FOR LIMITED CIRCULATION

THE GRAND CANYON MONITORING RESEARCH CENTER

SURVEY PROTOCOL EVALUATION PROGRAM

FINAL REPORT

OF THE PEER REVIEW PANEL

Submitted by

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EXECUTIVE SUMMARY

DEFINITION

This document reports the findings of the peer review panel commissioned by the Grand Canyon Monitoring Research Center (GCMRC) for the Survey Protocol Evaluation Program (PEP).

PURPOSE OF THE PANEL

The mandate of this Panel is to assist GCMRC in identifying optimum design and procedures for implementing an efficient and effective survey program that supports long-term monitoring of natural and cultural resources in the Colorado River Ecosystem (CRE). The peer evaluation process includes four specific tasks: 1) reviewing the technology, equipment, and methodology applied by GCMRC; 2) introducing new technology to reduce the impact of scientific field work in the Canyon corridor; 3) examining spatial data collected by GCMRC to ascertain whether user needs are being met; and, 4) recommending alternatives.

SCOPE

The scope of this mission includes review of terrestrial and hydrographic survey data collection methods and processing, data archiving, accuracy requirements and error determination, quality control and quality assurance, documentation and record keeping, spatial data standards, and survey control networks for both conventional (land based) and remotely sensed (airborne) survey data collection.

The scope further includes requirements for spatially referencing and assessing aerial acquisition and other remotely sensed data sets. The review also covers requirements for automated spatial data processing methods using a geographic information system, image processing, and softcopy techniques for mapping and change detection of natural and cultural resources.

In addition, since the impact of science in the Grand Canyon is a main concern, GCMRC aims at expanding the geographic extent of monitoring in a least impacting, yet in a cost effective manner. Therefore, the scope extends to review of the acquisition and processing protocols of aerial and other remotely sensed data sets intended for seamless integration with land-based survey data.

OVERVIEW

Members of the Panel represented a variety of specialized and overlapping expertise relating to the review objectives. A listing and contact information of all panelists is found in Appendix I.

The protocol review process consisted of four parts: 1) pre-review orientation and application descriptions, 2) on-site assessment of the operation area including a river trip from the Glen Canyon Dam to Lee' s Ferry, 3) technical briefing session, and 4) group discussion and drafting of report.

At the pre-review orientation, the Panel was briefed on the various applications within the GCMRC mandate where survey data sets are exploited. The objective was to assess whether, or not, the spatial requirements of the data sets are being met with respect to these applications.

The field trip allowed the Panel to closely observe some of the most dramatic and difficult areas within the CRE where most of the surveying activities were conducted. The Panel had the chance to see and hear about current research and monitoring studies and observe first hand the issues surrounding mapping and spatial referencing data collected in the ecosystem.

The technical briefing session included several presentations on specific surveying activities, protocols, and practices at the GCMRC. The presenters and other staff members were queried by the Panel and asked to provide clarifications and further information.

The Panel met privately the next day and reviewed the information from the field trip, written material, briefings, and presentations. A general discussion helped shape an overall assessment of the survey operations, strengths and weakness, and general recommendations. The submitted written questions were then addressed systematically, and Panel members with pertinent expertise helped answer them. The answers have been compiled and documented in this report.

ORGANIZATION OF THE REPORT

The report is divided into two parts, I and II. These two parts are based on the set of questions submitted by GCMRC to the Panel, as shown in Appendix II. The first part consists of 11 questions, and the second of 7 questions. Most of the questions have sub-questions. The Panel addressed each of the questions and sub-questions with direct answers, findings, and recommendations. In addition, pointers and links to references and external reports were provided. Summaries of the findings and recommendations are listed in the executive summary.

The report has four appendices. Appendix III documents email communication between GCMRC and USGS regarding advice on most appropriate coordinate system to use. Appendix IV lists abbreviated terms used throughout the report.

FINDINGS

The findings of the panel are summarized below under each category.

Terrestrial Surveying:

- Current control networks, documentation, and collection protocols cannot be generalized as adequate at all scales, accuracy requirements, and project specifications.
- Control points locations are not adequate for vertical measurements.
- Although the local geoid requires improvement, its impact on accuracy may not constitute a high priority considering the cost-benefit aspects.
- Datum conversion between National Geodetic Vertical Datum of 1929 (NGVD 29) and North American Vertical Datum of 1988 (NAVD 88) may not achieve high accuracy because of the lack of sufficient National Spatial Reference System (NSRS) benchmarks in the region.

Aerial Surveying:

- GCMRC provides adequate scope of work (SOW) to airborne surveying contractors.
- Capabilities and resources are not currently compatible to make full use of the historical, near future, and mid-future photographic acquisition missions.
- Current online and offline archiving capabilities are severely inadequate to support high-volume aerial and remote sensing operations. This issue will become even more problematic if historical photography is to be converted into digital files.
- Specifications for aerial and remote sensing data are deficient, particularly in relation to the requirements of the intended application. This is especially critical since it impacts the cost of: acquisition, processing, and dissemination.

Hydrographic Surveying:

- The panel found that equipment, methods, and protocols for hydrographic surveying were adequate and meet accepted survey practices based on what was available for review. The exceptions are the heading sensor and survey documentation.
- In the panel's opinion, the current heading sensor is not adequate and other heading sensor options should be considered.
- In the panel's opinion, it is likely that the present attitude sensor technology utilized by GCMRC will result in heave artifacts under some lateral motion circumstances.
- The panel cautions that automated statistical filtering techniques may eliminate actual data that are helpful in the analysis of anomalies and true bottom detection. One potential result is mapping the top of aquatic vegetation instead of the seabed.

Standards and Specifications:

- Adherence to declared standards is not consistent, nor is there established protocol to verify adherence to accuracy specification. In the panel's opinion, this represents a serious flaw that, in extreme cases, may render the delivered data useless.
- The Panel found no specific documentation of quality assurance / quality control (QA/QC) procedures, as well as no error determination protocols that apply, adequately, to any of the of survey categories.

- The Panel found no established procedures to ensure consistency among staff. Such consistency becomes critical especially when SOW, specifications, data, and procedures were communicated among various organizational units of GCMRC.

Staffing and Outsourcing:

- Contracting of a surveying mission, end-to-end, has the potential of improving the ability of GCMRC to achieve its stated goals. Because of specific factors, this issue needs careful consideration and assessment of its efficacy.
- GCMRC is at serious risk because of the size of its surveying staff. Very few individuals have intimate knowledge of all unique procedures, specifics of surveying projects, and other vital information on all aspects of spatial referencing of the area.

RECOMMENDATIONS

Terrestrial Surveying: The Panel recommends:

Establishing, in critical experimentation areas, sets of GCPs that satisfy certain specifications of inter-visibility, access, and link to Global Positioning System (GPS).

- Coordinating with the National Park Service (NPS) and the Federal Geodetic Control Subcommittee to place new monuments and preserve existing control points.
- Evaluation of the effects of varying geoid undulations on accuracy and its economical impact; and, if justified, cooperation with the National Geodetic Survey (NGS) and the U.S. Geological Survey (USGS) to improve the geoid locally.
- Using North American Datum of 1983 (NAD 83) and NAVD 88 as the vertical datum.
- That all equipment undergoes regular testing, adjustment, and calibration according to established schedules and procedures.

Aerial Surveying: The Panel recommends that:

Numerical, quantifiable, and other descriptive specifications, including the number and distribution of ground control points (GCPs), be defined in conjunction with the intended project goals, and such specifications be incorporated into all future requests for proposals.

- GCMRC expand its in-house photogrammetric and image analysis capabilities.
- Where practical, airborne integrated GPS and integrated measurement unit (IMU) should be used in all aerial and remote sensing coverage to reduce the GCP requirements for photogrammteric processing.
- More detailed specifications stipulating the methods, technologies, and accuracy standards employed in the aerial acquisition.
- Storage, archiving, and networking needs be evaluated based on the volume requirements of post-conversion softcopy processing of historical photography.

Hydrographic Surveying: The Panel recommends:

- the use of a multibeam sonar system with wider angular swath width (e.g., 150 degrees) to allow better coverage in shallow water and increase shoreline mapping capabilities,
- that detailed patch test results be included in each survey report,
- careful analysis of the dynamics of the survey platform (from existing navigation, bathymetry and attitude data) be performed; and a comprehensive error budget be developed for the survey system,
- conducting careful evaluation of potential sensors upgrades, including field trials and subsequent analysis.
- that automated statistical analyses be conducted with extreme caution.
- Proper reporting of: processing methods, technical data, and tests results; and improving documentation of confidence checks.

Standards and Specifications: The Panel recommends:

- conformity with the latest national standards for geospatial positioning accuracy, in terms of reporting methodology, control networks, and specifications.
- strict adherence to systematic and detailed documentation of meta data.
- establishing appropriate QA/QC procedures for each of the four survey categories.
- that contractors and subcontractors submit their QA/QC procedures specifically used to realize the contracted specifications.
- establishing internal verification and validation protocols, including methodology, equations, checkpoints, and certification; and that GCMRC staff, or an independent third party, verify adherence to these protocols in internal as well as contracted work..

