Tropical Storm Allison Recovery
DR-1379 Harris County, Texas

Benchmark Control Network

Technical Report

Luce Bayou, Armand Bayou, Cedar Bayou, Clear Creek, Jackson Bayou, San Jacinto River, Galveston and Spring Gully/Goose Creek

September 2002 - June 2003

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Baseline Corporation would like to give you all a profound and grateful thank you.

J. Patrick Going R.P.L.S.,
Executive Vice President
Baseline Corporation
Houston, Texas
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1. Introduction

This project was performed under a contract between Harris County Flood Control District (HCFCD) and Baseline Corporation. The purpose of this project was to perform a survey of a large network of benchmarks known as Reference Marks (RMs) to be incorporated into the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) program, which is being updated by HCFCD. Baseline Corporation was assigned the watersheds of Cedar Bayou, Luce Bayou, Armand Bayou, Clear Creek, Jackson Bayou, San Jacinto River, Galveston Bay and Spring Gully/Goose Creek. All RMs, which will be shown on the new FIRM that fall within these watersheds, were a part of this survey. The survey work, including all reconnaissance, documentation, GPS observation, leveling data processing, support and office work, was performed from September 2002 to May 2003.

2. General requirements for the Control

All of the bayous, creeks, bays, streams, and major drainage channels within Harris County's 22 watersheds were surveyed for HCFCD by other firms in 2001 and 2002. Those surveys were tied in to existing permanent benchmarks, or, where no mark existed, temporary benchmarks, which were set on site. This survey had to include all of the existing permanent and temporary benchmarks, which were used for the channel surveys. Where no permanent benchmark existed, a new one had to be set. The spacing requirements were generally one monument (either existing or new) for every mile along the main stem of studied streams, and two monuments per FIRM panel.

2.1. Project Standards

This survey was to be performed as much as possible with GPS. The NGS 2-cm standard, as published in NOAA Technical Memorandum NOS NGS-58 dated November 1997, was therefore chosen as the project's vertical surveying standard. It is not intended that the data be submitted to NGS for "Blue Book" processing. The horizontal standard that was chosen was the NGS Second Order Class I standard as published in the Federal Geodetic Control Committee (FGCC) document entitled "Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques" dated August 1, 1989. In areas where it is impossible to use GPS due to conditions such as obstructed sky visibility, precise differential leveling will be performed to connect such obstructed benchmarks to the rest of the network. The NGS Second Order Class II vertical standard for leveling, as published in the FGCC document entitled "Standards and Specifications for Geodetic Control Networks" dated September 1984, was chosen for such work. All of the above referenced standards were substantially complied with throughout the execution of this project.

2.2. Categories of Benchmarks

There were five types of Benchmarks involved in this project. They have been established by different agencies in the course of survey for Federal Emergency Management Agency (FEMA) or Harris County Flood Control District (HCFCD), National Geodetic Survey (NGS), US

Geological Survey (USGS), Texas Department of Transportation (TxDoT), US Army CORPS of Engineers, City of Houston (COH).
All these Benchmarks being categorized as follows

Existing permanent Benchmark used by TSARP IDIQ
New Benchmarks
Releveled Existing Benchmarks
HGCSD (Existing NGS Control)
New Benchmarks in the vicinity of temporary IDIQ RM's

2.3. Existing Permanent Benchmark used by TSARP IDIQ

Existing Permanent Benchmarks that were established by the different agencies, TSARP IDIQ had releveled them in past years. Most of these Existing Permanent Benchmarks did not have the detailed information of their location or sketches. In this project, Baseline Corporation found most of these Existing Permanent Benchmarks and described them in detail and releveled them as required.

2.4. New Benchmarks

Using TSARP management guidance and instructions new Benchmarks have been established near to the Watershed considering the suitability for GPS observation, stability and accessibility to the station. There were two types of monuments used in this project. They were Brass Disks marked "Flood Plain Reference Mark, Est. 2002" and stamped with "TSARP RM number" and modified type "A" monument with TSARP RM number stamped on the ring of the top cover. All of these monuments have been described in detail and leveled in this project.

