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Survey Report
for the
Quality Control – Quality Assurance Data Collection
for
Dewberry & Davis
on the
Island of Hawaii Along the Westerly and Southerly Coastlines

REVISED 02/28/07

OVERVIEW

Surveyed by: *McGee Surveying Consulting of 5290 Overpass Rd., Ste#107 Santa Barbara, CA 93111*
Survey Method: *GPS static, RTK and conventional*
Client: *Dewberry & Davis Corp.* **; Project. Number***: EMF-2003-CO-0047* **Project Name***: TO-26*
Location: *West & South Coastlines of Hawaii Island*
City: *none* **; County:** *Hawaii***; State:** *Hawaii*
Attachments: *Find the following Documents*

-Coordinate Information: XCL Spreadsheet Listing Points with Geodetic Coordinate & Ellipsoid Heights, State Plane Grid Coordinate & Local Tidal Elevations in meters and feet; Points Descriptions, Land Categories and Photos
-GPS Network Maps: GPS Control Network of measured vectors (5 pages)
-Point Location Maps: QAQC Points, New Control, NGS Control (11 pages)
-Photos of Points (on a separate CD)
-Project Data Sheets: Control Points/Benchmark Data & Descriptions Referenced in this Survey

This document serves as a summary report on the above referenced QAQC survey. The purpose of which is to establish ground truthing points for validation of the Lidar measurements and DEM for the westerly and southerly coastlines up to 10 meters above sea level on the Island of Hawaii. The lidar mapping survey was performed by Airborne 1 Corporation of Los Angeles, California and utilized a laser mounted in an aircraft. The project required that 60 elevation test points be collected in three Land Categories as follows : A- Open Bare Terrain; B- Vegetated Terrain, Forests, Crops; and C- Built Up, Paved Streets, Parking Lots, Buildings. Included in this survey are 69 points with photos in six general locations listed on the attached QAQC Point List.

The main concern for the survey of the Big Island of Hawaii is to develop elevations of the QAQC points that would be recoverable and in harmony with existing and future surveys on the Island. There exists sufficient HARN and CORS stations to establish consistent and reliable horizontal positions and ellipsoid heights as noted below. What is lacking on the Islands is an intra-island vertical orthometric network.

The NGS established about 3 kilometers of leveling at the South Point of the Island circa 1964 as indicated by published Data Sheets. This present survey included benchmark TU0011 from the 1964 survey. Circa 1975 the NGS established a leveling network (indicated by published Data Sheets) extending from Hilo on the east coast southwesterly about 80 kilometers up Mauna Loa. This network incorporated existing benchmark monuments dated back to 1926. The actual datum basis for this network is not known; however, a number of the Hilo Tide Station Tidal Benchmarks were included in the circa 1975 survey which allowed for a comparison with the observed mean sea level discussed hereafter. The Hawaii Volcano Observatory re-leveled the 1975 network in 1989 and provided their results in an elevation listing.

This survey based the vertical datum on the work performed by the NGS circa 1975 fixing a benchmark at Hilo and checking three other benchmarks along the run to Mauna Loa listed hereafter. NOAA Tidal Benchmarks were utilized at Hilo on the east coast, at Kawaihae on the northwest coast located about 90 kilometers west-northwest of Hilo, and at South Point located about 110 kilometers southwest of Hilo to further validate the orthometric accuracy ands reliability

of the combined GPS measured ellipsoid heights and the Geoid 03 Model. A Tidal Benchmark at Hilo (discussed hereafter) was used to equate Mean Sea Level on the present 1983-01 Tidal Epoch to the NGS 1975 leveling. The equation was applied to the Kawaihae and South Point Tide Stations finding them in agreement at 0-7 centimeters. Therefore, the basis for orthometric heights for this survey is the Local Tidal as realized by the circa 1975 NGS leveling and confirmed by relating to Mean Sea Level at these Tide Stations.