Staffing and Outsourcing: The Panel recommends:

- doubling the number of permanent surveying staff, and adding part time geodesist.
- knowledge of the area be systematically documented, archived, and disseminated within other GCMRC groups.
- developing contingency plans to minimize the risks of staff relocation, downsizing, and retirement.
- Contractor and subcontractor selection should be based on qualifications and not cost
- joint ventures or subcontracting options, rather than end-to-end outsourcing, for terrestrial and hydrographic surveying missions, and
- close monitoring and evaluation by GCMRC over the contracted work, and strict adherence by the subcontractor(s) to QA/QC procedures and delivery schedule.

PART I

1. **Are control networks, conventional survey, and remotely sensed data collection protocols adequate for integrating land based survey data with remotely sensed?**

ANSWER:

The Panel finds current control networks and surveying methods adopted by GCMRC to be adequate to support further ground surveys. For instance, conventional (total station) surveying methods are adequate for collecting data on shorelines, for archeological, environmental, and topographic surveys. Current control networks, documentation, and collection protocols are found to be consistent with similar endeavors of integrating land-based survey data with remote sensing imagery, such as in mapping and geographic information system (GIS).

The Panel, nevertheless, advises that these protocols cannot be generalized as adequate at all scales, accuracy requirements, and project specifications. Consequently, the Panel recommends that GCMRC evaluates, on a case-by-case basis, the number and distribution of ground controls specific to any aerial acquisition. This aspect is independent of the remote sensing collection method, whether it is photographic (film-based) or direct digital acquisition.

Panel's recommendation for network improvements include: Test and evaluation of local Continuously Operating Reference Station (CORS) network (South Rim, Hoover and Glen Canyon Dams), and application of precise GPS orbits to data processing programs.

2. A. Are site locations for control and other survey sites appropriate?
B. Are they being appropriately monumented?

ANSWER:

A. Are site locations for control and other survey sites appropriate?

The Panel found that control points were located in a way that makes vertical measurements rather difficult. The kind of environment at the Grand Canyon poses several limitations, such as lack of access, sky visibility, and points' inter-visibility. In critical areas, such as beaches, the Panel recommends that a minimum of three control points be installed. Each of the three points must be inter-visible with the other two. The groups (of three points) themselves, however, do not have to be inter-visible with each other's but linked using GPS.

B. Are they being appropriately monumented?

The Panel found that control points were not properly monumented. The current '+' method impedes efficiency because of their difficulty to locate. Panel's recommendation is that improved, highly stable, easily identifiable and recoverable monumentation to be established. This could include the design of a primary and secondary monument types (e.g., brass disks, bolts). The design should result in minimal impact yet permanence.

FURTHER RECOMMENDATIONS:

The Panel suggests coordinating with the NPS for permission to place new monuments and preserve existing control points. These can be strategically placed out of the general park visitors view. The Panel further advises GCMRC to coordinate between NPS representatives and the Federal Geodetic Control Subcommittee (FGCS).

3. Are the data standards relating to spatial data appropriate (section F)?

ANSWER:

The Panel endorses GCMRC's conformity with national data standards such as the National Spatial Data Infrastructure (NSDI), the National Biological Information Infrastructure (NBII), and the metadata protocols developed by the Federal Geographic Data Committee (FGDC). The Panel however finds that adherence to these standards is not consistent. The three examples of metadata delivery, s5geolgeom, fl0001exp0001, and fl0002exp0001, were marred with missing information. Most critical of these are accuracy standards. In the Panel's opinion, this represents a serious flaw that, in extreme cases, may render the delivered data useless. The Panel questions the acceptance and certification by GCMRC of such deliveries from commercial contractors.

The Panel recommends strict adherence to the standards declared in the protocols. The Panel further recommends that GCMRC conform to geospatial positioning accuracy standards, in terms of reporting methodology, control networks, and specifications. The FGDC has established the Geospatial Positioning Accuracy Standard. The standard is described in the following documents:

Geospatial Positioning Accuracy Standard:

Part 1, Reporting Methodology, FGDC-STD-007.1-1998

Part 2, Geodetic Control Networks, FGDC-STD-007.2-1998

Part 3, National Standard for Spatial Data Accuracy, FGDC-STD-007.3-1998

FURTHER RECOMMENDATIONS:

The Panel recommends that accuracy of surface data from active sensors, such as Light Detection and Ranging (LIDAR), be evaluated using standards developed by USGS-National Digital Elevation Program and the Federal Emergency Management Agency (FEMA)-Flood Hazard Mapping Programs. Guidelines are being established for a QA/QC procedures and evaluation of data sets in variable vegetation conditions. References may be found at:

http://www.ndep.gov/TechSubComm.html

http://www.fema.gov/mit/tsd/lidar_4b.shtm

http://www.ncfloodmaps.com/pubdocs/default.htm

4. **A. Is the current remote sensing statement of work sufficiently defined relative to spatial positioning of remotely sensed data?**

   B. Please include a review of GPS position dilution of precision (PDOP), minimum epoch update rate and synchronization, and simultaneous processing or averaging of multiple base-line vectors.

ANSWER:

A. Is the current remote sensing statement of work sufficiently defined relative to spatial positioning of remotely sensed data?

The protocol spells out the objectives and applications that justify the collection of remote sensing data as well as highly detailed and specific information about flying heights, GPS control, and deliverables. The Panel, however, finds that critical specifications of aerial and remote sensing data were severely missing. These acquisitions need detailed specifications, defined based on the requirements of the intended application. For instance, the ground sampling distance, positional accuracy, and spectral channels and bandwidth must all be defined according to the goals of the application. This is particularly important since it impacts, very substantially, the cost of: acquisition, processing, and dissemination. The Panel recommends that numerical, quantifiable, and other descriptive specifications be defined in conjunction with the intended application; and that such definitions be incorporated into all future RFP's.

Advanced technologies and concepts are being constantly introduced in nearly every aspect of remote sensing, such as airborne GPS, inertial measurement units, direct georeferencing, automatic surface generation, and active sensors. The Panel thus emphasizes that the most effective technology and methodology for obtaining services and products should be defined based on the nature and specifications of the deliverables. This process would allow for industry service providers to respond to solicitations utilizing the latest technologies and expertise available. The selection of the best vendor to meet GCMRC's program requirements is therefore expected to utilize a QBS process.

B. Please include a review of GPS PDOP, minimum epoch update rate and synchronization, and simultaneous processing or averaging of multiple base-line vectors.

The protocol stipulates PDOP values not to exceed 3.5 on the aircraft and 5 on the base station. The Panel finds these to be generally adequate. The Panel advises that under no conditions the PDOP values should exceed 6. The Panel also finds the epoch update rate and synchronization of 1 sec to be adequate in general for ground survey applications.

The Panel recommends that for reliable results in the Grand Canyon, GPS surveying activities should be conducted within 30 km from the established base station, with an absolute maximum of 50 km. For projects having a potential for GPS failure, multiple base stations are recommended for airborne or ground surveys.

5. A. Because geoids are modified periodically and positional data are acquired for many GCMRC program requirements on an annual basis, what is the most appropriate format (level of processing) for permanent storage of collected data that are used for historical or temporal analyses?

B. Should all the coordinate values be archived, maintained, adjusted, and published as Cartesian and/or World Geodetic System 1984 (WGS 84) values to bypass geoid model problems?

ANSWER:

A. Because geoids are modified periodically and positional data are acquired for many GCMRC program requirements on an annual basis, what is the most appropriate format (level of processing) for permanent storage of collected data that are used for historical or temporal analyses?

The Panel recommends permanent storage in lat/long as well as Cartesian, such as the Earth-Centered Earth-Fixed (ECEF) State Plane, and the Universal Transverse Mercator (UTM) coordinate system, i.e., three systems in total. GCMRC staff received another advice[1], as shown in Appendix III, to limit the use to Cartesian, and to specifically avoid latitude and longitude system. The Panel interprets this advice in relation to the use of coordinates, rather than storage and archiving. If this interpretation holds true, then the Panel concurs with this advice.

The Panel's recommendation that the original source of all raw measurements be archived primarily in Lat/Long aims to maintain a backup data in case if an error is found in the projection parameters or if another projection is used in the future. Furthermore, the source data for GPS observations are in geographic coordinates (latitude/longitude). Archive of geographic coordinates is required under the National Oceanic and Atmospheric Administration (NOAA) charting surveys (ref. http://chartmaker.ncd.noaa.gov/hsd/specs/specs.htm Section 8.5.3).

B. Should all the coordinate values be archived, maintained, adjusted, and published as Cartesian and/or WGS 84 values to bypass geoid model problems?

The Panel recommends that all data be adjusted and processed in the latest solution of NAD 83. Except where there are specific needs for orthometric heights, all elevations should be determined in NAD 83 ellipsoidal heights.

Archiving issues were addressed in Section I.5.A above. Publishing issues are subjective and depend on the data user. However, once the coordinate system and reference surface are defined (hence the meta data requirement), transforming from one coordinate system to another can be performed with publicly or commercially available conversion tools.

