together, but have not been tied together by a baseline. Because of the possibility of the production of deceptive results, the user must take special care when reviewing these values. In the constrained adjustment shown, the major semi-axis and minor semi-

axis are of the mm level (0.0045 and 0.0036 for the baseline 2001->2002). The project precision in parts per million (ppm) is also listed in this portion of the adjustment and should be checked.

b. The histograms in the GEOLAB adjustments were reviewed. The histogram is a visual representation of the standardized (normalized) residuals. The histogram shows whether the residuals are symmetrical about the mean residual, the total spread of values of the residuals, the frequencies of the different values, and how peaked or how flat the distribution of the residuals may be. A generally good looking histogram has data that, when graphed, is in the shape of a bell curve.

c. The free adjustment line accuracy precessions shown on Figure F-11 are the primary criteria used to evaluate the survey adequacy. The worst precision (4.182 ppm between 2001 and 2013) equates to 1:239,000. This far exceeds the required project accuracy (1:10,000). The relative line accuracy between 2001 and 2002 on the constrained adjustment was 3.846 ppm, or 1:260,000. This indicates excellent connections with existing control.

d. The variance factor shown on each adjustment is within acceptable limits (0.5 to 1.5). As such, it could be used to determine outlier limits for rejection of data, as explained in Chapter 11.

e. The residual corrections to each baseline component are shown on each adjustment. Special review is made of the Standardized Residuals, which one will find is approximately comparable to Normalized Residuals in GEOLAB software. None of the residuals were flagged (based on Tau Max testing) for exceeding tolerance.

f. The 3-D positional and relative confidence regions (ellipsoid) and 3-D line accuracy precessions are shown at the end of each adjustment. These statistics are not applicable for most USACE work.

g. Of all the output statistics, only the residuals, standardized residuals, relative 2-D/1-D line precessions, and variance factor have useful application for USACE work. The histograms, Chi-square tests, 3-D ellipsoid, etc. are useful only if one understands their derivation and application.

h. The results of the free and constrained adjustments in this example were not significantly different. This is usually not the case--typically, station/line accuracies degrade on the constrained adjustment.

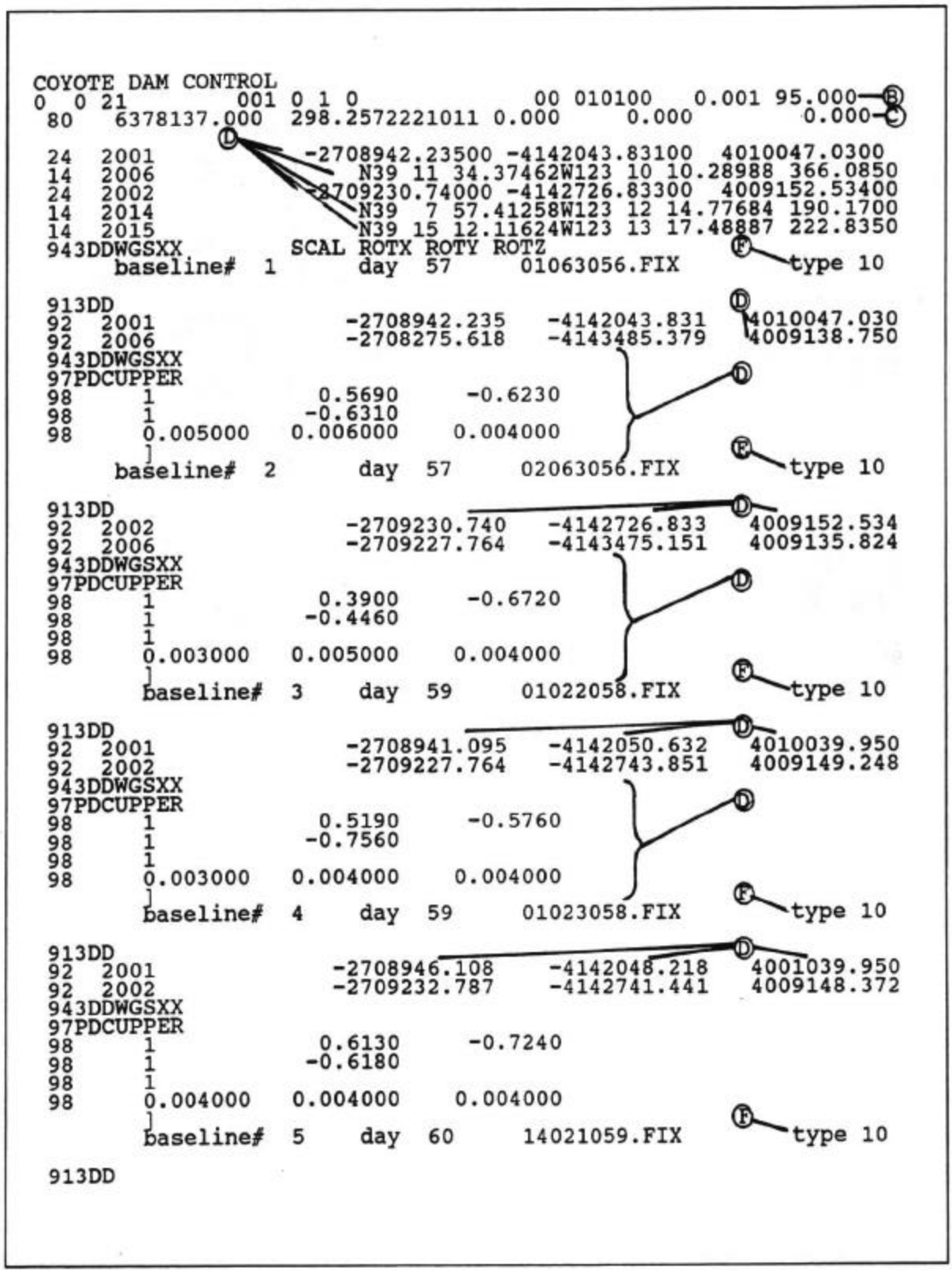


Figure F-10a. GEOLAB Input (Ukiah)