2.5. Releveled Existing Benchmarks

The benchmarks established by different agencies and used in the past have been identified and described with details. Some of them did not have proper location details and stamp information. Considering the suitability for GPS observation, stability and accessibility these Existing Benchmarks have been included in the new Benchmark Network and re-leveled.

2.6. HGCSD (Existing NGS Control)

Even though subsidence affected the elevation of some of the existing HGCSD (existing NGS control) stations, computations show they are stable in horizontal position. Therefore, these HGCSD monument horizontal coordinates have been used for horizontal control in the Benchmark Network.

2.7. New Benchmarks in the vicinity of temporary TSARP IDIQ RM's

Some of the Benchmarks provided by TSARP, included in this project, were established in the past and named "temporary TSARP IDIQ RM". The type of monument set for these temporary TSARP IDIQ RMs were not of uniform standard. Some of them were "X" marks on a concrete structure or 5/8" iron rod set in the ground. Therefore, considering the instant standards and field procedures, new Benchmarks have been established at a nearby location without destroying or

disturbing the old temporary marks. Procedures for description preparation and establishing its position were the same as new Benchmarks.

3. Surveyor's Certification

I, J. Patrick Going, a Registered Professional Land Surveyor in the State of Texas, do hereby certify that the surveying work reported herein was performed under my direct supervision.

_____ date_____

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4. Chronological Summary of Field Operations

The reconnaissance and monumentation were completed between September 27, 2002 and January 24, 2003. GPS observations were completed between January 27, 2002, and April 17, 2003. Armand Bayou was surveyed first, and followed by Luce Bayou, Clear Creek, Jackson Bayou, San Jacinto River, Galveston Bay and Spring Gully/Goose Creek. Some overlapping of surveying between watersheds occurred when tying to nearest existing control monuments.

In general, terms the tasks to be performed were as follows:

- Reconnaissance of existing or proposed sites. Included tasks are detail sketch, route sketch, to reach description, obstruction diagram, photos, and rubbings.
- Construction of new monuments (Brass Disk or Aluminum Rod).
- GPS observations.

4.1. Benchmark construction

The reconnaissance, description preparation and construction of TSARP proposed locations for new Benchmarks was completed during the period of September 27, 2002 and January 24, 2003. Cedar Bayou was the first one started for reconnaissance, followed by Luce Bayou, Armand Bayou, Clear Creek, Jackson Bayou, San Jacinto River, Galveston Bay and Spring Gully/Goose Creek. Some locations had to be changed or deleted after considering the following factors.

(a) GPS observability
(b) Accessibility
(c) Stability and
(d) Cost for Monumentation

4.2. Existing Benchmark

Reconnaissance and description preparation of Existing Benchmarks was completed during the above mentioned period of Sept. 27, 2002 thru January 24, 2003. A minimum of two Survey Crews were involved in this task, starting with Cedar Bayou and followed by Luce Bayou, Armand Bayou, Clear Creek, Jackson Bayou, San Jacinto River, Galveston Bay and Spring / Goose Creek Watersheds.

4.3. Survey Control Basis

The survey control points, which were to be used as a basis for all of the surveying performed for this project, were the Harris Galveston Coastal Subsidence District (HGCSD) monuments that were last surveyed in 2000 and published by the National Geodetic Survey (NGS) in the latter part of 2001. These points were First Order or better horizontal control stations, with orthometric heights determined using GPS and the GEOID99 geoid model. In addition to the HGCSD monuments, Continuously Operating Reference Stations (CORS) operated by NGS, and the HGCSD "Port-a-Measure" units (PAMs) were also tied in to the network. During the course of this project, it became apparent that most of the HGCSD 2000 benchmarks had been affected in a vertical direction and in varying amounts by subsidence, and we were therefore unable to hold their elevations in the final network adjustments.

4.3.1. CORS station data

NETP (North East Treatment Plant) CORS station and LKHU (Lake Houston) CORS station coordinates (2001 adjustment 1997 epoch) have been held horizontally and NETP CORS published ellipsoidal height has been held vertically for the Primary Network adjustment.