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[1] In terms of Cartesian coordinate systems, this recommendation concurs with that by Mr. Philip A. Davis, Jr. of the Astrogeology Group of USGS (520-556-7133) based on recommendation by Mr. Mike Pace of the Mid-continent Mapping Center of USGS (573-308-3771). This is documented in an email communication (no date provided) with Mr. Steve Mietz of GCMRC as shown in Appendix III.

FURTHER RECOMMENDATIONS:

1. The Panel endorses strict adherence to systematic documentation of meta data as described in the protocols, namely using *Content Standard for Digital Geospatial Metadata Version 2 - June 1998* published by the FGDC.
2. The Panel recommends accessing advice from a government agency or commercial consulting services if further evaluation of this question is needed.

6. **Geoids are established using available gravity data for a region. The Grand Canyon is a narrow; deep void that has dramatic changes in bedrock densities along its corridor, both of which effect local gravity.**

   A. What effect does (can) each of these two factors have on surveys within the Grand Canyon that currently use control established from canyon-rim base stations?

   B. What are the potential magnitudes of these effects on positional accuracy?

   C. Can they exceed the target positional accuracy for GCMRC?

   D. If, so, how can better control be established?

ANSWER:

A. What effect does (can) each of these two factors have on surveys within the Grand Canyon that currently use control established from canyon-rim base stations?

A geoid is modeled based on the assumption that the potential of gravitational force is the same on the same surface, hence equipotential surface. In a specific region, like the Grand Canyon, the Earth's mass may be irregularly distributed throughout the core, mantle and crust. These differences in mass concentrations can be treated as mass anomalies, which result in variations in the gravitational forces in that region. These changes in the gravitational forces affect the flatness of the geoid surface, upon which line-of-sight leveling measurements are based.

To model the effect of these changes, a standard geoid model is first established. Then, the deviations of gravity resulting from Earth's true mass distribution are treated as anomalies. At regions where mass is concentrated, anomalies are treated positive thus causing higher local potentials of gravitation. On the other hand, places where there is mass deficiency, local gravitational potentials are lower, hence negative anomalies. Consequently, the equipotential surface where the leveling measurement is conducted will undulate with changing deflections of the vertical, as shown in Figure 1. This, in turn, will affect the ellipsoidal heights of the observed points. The magnitude of such an effect, however, is very much dependent on the deflection angle, which is a function of the anomalies.

B. What are the potential magnitudes of these effects on positional accuracy?

It is in the Panel's opinion that these effects are negligible in terms of GCMRC's line-of-sight leveling survey work. It is worth noting however that current national geoid model (GEOID99) is not sufficiently refined to model gravity anomalies in the Canyon to the required accuracy. As a result, the magnitudes of these effects on positional accuracy cannot be accurately estimated absent of experimental evaluation of a best-fit equipotential surface.

C. Can they exceed the target positional accuracy for GCMRC?

They are unlikely to affect the positional accuracy. Notwithstanding, the Panel recommends controlled tests to quantify the anomalies of the geoid model in the area so that the effects on accuracy can be numerically analyzed.

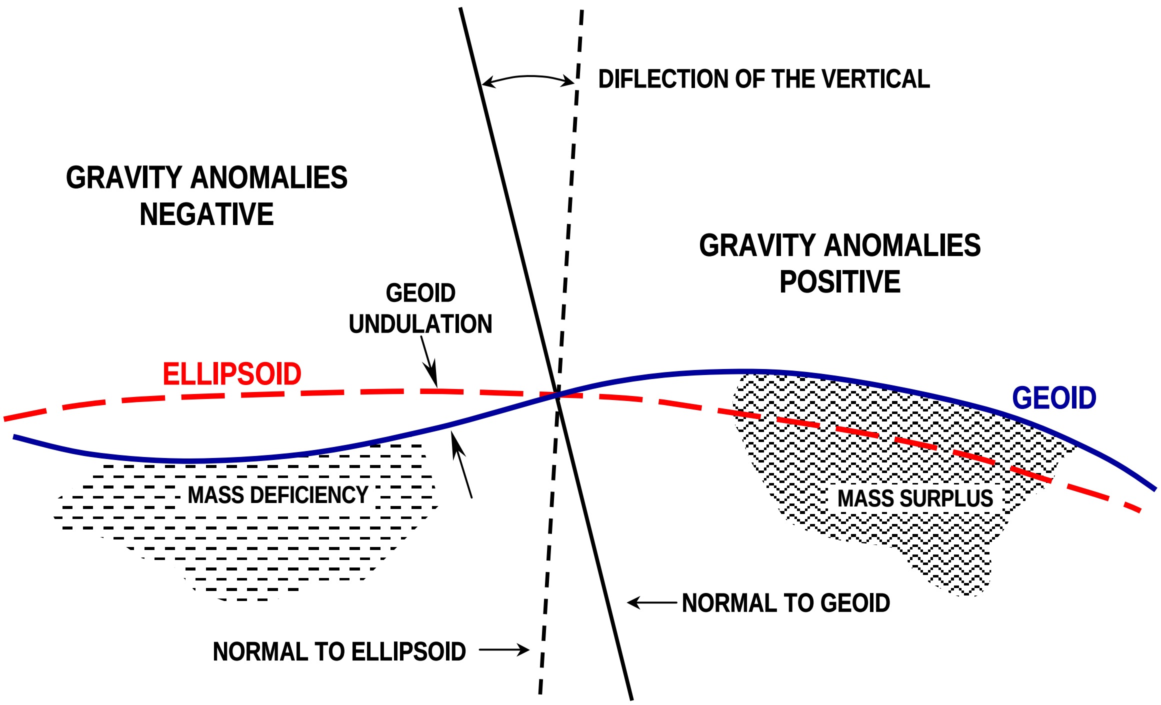

Figure 1. Effect of Mass Anomalies on the Geoid. (Source: Geodesy for the Layman, the Defense Mapping Agency)

D. If, so, how can better control be established?

This will be needed only if controlled tests are conducted and found sufficient degradation in accuracy to warrant new controls. The design of the network will then depend primarily on the results from the controlled tests.

7. A. Do we need to improve the geoid locally?

B. If so, how?

ANSWER:

A. Do we need to improve the geoid locally

The Panel found that the local geoid require improvement. The impact of the current geoid on accuracy may not constitute an immediate concern, however, especially considering the cost-benefit aspects. The document *Geoid Modeling at NOAA* by Dru A. Smith offers a good example of the financial impacts of a geoid model, NOAA resources and partnerships, and future directions. Another document (Milbert, Undated) from NGS provides a good example of accuracy assessment of the geoid model in limited geographic area.

B. If so, how?

The Panel recommends cooperative effort between GCMRC, the NGS and the USGS. The geoid can be improved by including observation of absolute gravity sites as well as relative gravity measurements using a marine gravimeter and GPS. These observations should be conducted on existing NAVD 88 benchmarks published by NGS as part of the NSRS. For a detailed step-by-step methodology of geoid modeling and the needed data, please refer to *Gravity and the Geoid at NGS*, by D. Smith. This document also includes a brief look at GEOID99 and a discussion of GPS-derived orthometric heights.

FURTHER RECOMMENDATIONS:

As an interim solution, the Panel recommends continuing the long-term static GPS control surveys GCMRC currently conducting. The current geoid may have insignificant impact on critical areas as the relative difference in elevations does. If that is the case, the observations of relative differences in ellipsoid heights should be sufficient between areas. The Panel, however, recommends that the impact of varying geoid undulations be assessed, quantified, and evaluated in terms of the short- and long-term economics.

REFERENCES:

Milbert, Dennis G., ***An Accuracy Assessment of the GEOID96 Geoid Height Model for the State of Ohio***, National Geodetic Survey, NOAA, Undated.
http://www.ngs.noaa.gov/PUBS_LIB/oh-rep.html

Smith, Dru A., ***Geoid Modeling at NOAA***, National Geodetic Survey, National Ocean Service, NOAA, November 13, 2000
http://www.ngs.noaa.gov/GEOID/PRESENTATIONS/2000_11_ScottGudes_SilverSpring_Geoid_at_NGS/index.htm

Smith, Dru A., ***Gravity and the Geoid at NGS***, National Geodetic Survey, Presented at the 2000, Geodetic Advisor Convocation, Silver Spring, MD, April 11, 2000
http://www.ngs.noaa.gov/GEOID/PRESENTATIONS/2000_04_Convocation_Silver_Spring_Gravity_and_Geoid/index.htm

8. A. What are the issues surrounding conversion between the National Geodetic Vertical Datum of 1929 (NGVD 29) and NAVD 88?

B. Which vertical datum do you recommend using?

ANSWER:

A. What are the issues surrounding conversion between the NGVD 29 and NAVD 88?

An important feature of the NAVD 88 program was the re-leveling of much of the first-order NGS vertical control network. The dynamic nature of the network requires a framework of newly observed height differences to obtain realistic, contemporary height values from the adjustment. Consequently, NGS identified 50,600 miles for leveling. Replacement of disturbed and destroyed monuments preceded the actual measurements. This effort also included the establishment of stable "deep-rod" benchmarks, which would provide reference points for future line-of-sight as well as space-based GPS measurements. Field leveling of the 50,600 miles network was accomplished to Federal Geodetic Control Committee (FGCC) first-order, class II specifications, using the "double-simultaneous" method (Whalen and Balazs 1976).