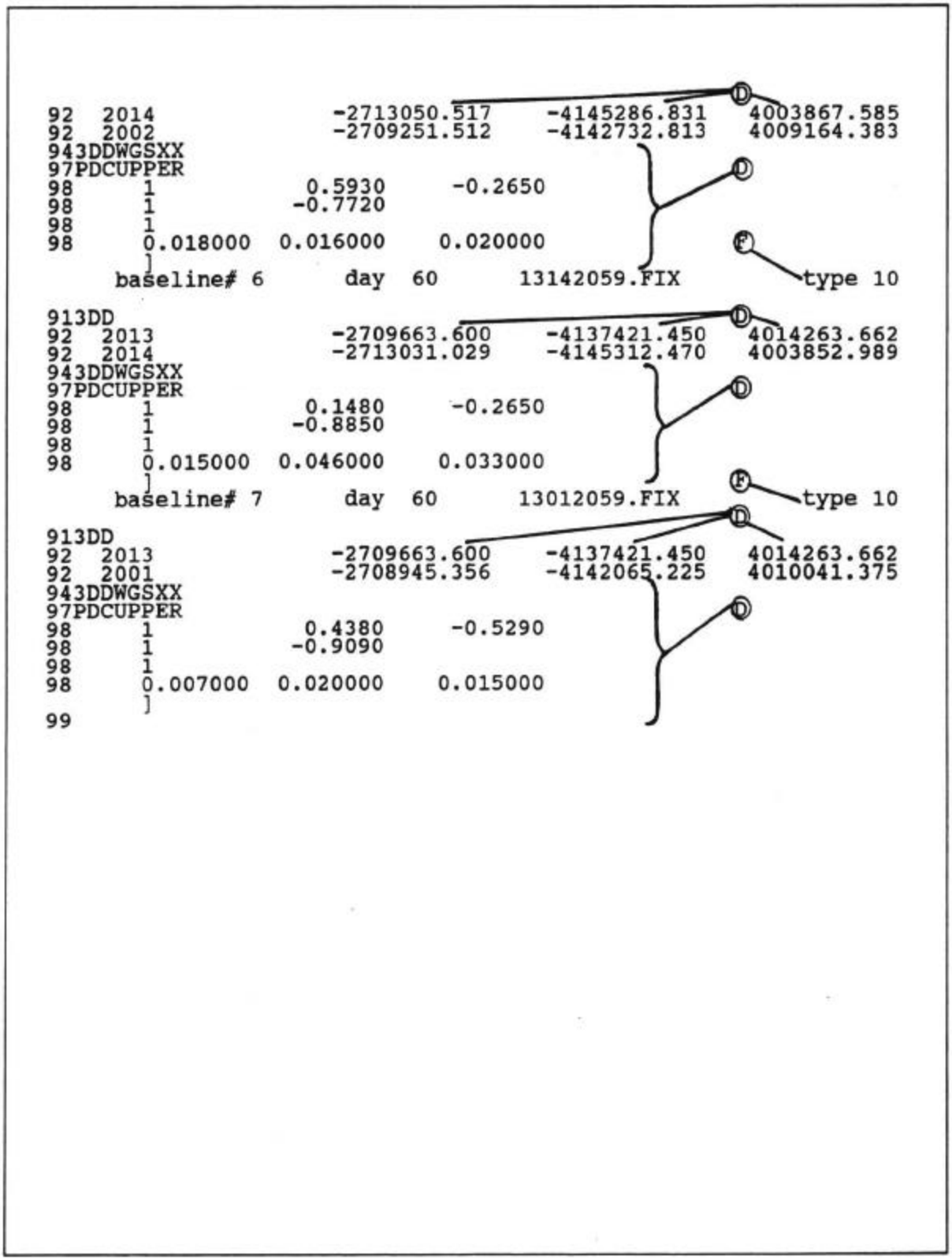


Figure F-10b. GEOLAB Input (Ukiah)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM FREE ADJUSTMENT NAD-83

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

PREPARE: ASCII input file: <coyote_2.iob>.
PREPARE successfully completed.

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GETUP:

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
All Stations	5	Directions	0
Fixed Stations	1	Distances	0
Free 3-D Stations	4	Azimuths	0
Free 2-D Stations	0	Vertical Angles	0
Free 1-D Stations	0	Zenithal Angles	0
Coord. Parameters	12	Angles	0
Astro. Latitudes	0	Heights	0
Astro. Longitudes	0	Height Differences	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	0	2-D Coords.	0
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	0	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	21
Rotation Pars.	0		
Translation Pars.	0		
Total Parameters	12	Total Observations	21

Degrees of Freedom = 9

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SUMMARY OF SELECTED OPTIONS

OPTION	SELECTION
Computation Mode	Adjustment
Linear Unit	Metre
Maximum Iterations	2
Confidence Regions Selected	All
Confidence Region Dimensions	1-D, 2-D, and 3-D
Print Input Station Data	On
Variance Factor Knowledge	Known
Confidence Level for Statistics	95.000
Dual-Height Mode	Off
Print Solution Vector	On All Iterations
Printed Ellipsoidal Coordinates	5 Decimal Places
Print Adjusted X, Y, Z	On
Print Histograms	On
Print Misclosures	On All Iterations
Print Residuals	All
Variance Factor Usage	Scale Confidence Regions
Residual Rejection Criterion	Tau Max
Angular Misclosure Limit Factor	10
Linear Misclosure Limit Factor	10
Convergence Criterion	0.001000

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Figure F-11a. GEOLAB Adjustment Output (Free)

```
                    U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              COYOTE DAM     FREE ADJUSTMENT
A=  6378137.000 B=  6356752.314 X0=       0.000 Y0=       0.000 Z0=       0.000
-------------------------------------------------------------------------------
CODE IDENT.    DESCRIPTOR       INITIAL VALUES
---- ------    ----------       --------------

 14  2006
                ELLIPSOIDAL :   39 11 34.37462 -123 10 10.28988        336.0850
                ASTRONOMIC  :   39 11 34.37462 -123 10 10.28988        336.0850
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2708280.4788    -4143494.7721    4009147.8933

 24  2001
                ELLIPSOIDAL :   39 12 14.43422 -123 11  6.45941        243.8658
                ASTRONOMIC  :   39 12 14.43422 -123 11  6.45941        243.8658
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2708942.2350    -4142043.8310    4010047.0300

 24  2002
                ELLIPSOIDAL :   39 11 37.00656 -123 11  0.94286        243.8815
                ASTRONOMIC  :   39 11 37.00656 -123 11  0.94286        243.8815
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2709230.7400    -4142726.8330    4009152.5340

 24  2014
                ELLIPSOIDAL :   39  7 57.44196 -123 12 15.70589        188.7219
                ASTRONOMIC  :   39  7 57.44196 -123 12 15.70589        188.7219
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2713050.5170    -4145286.8310    4003867.5850

 24  2013
                ELLIPSOIDAL :   39 15 11.55819 -123 13 17.15396        220.5009
                ASTRONOMIC  :   39 15 11.55819 -123 13 17.15396        220.5009
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2709663.6000    -4137421.4500    4014263.6620
GETUP successfully completed.
-------------------------------------------------------------------------------
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-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
FORMEQ: NOTE 6:          Reordering was done.
AT       TO       OBS TYPE              OBSERVATION  APPROX.SIG.   MISCLOSURE
-------- -------- --------------- --------------- ------------ ------------
2001     2006     3-D X-Coord Diff       666.6170       0.0037       -4.8608
2001     2006     3-D Y-Coord Diff     -1441.5480       0.0045       -9.3931
2001     2006     3-D Z-Coord Diff      -908.2800       0.0028        9.1433
2002     2006     3-D X-Coord Diff       953.2950       0.0022       -3.0338
2002     2006     3-D Y-Coord Diff      -748.3180       0.0044      -19.6211
2002     2006     3-D Z-Coord Diff       -16.7100       0.0029       12.0693
2001     2002     3-D X-Coord Diff      -286.6690       0.0024       -1.8360
2001     2002     3-D Y-Coord Diff      -693.2190       0.0026       10.2170
2001     2002     3-D Z-Coord Diff      -891.5890       0.0025       -2.9070
2001     2002     3-D X-Coord Diff      -286.6790       0.0026       -1.8260
2001     2002     3-D Y-Coord Diff      -693.2230       0.0030       10.2210
2001     2002     3-D Z-Coord Diff      -891.5780       0.0026       -2.9180
2014     2002     3-D X-Coord Diff      3799.0050       0.0129       20.7720
2014     2002     3-D Y-Coord Diff      2554.0180       0.0101        5.9800
2014     2002     3-D Z-Coord Diff      5296.7980       0.0113      -11.8490
2013     2014     3-D X-Coord Diff     -3367.4290       0.0142      -19.4880
2013     2014     3-D Y-Coord Diff     -7891.0200       0.0210       25.6390
2013     2014     3-D Z-Coord Diff    -10410.6730       0.0147       14.5960
2013     2001     3-D X-Coord Diff       718.2440       0.0059        3.1210
2013     2001     3-D Y-Coord Diff     -4643.7750       0.0083       21.3940
2013     2001     3-D Z-Coord Diff     -4222.2870       0.0059        5.6550
FORMEQ successfully completed.
-------------------------------------------------------------------------------
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```

Figure F-11b. GEOLAB Adjustment Output (Free)

