Survey Report

2001 Geodetic Control Densification

of

Jefferson County, Kentucky

January 22, 2002

GRW Aerial Surveys, Inc.
801 Corporate Drive
Lexington, KY 40503

OPENING STATEMENT:

This report provides a general narrative explanation as to the purpose, scope, and methods used in the execution of this survey. Several other documents and exhibits are provided in conjunction with this document which further amplify and detail the project and its results.

Please refer to the following for further detail:

CONVENTIONAL DIFFERENTIAL LEVELING REDUCTION & ADJUSTMENT.pdf

CONVENTIONAL HORIZONTAL COMPUTATIONS.pdf

FINAL OBSERVATION SCHEDULE AS OBSERVED.pdf

GEOID 99 MAP.pdf

NEW MONUMENT DESIGN SKETCH.pdf

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PHASE 1 LOOP CLOSURES.pdf

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CORPSCON CONVERSION TO GRS 80.pdf

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DESCRIPTION SHEETS FOR NGS CONTROL USED IN THIS PROJECT.pdf

INTRODUCTION:

There are numerous existing horizontal and vertical control systems in Jefferson County from sources including the United States Coast & Geodetic Survey (USC&GS), National Geodetic Survey (NGS), United States Geological Survey (USGS), Kentucky Department of Transportation (KDOT), U.S. Army Corps of Engineers (USACE), historical City of Louisville, Louisville Metropolitan Sewer District (MSD), other local utilities, and myriad public/private projects. Existing horizontal & vertical control monuments are spatially sporadic and vary in currency, datum and accuracy. The overall goal of this project is to establish a unified network of monumented horizontal and vertical control and reference marks at a consistent datum and level of accuracy to serve the various needs of the Louisville/Jefferson County Information Consortium (LOJIC) Geographic Information System (GIS) partnership and the community's public and private sectors.

To this end GRW Aerial Surveys, Inc. (GRWAS) was contracted by LOJIC in June, 2001 to recover selected existing control monuments, locate and install new monuments, survey the selected existing and newly installed monuments using Global Positioning System (GPS) surveying techniques to provide a uniform county wide Geodetic Control Network.

SPECIFICATIONS:

Horizontal Datum:	North American Datum of 1983 (NAD 83) tied to the NGS's High Accuracy Reference Network (HARN)
Vertical Datum:	North American Vertical Datum of 1988 (NAVD 88)
Accuracy:	1:100,000 (10ppm)
New Monuments:	3 ½" standard survey disk set in a poured in place 10" diameter concrete cylinders drilled to a depth of 40" or drilled and grouted into a solid rock outcropping or massive concrete structure.
All Monuments:	Most monuments to be installed in intervisable pairs. Exceptions are some outlying monuments which fall outside of Jefferson County or in a location which does not provide space for a second monument in which case a readily identifiable physical feature may be used as a azimuth mark.

CONTRACTORS/RESPONSIBILITY:

GRW Aerial Surveys, Inc. (GRWAS)
801 Corporate Drive
Lexington, Ky. 40503

GRWAS was the prime contractor for this project. Their responsibilities included:

- Project administration, coordination, and quality control and quality assurance.
- Site reconnaissance.
- The selection of existing monuments to be used.
- The selection of new monument locations.
- New monument installation.
- GPS network design.
- GPS observations.
- GPS data reduction.
- GPS network adjustment.
- Preparation and delivery of the survey data and report.

Hall-Harmon Engineers, Inc. (HHE)
1081 Dove Run Road, Suite 203
Lexington, Ky. 40502

Hall-Harmon Engineers, Inc. was subcontracted by GRWAS as a WBE. Their responsibilities included:

- The generation of sketches for Control Monument Description Sheets.

ClasSickle, Inc.
4601 Bardstown Road
Louisville, Ky. 40218

ClasSickle, Inc. was subcontracted by GRWAS as a MBE. Their responsibilities included:

- The generation of sketches for Control Monument Description Sheets and reconnaissance.

Chaz Concrete Co., LLC
4121 Alonquin Parkway
Louisville, Ky. 40210

- Chaz Concrete Co, LLC is a MBE and was GRWAS source for ready mix concrete used in monument installation.