The new general final adjustment completed in June 1991. The resulting overall differences for the conterminous United States between orthometric heights referred to NAVD 88 and to NGVD 29 ranged from -40 cm to +150 cm. Examples of these differences are shown in Figure 2. In most "stable" areas, relative height changes between adjacent benchmarks appear to be less than 1 cm. In many areas, a single bias factor, describing the difference between NGVD 29 and NAVD 88, can be estimated and used for most mapping applications.

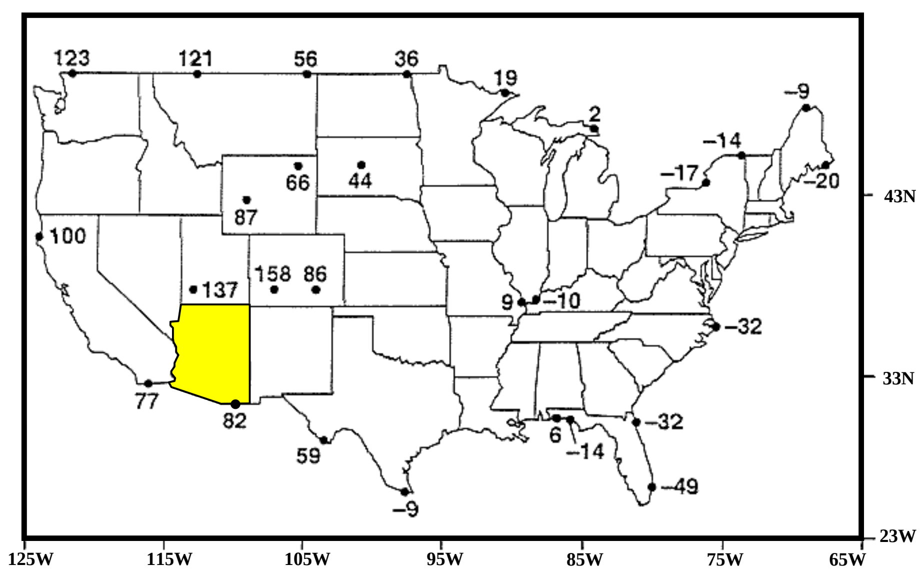

Figure 2. Height differences between NAVD 88 and NGVD 29 due to local effects in conterminous United States [After Zilkoski et al., 1992].

In the GCMRC operation area, however, a datum conversion between NGVD 29 and NAVD 88 may not achieve 1-2 cm accuracy. This is due to the lack of sufficient NSRS benchmarks in the region to compute high accuracy conversion.

The Panel recommends conducting an investigation to address this lack of benchmarks. The investigation would involve three parts. First part is the inclusion in the NSRS of all historic USGS leveling, new benchmarks, and other high-order leveling networks.

The second is the partitioning of all benchmarks and associated observations into manageable blocks, and performing a simultaneous least-squares adjustment of the entire data set. The third is conducting error analysis of datum conversion between NGVD 29 and the adjusted NAVD 88 to determine if it can achieve the target conversion accuracy.

B. Which vertical datum do you recommend using?

The Panel recommends using NAVD 88.

FURTHER RECOMMENDATIONS:

In the Panel's opinion, the cost benefit ratio of establishing new benchmark coverage needs to be examined. Existing leveling data should be utilized in a first attempt re-adjustment of the datum. The GCMRC staff has utilized reciprocal level techniques with some success. These could be utilized in conjunction with historic networks and conventional level runs along the Tonto Plateau.

REFERENCES

Whalen, C. T., and E. I. Balazs. 1976. "Test Results of First-Order Class III Leveling." NOAA Technical Report, NOS 68. Rockville, Maryland: National Geodetic Information Center, NOAA.

Zilkoski, David B., John H. Richards, and Gary M. Young, Special Report: Results of the General Adjustment of the North American Vertical Datum of 1988, , American Congress on Surveying and Mapping, Surveying and Land Information Systems, Vol. 52, No. 3, 1992, pp.133-149. http://www.ngs.noaa.gov/PUBS_LIB/NAVD88/navd88report.htm

9. What are the issues surrounding ellipsoid to orthometric height conversion?

ANSWER:

The ellipsoid height of a point on the Earth's surface is the distance from the reference ellipsoid to the point, measured along the line normal to the ellipsoid. GPS-based points, on the other hands, are based on geocentric ellipsoid reference surface, hence ellipsoidal heights.

Orthometric heights, shown in Figure 3 are based on an equipotential reference surface, e.g., the geoid. The orthometric height of a point on the Earth's surface is the distance between the geoid surface and the equipotential (level) surface passing through point itself, measured along the plumb line normal to the geoid. All line-of-sight leveling runs are based on equipotential surfaces passing through the points where measurements are conducted.

Differences in mass concentrations result in gravitational anomalies, which undulates the flatness of the geoid and equipotential surfaces. As explained in Section I.6.A., the anomalies on the equipotential surfaces affect the ellipsoidal heights of the observed points. An accurate geoid model needs to be available to accurately convert orthometric heights to ellipsoidal heights.

Issues concerning the accuracy of the current geoid model and potential effects on elevation accuracy have been discussed at Section I.6.C and I.7.

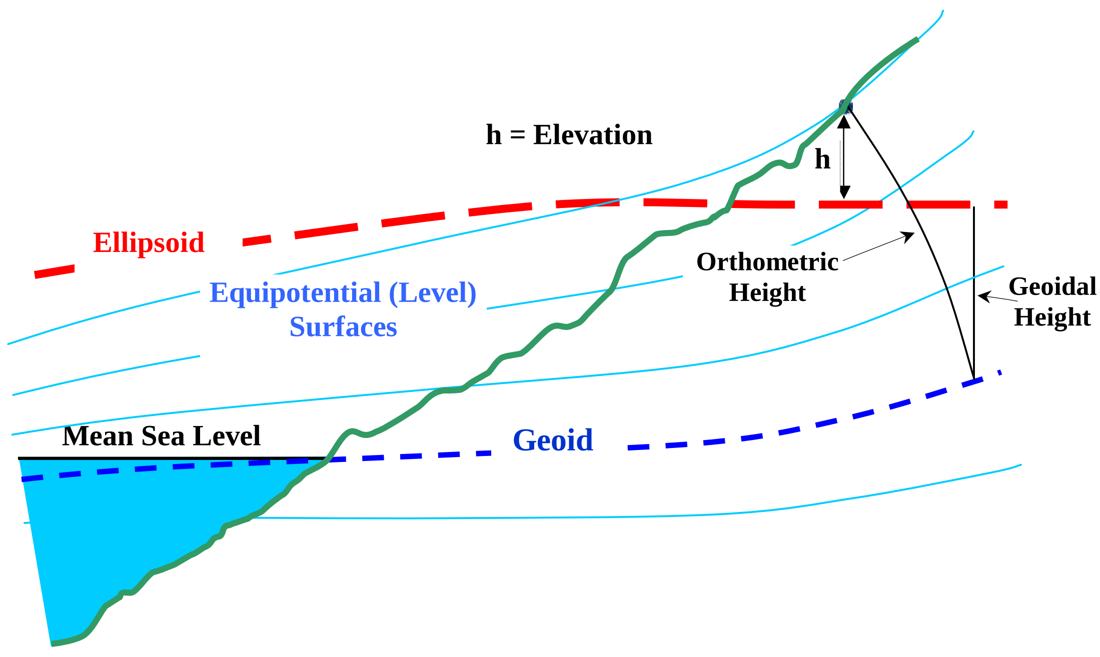

Figure 3 Relationships between Ellipsoid, Geoid, and Orthometric Heights.

10. Due to the extreme nature of the Canyon environment, is it reasonable to contract terrestrial and hydrographic surveying firms to perform or assist the GCMRC survey department in Colorado River Ecosystem operations?

ANSWER:

In general principle, the Panel contends that contracting terrestrial and hydrographic surveying can improve the ability of GCMRC to achieve its stated goals. Several factors, however, necessitate careful consideration and assessment of the efficacy of this approach. These factors include:

- the unique and difficult nature and conditions in the Grand Canyon
- the need for specialized and expensive equipment for such surveying missions, and
- the internal resistance and apprehension due to a track record of failed contracts.

As a result, contracting of a surveying mission, end-to-end, may face a real potential of budget over-run and untimely delivery. Since other tasks depend on the results of these surveys, such failure may have ripple effects on overall GCMRC operations.

The Panel recommends joint ventures or subcontracting options for these surveys. Subcontractors and temporary crews, highly skilled in the particular type of survey and closely working with the GCMRC staff, would certainly help in realizing the desired goals. While the GCMRC surveying staff has the river and terrain experiences unique to the area, a subcontractor may bring the required addition of labor and surveying expertise.

The Panel stresses two critical factors as key to the success of future surveying missions. The first is close monitoring and evaluation by the GCMRC staff over the contracted work. This can be realized by making a payment contingent upon approval of a completed phase or milestone. The second is strict adherence by the subcontractor(s) to QA/QC procedures and delivery schedule. The Panel further recommends imposing specific and enforceable stipulations to be embedded in any contract. These stipulations may include non-compliance and delay penalties, third party validation requirement, and adherence to the latest national standards for services and products specified in the contract.