```
                    U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              COYOTE DAM     FREE ADJUSTMENT
A=  6378137.000 B=  6356752.314 X0=       0.000 Y0=       0.000 Z0=       0.000

SOLVE:            Solution (Iteration Count = 1):
CODE IDENT.   TYPE                    INITIAL            DX                UPDATED
---- -------- --------- ------------------ -------------- ------------------
 24  2001     LATITUDE     39  12  14.43422       0.01413    39  12  14.44836
 24  2001     LONGITUDE  -123  11   6.45941       0.04476  -123  11   6.41465
 24  2001     HEIGHT                243.86577      13.93969          257.80546

 24  2002     LATITUDE     39  11  37.00656      -0.06729    39  11  36.93927
 24  2002     LONGITUDE  -123  11   0.94286       0.34171  -123  11   0.60115
 24  2002     HEIGHT                243.88154      21.63376          265.51530

 24  2014     LATITUDE     39   7  57.44196      -0.02938    39   7  57.41258
 24  2014     LONGITUDE  -123  12  15.70589       0.92905  -123  12  14.77684
 24  2014     HEIGHT                188.72193       1.44519          190.16712

 24  2013     LATITUDE     39  15  11.55819       0.55805    39  15  12.11624
 24  2013     LONGITUDE  -123  13  17.15396      -0.33491  -123  13  17.48887
 24  2013     HEIGHT                220.50094       2.33476          222.83570
SOLVE successfully completed.
------------------------------------------------------------------------------
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------------------------------------------------------------------------------

FORMEQ:           FORMEQ successfully completed.
------------------------------------------------------------------------------
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------------------------------------------------------------------------------

SOLVE:            Adjusted Values (Iteration Count = 2):
CODE IDENT.   TYPE                    INITIAL            DX               ADJUSTED
---- -------- --------- ------------------ -------------- ------------------
 14  2006     LATITUDE     39  11  34.37462          FIXED
 14  2006     LONGITUDE  -123  10  10.28988          FIXED
 14  2006     HEIGHT                336.08500          FIXED

 24  2001     LATITUDE     39  12  14.44836      -0.00000    39  12  14.44836
 24  2001     LONGITUDE  -123  11   6.41465      -0.00000  -123  11   6.41465
 24  2001     HEIGHT                257.80546      -0.00000          257.80546

 24  2002     LATITUDE     39  11  36.93927       0.00000    39  11  36.93927
 24  2002     LONGITUDE  -123  11   0.60115      -0.00000  -123  11   0.60115
 24  2002     HEIGHT                265.51530       0.00001          265.51530

 24  2014     LATITUDE     39   7  57.41258      -0.00000    39   7  57.41258
 24  2014     LONGITUDE  -123  12  14.77684      -0.00000  -123  12  14.77684
 24  2014     HEIGHT                190.16712       0.00004          190.16716

 24  2013     LATITUDE     39  15  12.11624      -0.00000    39  15  12.11624
 24  2013     LONGITUDE  -123  13  17.48887      -0.00000  -123  13  17.48887
 24  2013     HEIGHT                222.83570       0.00003          222.83573
------------------------------------------------------------------------------
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------------------------------------------------------------------------------

                        Adjusted Cartesian Coordinates:
CODE IDENT.        X-COORDINATE        Y-COORDINATE        Z-COORDINATE
---- -------- ------------------ ------------------- ------------------
 24  2001        -2708947.0978       -4142053.2284       4010056.1788
 24  2002        -2709233.7714       -4142746.4510       4009164.5970
 24  2014        -2713032.7730       -4145300.4675       4003867.7943
 24  2013        -2709665.3421       -4137409.4529       4014278.4662
SOLVE successfully completed.
------------------------------------------------------------------------------
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```

Figure F-11c. GEOLAB Adjustment Output (Free)

```
                    U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              COYOTE DAM     FREE ADJUSTMENT
A=  6378137.000 B=  6356752.314 X0=       0.000 Y0=       0.000 Z0=       0.000

INVERT:          INVERT successfully completed.

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RESID:
STATION    3-D COORD DIFFS    STD.DEV.    RESIDUAL    STD.DEV.   STAN.RES.
--------   --------------   ----------  ----------  ----------  ----------
2001         -2708942.2350
             -4142043.8310
              4010047.0300
2006         -2708275.6180      0.0050      0.0020      0.0040      0.4913
             -4143485.3790      0.0060      0.0043      0.0044      0.9722
              4009138.7500      0.0040     -0.0055      0.0026     -2.1131
============================ End of Observation Set ============================
2002         -2709230.7400
             -4142726.8330
              4009152.5340
2006         -2708277.4450      0.0030     -0.0024      0.0015     -1.5684
             -4143475.1510      0.0050     -0.0031      0.0031     -1.0050
              4009135.8240      0.0040      0.0063      0.0026      2.4021
============================ End of Observation Set ============================
2001         -2708941.0950
             -4142050.6320
              4010040.8370
2002         -2709227.7640      0.0030     -0.0046      0.0020     -2.2695
             -4142743.8510      0.0040     -0.0036      0.0031     -1.1723
              4009149.2480      0.0040      0.0072      0.0032      2.2790
============================ End of Observation Set ============================
2001         -2708946.1080
             -4142048.2180
              4010039.9500
2002         -2709232.7870      0.0040      0.0054      0.0033      1.6114
             -4142741.4410      0.0040      0.0004      0.0031      0.1290
              4009148.3720      0.0040     -0.0038      0.0032     -1.1996
============================ End of Observation Set ============================
2014         -2713050.5170
             -4145286.8310
              4003867.5850
2002         -2709251.5120      0.0180     -0.0034      0.0132     -0.2586
             -4142732.8130      0.0160     -0.0015      0.0077     -0.1983
              4009164.3830      0.0200      0.0047      0.0129      0.3661
============================ End of Observation Set ============================
2013         -2709663.6000
             -4137421.4500
              4014263.6620
2014         -2713031.0290      0.0150     -0.0019      0.0092     -0.2019
             -4145312.4700      0.0460      0.0054      0.0407      0.1332
              4003852.9890      0.0330      0.0011      0.0275      0.0389

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RESID:
STATION    3-D COORD DIFFS    STD.DEV.    RESIDUAL    STD.DEV.   STAN.RES.
--------   --------------   ----------  ----------  ----------  ----------
============================ End of Observation Set ============================
2013         -2709663.6000
             -4137421.4500
              4014263.6620
2001         -2708945.3560      0.0070      0.0003      0.0021      0.1596
             -4142065.2250      0.0200     -0.0005      0.0076     -0.0670
              4010041.3750      0.0150     -0.0004      0.0055     -0.0743
============================ End of Observation Set ============================

GeoLab - V1.82S, (C) 1985/86/87 BitWise Ideas Inc. [103207696]      Page     11
```

Figure F-11d. GEOLAB Adjustment Output (Free)