PERSONNEL/CAPACITY:

LOJIC:

Curt Bynum: LOJIC GIS coordinator and project administrator.

Frank Fowler PLS – An independent surveyor contracted by LOJIC to provide oversight as described in the Quality Control and Quality Assurance Report.

GRWAS:

Ed Rinehart PLS - Vice President: Project Management, Recon, New monument site selection, Procurement, Monument field sketches/descriptions, Digital photographs of monuments,GPS receiver operation, QA/QC.

Wolfgang Ziegler PLS – GPS Manager: Recon, New monument site selection, GPS Network Design, GPS observation reduction, GPS network adjustment, Database preparation, Report preparation, Computer programming, Monument field sketches/descriptions, Digital photographs of monuments, QA/QC.

John Mickelson PLS, PG – Digital photograph organization, Control monument description sheet preparation, Preparation of network diagrams, GPS observations, Database preparation, QA/QC.

Jeremy Mullins – Program Analyst Specialist: Shape file generation.

Barry Zulauf – GPS Specialist: Recon, New monument site selection, GPS observation party chief, Monument installation party chief, Monument field sketches/descriptions, Digital photographs of monuments, QA/QC.

Jay Abby – GPS receiver operator, Monument installation.

Pat Greene – Equipment Operator, Monument installation, GPS receiver operator.

Malcom Smith – GPS receiver operator, Monument installation.

Ron Redmon – GPS receiver operator, Monument field sketches/descriptions, Digital photographs of monuments, QA/QC.

Don Redmon PLS – GPS field party chief, Monument field sketches/descriptions, Digital photographs of monuments.

Terry Jessie – GPS receiver operator, Monument installation.

Allen Runyon – GPS receiver operator, Monument installation.

Jay Jones – GPS receiver operation, Monument installation.

HHE:

Larry Harmon – Supervisor.

Danny Britt – CADD work on sketches for Control Monument Description Sheets.

Bill McNutt – CADD work on sketches for Control Monument Description Sheets.

ClasSickle:

James Croan PLS – Supervisor.

Edgar Linares LSIT – Supervisor, Recon, CADD work on sketches for Control Monument Reference Sheets.

Benjamin Deetsch LSIT – CADD work on sketches for Control Monument Reference Sheets.

Paul Bridwell – Recon, CADD work on sketches for Control Monument Reference Sheets.

Douglas Johnson – CADD work on sketches for Control Monument Reference Sheets.

Greg McFal – Recon.

ClasSickle personel also collected a small amount of GPS data, tying two pairs of monuments that they installed for the Louisville Metropolitan Sewer District (MSD) at the West County and Morris Forman treatment plants. This data was processed by GRWAS and incorporated in the Phase II network adjustment.

MAJOR EQUIPMENT USED:

TRIMBLE 4000ssi dual frequency GPS receiver # 0263

TRIMBLE 4000ssi dual frequency GPS receiver # 0498

TRIMBLE 4000ssi dual frequency GPS receiver # 9792

TRIMBLE 4000ssi dual frequency GPS receiver # 8405

TRIMBLE 4000ssi dual frequency GPS receiver # 8698

TRIMBLE 4000ssi dual frequency GPS receiver # 3759

TRIMBLE 4700 dual frequency GPS receiver # 3074

TRIMBLE 4800 dual frequency GPS receiver # 7607

WILD NA2000 digital level

TOPCON GTS 300 digital total station

Two Javad dual frequency GPS receivers owned and operated by ClasSickle

Two man auger

Bob Cat with auger attachment

Dingo with auger attachment

SOFTWARE:

Trimble's GPSurvey software suite – GPS observations planning, GPS baseline reduction, Network Adjustment, Loop closures, QA/QC.

AUTODESK'S AUTOCAD – Control Monument Reference Sheet graphics, Monument location & GPS network planning, GPS network diagrams, other miscellaneous graphic tasks.

ESRI's ArcView – Shape file generation.

Adobe's Acrobat – Conversion of various planning and report documents into Adobie's Portable Document Format (PDF).

Microsoft's WORD – Produce this document and other report components.

Microsoft's – EXCEL – Database components and QA/QC checklists.

USACE's CORPSCON – perform conversions between coordinate systems and datums.