11. Is the staffing level and qualifications of the survey department appropriate?

ANSWER:

While reliance on skilled volunteers seems to be an innovative and cost effective approach, the Panel recommends increasing the number of permanent staff. Specifically, the Panel advises adding two full time survey staff to the already existing two staff members. The Panel further recommends that the group should be supplemented with a skilled geodesist, either as an employee (50% time) or contract such services with a government agency or outside consultant.

FURTHER RECOMMENDATIONS:

1. The Panel recommends that the survey staff be offered training and continuing education on regular basis. This is particularly in subjects like geodesy, emerging technologies such as LIDAR, advanced imaging systems, etc.

2. The Panel warns that GCMRC is at risk because of the size of its surveying staff. Very few individuals have intimate knowledge of all unique procedures, specifics of surveying projects, and other vital information on all aspects of spatial referencing of the area. The Panel recommends that such knowledge be systematically documented, archived, and disseminated to other related missions within GCMRC. The Panel further recommends contingency plans be developed to deal with risks of staff relocation, downsizing, and retirement. The Panel recommends that workshops be conducted to educate other GCMRC departments about all controls, surveying missions, and spatial standards, and emerging technologies.

PART II

1. **For each of the following five categories:**
   A. Ground based terrestrial surveying,
   B. Airborne terrestrial surveying,
   C. Ground based hydrographic surveying,
   D. Airborne hydrographic surveying, and
   E. Surveying from historical stereo photos;

   Please describe the requirements, limitations, relative cost, level of difficulty, sources and magnitude of error, operational status, and required quality control and quality assurance of all surveying technology/technique combinations that can be used to locate points on the Earths surface in two or three dimensions using real world coordinates to within 3 m (meters), 1 m, 0.3 m, and less than or equal to 0.1 m. In addition to a detailed discussion in the report, please summarize your findings in the table below.

ANSWER:

A. Ground based terrestrial surveying:

The positioning orientation systems for land vehicles are opening many new venues for ground based terrestrial surveying. One of the biggest applications is that of mobile mapping. Designed for vehicle applications, position orientation systems, such as the Applanix POS-LV, provide high dynamic accuracy in position, roll, pitch and true heading. These ground based terrestrial surveying systems are ideally suited for use in applications where GPS outages can be an issue. Such an advantage makes them ideal for GIS data collection where line of sight is problematic for corridor surveys and river mapping.

B. Airborne terrestrial surveying:

These methods can be used with film-based aerial photography, direct digital airborne acquisition, low-cost digital cameras, and high-resolution satellite imagery. These acquisition technologies do not merely produce different data sources, but they impact the whole processing approach as well as the expected accuracies.

a. Film-Based Photogrammetric Methods: This approach includes both conventional (i.e., hardcopy) as well as post-scanning softcopy production. In this approach, industry standards indicate that two- and three-dimensional accuracy of 0.1 meter can be achieved, provided that all photogrammetric requirements are met. These include, but not limited to, a Camera Calibration Report supplied by the USGS; appropriate number and distribution of GCPs; trained photogrammetrists, and QA/QC procedures.

b. Airborne Integrated GPS/Inertial System for Direct Geopositioning: There are two different technologies being introduced to the commercial market, (1) airborne analog camera integrated with GPS/Inertial Navigation Systems (INS) and (2) airborne digital camera integrated with GPS/INS. They are designed for direct geopositioning, thereby in the case of the analog camera bypassing aerial triangulation and in the case of airborne digital cameras the conversion of film into digital image through precise scanning. This approach has been tested in production and may offer an option to conventional mapping in the very near future. Currently, Z/I Imaging, Intergraph, Emerge Direct Digital Imagery, Integraph, and Leica GeoSystems, are a few that offer advanced integrated digital/GPS/INS for mapping. The 3 to sub- meter accuracy levels are potentially achievable using this technology. For more information on the applicability of airborne aerial cameras integrated with GPS/INS see USGS Open-File Report 02-222, Positional Accuracy of Airborne Integrated GPS/INS for Mapping in Glen Canyon, Arizona.

c. Low-cost Digital Camera: This technology, such as the Kodak MegaPlus 16.8I digital camera, is not a viable option for standard photogrammetric work with high accuracy expectations with one or less meters. However, it may be a viable option to achieve the 3 meters accuracy levels, assuming all standard photogrammetric requirements are met. New digital sensor cameras by Z/I, LeicaGeoSystems, and others may offer greater potential and should be investigated.

d. Remote Sensing Methods:
This application is mainly based on commercial high-resolution satellite imagery. The Quickbird satellite provides the highest resolution available at the present time. It is 0.6 meter panchromatic, and thus may be a viable option for accuracies better (i.e., numerically smaller) than 3 meters. This option needs to be examined in more details with a pilot project. If the intended accuracy is found to be achievable, the cost effectiveness of high-resolution satellite imagery becomes a compelling factor.

C. Ground based hydrographic surveying:

The best current methods (under the restrictions of working in the Canyon) will come from using relatively narrow swath, high resolution, high frequency multibeam sonar in conjunction with precision navigation and attitude sensors and methodical calibration techniques. Refer to NOAA Specifications and Deliverables (http://chartmaker.ncd.noaa.gov/hsd/specs/specs.htm Section 5 Depth Sounding) for error sources, quality control and quality assurance.

There is probably no heading and attitude reference that will work in the Canyon that is as good as that provide by GPS-aided inertial platform such as the POS/MV-320 from Applanix. This approach will not work in most of the Canyon. A careful field trial using an IXSEA PHINS ring-laser gyro should be evaluated.

D. Airborne hydrographic surveying:

LIDAR from aircraft will provide fast, synoptic mapping of the bottom of the river in the canyon but the impact of flying a relatively large plane (Twin Otter) low over the river may be an issue.

Perhaps more importantly, the spatial resolution of current generation systems is on the order of one meter and is perhaps a factor of ten too crude, and the water surface roughness and turibity may not allow for quality data acquisition.

E. Surveying from historical stereo photos:
It is in the Panel's opinion that capabilities and resources at GCMRC are not currently compatible to make full use of the historical, near-future, and mid-future photographic acquisition missions. These deficiencies include current staffing, expertise requirements, level of analysis difficulty, sources and magnitude of error, operational status, and quality control and quality assurance protocols.

FURTHER RECOMMENDATIONS:

- The Panel recommends that resources from other divisions within the USGS Campus, as well as outside contractors, be mobilized to execute specific missions. While this practice may be a good solution for the time being, the Panel recommends that GCMRC expand its in-house photogrammetric quality control and image analysis capabilities[2].
- GPS and IMU are technologies that have the potential of reducing, rather drastically, the GCP requirements for photogrammetric processing. The Panel recommends however that additional GCPs are provided in any photogrammetric coverage, and they must be sufficient in number, accuracy, and distribution. These points serve two purposes: first, for QC/QA, and second as a back up in case of GPS/IMU failures.

[2] A photogrammetric process includes all primary tasks starting with scanning, reformatting, interior orientation, exterior orientation, surface generation, editing, error assessment, and ending with orthophoto production. Image analysis include temporal, spectral, as well as sensor fusion capabilities.

Table 1: Summary of technology requirements for various accuracies

Accuracy meters	Technology/ Technique	Requirements	Limitations	Relative Cost	Level of Difficulty	Sources and Magnitude of Error	Op. Status	Required QC and QA
3	Photo-grammetry, Direct Geo-referencing	Aircraft/ Geodetic quality Camera Code-phase GPS receivers	Clear sky for observation. Not all points in the Canyon are visible from the air	Mission-dependent	Highly specialized data collection, analysis and processing	GCP, Photo quality, scanning, and operator	V.Good	High density of geodetic monuments and/or CORS, and staff trained in photogrammetry
1	Photo-grammetry	Aircraft/ Geodetic quality Camera	Same as above	Mission-dependent	As above	As above	V.Good	As above, also may require outsourcing
1	GPS	Code-phase GPS receivers	Parts of the Canyon are difficult to obtain GPS measurements	Back-pack units available for >$4,000	Relatively easy to train new users	Significant multipath error	V.Good	Staff trained in surveying and geodesy
0.3	GPS	dual-frequency carrier-phase GPS	Parts of the Canyon are difficult to obtain GPS measurements	Quality GPS units for $8-15k	Extensive training required for GPS	Significant multipath error	Good	Same as above
0.3	Traverse	Total stations	Intervisibility and ability to place definable permanent monuments	Total stations for $7-15k	Extensive data processing	Systematic errors; Magnitude: depends on specs of instruments; ≤ 1/15000.	Good	High density of geodetic monuments and/or CORS, and staff trained in surveying and geodesy
<0.1	GPS	Dual-frequency Carrier-phase	Parts of the Canyon are difficult to obtain GPS measurements	Quality GPS units for $12-15k	Extensive training for GPS data processors	Significant multipath error	Good	High density of geodetic monuments and/or CORS, and staff trained in surveying and geodesy

2. For conventional ground based terrestrial surveying please include a review of:

A. Equipment (sent as part of the previous mailing)

B. General calibration including maintenance and adjustments of instruments and tribrachs

C. Multiple angle and distance measurements to derive various levels of

D. Minimum and maximum distances traversed in combination with strength of measured angles

E. Adjustment procedures that should be used with conventional traverse measurements

F. Instrument and target height measurements

G. Back-sight checks

H. Atmospheric calibration of electronic distance measuring equipment (EDM)

I. Scale factor, etc.

ANSWER:

A. Equipment (sent as part of the previous mailing):

In the Panel's opinion, equipment is modern and adequate.