Second Order triangulation Stations were included across the survey for the purpose of investigating their suitability for vertical control. The accuracy of these stations proved to be several meters horizontal and a meter or more vertical and are listed here as new positions intended to supersede their published position on the NGS Data Sheets.

PROJECT DATUMS, REFERENCE SYSTEM

Horizontal Datum: *North American Datum of 1983 (NAD83)(PACP00)***; Epoch:** *1993.62* (CORS 2002.00*)*
Reference Network: *High Accuracy Reference Network (HARN) & CORS*
Vertical Datum: *"Local Tidal" per NGS Benchmark TU0029 Data Sheet which is based on a leveling network established circa 1975. Local Tidal by this definition is not the observed NOAA Mean Sea Level for the 1983-2001 Tidal Epoch discussed hereafter.*
Reference Network: *NGS Benchmarks and NOAA Tidal Benchmarks.*
Geoid Model: *Geoid03*
Projection: *Hawaii State Plane Zone 1*
Units for Deliverables: *Feet & Meters*
Notes/Comments: *The horizontal datum in Hawaii and this Pacific Region is consistent with an NAD83 Datum realization for an epoch date of 1993.62 (Aug. 14, 1993) and is designated as NAD83(PACP00). Quoting from "Introducing Two Spatial Reference Frames for Regions of the Pacific Ocean" by Richard Snay available from the NGS, "users of these frames do not have to cope with changing positional coordinates". This survey utilized CORS published on the 2002.00 Epoch which is shown hereafter to be consistent with the 1993.62 Epoch.*

History: *Circa 1964 a Second Order Class 0 leveling network was established at South Point by the NGS. Circa 1975 a First Order Class 1 leveling network was run from Hilo southwesterly to Mauna Loa and utilized for this survey. Circa 1993 the NGS performed a High Accuracy Reference Network (HARN) GPS survey on the Island from which the NAD83 PACP00 1993.62 Epoch Adjustment originated.*

NETWORK ADJUSTMENTS & ANALYSIS

Adjustment Type: *Minimally Constrained & Constrained listed hereafter*
Horizontal Control*: The NGS CORS HILO was fixed on the 1993.63 Epoch as realized by the 2002.00 CORS Epoch in the Minimally Constrained Adjustment and found in agreement with other NGS stations as shown below. The four NGS CORS were fixed in the Constrained Adjustment to develop positions for this survey.*
Vertical Control*: Ellipsoid Heights are based on the HILO CORS in a Minimally Constrained Adjustment; Orthometric Heights are based on the NGS Benchmark TU0029 fixed in a Minimally Constrained Adjustment and checked to NGS benchmarks or NOAA Tidal Benchmarks at five other locations around the Island.*
Number of Points in Network*: 31 points connected by 87 static vectors of which 13 were removed due to excessive residuals; QAQC Points were positioned with 686 RTK vectors measured by collecting 4 measurements per point and 4 additional measurements at a different time approaching static accuracies.*
New Points*: QAQC Points and Primary Control established by this survey are Points in the 501+ and 601+ series*
Station Comments*:. Existing NGS Stations were assigned their PID for identification in this survey and other stations were assigned their local designation. Two HARN stations AA3600 and AA3601; four NGS CORS stations HILO, PAH1, MKEA, and MLO1; and two HVO CORS stations YEEP and HP7 were included as listed below in the "3D/Ellipsoid Height Adjustment". The HVO CORS were treated as additional new Control Stations to build redundancy in the network. The balance of existing Control are Second Order Triangulation Stations listed on the Coordinate List.*

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Network: *Continuously operated GPS receivers aka CORS were utilized extensively in this survey to build an intra-island network. This survey created a linear network of Primary Base Stations along the coastline interconnected by vectors from CORS to add strength and redundancy to the adjustment. Six "Areas" along the coastline were identified as candidate areas for testing because of the near shore and low lying commercial and residential uses. A Base Station receiver was setup at a secure site within an Area while a roving receiver occupied QAQC and Control points in a radial fashion. Simultaneously, a second operation was running in an adjacent Area resulting in inter-Area connections and connections to CORS based on 2-6 hour static vectors. The survey of each Area was repeated and all points were occupied a second time generally at a different time of the day on different days. RTK vectors were used to position the intra-Area QAQC points. The Control and Base Stations were connected with static vectors. The rinex files for the four NGS CORS were imported from the NGS web site. The rinex files for the two HVO CORS were made available by the University of Hawaii and the Hawaii Volcano Observatory (Asta Miklius). The rapid or precise ephemeris was imported for processing.*