Miscellaneous small custom programs produced by GRWAS, used to facilitate the construction of the database, shape file, and Monument Description Sheets.

PRELIMINARY PLANNING:

LOJIC provided GRWAS with a Geo Referenced "Shape File" depicting the locations of known existing monuments in Jefferson County, along with their corresponding reference material, recent monument recovery reports with recommendations for new monument locations, a "Shape File" depicting a two mile grid to be used as a guide in the selection of existing monuments to be used in this project and the selection of new monument locations.

GRWAS imported the above mentioned shape files into an AutoCad drawing along with all NGS horizontal control stations and bench marks in and about Jefferson County, which were extracted from the NGS data base. These materials were used to form a tentative monument location scenario.

RECONNAISSANCE:

Personnel were dispatched in two man teams. Each team consisted of a man from GRWAS and a man from ClasSickle. Each team was equipped with a LOJIC/Jefferson County street atlas, a Jefferson County road map, a set of monument description sheets for the existing monuments, a plot of the planning map depicting the tentative monument locations overlaid on a digital USGS quadrangle map background, and a digital camera.

As existing monuments were recovered and new monument locations were selected, they were staked and marked with survey flagging, spotted on a map, photographed, and hand drawn sketches of the sites were produced. New monument locations where digging posed a potential threat to underground utilities were also noted.

Existing NGS HARN stations and bench marks in and about Jefferson County were also recovered, to be used as project control.

MONUMENTATION:

GRWAS personal were dispatched to install the new monuments. Several different tools were used to dig the holes for the monuments. A two man auger, a skid loader with a auger attachment, a "DINGO" with an auger attachment, and manual "Clam Shell" post hole diggers. The Dingo and the post hole diggers proved to be the most effective tools for digging the holes for the poured in place monuments. Ready mix concrete was either transported to the monument sites using a “Concrete Buggy” or mixed on site by a “Mobile Mix” concrete truck, or transported to the site in bags and mixed by hand on site. All new poured in place monuments are equipped with a 30” long piece of #4 rebar to serve as a magnetic locator to aid in future monument recovery.

A few of the new monuments consist of an aluminum survey disk set in massive concrete structures. In these instances a gasoline powered portable generator with a ½” hammer drill were used to drill a hole into which the disk shaft was epoxied. (See: NEW MONUMENT DESIGN SKETCH.PDF)

NETWORK DESIGN:

Once the new and existing monument locations were finalized, existing NGS HARN stations and benchmarks were selected as project control. Control was selected in a configuration optimized for both horizontal and vertical support of the GPS network(s) and in accordance with the FGCC guidelines (GEOMETRIC GEODETIC ACCURACY STANDARDS AND SPECIFICATIONS FOR USING GPS RELATIVE POSITIONING TECHNIQUES, FEDERAL GEODETIC CONTROL COMMITTEE, V.5.0, August 1, 1989) with sufficient redundancy to allow for control quality evaluation and blunder detection. (See: DESCRIPTION SHEETS FOR NGS CONTROL USED IN THIS PROJECT.PDF)

The project was broken into two phases. Phase I largely consisted of existing NGS horizontal and vertical control and was designed to evaluate the existing control, independent of the new and existing monuments to be controlled. Phase II is tied to Phase I and was designed to establish GPS positions and elevations for the new and existing monuments to be controlled. (See: PHASE I NETWORK DIAGRAM.PDF, PHASE II NETWORK DIAGRAM.PDF, and FINAL OBSERVATION SCHEDULE AS OBSERVED.PDF)

Where existing NGS benchmarks could not be directly occupied; a temporary eccentric point was set at a nearby occupiable location. Conventional differential leveling techniques were used to transfer an elevation from the benchmark to the eccentric point. (See: CONVENTIONAL DIFFERENTIAL LEVELING REDUCTION & ADJUSTMENT.PDF)

In one instance (GPS86-43) a suitable location for an azimuth monument (Buddy) could not be found. A GPS occupiable temporary point was set and controlled as a part of the network. It was later used as an azimuth mark in determining a direction to a physical feature azimuth mark (Cupola). (See: CONVENTIONAL HORIZONTAL COMPUTATIONS.PDF)

DATA PROCESSING, QUALITY CONTROL, & QUALITY ASSURANCE:

The GPS data was processed on a daily basis as it was collected.