B. General calibration including maintenance and adjustments of instruments and tribrachs:

The Panel recommends that GCMRC adopt calibration procedures for all the equipment. The Panel further recommends maintenance, check up, and calibration schedules be established and adhered to. A calibrated base line should also be set up for calibrating total station and EDM instruments. The Panel recommends comprehensive calibration of all surveying instruments at least once a year. In addition, the Panel recommends that tribrachs be checked in the field prior to each survey mission.

C. Multiple angle and distance measurements to derive various levels of control: In the Panel's opinion, these procedures are adequate for the intended accuracy standards from the surveys.

D. Minimum and maximum distances traversed in combination with strength of measured angles:

In the Panel's opinion, these procedures are adequate for the intended accuracy standards from the surveys.

E. Adjustment procedures that should be used with conventional traverse measurements:

Please refer to B above. If an instrument displays large errors, the Panel recommends comprehensive calibration by a certified survey instrumentation specialist.

F. Instrument and target height measurements:

In the Panel's opinion, these procedures are adequate for the intended accuracy standards from the surveys.

G. Back-sight checks:

In the Panel's opinion, these procedures are adequate for the intended accuracy standards from the surveys.

H. Atmospheric calibration of EDM:

The Panel recommends that proper calibration procedures be established in accordance with the manufacturer's specifications.

I. Scale factor, etc.:

In the Panel's opinion, these procedures are adequate for the intended accuracy standards from the surveys.

FURTHER RECOMMENDATIONS:

It is in the Panel's opinion that, based on information provided, the methods and protocols are adequate for the intended accuracy standards of the terrestrial survey. The Panel strongly recommends, however, that testing, adjusting, and calibration issues be addressed sufficiently. These include calibration procedures, frequency, certification, etc.

3. For ground based GPS terrestrial surveying please include a review of GIS/database integration strategies and whether or not:

A. International Terrestrial Reference Frame (ITRF) values should be considered

B. We should be maintaining control ellipsoid or geoid values

C. We should be using tribrachs or fixed pole height set-ups for GPS observations

D. We should use "fast static" or kinematic applications

E. Whether or not adjusted GPS values be finalized without precise ephemeris data

ANSWER:

A. ITRF values should be considered:

The Panel recommends using ITRF for this purpose.

B. We should be maintaining control ellipsoid or geoid values:

The Panel recommends using NAVD 83, as well as keeping all measured data archived.

C. We should be using tribrachs or fixed pole height set-ups for GPS observations:

The Panel recommends using collapsible fixed height poles on the rim and in the canyon.

D. We should use "fast static" or kinematics applications:

This depends on the specific project and its specifications. The Panel recommends, in general, using fast static approach for critical controls.

E. Whether or not adjusted GPS values be finalized without precise ephemeris data:

The Panel recommends, strongly, that adjustment of GPS be carried out with ephemeris data.

4. For airborne terrestrial surveying please include a review of:
   A. Maximum PDOP values
   B. Minimum baseline distance
   C. Minimum number of base stations operating simultaneously
   D. Minimum epoch update rate and synchronization
   E. Requirements of simultaneous processing or averaging of multiple base-line vectors

ANSWER:

A. Maximum PDOP values:

Please refer to Question 4 Section B in Part I.

B. Minimum baseline distance:

Please refer to Question 4 Section B in Part I.

C. Minimum number of base stations operating simultaneously:

The minimum number of base stations in a simultaneous operation is an integral part of the survey design process. Typically, the 30 km rule applies, but whenever unusual terrain or signal blocking may occur, then additional base stations are required. The survey design should be laid out using a adequate terrain model and 3D software allowing for the analysis of direct base station to sensor to satellite communication.

In an area like the Grand Canyon with extreme terrain differences and corners/turns, it is likely that twice as many base stations would be required compared to traditional survey guidelines.

D. Minimum epoch update rate and synchronization:

This was previously answer as a 1 second update rate.

E. Requirements of simultaneous processing or averaging of multiple base-line vectors:

5. **For ground based hydrographic surveying please include a review of:**
   A. **Equipment**
   B. **Software (data collection, editing, and processing), boat positioning methods**
   C. **Hydro-acoustic frequency**
   D. **Patch test**
   E. **Integration of motion sensor**
   F. **Effect of heave component on lateral motion**
   G. **Motion compensation relative to eliminating heave component**
   H. **Yaw correction**
   I. **Accuracy of fluxgate compass**
   J. **Accuracy of fiber optics gyro**
   K. **Scan angle**
   L. **Automated statistical filtering**

ANSWERS:

A. Equipment:

Current GCMRC multi-beam system is a Reson Seabat 8124. This system has a flat array, which is prone to refraction at the sonar head and requires real-time measurement of the speed of sound at the array. Refraction at the head is not an issue with a curved array, such as the 8101, and would eliminate the need for an acoustic velocimeter at the head. Side scan sonar (SSS) capability is a valuable option and can be used for anomaly detection in editing and aid in substrate delineation.

The Panel recommends the use of a multibeam system with wider angular swath width (150 degrees). Table 2 shows a comparison of the two systems. A Reson 8101 mounted at a 15° offset would enable mapping from nadir (directly below the sonar head) out to horizontal from the sonar head (90 degrees from nadir) to one side of the vessel and from nadir through 60 degrees from nadir to the opposite side of the vessel. This would allow for better coverage on shoreline runs. Disadvantages of the Reson Seabat 8101 are: The sonar head weight (59lbs) and expense. Advantages are: Increased swath width, better range resolution and illuminates the need for a velocimeter at the head.

Table 2 Comparison of Reson Seabat models 8124 and 8101

Multibeam System	Freq. (kHz)	Range Resolution	Array	Swath Width	SSS Opt.	Beam Angle	Power Requirements
Reson Seabat 8124	200	5 cm	Flat	3.5 x dpth	Yes	1.5	200W – 110V
Reson Seabat 8101	240	1.25 cm	Curved	7.5 x dpth	Yes	1.5	62W – 110V

B. Software (data collection, editing, and processing), boat-positioning methods:
Hypack MAX is an excellent choice for data acquisition. Better software is available for data editing, analysis and presentation (Caris HIPS) but may require some modification for this unique application. The current range-azimuth positioning is the best solution given the state of technology, but it is costly. GPS/INS technology may, in the future, become capable to address the unique problems encountered in the steep canyons. Current systems, such as the POS/MV-320 from Applanix, are not suitable because of the limited visibility of the GPS constellations from the canyon floor.

C. Hydro-acoustic frequency:
Operating frequency in the 200-250 kHz is ideal. It matches the existing (and historical) single beam frequency of 210 kHz of the GCMRC Innerspace echo sounder. High frequency (>300 kHz) would provide improved range resolution but is likely to be too noisy for conditions and would not be consistent with 210 kHz single beam system. Lower frequencies (<100 kHz) are likely to degrade range resolution and would require a larger transducer to maintain the same angular resolution. Lower frequencies have a tendency to penetrate into fine sediments, thus increasing the ambiguity of the observations.

D. Patch test:
The Panel makes the following recommendations. Improved patch test procedures should be established and adhered to. A robust set of patch tests should be run for each field program. All lines should be run at slow speeds except for the compliment to the latency line. Roll test lines should be run in deep water over a uniform bottom. Routine latency tests should include lines run at different speeds (5 knot difference if possible), in shallow water, with nadir beams over target of opportunity (TOP), such as a 2 meter boulder on a uniform bottom. Pitch test should include running reciprocal lines over a TOP or slope in deep water. Use only nadir beams in pitch analysis. Include multiple test lines for confidence in computed values. Run patch test at beginning and end of deployment and if sonar head grounds or suspected change in alignment. Confirm bias values with swath overlap on TOP on regular basis. The detailed patch test results should be included in each survey report.

E. Integration of motion sensor:
The Panel recommends setting MRU pitch and roll reference to read 0 degrees, prior to patch test, with plumb prism/sonar head mounting pole for accurate position translation to sonar head.

F. Effect of lateral motion on heave component:
In the Panel's opinion, it is likely that the present attitude sensor (DMS-05) will result in heave artifacts under some circumstances. The Panel recommends careful analysis of the dynamics of the survey platform (from existing navigation, bathymetry and attitude data). The results of such an analysis should indicate whether the current senor is adequate. In the event that there are significant motion induced (or other) artifacts in the existing data sets, the Panel then recommends development of a

comprehensive error budget for the survey system (including the sonar, the attitude sensor, the heading reference and the navigation.) Such an error budget can then be used to evaluate expected results from improved equipment (Hare et al., 1995). The Panel recommends that GCMRC staff review some references on error budgets and survey practices published by the Hydrographic Society of America, http://www.thsoa.org/references.htm.
If the results of the analysis warrant procurement of better sensors, the Panel recommends conducting careful evaluation of potential upgrades, including field trials and subsequent analysis. This is to clearly identify an appropriate attitude reference system.