A minimally constrained adjustment fixing the HILO CORS was processed to develop geodetic closures. The closures at other NGS CORS and HARN stations are listed below.

3D/Ellipsoid Heights: Minimally Constrained Adjustment Results:
The adjustment results follow with Coordinate Changes from record to computed in meters.

Station	dN	dE	dZ	Comment
AA3600	-0.014	0.081	0.008	HARN
AA3601	-0.037	0.030	-0.237	HARN
HILO	0.000	0.000	0.000	CORS Fixed
MKEA	0.012	-0.007	-0.190	CORS
MLO1	0.017	0.004	-0.149	CORS
PAH1	0.012	0.005	-0.002	CORS

HILO, PAH1 and AA3600 are in good agreement vertically. MKEA and MLO1 are on the tops of Mauna Kea and Mauna Loa respectively and agree relatively in the vertical at 4 centimeters but greater than expected in the absolute. The ellipsoid heights are updated by this survey. A constrained adjustment fixed all CORS horizontally and HILO & PAH1 in the vertical to develop ellipsoid heights and geodetic positions. The closures at other NGS CORS and HARN stations are listed below.

3D/Ellipsoid Heights: Constrained Adjustment Results:
The adjustment results follow with Coordinate Changes from record to computed in meters.

Station	dN	dE	dZ	Comment
AA3600	-0.024	0.080	0.008	HARN
AA3601	-0.051	0.027	-0.236	HARN
HILO	0.000	0.000	0.000	CORS Fixed H & V
MKEA	0.000	0.000	-0.189	CORS Fixed H
MLO1	0.000	0.000	-0.148	CORS Fixed H
PAH1	0.000	0.000	0.000	CORS Fixed H & V

Vertical Control Issues: *The benchmark TU0029 at Hilo Bay was fixed as published by the NGS circa 1975 and compared with benchmarks TU0031, TU0050 and TU0111 of that era survey within a few centimeters as shown below. Three NOAA Tide Stations on the Island were incorporated as additional orthometric control by equating the local Mean Sea Level to the circa 1975 vertical datum benchmarks. The Tide Stations at Hilo Bay (Tide Station ID 1617760) represented by Tidal Benchmark "E 2 1926" (NGS PID TU0017), Kawaihae (Tide Station ID 1617433) represented by Tidal Benchmarks "7433 A 1989", "7433 G 1994" and "7433 B 1989" and Ka Lae at South Point (Tide Station ID 1618739) represented by Tidal Benchmark "8739 A 1979" (NGS PID AA3601) were utilized. The Mean Sea Level (MSL) on the 1983-2001 Tidal Epoch at the Hilo Tidal Benchmark "E 2 1926" was found to be 0.16 meter lower than the "Local Tidal" elevation published in the Data Sheet for TU0017. This was confirmed indirectly by comparing the 1989 leveling by HVO where the difference at Tidal Benchmark "NO 4 1951" was found to be 0.15 meters lower.*

For the purpose of creating additional vertical (orthometric) checks across the Island, the 0.16 meter difference was applied to the height above MSL on the 1983-2001 Tidal Epoch (MSL+0.16m) at the three Kawaihae Tidal Benchmarks. The 0.16 meter difference was also applied to the height above Mean Tide Level on the 1960-1978 Tidal Epoch at the Ka Lae South Point Tidal Benchmark. An additional adjustment of -0.031 meters was applied for the rise in sea level between the Epochs and was determined by comparing the 1960-1978 Tidal Epoch and the 1983-2001 Tidal

Epoch published for Hilo Bay Tide Station. The computed elevations are listed in the attached Coordinate List and were used for computing the closures listed below.