After the field collected observation data was transferred from the GPS receivers to the computer (downloaded), it was “checked into” GPSurvey. During this process, the occupation start/stop times, operator entered station name, autonomous position, and operator entered antenna height were examined and evaluated. Two common blunders, mis-keyed station name and/or antenna height were detected during this operation, by comparing the entered data to the observation schedule and the observation log sheet that the receiver operators filled out for each observation.

The data was then processed (differentially corrected) using Trimble’s WAVE baseline processing module. Four key pieces of information were generated during this process. The integer ratios, reference variances, satellite phase tracking summaries, and residual plots all of which provided an indication of the quality of the corrected baselines. The tracking summaries graphically depicted which satellite signals were being received at each receiver and if signal blockage occurred. This aided the data processor in determining if enough data was available to successfully process the baseline. The residual plots provided a graphic display of the residuals for each satellite, allowing the detection of multipath and/or ionospheric disturbances. The integer ratio provided an indication of how likely the software computed the correct set of integers when resolving the integer ambiguity (number of full carrier wave cycles between the satellite and the receiving antenna). The reference variance provided a statistical indication of how much variance there was in the baseline solution. Together these indicators gave the GPS data processor an indication of the quality of each baseline (flagged potentially troublesome baselines). In some instances a weak solution may have been be improved by adjusting the processing parameters and reprocessing the data.

The next step in the data analysis process involved connecting baselines (vectors) together, head-to-tail, forming closed loops of independently observed baselines (much like a closed traverse). This was performed using Trimble’s loop closure utility. In these well-conditioned networks, defective baselines were thus detected and isolated. Where sufficient redundancy existed in the networks, defective baselines were simply discarded; otherwise they were re-observed.

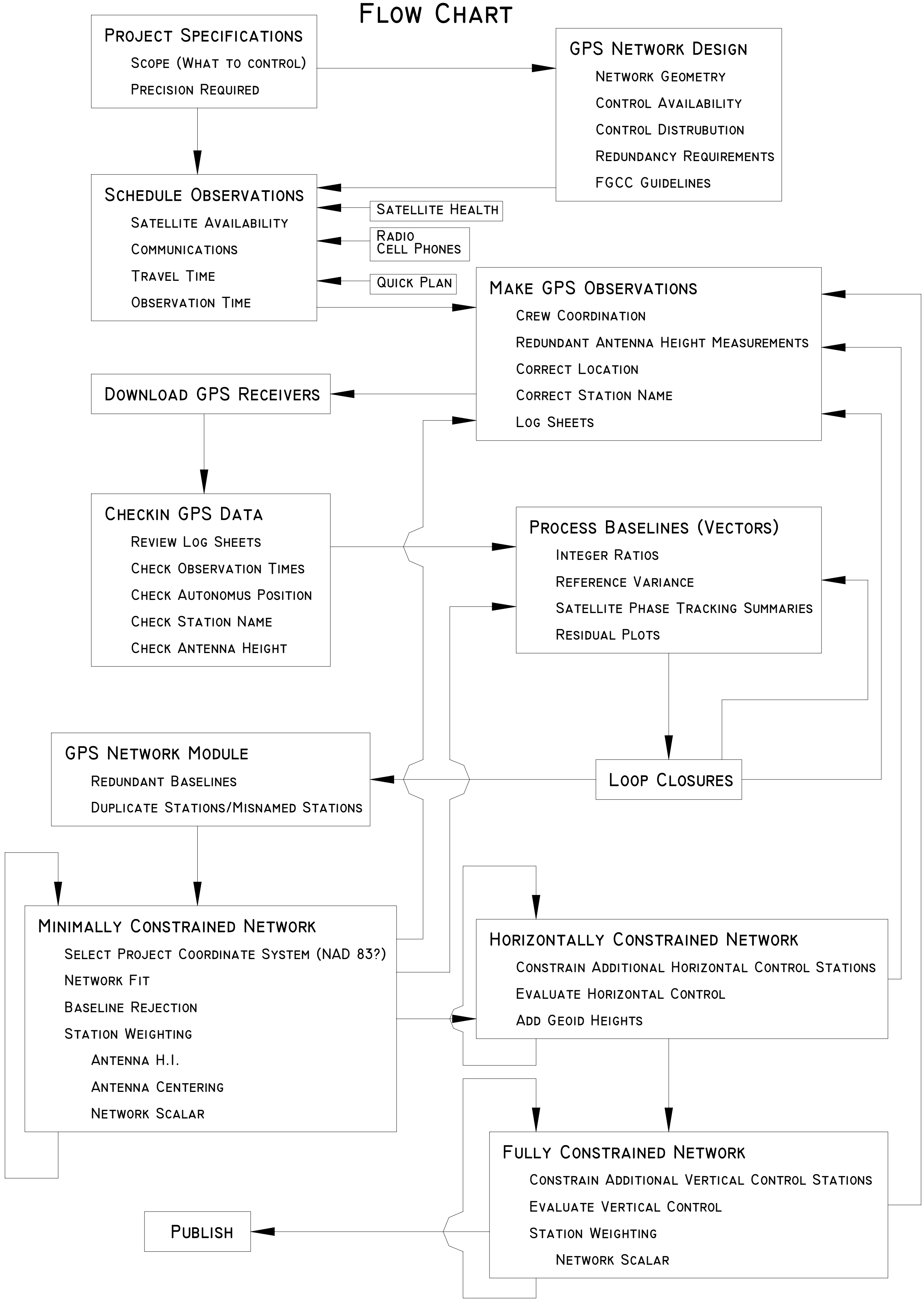
After the above-described preliminary data screening, the baselines were imported into Trimble’s network adjustment module TRIMNET. Here, tools for the comparison of redundant baselines and the detection of duplicate stations (misnamed points) were used to further screen the data and detect blunders. Up to this point all coordinate data was expressed either in ECEF (Earth Centered Earth Fixed) or WGS 84 (latitude & longitude). At this point the project coordinate system was selected (NAD 83 Ky. S.P.C.S. North Zone HARN). Next a single point with known horizontal coordinates and ellipsoidal height was held fixed and minimally constrained least squares adjustment were performed. This gave an indication of how well all the baselines fit together within the networks, independent of the rest of the control. Several iterations of the adjustments were performed. After each iteration; the results were evaluated; miss-fitting baselines were reprocessed, rejected, or re-observed. The networks weights were also adjusted (H.I.