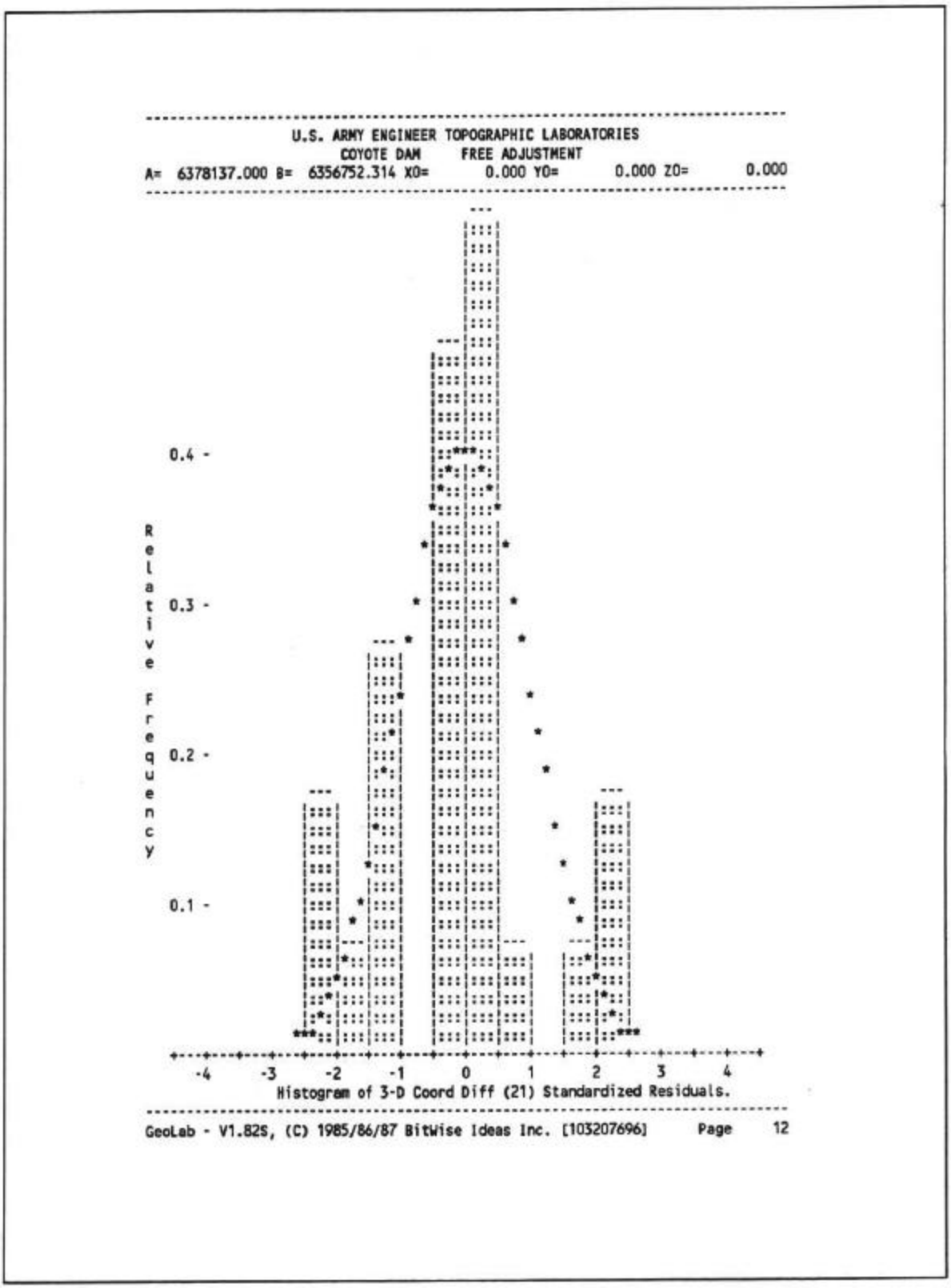
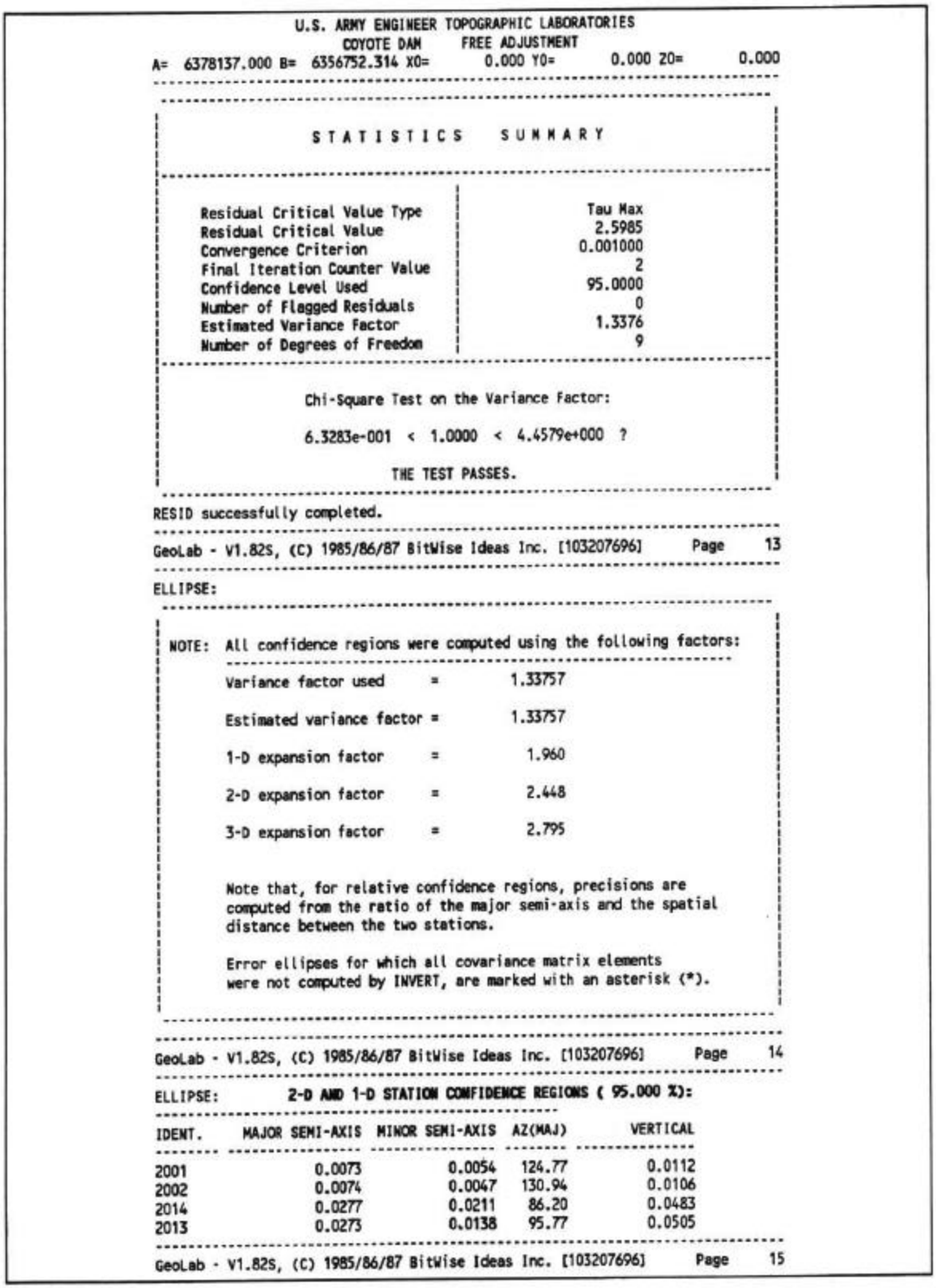


Figure F-11e. GEOLAB Adjustment Output (Free)



U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM FREE ADJUSTMENT
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

STATISTICS SUMMARY

Residual Critical Value Type	Tau Max
Residual Critical Value	2.5985
Convergence Criterion	0.001000
Final Iteration Counter Value	2
Confidence Level Used	95.0000
Number of Flagged Residuals	0
Estimated Variance Factor	1.3376
Number of Degrees of Freedom	9

Chi-Square Test on the Variance Factor:

6.3283e-001 < 1.0000 < 4.4579e+000 ?