Orthometric Heights: Minimally Constrained Adjustment Determined by Combining the Measured Ellipsoid Height Differences with Geoid Heights.

In the following adjustment results, the Geoid03 modeled heights were utilized. HILO CORS was fixed horizontal and the NGS Benchmark TU0029 was fixed vertically at its published orthometric height. The differences from record to computed in meters listed below.

Station	dN	dE	dZ	Comments
514	n/a	n/a	-0.004	Eccentric: PK Nail leveled from NGS BM TU0050
528	n/a	n/a	-0.030	Eccentric: PK Nail leveled from BM "HVO 23 1964"
921	n/a	n/a	0.010	Eccentric: PK Nail leveled from NGS BM TU0031
7433A	n/a	n/a	-0.025	Tidal BM: Brass cap "7433 A 1989"
7433B	n/a	n/a	0.003	Tidal BM: Brass cap "7433 B 1989"
7433G	n/a	n/a	~~-0.076~~	Tidal BM: Brass cap "7433 G 1991" (unchecked don't use)
AA3600	-0.012	0.077	0.144	HARN, ortho ht per NGS Data Sheet in decimeters
AA3601	-0.041	0.026	0.066	HARN, ortho ht computed from Mean Tide Level
HILO	0.000	0.000	-0.337	CORS (difference is an estimate of the geoid model bias)
TU0011	1.975	-1.884	-1.121	Benchmark circa 1964 a kilometer west of AA3601 (disregarded)
TU0029	0.024	0.054	0.000	Benchmark & Tri-Station circa 1975 Fixed Vertical
TU0050	n/a	n/a	-0.019	Benchmark circa 1975 unsuitable/GPS, use Eccentric Point #514
TU0111	n/a	n/a	-0.033	Benchmark circa 1975
TU2447	1.270	-1.697	-0.672	Triangulation Station (disregarded)
TU2483	1.994	-1.588	-0.589	Triangulation Station (disregarded)
TU2535	1.281	-1.073	0.710	Triangulation Station (disregarded)
TU2545	1.267	-1.202	1.102	Triangulation Station (disregarded)
TU2581	1.269	-0.625	-0.329	Triangulation Station (disregarded)
TU2583	1.216	-0.525	0.697	Triangulation Station (disregarded)
TU2602	0.697	0.150	0.202	Triangulation Station (disregarded)

Notes/Comments: *Holding TU0029 at Hilo as published by the NGS finds the following: TU0031, 1 kilometer southwest represented by eccentric point #921 agrees 1 centimeter; TU0050, 11 kilometer south-southeast represented by eccentric point #514 agrees 0 centimeters; TU0111, 40 kilometer southwest agrees 3 centimeters; Tidal Benchmarks "7433 A" and "7433 B", 90 kilometers west-northwest agree 2 and 0 centimeters respectively; and Tidal Benchmark "8739 A 1979" aka AA3601, 110 kilometers southwest agrees 7 centimeters.*

Point 528 is an eccentric point to HVO benchmark HVO-23 a kilometer west of TU0111 whose elevation relative to TU0111 was available from the HVO. The measured differences between 528 and TU0111 agree 0 centimeters validating the GPS measurement to TU0111. The difference of 1.12 meters at TU0011 at South Point which is about a kilometer west of AA3601 cannot be explained; however, the circa 1964 leveling on TU0011 precedes the Tide Station observations used for the Tidal Benchmark "8739 A 1979"aka AA3601 by 15 years.

The results of this survey indicate the Geoid 03 Model is reliable at the 5 centimeter level across the Island and satisfies the requirements for this survey. Note, the Geoid model is not correlated to the Local Datum as in the case of NAVD88 in the continental US and applying geoid heights to ellipsoid heights will not result in correct orthometric heights without removing a 0.3+/- meter bias.