Station Name	PID	Geodetic Coordinates Latitude	Longitude	Ellipsoid Height
NETP	AJ6430	29 47 28.14234 N	095 20 03.16582 W	-30.249 US feet
LKHU	AF9521	29 54 48.43963 N	095 08 44.68952 W	-not used-

4.3.2. PAM station data

PAM stations near the project area also were used to tie in the Primary Network and the Benchmark Network. After careful consideration of differences shown in the preliminary results and subsidence, some PAM stations were removed from the Benchmark Network to avoid the influence from their difference in elevations.

4.3.3. HGCSD station data

HGCSD stations in the project area have been included in this project and the final adjusted horizontal coordinates have been checked with the published NGS values (2001 adjustment 1997

epoch). After considering their differences, the published NGS (2001 adjustment 1997 epoch) data for HGCSD control stations and the above mentioned CORS stations data were used to constrain the Benchmark Network.

5. Project planning

Planning is the most important part of the performance of a control survey utilizing GPS survey technique. It gives the confidence of quality of data, results and assures the achievement of project goals.

6. Field Survey narrative

The major tasks associated with this project were the field survey, including; reconnaissance, monumentation, and GPS observation. As the proposed monuments needed to satisfy certain criteria and conditions, this task took a considerable level of effort to complete. For various reasons some monuments had to be re-located from their planned position, modified as to monument type, or deleted from the system all together.

GPS observations have been performed according to the 2cm standard published in NOAA Technical Memorandum NOS NGS-58 dated November 1997.

6.1. Reconnaissance

All of the Benchmarks provided by TSARP have been visited and identified except Benchmarks which were destroyed. As a result all of the new descriptions of existing Benchmarks have a new location sketch, key map page, to reach description and stamping data. Additionally, rubbing was performed for quality assurance/quality control (QA/QC) for every existing Benchmark to counter check their identification by examining stamping if available. Also after setting new monuments, their descriptions have been prepared accordingly.

6.2. One-call for new monuments

Prior to setting any modified “A” type monuments in the ground, the location was marked by a stake and Texas “one-call” was notified. They responded with a fax showing clearance or the conflict with a utility. After coordinating with the different agencies involved this task was completed without any conflict. If there was any conflict with property owners or utility companies the location of the monument was relocated to a suitable and secure location, or deleted with TSARP program manager’s prior permission.

6.3. Monument setting

Benchmark stability was a prime consideration in the selection of new benchmark sites and the type of construction materials used. The initial approximate locations for all new benchmarks were provided by the TSARP program managers. If a substantial reinforced concrete structure such as a bridge was available in the vicinity of the selected location, a brass disk was set in a drilled hole in the concrete and fastened with epoxy. If no such structure of a substantial nature

was available, an aluminum rod was driven into the ground to refusal or a minimum depth of 24 feet. The monument was surrounded at the top three feet with a greased sleeve and 6 inches of sand, with 12-inch diameter concrete around the outside and a metal protective cover over the top. For reasons of economy, the disk in concrete option was used wherever possible, and in some cases, benchmark locations were moved as much as one-half mile in order to utilize an appropriate structure. In such cases, the moves were approved by the TSARP program managers.

6.4. GPS observations

GPS observations contain five segments as follows.

Network diagrams
Mission planning
Schedule of observation
Obstructions and re-scheduling
Additional observations

6.4.1 Network diagrams

Network diagrams have been prepared for all existing and new Benchmarks, and with HGCSD control stations in this project area. The diagram shows the baseline connections with HGCSD stations, as well as any nearby Benchmarks. This baseline connection satisfied the criteria for GPS field procedures and standards for this project.

6.4.2 Mission planning

The following described issues regarding GPS Satellites were considered before and during the course of survey. Those were GPS Satellite Health, Satellite Constellation, Satellite Geometry and Geometric Dilution of Precision (GDOP) using manufacturer (Leica) software, based on the latest GPS data and station recovery information. Mission planning was performed.