G. Motion compensation relative to eliminating heave component:
Currently the heave component is not applied. In relatively calm waters this will result in better vertical resolution provided use of 6 Hz update from range-azimuth system. Survey log should note if conditions include wind chop or significant waves from rapids. These areas should be examined for heave artifacts during processing and potential application of heave relative to 6Hz range-azimuth vertical reference.

H. Yaw correction:
The Panel recommends improving the accuracy of current heading sensor. It is possible that using a north seeking ring laser gyro, such as the Octans and PHINS from iXSEA, could provide an acceptable heading reference. It would also be a superior pitch, roll, and heave sensor. Technical data about Octans gyro can be found in http://www.ixsea.com/

I. Accuracy of fluxgate compass:
The fluxgate compass is prone to magnetic field interference from local attraction and systems aboard survey vessel and is not accurate enough. Currently available mechanical gyrocompasses or GPS/INS are not a viable solution. It is possible that the Octans Fiber Optic Gyrocompass (FOG) described above could be an effective solution. Until a replacement is available, GCMRC may have to continue to use the fluxgate compass. The Panel recommends testing magnetic field interference from power sources and instrumentation to locate source of observed problem when boat turns. The Panel recommends relocation of sensor and using more frequent yaw tests on bottom features with reciprocal lines and 10-20% overlap of outer beams.

J. Accuracy of fiber optics gyro:
Accuracy of previously available fiber optic gyrocompasses are substandard for the required accuracy due to drift problems because they are rate gyros. Newer, north seeking FOGs such as the Octans or PHINS may prove adequate. The Panel recommends detailed evaluation of one or more current-generation FOGs. The Panel further recommends using frequent yaw and repeatability patch tests on bottom features with reciprocal lines and 10-20% overlap of outer beams.

K. Scan angle:
The scan angle is a function of depth and reflectance angle. There is no reason why GCMRC can not use beams up to 85 or 90 degrees from nadir on shoreline runs with short ranges to shore and >40 degree reflectance angle. The Panel recommends that GCMRC document acceptable range for integrated system by redundant comparisons. The Panel further recommends that both shallow and deep-water cross-line analysis be run and documented for angle cutoff used in data processing. In addition, the Panel recommends that documentation include histogram of cross-line error analysis. It is possible that sound speed profile differences in backwaters and eddies may result in significant errors at wider angular swaths. GCMRC operates under the assumption that the entire water mass is isovelocity. The Panel recommends unbiased analysis to demonstrate whether this assumption is valid.

L. Automated statistical filtering:
The Panel cautions that such techniques could eliminate data that is helpful in analysis of anomalies and true bottom detection. One potential result is mapping the top of aquatic vegetation instead of the targeted bottom. Thus, the Panel recommends that such analyses be conducted with extreme caution. The Panel further recommends that detailed documentation of all processing methods be included in each data report. The Panel points to work by Brian Calder at CCOM/UNH who has recently made significant progress on this front. His existing methods, however, require substantial redundancy in the survey data, which may result in increased time on the water, cost and survey complexity.

REFERENCES:

Hare, R., A. Godin, and L. Mayer, ***Accuracy Estimation of Canadian Swath (Multi-beam) and Sweep (Multi-Transducer) Sounding Systems***, Canadian Hydrographic Service Report Series, 1995.

Blackinton, J. G., (1991), ***Bathymetric Resolution, Precision and Accuracy Considerations for Swath Bathymetry Mapping Sonar Systems***, IEEE Oceans '91, Honolulu, Hawaii, IEEE.

Calder, B. R. and L. A. Mayer, ***Robust Automatic Multi-beam Bathymetric Processing,*** http://www.thsoa.org/pdf/h01/3_4.pdf

6. **Based upon the written communication you have received and the oral presentation during the technical briefing session, please answer the following for each of the first four categories where protocols have already been established:**
   - **A. Is the method of error determination appropriate?**
   - **B. Are the survey data collection methods and technologies employed appropriate?**
     - **a. Do they meet "accepted survey practices" for required accuracy and precision?**
     - **b. Are there new or more appropriate methods and technologies?**
   - **C. Are the data processing methods being utilized appropriate?**
   - **D. Is the data being archived appropriately?**
   - **E. Is the QA/QC appropriate?**
     - **a. Consistency among staff**
     - **b. Internal accuracy checks**
   - **F. Is the documentation and record keeping appropriate?**
     - **a. Field notes**
     - **b. Office records**

ANSWERS:

A. Is the method of error determination appropriate?

Ground based terrestrial surveying: The Panel feels that the method of error determination is appropriate, and that the GCMRC staff has sufficient training to address this task.

Airborne terrestrial surveying: The Panel finds no protocols or procedures that appropriately apply to error determination for airborne terrestrial surveying.

Ground based hydrographic surveying: The Panel finds no protocols or procedures that appropriately apply to error determination for ground based hydrographic surveying. NOAA has established specifications for contract surveys (see: http://chartmaker.ncd.noaa.gov/hsd/specs/specs.htm Section 5 Depth Sounding). Although GCMRC is looking for tighter tolerances, these procedures should be followed to evaluate and minimize errors. The Panel recommends proper documentation of system comparisons and quality checks to improve confidence level by users and external evaluation. Specifically, the Panel recommends that GCMRC report the following: the results of patch tests, cross-line analysis, and sounding comparison to alternate source (pole sounding or overlap of topographic data); documentation of stated error budget, acquisition and processing methods, frequency and location of sound velocity casts, and calibration reports for velocity profiler.

Airborne hydrographic surveying:
The Panel recommends that a careful evaluation of the current capability of airborne LIDAR systems be made. A primary purpose for such evaluation is to assess the feasibility of implementing a carefully designed and controlled experiment to determine the efficacy of this technique in the Canyon. Among many other things,

the impact of low altitude flight needs to be evaluated versus the potential quality of data. NOAA has had good results with the Tenix LADS Corporation (http://www.tenix.com/Main.asp?ID=30) that owns and operates the Laser Airborne Depth Sounder (LADS). Although currently not in use by GCMRC, similar redundant comparisons recommended for ground based hydrographic surveying should be used to develop a level of confidence in the data.

B. Are the survey data collection methods and technologies employed appropriate?

a. Do they meet "accepted survey practices" for required accuracy and precision?

Ground based terrestrial surveying: Answered in Section II.2.

Airborne terrestrial surveying: GCMRC contracts aerial photographic acquisition to specialized firms. In general, these firms are equipped with appropriate acquisition methods and technologies, and GCMRC provides adequate SOW to these firms. The Panel strongly recommends however that more detailed specifications be provided describing the methods and technologies employed in the aerial acquisition; and stipulating penalties in case of noncompliance.

Ground based hydrographic surveying: The Panel finds that ground based hydrographic surveying meet accepted survey practices, but methods should be improved to obtain stated accuracy specifications. The Panel recommends improving documentation of confidence checks. The Panel recommends as a reference NOAA's document titled Specifications and Deliverables for Hydrographic Surveys (http://chartmaker.ncd.noaa.gov/hsd/specs/specs.htm).

Airborne hydrographic surveying: This technique is not yet proven useful in the Canyon. The results of the evaluation suggested above may eventually require re-evaluation of the method.

b. Are there new or more appropriate methods and technologies?
Most of this question has been already answered. Please refer to respective sections as appropriate:

Ground based terrestrial surveying: The Panel endorses GCMRC's use of total station instruments, since it is the best current technology available for ground based terrestrial surveying.

Airborne terrestrial surveying: Answered in Section II.1.B.

Ground based hydrographic surveying: Answered in Section II.5. In addition, there have been advances in heading sensors which would improve overall system accuracy.

Airborne hydrographic surveying: The Panel finds that current technology may not meet GCMRC accuracy requirements.

C. Are the data processing methods being utilized appropriate?

Ground based terrestrial surveying: Answered in Section II.2.

Airborne terrestrial surveying: The Panel found that GCMRC did not have in-house capabilities to process aerial and remote sensing imagery using standard photogrammetric procedures.

Ground based hydrographic surveying: Answered in Section II.5. No review or documentation of data processing methods was provided. The Panel recommends that GCMRC implements procedures described earlier to document survey and data processing methods. In addition, Hypack continues to improve on data processing abilities and is adequate.

Airborne hydrographic surveying: GCMRC does not conduct hydrographic surveying using airborne platforms. Unless a need arises in the future, the Panel does not recommend this approach at the present.

D. Is the data being archived appropriately?

Ground based terrestrial surveying: Based on the description provided for review, the Panel finds current archiving procedures to be appropriate for ground based terrestrial surveying. It is important that some type of back up system exists such as tape.

Airborne terrestrial surveying: The Panel found that current online and offline archiving capabilities support only fraction of aerial and other remote sensing imagery. These needs will become more critical if historical photography is to be converted into digital files. Additional storage and archiving capabilities with robust software will be needed for derivative and processed imagery.