measuring error, antenna centering error, & network scalar) until acceptable solutions were obtained.

Once acceptable minimally constrained adjustments were obtained, geoid heights were interpolated (using Trimble's GEOID module) and incorporated into the networks. Additional horizontal control stations were then constrained and adjusted iteratively. This gave an indication of how well the existing horizontal control fit the GPS data. Historically (before the existence of the HARN system) the quality of the GPS data was far better than the available existing control. However, when tying a GPS network to HARN monuments the fit is generally very good.

Once acceptable horizontally constrained networks were achieved, additional vertical control was iteratively added into the adjustments. Again network/control fit was examined and network weights were adjusted until acceptable fully constrained solutions were achieved.

GPS Data Processing
Quality Control/Quality Assurance
Flow Chart



RESULTS:

Phase I:

All loop closures < 1ppm. (See: PHASE 1 LOOP CLOSURES.PDF)

Several adjustment scenarios were performed along with loop closure evaluation during the adjustment process. Three adjustment reports were included as support documents: a minimally constrained, partially constrained, and a fully constrained network. (See: PHASE 1 MINIMALLY CONSTRAINED NETWORK ASJUSTMENT REPORT.PDF, PHASE 1 PARTIALLY CONSTRAINED NETWORK ADJUSTMENT REPORT.PDF, and PHASE 1 FULLY CONSTRAINED NETWORK ADJUSTMENT REPORT.PDF)

In the minimally constrained adjustment I64 L 21 was held fixed both horizontally and vertically (ellipsoid height). The weighting scheme used was 0.001 meters horizontally and 0.001 meters vertically with a scalar of 5.25. The summary of covariances indicated a 3d level of precision much better than the required precision of 1:100,000 (10ppm). The error ellipses indicated a 3d relative positional accuracy of ±0.01 meters.