6.4.3 Schedule of observation

Considering the accessibility of the stations, connectivity, and satellite constellation the daily schedule of GPS observation was prepared. A special format of schedules includes all the receiver, antenna, and controller information, support-contacting information, monument occupation details, and if needed, modification from a 2.0m fixed pole to a 0.2m fixed pole bridge bracket. Also a 5 to 15 minute tolerance was added to the traveling time to preclude deviation from the schedule.

6.4.4 Obstructions and re-schedule

Occasionally un-avoidable circumstances and unpredicted satellite information would inhibit pre-scheduling. Crews would then be rescheduled on a case-by-case basis.

6.4.5 Additional observations

After baseline computations were completed, some identified un-resolved baselines had to be re-scheduled for additional observations.

6.5. Differential leveling

In a few instances, it was necessary to use differential leveling procedures. Some of the TSARP RMs were unable to be resolved in the GPS processing. In those cases, closed loop differential levels were run from the nearest RM point to the specific RM point and back. Differential levels were run using Digital level and bar-coded staff. All of the levels that were used are models that are approved by the FGCC for Second Order differential leveling work. In such cases, these RMs have not been included in the Benchmark Control Network adjustment. The horizontal position of these RMs is only provided to nearest one foot.

7. Data processing narrative

Data processing mainly contains seven segments as follows,

Check and edit raw data
Import to GPS project
Baseline computation
Analysis of baseline results
Minimal constrained adjustment and analysis
Fully constrained adjustment and analysis
Coordinate output files

7.1 Check and edit raw data

Observation data has been checked with the schedule, log, and rubbing sheet for quality control of the data. In addition, edits were performed where needed, such as antenna types, height, or station ID.

7.2 Import to GPS project

Edited and corrected data has been imported to the GPS project database. Because this project uses NGS CORS station data all the antenna manufacturer designations have been changed to NGS defined antenna designations in order to process the data.

7.3 Baseline computation

A user defined set of parameters was used for baseline computation, and instead of broadcast ephemeris, the precise ephemeris was used for all baseline computations. For solution type “ionospheric free fixed” solution type was used and “automatic model” was selected as a model. Additionally 10 Km distance medium activity stochastic modeling was used for every baseline computation. Most of the other parameters used are shown as default parameters.

7.4 Analysis of baseline results

Only baselines with the ambiguity resolved have been used for adjustment of computations. No baseline was resolved by increasing cut-off angle of disabling satellites or increasing Root Mean Square (RMS) threshold value in the event the baselines were not resolved with the selected parameters. "Individual baseline processing" has been done in some cases, such as selecting only the stations involved for un-resolved baseline vectors. Un-resolved baselines were re-scheduled for re-observation. After analyzing the position quality, height quality and standard deviation of the baseline vectors resolved baselines were stored for adjustment.

7.5 Minimal constrained adjustment

Holding NETP (North East Treatment Plant) CORS station Geodetic coordinates and published ellipsoid height (2001 adjustment 1997 epoch: 29 47 28.14234 N 095 20 03.16582 W -30.249 US feet) minimally constrained adjustment were computed for the Primary Network, as well as Benchmark Network. The results have been checked with existing LKHU(Lake Houston)CORS station, HGCSD as well as PAM stations published coordinates.

7.6 Fully constrained adjustment

The results from the minimally constrained adjustment and comparing the measured and published coordinates of CORS, HGCSD, and PAM stations, a fully constrained adjustment has been prepared holding NETP CORS in three dimensional (3D) and LKHU, other HGCSD, and PAM stations in two dimensional (2D). The results have been analyzed with 95 % confidence level precision, F-test adjusted observation standard deviation(sd) and baseline vector residual ppm (parts per million) values.

7.7 Coordinate output files

Adjusted WGS Geodetic coordinates have been converted to State Plane Coordinates (SPC) Texas South Central Zone, in US survey feet. Computed geiod height and orthometric height using Geiod99 and scale factors from Leica user defined file transfer format also provided an output file.