The Panel recommends evaluation of storage, archiving, and networking needs based on post-conversion softcopy processing of historical photography.

Ground based hydrographic surveying: The Panel found no archiving protocols or resources specific to ground based hydrographic surveying.

The Panel recommends that all raw data files be archived along with files generated at all stages of the processing pipeline.

Airborne hydrographic surveying: The Panel found no archiving protocols or resources specific to airborne hydrographic surveying.

E. Is the QA/QC appropriate?

This question has been partially answered in Section II.1. In addition, there was no specific documentation of QA/QC procedures to review during the protocol evaluation. The Panel therefore recommends establishing appropriate QA/QC procedures for each of the four measurements categories. The Panel further recommends that contractors and subcontractors submit their QA/QC procedures specifically used to realize the contracted specifications.

a. Consistency among staff:

The Panel found no established procedures to ensure consistency among staff. Such consistency becomes critical especially when SOW, specifications, data, and procedures are communicated among various organizational units of GCMRC.

b. Internal accuracy checks:

The Panel found no established procedures to verify adherence to accuracy specification. This applies to internal operations as well as contracted work. Section I.10 addresses QA/QC adherence requirement and enforcement recommendations. The Panel recommends establishing internal verification and validation protocols, including methodology, equations, checkpoints, and certification. The Panel recommends that GCMRC staff, or an independent third party, verify adherence to these protocols in internal as well as contracted work.

F. Is the documentation and record keeping appropriate?

a. Field notes
b. Office records

The Panel stated specific findings and made recommendations throughout this document. These include Section I.3 on data standards and delivery; Section I.5 on coordinates; Section II.6.A on error determination; and Section II.5 on hydrographic measurements.

7. Please provide recommendations to correct observed deficiencies:

ANSWER:

Recommendations previously noted following each question.

Appendix I

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Appendix II
Survey Protocol Evaluation Panel Questions

Part I: General Questions:

1. Are control networks, conventional survey, and remotely sensed data collection protocols adequate for integrating land based survey data with remotely sensed?

2. Are site locations for control and other survey sites appropriate? Are they being appropriately monumented?

3. Are the data standards relating to spatial data appropriate (section F)?

4. Is the current remote sensing statement of work sufficiently defined relative to spatial positioning of remotely sensed data? Please include a review of PDOP, minimum epoch update rate and synchronization, and simultaneous processing or averaging of multiple base-line vectors.

5. Because geoids are modified periodically and positional data are acquired for many GCMRC program requirements on an annual basis, what is the most appropriate format (level of processing) for permanent storage of collected data that are used for historical or temporal analyses? Should all the coordinate values be archived, maintained, adjusted, and published as Cartesian and/or WGS 84 values as to bypass geoid model problems?

6. Geoids are established using available gravity data for a region. The Grand Canyon is a narrow, deep void that has dramatic changes in bedrock densities along its corridor, both of which effect local gravity. What effect does (can) each of these two factors have on surveys within the Grand Canyon that currently use control established from canyon-rim base stations? What are the potential magnitudes of these effects on positional accuracy and can they exceed the target positional accuracy for GCMRC? If, so, how can better control be established?

7. Do we need to improve the geoid locally? If so, how?

8. What are the issues surrounding conversion between NAVD29 and 88? Which vertical datum do you recommend using?

9. What are the issues surrounding ellipsoid to orthometric height conversation?

10. Due to the extreme nature of the Canyon environment, is it reasonable to contract terrestrial and hydrographic surveying firms to perform or assist the GCMRC survey department in Colorado River Ecosystem operations?

11. Is the staffing level and qualifications of the survey department appropriate?

Part II: For each of these five categories:

A. Ground based terrestrial surveying
B. Airborne terrestrial surveying
C. Ground based hydrographic surveying
D. Airborne hydrographic surveying
E. Surveying from historical stereo photos

1. Please describe the requirements, limitations, relative cost, level of difficulty, sources and magnitude of error, operational status, and required quality control and quality assurance of all surveying technology/technique combinations that can be used to locate points on the Earths surface in two or three dimensions using real world coordinates to within 3 m (meters), 1 m, 0.3 m, and less than or equal to 0.1 m. In addition to a detailed discussion in the report, please summarize your findings in a table of which an example is provided below.

Accuracy in meters	Technology/ Technique	Requirements	Limitations	Relative cost	Level of difficulty	Sources and magnitude of error	Operational status	Required quality control and quality assurance
3								
1								
0.3								
<0.1								

2. For conventional ground based terrestrial surveying please include a review of:
   - equipment (sent as part of the previous mailing)
   - general calibration including maintenance and adjustments of instruments and tribrachs
   - multiple angle and distance measurements to derive various levels of control
   - minimum and maximum distances traversed in combination with strength of measured angles
   - c adjustment procedures that should be used with conventional traverse measurements
   - instrument and target height measurements
   - back-sight checks
   - atmospheric calibration (edm ppm)
   - scale factor, etc.

3. For ground based GPS terrestrial surveying please include a review of GIS/database integration strategies and whether or not:
   - ITRF values should be considered
   - we should be maintaining control ellipsoid or geoid values
   - we should be using tribrachs or fixed pole height set-ups for GPS observations
   - we should use “fast static” or kinematic applications
   - whether or not adjusted GPS values be finalized without precise ephemeris data

4. For airborne terrestrial surveying please include a review of:

    - maximum PDOP values
    - minimum baseline distance
    - minimum number of basestations operating simultaneously
    - minimum epoch update rate and synchronization
    - requirements of simultaneous processing or averaging of multiple base-line vectors

5. For ground based hydrographic surveying please include a review of:

    - equipment
    - software (data collection, editing, and processing), boat positioning methods
    - hydro-acoustic frequency
    - patch test
    - integration of motion sensor
    - effect of heave component on lateral motion
    - motion compensation relative to eliminating heave component
    - yaw correction
    - accuracy of fluxgate compass
    - accuracy of fiber optics gyro
    - scan angle
    - automated statistical filtering

6. In addition, based upon written communication you have received and oral presentation during the technical briefing session, please answer the following for each of the first four categories where protocols have already been established:
    A. Is the method of error determination appropriate?
    B. Are the survey data collection methods and technologies employed appropriate?
        a. Do they meet "accepted survey practices" for required accuracy and precision?
        b. Are there new or more appropriate methods and technologies?
    C. Are the data processing methods being utilized appropriate?
    D. Is the data being archived appropriately?
    E. Is the QA/QC appropriate?
        a. Consistency among staff
        b. Internal accuracy checks
    F. Is the documentation and record keeping appropriate?
        a. Field notes
        b. Office records

7. Please provide recommendations to correct observed deficiencies.

Appendix III
Documentation of advice

Steve,
I talked with a mapping expert at the Mid-continent mapping center (USGS) in Rolla, MO today. His name is Mike Pace (573-308-3771). He is One hour ahead of AZ. He teaches a mapping course on Monday, but will be in the office today and the rest of next week.

One definitive piece of advice he gave was NOT to put the data in geographic lat, long because it induces too much distortion. The remaining options are UTM and State Plane, each has their own drawbacks and advantages. Both projections are conformal and designed to retain shape, but not true area. Both have errors associated with distance measurements, but the State Plane is more accurate giving on 1 part per 10,000 error in distance, whereas UTM gives 4 parts error per 10,000 units of distance.,which is why state's adopted their own state plane projections to minimize the error in distance measures for a particular region. Although UTM would produce a single database within a single zone, its error is higher and reprojection to the state plane quadrants would require resampling of data because UTM and state plane have different orientations. He said the disadvantage of state plane is that the study area crosses three different SP quadrants and G1S .software (as far as he knows) cannot handle analyses on an area with I1multipleprojectios. He said it might be advisable to keep the data in two projections: one for the site specific studies that require high accuracy measurements(SP)and another that can display all of the GCMRC area as a single database (UTM). If SP is the projection for storing the original data (to maintain accuracy), can EQ process their data into 3 SP quadrants?

I told Mike Pace that you might call him later today or next week to get this information directly. He said that is fine. He will be out all day Monday teaching a class.

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Appendix IV
Abbreviations of Terms used in the Report

CORS	Continuously Operating Reference Station
CRE	Colorado River Ecosystem
ECEF	Earth-Centered Earth-Fixed
EDM	electronic distance measuring equipment
FEMA	Federal Emergency Management Agency
FGCC	Federal Geodetic Control Committee
FGCS	Federal Geodetic Control Subcommittee
FGDC	Federal Geographic Data Committee
FOG	Fiber Optic Gyrocompass
GCMRC	Grand Canyon Monitoring Research Center
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
INS	Inertial Navigation Systems
IMU	Integrated Measurement Unit
ITRF	International Terrestrial Reference Frame
LIDAR	Light Detection and Ranging
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NBII	National Biological Information Infrastructure
NGS	National Geodetic Survey
NGVD 29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NSDI	National Spatial Data Infrastructure
NSRS	National Spatial Reference System
PDOP	position dilution of precision
PEP	Protocol Evaluation Program
QA/QC	Quality Assurance / Quality Control
SOW	scope of work
SSS	Side scan sonar
TOP	target of opportunity
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WGS 84	World Geodetic System 1984