THE TEST PASSES.

RESID successfully completed.

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ELLIPSE:

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

Variance factor used	=	1.33757
Estimated variance factor	=	1.33757
1-D expansion factor	=	1.960
2-D expansion factor	=	2.448
3-D expansion factor	=	2.795

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.

Error ellipses for which all covariance matrix elements were not computed by INVERT, are marked with an asterisk (*).

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ELLIPSE: 2-D AND 1-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MINOR SEMI-AXIS	AZ(MAJ)	VERTICAL
2001	0.0073	0.0054	124.77	0.0112
2002	0.0074	0.0047	130.94	0.0106
2014	0.0277	0.0211	86.20	0.0483
2013	0.0273	0.0138	95.77	0.0505

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Figure F-11f. GEOLAB Adjustment Output (Free)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM FREE ADJUSTMENT
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

ELLIPSE: 2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS (95.000 %):

FROM	TO	MAJ.SEMI	MIN.SEMI	AZ(MAJ)	VERTICAL	SPATIAL DIST.	PRECISION
2001	2002	0.0045	0.0038	105.27	0.0082	1165.1856	3.881 PPM
2001	2014	0.0272	0.0204	84.07	0.0475	8095.2706	3.363 PPM
2001	2013	0.0264	0.0125	94.67	0.0494	6317.2966	4.182 PPM
2002	2014	0.0271	0.0203	83.67	0.0473	7000.8237	3.871 PPM
2002	2013	0.0267	0.0130	94.73	0.0499	7404.1516	3.612 PPM
2014	2013	0.0359	0.0216	91.44	0.0607	13490.3592	2.665 PPM

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ELLIPSE: 3-D STATION CONFIDENCE REGIONS (95.000 %):

IDENT.	MAJOR SEMI-AXIS	MEDIUM SEMI-AXIS	MINOR SEMI-AXIS
2001	0.0161	0.0082	0.0059
	A=180.0 V= 80.4	A=298.9 V= 4.7	A= 29.6 V= 8.3
2002	0.0152	0.0082	0.0054
	A=161.8 V= 79.9	A=307.9 V= 8.4	A= 38.7 V= 5.6
2014	0.0690	0.0316	0.0237
	A=345.0 V= 86.1	A= 85.7 V= 0.7	A=175.8 V= 3.8
2013	0.0754	0.0219	0.0157
	A= 94.5 V= 72.1	A=279.0 V= 17.9	A=188.6 V= 1.3

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ELLIPSE: 3-D RELATIVE STATION CONFIDENCE REGIONS (95.000 %):

FROM	TO	MAJOR-SEMI	MED.-SEMI	MINOR-SEMI	SPATIAL DIST.	PRECISION
2001	2002	0.0117	0.0051	0.0044	1165.1856	10.011 PPM
		A= 0 V=90	A= 90 V= 0	A= 0 V= 0		
2001	2014	0.0679	0.0311	0.0228	8095.2706	8.392 PPM
		A=347 V=86	A= 84 V= 1	A=174 V= 4		
2001	2013	0.0739	0.0201	0.0142	6317.2966	11.704 PPM
		A= 93 V=72	A=279 V=18	A=188 V= 2		
2002	2014	0.0677	0.0309	0.0226	7000.8237	9.666 PPM
		A=342 V=85	A= 83 V= 1	A=173 V= 4		
2002	2013	0.0745	0.0210	0.0148	7404.1516	10.064 PPM
		A= 93 V=72	A=278 V=18	A=188 V= 1		
2014	2013	0.0887	0.0363	0.0245	13490.3592	6.577 PPM
		A= 85 V=76	A=275 V=14	A=185 V= 2		

ELLIPSE successfully completed.

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Figure F-11g. GEOLAB Adjustment Output (Free)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM CONSTRAINED ADJUSTMENT NAD-83

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

PREPARE: ASCII input file: <coyote_1.iob>.
PREPARE successfully completed.

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GETUP:

PARAMETERS		OBSERVATIONS	
Description	Number	Description	Number
All Stations	5	Directions	0
Fixed Stations	3	Distances	0
Free 3-D Stations	2	Azimuths	0
Free 2-D Stations	0	Vertical Angles	0
Free 1-D Stations	0	Zenithal Angles	0
Coord. Parameters	6	Angles	0
Astro. Latitudes	0	Heights	0
Astro. Longitudes	0	Height Differences	0
Geoid Records	0	Auxiliary Params.	0
All Aux. Pars.	4	2-D Coords.	0
Direction Pars.	0	2-D Coord. Diffs.	0
Scale Parameters	1	3-D Coords.	0
Constant Pars.	0	3-D Coord. Diffs.	21
Rotation Pars.	3		
Translation Pars.	0		
Total Parameters	10	Total Observations	21
Degrees of Freedom =	11		

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GETUP: SUMMARY OF SELECTED OPTIONS

OPTION	SELECTION
Computation Mode	Adjustment
Linear Unit	Metre
Maximum Iterations	2
Confidence Regions Selected	All
Confidence Region Dimensions	1-D, 2-D, and 3-D
Print Input Station Data	On
Variance Factor Knowledge	Known
Confidence Level for Statistics	95.000
Dual-Height Mode	Off
Print Solution Vector	On All Iterations
Printed Ellipsoidal Coordinates	5 Decimal Places
Print Adjusted X, Y, Z	On
Print Histograms	On
Print Misclosures	On All Iterations
Print Residuals	All
Variance Factor Usage	Scale Confidence Regions
Residual Rejection Criterion	Tau Max
Angular Misclosure Limit Factor	10
Linear Misclosure Limit Factor	10
Convergence Criterion	0.001000