8. Analysis of results of control survey

Baseline Corporation, as well as two other surveying firms contracted for this project performed minimally constrained adjustments based on the most centrally located CORS extensometer site, NETP (North East Treatment Plant). The three survey companies compared their minimally constrained results and found that two or more companies tied the existing control station, the difference of that common station's position matched very closely. Horizontally 24 of 31 common stations matched within 0.02 feet, and none exceeded 0.035 feet. Vertically 24 of 31 common stations (ellipsoid heights) matched within 0.04 feet, and none exceeded 0.083 feet. The average difference between two companies' positions was 0.01 feet horizontally and 0.02 feet vertically. This indicated a high level of consistency in survey quality throughout the network and across all three firms.

Comparisons were made between the existing control stations published values from adjustment 2001 data and the measured values from this survey's minimally constrained adjustment. Horizontally the average difference was 0.03 feet. 84 of 111 stations matched horizontally within 0.05 feet, and virtually all of the control station positions, relative to its closest neighboring control station, matched within the tolerance for NGS 1st-Order Specifications.

Vertically the differences between published ellipsoid heights from Adjustment 2001 and this survey's measured values were much higher. They averaged -0.13 feet and ranged from an apparent rise of 0.20 feet to an apparent subsidence of 0.48 feet. The majority of the marks were found to be lower in 2003 than in 2000 relative to the one extensometer benchmark held in the minimally constrained adjustment. It became apparent that most of the HGCSD 2000 benchmarks and PAMs had been affected in a vertical direction and in varying amounts by subsidence, and we were therefore unable to hold their elevations in the final network adjustments.

Based on the above analysis, the three survey firms agreed as to how the network should be finally constrained. The recommendations were presented to the TSARP program managers and accepted. A summary of the final network constraints are as follows:

8.1. Minimally constrained control station comparisons

The results have been compared with existing LKHU (Lake Houston) CORS station, and HGCSD stations, as well as PAM station published coordinates after a minimally constrained adjustment was prepared for the Primary Network, as well as the Benchmark Network by fixing NETP (North East Treatment Plant) CORS station Geodetic coordinates and published ellipsoid height (2001 adjustment 1997.00 Epoch: 29 47 28.14234 N 095 20 03.16582 W -30.249 US feet).

8.2. Fully constrained control station comparisons

After careful analysis of the results from the minimally constrained adjustment and comparison between the measured and published coordinates of CORS, HGCSD and PAM stations, a fully constrained adjustment has been prepared holding NETP CORS in three dimensional (3D) and LKHU, other HGCSD and PAM stations in two dimensional (2D). The results have been analyzed with 95% confidence level precision , F-test and adjusted observation standard deviation(sd) and baseline vector residual ppm (parts per million) values.

9. Horizontal constraints

It was agreed that most or all of the 2001 adjustment control that was surveyed for the TSARP project matches within the 1st-Order tolerance (1:100,000) and could therefore be held in the final adjustment. The recommended method for determining whether this is true for any given point will be as follows:

For a given point A, determine the distance to the closest control point B. Calculate the combined 2-d positional difference for the two points. Calculate the maximum allowable difference for line AB (distance AB x .00001). If the combined difference is less than the

maximum allowed, the baseline passes the test and the published value of point A may be held. For example, given a line AB which is 15,000 feet long; Point A's delta N = -0.05 feet and delta E = 0.04 feet; Point B's delta N = 0.03 feet and delta E = - 0.02 feet. The combined differences are delta N = 0.08 feet and delta E = 0.06 feet and the 2-d difference = 0.10 feet. The maximum allowable difference = 0.15 feet and point A can therefore be held in the final adjustment.

The metadata will contain the following reference regarding horizontal control: "Unit of measure is the U. S. Survey Foot. Horizontal positions are referenced to NAD83, Adjusment 2001, 1997.00 Epoch. Coordinates are referenced to the Texas State Plane Coordinates South Central Zone. Positions obtained using GPS substantially conform to NGS Second Order Class I Specifications."

10. Vertical constraints

It was agreed that, because of subsidence in varying amounts over the approximate 2.5 years that have elapsed between the two surveys, all of the adjustment 2001 benchmarks couldn't be held. After further discussion, it was concluded that even holding a few benchmarks might introduce distortions in the network that would be undesirable, especially at the outer fringes of the network. It was therefore agreed that a minimally constrained adjustment in the vertical component would be performed, holding the ellipsoid height of the CORS station at Northeast Treatment Plant (NETP – PID AJ6430), based on the 1997.00 Epoch. The differences due to subsidence between the TSARP channel surveys in 2001 and the TSARP control survey in 2002-2003 will be about half of the subsidence rates seen since October 2000 and in general should not exceed about 0.20 feet.