The stations with excessive differences published in the attached Coordinate List for the purpose of this survey are intended to supersede the NGS Data Sheets.

DATA COLLECTION& PROCESSING

Date of Field Surveys: *11/13/2006 to 11/22/2006;* **Description:** *Network Control and QAQC Data Collection*
GPS Survey Parameters:
Epoch Rate (seconds): *10" for static, 8-16 measurements averaged for RTK collection*
Minimum Satellites: *5* **; PDOP=<** *5* **; Elevation Mask for Data Collection & Processing (degrees):** *10 & 15*
GPS Observables: *L1 & L2 Carrier wave, C/A Code and P-Code*

Boulder K Index: *2-3*
Ephemeris*: Rapid and Precise for Static Post-Processing*

GPS Base Receiver Unit No.: *M3,* **Operator:** *McGee;* **Station Identification:** *varies*
Receiver Make & Model*: Leica 530* **; Antenna Make & Model**: *Leica AT502*
Antenna Mount: *Tripod***; Antenna Height***: varies*
GPS Rover Receiver Unit No.: *M4,* **Operator:** *McGee,* **Station Identification***: varies*
Receiver Make & Model*: Leica 530* **; Antenna Make & Model**: *Leica AT502*
Antenna Mount: *Fixed Height Pole***; Antenna Height***: 2.085m*
GPS Base Receiver Unit No.: *R1,* **Operator:** Reese*;* **Station Identification:** *varies*
Receiver Make & Model*: Ashtech Z-Extreme* **; Antenna Make & Model**: Novatel 702v3.0
Antenna Mount: *Fixed Ht pole***; Antenna Height***: 2.00m*
GPS Rover Receiver Unit No.: *R2,* **Operator:** *Reese,* **Station Identification***: varies*
Receiver Make & Model*: Leica 530* **; Antenna Make & Model**: *Leica AT502*
Antenna Mount: *Fixed Ht Pole***; Antenna Height***: 2.00m*

ACCURACY

Vector Residuals*: RTK vectors range up to 8.7 kilometers and average 2.7 kilometers. The two dimensional residuals range from 0 to 5 centimeters with a standard deviation of 1 centimeter, the vertical residuals range from -5 to +6 centimeters with a standard deviation of 2 centimeter, and the 95 percentile of the absolute value is 4 centimeters. The points measured with RTK were generally measured four times (recording four vectors over several minutes) and then measured four more times on a different day. therefore the actual accuracy would be better represented by the average of the first set compared to the average of the second set which would result in an improvement in the above statistics.*

Static vectors range up to 87 kilometers and average 23 kilometers. The static network consists of 87 vectors of which 13 were removed because the vertical residuals were greater than 8 up to 25 centimeters. In the final minimally constrained adjustment the two dimensional residuals average 1 cm with a standard deviation of 1 centimeter and a maximum value of 6 centimeters. The vertical residual average of the absolute values is 2 centimeters with a standard deviation of 2 centimeters and a range of -8 to +7 centimeters.

Relative Accuracy*: Expected to be better than 5 cm vertical at 95% Confidence. The accuracy of lidar mapping on clearly defined test points is expected to be greater than 15 centimeters, therefore the test points are at a level of accuracy of better than 3 times the lidar points.*
Absolute Accuracy*: Expected to be 0.03 meters horizontal and 0.05 meters vertical at 95% level of confidence relative to the constraints introduced in the adjustments. .*

QAQC ANALYSIS

Not included here, see Dewberry & Davis for analysis

REFERENCE POINTS/STATIONS/CORS DESCRIPTIONS

(see attached file "Project Data Shts.doc" Station Descriptions, values and for Tide Station Datum/Benchmarks)

SURVEYOR'S STATEMENT

This Report on the criteria and procedures used on this QAQC Survey was prepared by me on January 10, 2007 and revised on February 28, 2007 for the purpose of establishing an Island Control Network and validating the lidar acquired Digital Elevation Model (DEM) at the request of Tim Blak of Dewberry & Davis Inc.

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