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Figure F-12a. GEOLAB Adjustment Output (Constrained)

```
                    U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                              COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000

CODE IDENT.    DESCRIPTOR       INITIAL VALUES
---- ------    ----------       --------------

 14  2006
                ELLIPSOIDAL :   39 11 34.37462 -123 10 10.28988        336.0850
                ASTRONOMIC  :   39 11 34.37462 -123 10 10.28988        336.0850
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2708280.4788    -4143494.7721    4009147.8933

 14  2013
                ELLIPSOIDAL :   39 15 12.11624 -123 13 17.48887        222.8350
                ASTRONOMIC  :   39 15 12.11624 -123 13 17.48887        222.8350
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2709665.3418    -4137409.4525    4014278.4657

 14  2014
                ELLIPSOIDAL :   39  7 57.41258 -123 12 14.77684        190.1700
                ASTRONOMIC  :   39  7 57.41258 -123 12 14.77684        190.1700
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2713032.7742    -4145300.4693    4003867.7960

 24  2001
                ELLIPSOIDAL :   39 12 14.43422 -123 11  6.45941        243.8658
                ASTRONOMIC  :   39 12 14.43422 -123 11  6.45941        243.8658
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2708942.2350    -4142043.8310    4010047.0300

 24  2002
                ELLIPSOIDAL :   39 11 37.00656 -123 11  0.94286        243.8815
                ASTRONOMIC  :   39 11 37.00656 -123 11  0.94286        243.8815
                GEOIDAL     :    0  0  0.00000    0  0  0.00000          0.0000
                CARTESIAN   :    -2709230.7400    -4142726.8330    4009152.5340

 94  WGSXX
                3DD  SCAL   :          0.00000
                3DD  ROTX   :          0.00000
                3DD  ROTY   :          0.00000
                3DD  ROTZ   :          0.00000
GETUP successfully completed.

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FORMEQ:                  NOTE 6: Reordering was done.
AT       TO       OBS TYPE              OBSERVATION  APPROX.SIG.  MISCLOSURE
-------- -------- --------------- ---------------- ------------ ------------
2001     2006     3-D X-Coord Diff        666.6170       0.0037      -4.8608
2001     2006     3-D Y-Coord Diff      -1441.5480       0.0045      -9.3931
2001     2006     3-D Z-Coord Diff       -908.2800       0.0028       9.1433
2002     2006     3-D X-Coord Diff        953.2950       0.0022      -3.0338
2002     2006     3-D Y-Coord Diff       -748.3180       0.0044     -19.6211
2002     2006     3-D Z-Coord Diff        -16.7100       0.0029      12.0693
2001     2002     3-D X-Coord Diff       -286.6690       0.0024      -1.8360
2001     2002     3-D Y-Coord Diff       -693.2190       0.0026      10.2170
2001     2002     3-D Z-Coord Diff       -891.5890       0.0025      -2.9070
2001     2002     3-D X-Coord Diff       -286.6790       0.0026      -1.8260
2001     2002     3-D Y-Coord Diff       -693.2230       0.0030      10.2210
2001     2002     3-D Z-Coord Diff       -891.5780       0.0026      -2.9180
2014     2002     3-D X-Coord Diff       3799.0050       0.0129       3.0292
2014     2002     3-D Y-Coord Diff       2554.0180       0.0101      19.6183
2014     2002     3-D Z-Coord Diff       5296.7980       0.0113     -12.0600
2013     2001     3-D X-Coord Diff        718.2440       0.0059       4.8628
2013     2001     3-D Y-Coord Diff      -4643.7750       0.0083       9.3965
2013     2001     3-D Z-Coord Diff      -4222.2870       0.0059      -9.1487
FORMEQ successfully completed.

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```

Figure F-12b. GEOLAB Adjustment Output (Constrained)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM ADJUSTMENT NAD-83
A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

SOLVE: Solution (Iteration Count = 1):

CODE	IDENT.	TYPE	INITIAL	DX	UPDATED
24	2001	LATITUDE	39 12 14.43422	0.01413	39 12 14.44836
24	2001	LONGITUDE	-123 11 6.45941	0.04476	-123 11 6.41465
24	2001	HEIGHT	243.86577	13.93968	257.80545
24	2002	LATITUDE	39 11 37.00656	-0.06729	39 11 36.93927
24	2002	LONGITUDE	-123 11 0.94286	0.34171	-123 11 0.60115
24	2002	HEIGHT	243.88154	21.63406	265.51561
94	WGSXX	3DD SCAL	0.00000	-0.00161	-0.00161
94	WGSXX	3DD ROTX	0.00000	0.03270	0.03270
94	WGSXX	3DD ROTY	0.00000	-0.06406	-0.06406
94	WGSXX	3DD ROTZ	0.00000	-0.04338	-0.04338

SOLVE successfully completed.

FORMEQ: FORMEQ successfully completed.

SOLVE: Adjusted Values (Iteration Count = 2):

CODE	IDENT.	TYPE	INITIAL	DX	ADJUSTED
14	2006	LATITUDE	39 11 34.37462	FIXED	
14	2006	LONGITUDE	-123 10 10.28988	FIXED	
14	2006	HEIGHT	336.08500	FIXED	
14	2013	LATITUDE	39 15 12.11624	FIXED	
14	2013	LONGITUDE	-123 13 17.48887	FIXED	
14	2013	HEIGHT	222.83500	FIXED	
14	2014	LATITUDE	39 7 57.41258	FIXED	
14	2014	LONGITUDE	-123 12 14.77684	FIXED	
14	2014	HEIGHT	190.17000	FIXED	
24	2001	LATITUDE	39 12 14.44836	0.00000	39 12 14.44836
24	2001	LONGITUDE	-123 11 6.41465	0.00000	-123 11 6.41465
24	2001	HEIGHT	257.80545	-0.00000	257.80545
24	2002	LATITUDE	39 11 36.93927	0.00000	39 11 36.93927
24	2002	LONGITUDE	-123 11 0.60115	-0.00000	-123 11 0.60115
24	2002	HEIGHT	265.51561	0.00000	265.51561
94	WGSXX	3DD SCAL	-0.00161	0.00000	-0.00161
94	WGSXX	3DD ROTX	0.03270	-0.00000	0.03270
94	WGSXX	3DD ROTY	-0.06406	0.00000	-0.06406
94	WGSXX	3DD ROTZ	-0.04338	0.00000	-0.04338

Figure F-12c. GEOLAB Adjustment Output (Constrained)

```
                    U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=       0.000 Y0=       0.000 Z0=       0.000
--------------------------------------------------------------------------------
                          Adjusted Cartesian Coordinates:

CODE IDENT.        X-COORDINATE       Y-COORDINATE       Z-COORDINATE
---- -------- ------------------ ------------------ ------------------
 24  2001          -2708947.0978      -4142053.2284       4010056.1788
 24  2002          -2709233.7715      -4142746.4512       4009164.5972
SOLVE successfully completed.
--------------------------------------------------------------------------------
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--------------------------------------------------------------------------------
INVERT:          INVERT successfully completed.
--------------------------------------------------------------------------------
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--------------------------------------------------------------------------------
RESID:

STATION    3-D COORD DIFFS    STD.DEV.    RESIDUAL    STD.DEV.   STAN.RES.
--------   --------------   ----------  ----------  ----------  ----------
2001          -2708942.2350
              -4142043.8310
               4010047.0300
2006          -2708275.6180      0.0050      0.0020      0.0041      0.4865
              -4143485.3790      0.0060      0.0043      0.0045      0.9530
               4009138.7500      0.0040     -0.0055      0.0026     -2.1060
============================ End of Observation Set ============================
2002          -2709230.7400
              -4142726.8330
               4009152.5340
2006          -2708277.4450      0.0030     -0.0024      0.0016     -1.5309
              -4143475.1510      0.0050     -0.0031      0.0032     -0.9650
               4009135.8240      0.0040      0.0063      0.0026      2.3907
============================ End of Observation Set ============================
2001          -2708941.0950
              -4142050.6320
               4010040.8370
2002          -2709227.7640      0.0030     -0.0046      0.0020     -2.2625
              -4142743.8510      0.0040     -0.0036      0.0031     -1.1706
               4009149.2480      0.0040      0.0072      0.0032      2.2786
============================ End of Observation Set ============================
2001          -2708946.1080
              -4142048.2180
               4010039.9500
2002          -2709232.7870      0.0040      0.0054      0.0033      1.6090
              -4142741.4410      0.0040      0.0004      0.0031      0.1285
               4009148.3720      0.0040     -0.0038      0.0032     -1.1993
============================ End of Observation Set ============================
2014          -2713050.5170
              -4145286.8310
               4003867.5850
2002          -2709251.5120      0.0180     -0.0035      0.0149     -0.2328
              -4142732.8130      0.0160     -0.0015      0.0090     -0.1659
               4009164.3830      0.0200      0.0047      0.0141      0.3373
============================ End of Observation Set ============================
2013          -2709663.6000
              -4137421.4500
               4014263.6620
2014          -2713031.0290      0.0150     -0.0018      0.0105     -0.1739
              -4145312.4700      0.0460      0.0055      0.0419      0.1303
               4003852.9890      0.0330      0.0010      0.0293      0.0344