In the partially constrained adjustment geoid heights were added (GEOID 99) and EDWARD 2 and I64 L 21 were held horizontally fixed while 489.78 ECC, EDWARD 2, I64 L 21, and J 334 ECC were held vertically fixed (orthometric heights). The weighting scheme used was 0.003 meters horizontally and 0.008 meters vertically with a scalar of 4.05 and a geoid model scalar of 0.38. The summary of covariances again indicated a 3d level of precision much better than the required 1:100,000. The error ellipses indicated a horizontal relative positional accuracy of ±0.01 meters and ±0.03 meters vertically (orthometric). The observation adjustment showed acceptable rotations (<1.0seconds) and scale.

In the fully constrained adjustment EDWARD 2, HORRODS, I64 L 21, KY 05, KY 13, LOUISVILLE 1 CORS, LOUISVILLE SOUTH BASE RESET, SDF A, SDF E, and SNOW RMA were held horizontally fixed. 31 K ECC, 489.78 ECC, BOWMAN RESET, EDWARD 2,GOSHEN RM 1, H 232 ECC, I64 L 21, J 334 ECC, and X 349 were held vertically fixed (orthometric). The weighting scheme used was 0.003 meters horizontally and 0.008 meters vertically with a scalar of 4.76 and a geoid model scalar of 0.22. The summary of covariances again indicated a 3d level of precision much better than the required 1:100,000. The error ellipses were of the same order of magnitude as those in the partially constrained adjustment . The observation adjustment showed a small improvement in the rotations and scale.

Two coordinate comparison charts were prepared, the first compared the coordinate components (North, East, ellipsoid height) of the minimally constrained adjustment to the fully constrained adjustment; the second compared the partially constrained coordinate components (North, East, orthometric height) to the fully constrained adjustment. In the first, the largest horizontal difference was 0.01 meters with an average of North = 0.001 meters and East = 0.005 meters and the largest difference in ellipsoid height = 0.041

meters with an average of 0.027 meters. In the second comparison, the largest horizontal difference was 0.019 meters with an average of North = 0.006 meters and East = 0.005 meters the largest difference in orthometric height was 0.041 meters with an average of 0.003 meters. (See: PHASE 1 COORDINATE COMPARISON FULL–MIN WITH EHT.PDF and PHASE I COORDINATE COMPARISON FULL–PARTIAL WITH OHT.PDF)

These results were deemed satisfactory, none of the existing control was rejected.

Phase II:

All loop closures < 5ppm. (See: PHASE 2 LOOP CLOSURES.PDF)

Again several adjustment scenarios were performed along with loop closure evaluation during the adjustment process. Three adjustment reports were included as support documents: a minimally constrained, partially constrained, and a fully constrained network. (See: PHASE 2 MINIMALLY CONSTRAINED NETWORK ADJUSTMENT REPORT.PDF, PHASE 2 PARTIALLY CONSTRAINED NETWORK ADJUSTMENT REPORT.PDF, and PHASE 2 FULLY CONSTRAINED NETWORK ADJUSTMENT REPORT.PDF)

In the minimally constrained adjustment I64 L 21 was held fixed both horizontally and vertically (ellipsoid height). The weighting scheme used was 0.004 meters horizontally and 0.004 meters vertically with a scalar of 1.58. The summary of covariances indicated an overall 3d level of precision much better than the required precision of 1:100,000 (10ppm) . The error ellipses indicated a horizontal relative positional accuracy of ±0.02 meters with a relative vertical accuracy of ±0.01 meters.

In the partially constrained adjustment geoid heights were added (GEOID 99) and 489.78 ECC, BOWMAN RESET, EDWARD 2, I64 L 21, and J 334 ECC were held fixed both horizontally and vertically (orthometric heights). The weighting scheme used was 0.004 meters horizontally and 0.004 meters vertically with a scalar of 1.48 and a geoid model scalar of 0.74. The summary of covariances again indicated an overall 3d level of precision much better than the required 1:100,000. The error ellipses indicated a 3d (orthometric heights) relative positional accuracy of ±0.02 meters. The observation adjustment showed acceptable rotations (<1.0seconds) and scale.