Orthometric heights of all benchmarks were determined using a two-step process. First, the ellipsoid heights were converted to orthometric heights using the GEOID99 model. Then all elevations throughout the network were vertically translated by an additional amount, a single constant value for the entire network, in order to bring the orthometric height at NETP up to the published value. This constant is necessary to account for the fact that NGS ellipsoid and geoid heights do not directly correlate mathematically to NGS published orthometric heights. The constant needed to bring the orthometric heights up to the published value at NETP is 0.253 feet.

The metadata will contain the following reference regarding vertical control: "Elevations are referenced to the NAVD88 2001 adjustment based on the published elevation at NORTHEAST 2250 CORS ARP (PID AJ6430), 1997.00 Epoch. Elevations obtained by GPS substantially conform to the NGS 2 cm Standard."

11. Subsidence

The Harris Galveston Coastal Subsidence District (HGCSD)'s observed height changes at their PAM sites are in close agreement with the delta-elevations seen in the results of the TSARP control survey. It may be inferred that the delta-elevations seen by TSARP surveys at other adjustment 2001 benchmarks are also representative of subsidence in the vicinity of those other benchmarks. A model has been developed from this data, using the delta-elevations observed at all control stations of Stability Order A or B, that shows the Approximate Rate of Subsidence (AROS) for any given area within the network. The AROS value will be calculated for each RM

based on this model and provided in the database. As benchmarks continue to move, this data could be used in later years to reconcile differences in benchmark height observations.

12. Final station positions summery listing

The ultimate goal of this project was to develop newly updated FIRMs and Reference Marks in a digital format, which could be accessed through the Internet. Therefore all of the Benchmark control datasheets containing locative and positional data have been provided in Microsoft word format (doc) and Acrobat reader (Adobe pdf) formats. Additional submittals of technical reports and benchmark comparisons, as described elsewhere in this document, have also been submitted in digital formats. Results from fully constrained adjustments final database.xls file and comparison of existing Benchmark positions also included. Harris County Geodetic Control Stations page 1 and 2 contains their geo-reference data as well as other necessary information such as type of monument, and detail sketch, etc.

13. Personnel

The project was started in September 2002, and Baseline Corporation assigned three-survey crews on a fulltime basis for reconnaissance and setting of disks, as well as setting stakes for preliminary location of modified "A" type monuments. After reconnaissance and "one call" was completed, two four men survey crews were utilized to set modified "A" monuments.

Seven one-man survey crews were engaged in GPS observation during the last week of January through the first week of April 2003. In addition, a fulltime Field supervisor worked on this project in the course of GPS observation for trouble shooting and helping advise in various situations.

Two office technicians were involved fulltime, a GPS/GIS Department Manager and a Survey Technician, along with two additional technicians were involved from time-to-time during the project period to investigate data extraction, One Call inform and response, drafting, Network planning, GPS observation scheduling, data management, processing, computations, final data preparation, report and deliverables, and overall project supervision.

14 Equipment

All Leica System 500 equipment was used through out the project. The equipment information is as follows

	Manufacturer	**Model**	**Serial Number**		
Receiver	Leica	SR 530	0031854 0131355 0037755	0032301 0031935	0030500 0031950
Antenna	Leica	AT 502	02519 12446 08426	02209 02153	02552 02130
Tripod	SECO*	5115	NA		

Bridge Bracket*	NA	NA

* Fixed pole height (2.0m for SECO or 0.2m for specially made Bridge bracket) used for elimination of errors in height measurements.

References

NOAA Technical Memorandum NOS NGS - 58.
David Zilkoski ; Joseph D. D'Onofrio ; Stephen J. Frakes.

TXDOT GPS Manual of Practice
Michael J. Shelton ; Michael McGuiness ; Billy H. Ethridge.

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APPENDICES