--------------------------------------------------------------------------------
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```

Figure F-12d. GEOLAB Adjustment Output (Constrained)

U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
COYOTE DAM ADJUSTMENT NAD-83

A= 6378137.000 B= 6356752.314 X0= 0.000 Y0= 0.000 Z0= 0.000

STATION	3-D COORD DIFFS	STD.DEV.	RESIDUAL	STD.DEV.	STAN.RES.
========== End of Observation Set ==========					
2013	-2709663.6000				
	-4137421.4500				
	4014263.6620				
2001	-2708945.3560	0.0070	0.0003	0.0026	0.1237
	-4142065.2250	0.0200	-0.0004	0.0137	-0.0312
	4010041.3750	0.0150	-0.0005	0.0083	-0.0555
========== End of Observation Set ==========					

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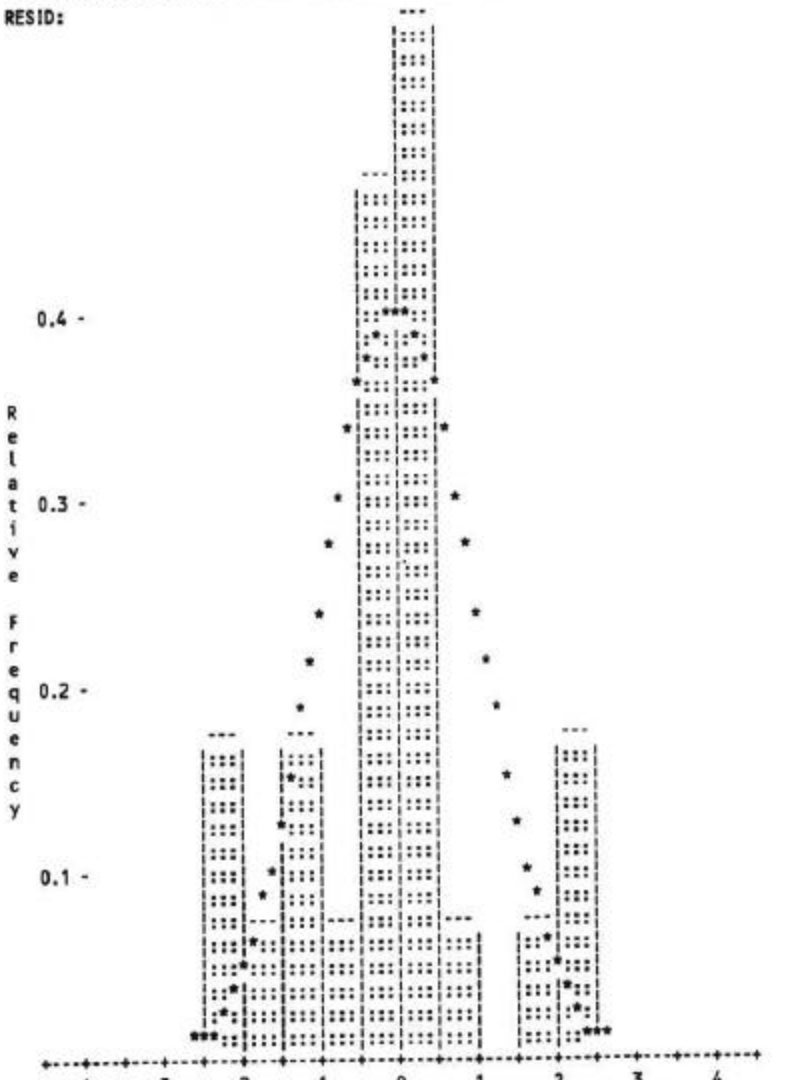
RESID:



Histogram of 3-D Coord Diff (21) Standardized Residuals.