In the fully constrained adjustment,31 K ECC,489.78 ECC, BOWMAN RESET,EDWARD 2,GOSHEN RM 1, H 323 ECC, I64 L 21, J 334 ECC,KY 05,LOUISVILLE SOUTH BASE RESET, SDF A, X 349, were held horizontally and vertically (orthometric height) fixed. The weighting scheme used was 0.004 meters horizontally and 0.004 meters vertically with a scalar of 1.57 and a geoid model scalar of 0.69. The summary of covariances again indicated an overall 3d level of precision much better than the required 1:100,000. The error ellipses were of the same order of magnitude as those in the partially constrained adjustment . The observation adjustment showed a small improvement in the rotations and scale.

Again two coordinate comparison charts were prepared, the first compared the coordinate components (North, East, ellipsoid height) of the minimally constrained adjustment to the fully constrained adjustment, the second compared the partially constrained coordinate components (North, East, orthometric height) to the fully constrained adjustment. In the first, the largest horizontal difference was 0.076 meters with an average of North = 0.005 meters and East = 0.033 meters and the largest difference in ellipsoid height = 0.005 meters with an average of 0.001 meters. In the second comparison, the largest horizontal difference was 0.027 meters with an average of North = 0.003 meters and East = 0.003 meters the largest difference in orthometric height was 0.063 meters with an average of 0.010 meters. (See: PHASE 2 COORDINATE COMPARISON FULL–MIN WITH EHT.PDF and PHASE 2 COORDINATE COMPARISON FULL–PARTIAL WITH OHT.PDF)

These results were deemed satisfactory.

COMMENTS:

The NAVSTAR Global Positioning System (GPS) and the GPS surveying techniques used in this survey are 3 dimensional in nature. In theory it should be possible to obtain ellipsoid heights at a precision comparable to the horizontal positions obtained using GPS surveying techniques. In practice however, the error observed in heights are generally on the order of twice those observed in horizontal position. In addition, conventional differential spirit leveling techniques historically used for vertical control surveys are performed in a creeping manner along the surface of the earth and follow the undulations of the geoid (surface of equipotential gravity, generally refered to as mean sea level). GPS surveys are not performed in a creeping manner and must rely on a gravity model (GEOID 99 in this project) to interpolate the geoid/ellipsoid separation at any given point. The accuracy and density of the geoid model used, in the vicinity of any GPS survey, is a nontrivial component in the determination of orthometric heights. (See: GEOID 99 INTERPOLATION OF GEOID HEIGHTS.PDF)

An examination of a map of the GEOID 99 geoid model used in this project indicates an irregularity of slope in the vicinity of this project. The quality of the orthometric heights (elevations) produced by network adjustments is limited to the accuracy of the underlying geoid model. (See: GEOID 99 MAP.PDF)

A well conditioned network with a sufficient number of well distributed bench marks is critical in the development of good elevations using GPS surveying techniques. The networks employed in this project are possessed of the necessary qualities to promote accurate usable elevations of a reasonably uniform nature. In some instances they may be superior to those that may have been developed using conventional surveying techniques.

The elevations produced by this survey should not be classified in the same manner as the horizontal coordinates. It is the opinion of the surveyor in charge of the design and computations for this survey that horizontally it meets or exceeds the design criteria of

1:100,000 (First Order). The elevations should not be considered “First Order” but referred to simply as “GPS”.

In examining the summary of covariances in the Phase II network adjustments, all baselines do not report a precision ratio greater than 1:100,000. This is due to the shortness of these baselines (typically azimuth/buddy pairs). The manufacturer’s precision specifications for the GPS receivers used in this project are horizontal 5mm + 1ppm and vertical 10mm + 1ppm. For extremely short lines, the base error may exceed the design criteria (in this case 1:100,000). This is sometimes unavoidable. The covariances for this project as a whole, along with loop closures indicate an overall level of precision in excess of 1:100,000.

After both GPS network adjustments were completed, CORPSCON was used to convert all monument coordinates from NAD 83 Ky. S.P.C.S. North Zone (1601)/NAVD 88 to GRS 80, NAD 27/NGVD 29, and UTM Zone 16. (See: CORPSCON CONVERSION TO GRS 80.PDF, CORPSCON CONVERSION TO NAD 27 & NGVD 29.PDF, and CORPSCON CONVERSION TO UTM.PDF)