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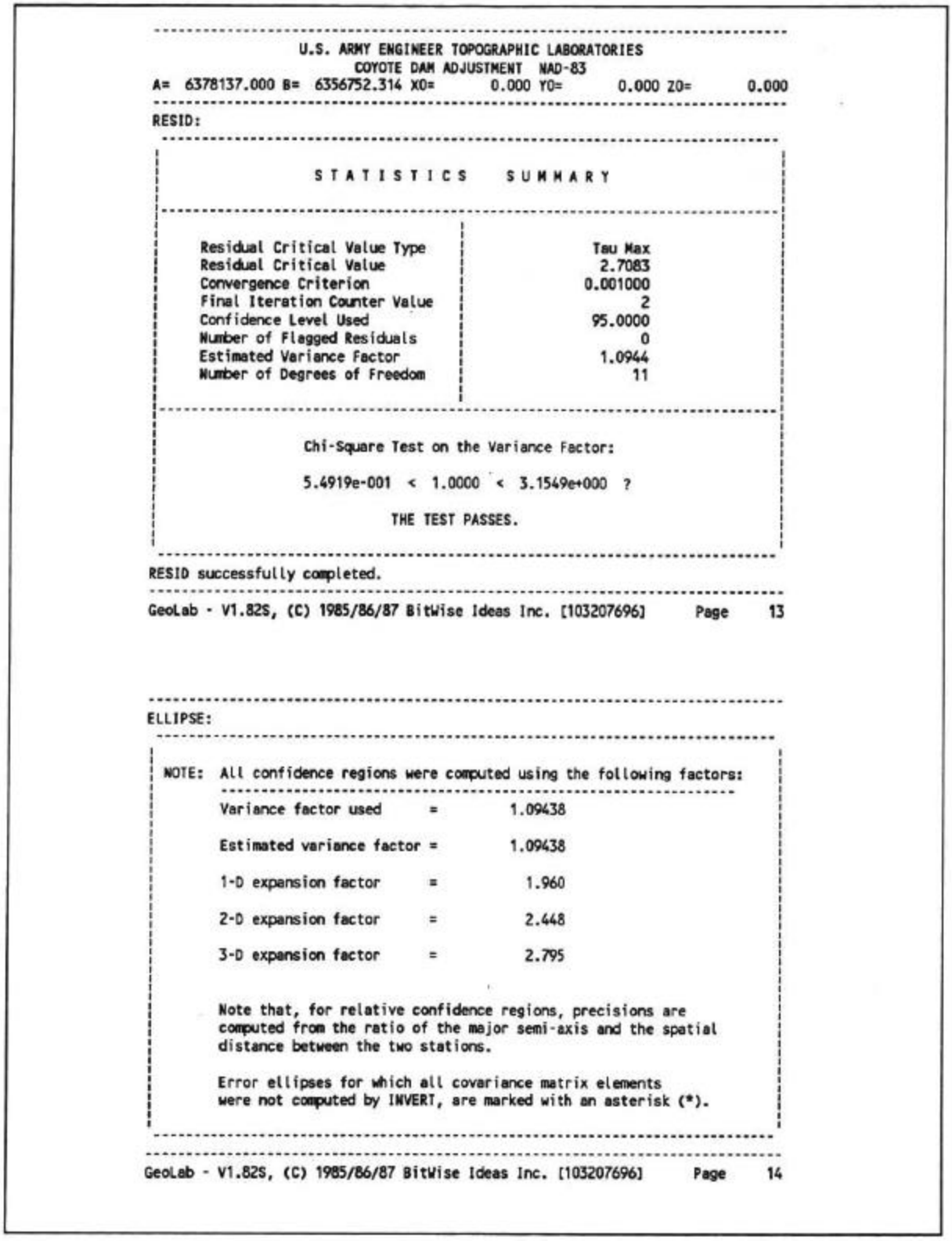
Figure F-12e. GEOLAB Adjustment Output (Constrained)



```
                U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                      COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000

RESID:

                    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                                2.7083
     Convergence Criterion                                  0.001000
     Final Iteration Counter Value                          2
     Confidence Level Used                                  95.0000
     Number of Flagged Residuals                            0
     Estimated Variance Factor                              1.0944
     Number of Degrees of Freedom                           11

                  Chi-Square Test on the Variance Factor:

                  5.4919e-001  <  1.0000  <  3.1549e+000  ?

                            THE TEST PASSES.

RESID successfully completed.

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ELLIPSE:

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

        Variance factor used      =        1.09438

        Estimated variance factor =        1.09438

        1-D expansion factor      =          1.960

        2-D expansion factor      =          2.448

        3-D expansion factor      =          2.795

        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.

        Error ellipses for which all covariance matrix elements
        were not computed by INVERT, are marked with an asterisk (*).

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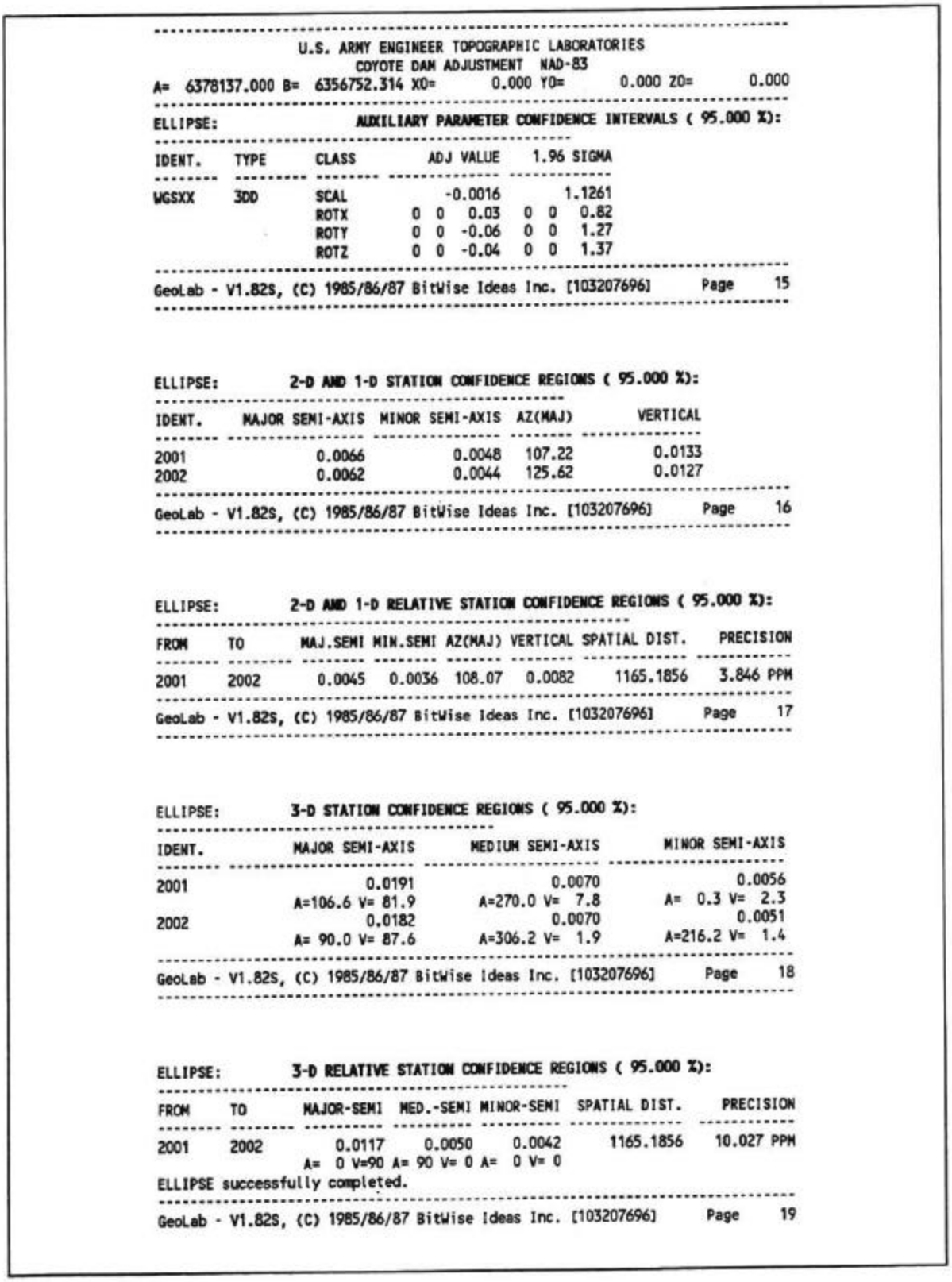
Figure F-12f. GEOLAB Adjustment Output (Constrained)



```
                    U.S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
                          COYOTE DAM ADJUSTMENT  NAD-83
A=  6378137.000 B=  6356752.314 X0=        0.000 Y0=        0.000 Z0=        0.000

ELLIPSE:                  AUXILIARY PARAMETER CONFIDENCE INTERVALS ( 95.000 %):

IDENT.    TYPE      CLASS          ADJ VALUE     1.96 SIGMA
--------  --------- -------- ---------------- -------------
WGSXX     3DD       SCAL             -0.0016        1.1261
                    ROTX       0  0    0.03   0  0    0.82
                    ROTY       0  0   -0.06   0  0    1.27
                    ROTZ       0  0   -0.04   0  0    1.37

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ELLIPSE:          2-D AND 1-D STATION CONFIDENCE REGIONS ( 95.000 %):

IDENT.     MAJOR SEMI-AXIS  MINOR SEMI-AXIS  AZ(MAJ)        VERTICAL
--------  ----------------- ----------------- -------- ---------------
2001                 0.0066            0.0048   107.22          0.0133
2002                 0.0062            0.0044   125.62          0.0127

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ELLIPSE:          2-D AND 1-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):

FROM      TO       MAJ.SEMI MIN.SEMI AZ(MAJ) VERTICAL SPATIAL DIST.    PRECISION
--------  -------- -------- -------- ------- -------- -------------  -----------
2001      2002       0.0045   0.0036  108.07   0.0082     1165.1856   3.846 PPM

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ELLIPSE:          3-D STATION CONFIDENCE REGIONS ( 95.000 %):

IDENT.          MAJOR SEMI-AXIS       MEDIUM SEMI-AXIS       MINOR SEMI-AXIS
--------  ---------------------- ---------------------- ----------------------
2001                      0.0191                 0.0070                 0.0056
                  A=106.6 V= 81.9        A=270.0 V=  7.8        A=  0.3 V=  2.3
2002                      0.0182                 0.0070                 0.0051
                  A= 90.0 V= 87.6        A=306.2 V=  1.9        A=216.2 V=  1.4

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ELLIPSE:          3-D RELATIVE STATION CONFIDENCE REGIONS ( 95.000 %):

FROM      TO       MAJOR-SEMI  MED.-SEMI MINOR-SEMI  SPATIAL DIST.    PRECISION
--------  -------- ---------- ---------- ---------- -------------  -----------
2001      2002         0.0117     0.0050     0.0042     1165.1856   10.027 PPM
                  A=  0 V=90 A= 90 V= 0 A=  0 V= 0

ELLIPSE successfully completed.

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Figure F-12g. GEOLAB Adjustment Output (Constrained)