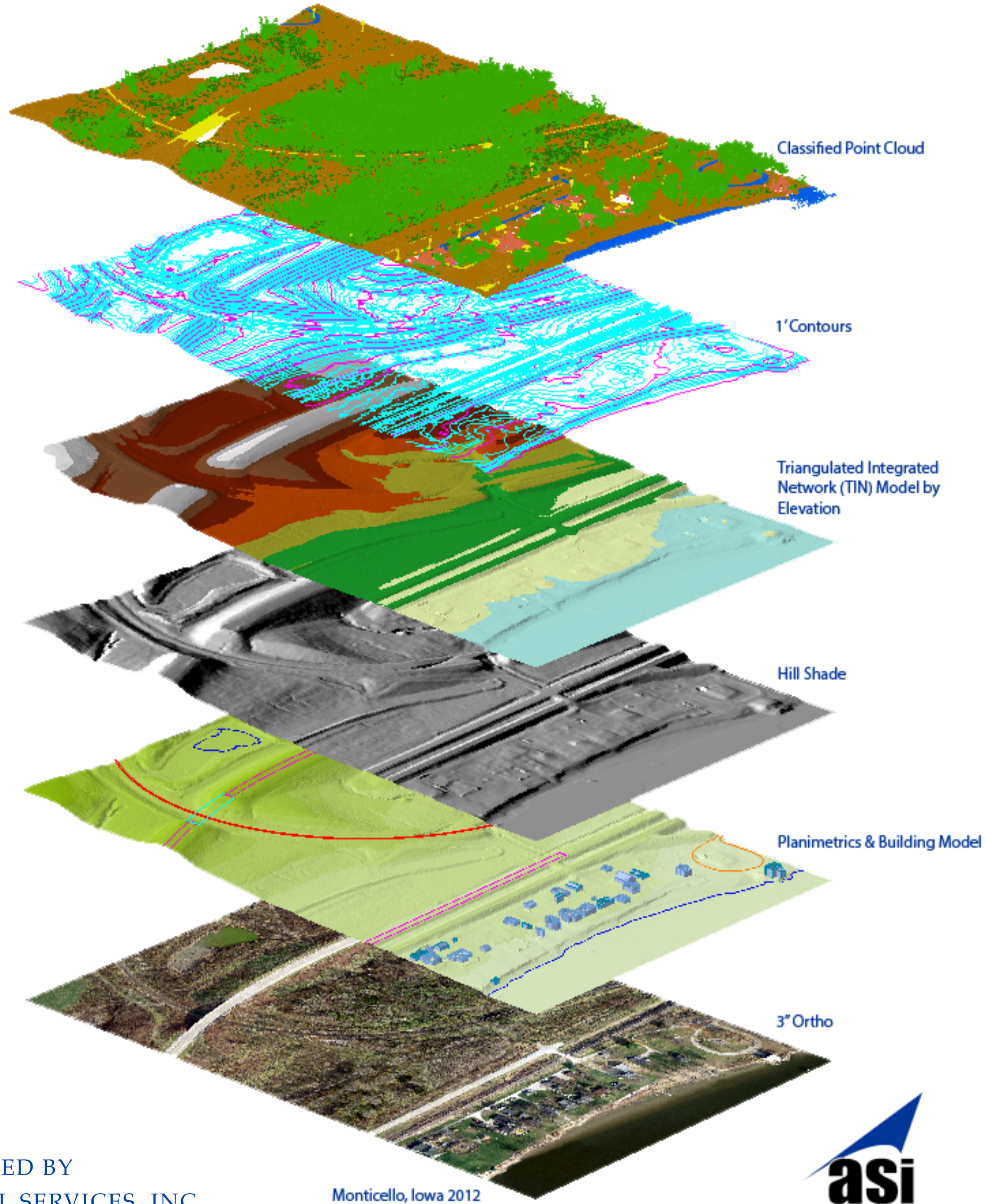
DEVELOPING AN INDEPENDENT COST ESTIMATE FOR GEOSPATIAL SERVICES

Geospatial Contracts Cost Estimating



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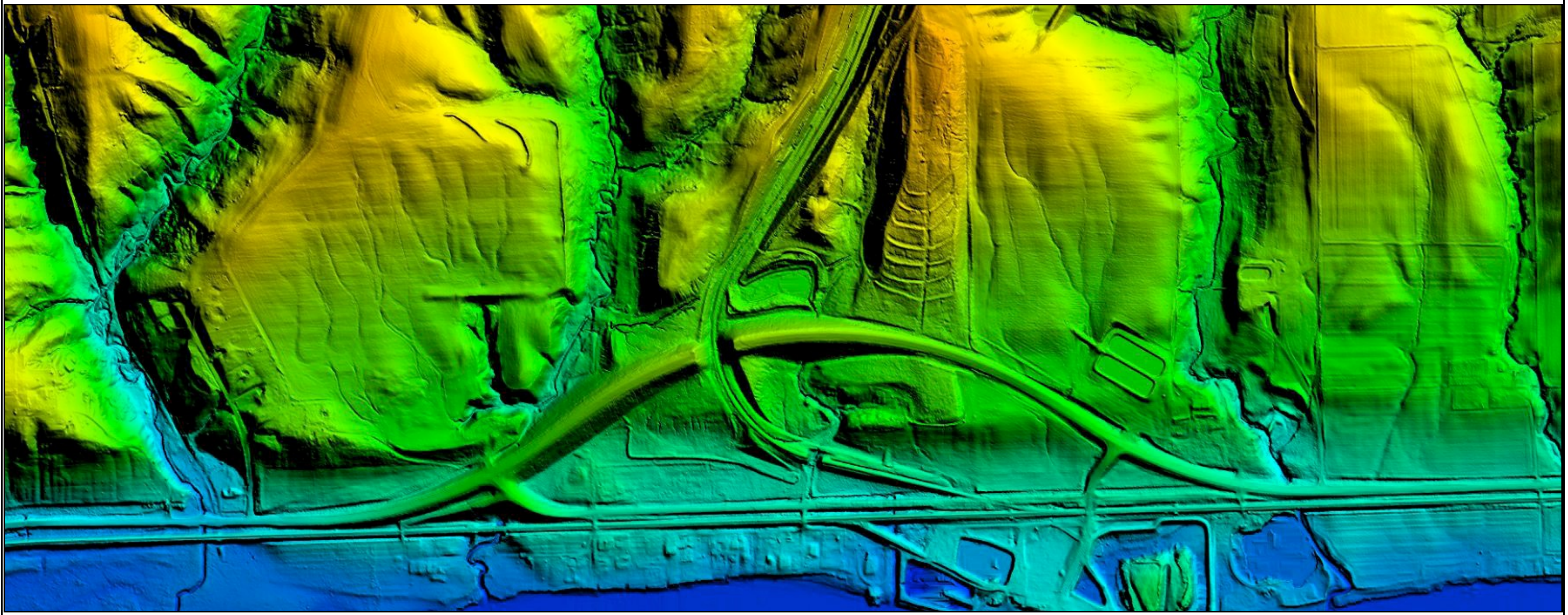
AERIAL SERVICES, INC.

CHAPTER 1

Research & Proposal



"Before writing an RFP or initiating a solicitation for professional services or data, it is important that the author understands the scope of the needs, the stakeholders, and what type of solicitation is required."

Project Scope

Orthoimagery

An ortho is a photograph prepared from a perspective photograph by removing displacements of points caused by tilt, relief, and perspective.

Before writing an RFP, performing Market Research, or initiating a solicitation for professional services or data, it is important that one understand the scope of the needs, the stakeholders, and what type of solicitation is required.

How best to procure and the eventual cost of the needed services is highly dependent on the scope of the project. Important questions to consider include the following:

Have the stakeholders (the individuals, organizations or groups that will bear the cost, use or benefit by the procured services) been identified?

Have the needs of the stakeholders been systematically identified and addressed? How will their needs affect scope, schedule, and costs?

Downstream Users: Have potential users (or benefactors) of the data or professional services been identified? Do their needs or use of the data affect the project scope?

Team Size: Will the solicitation require a single contractor or a large team of contractor(s) and subcontractors? The project can be an order of magnitude more complex to administer if multiple firms (or teams) are needed.

Capacity of Service Providers: Is the capacity of the profession sufficient to meet the needs in the required timeframe? Some projects' scope, timeframe, or specifications may be unachievable using available providers. Consider changing the scope or timeframe of the project.

Technology: Have we identified and do we understand the relevant technology and options needed for the required professional services and data?

Costs: Do we understand the relative effect on "costs" for each specification described? Have alternative solutions been discussed that meet our objectives?

Solicitation Type

What Quality Of Service Do You Need?

The method used for procuring professional services can have a significant bearing on the outcome of the project and quality or timeliness of the services and data rendered. Common sense, good judgment, and verification of qualifications are prerequisites to a successful procurement.

How professional services or data are solicited is often mandated by law. When a specific method is not mandated, there are several methods available. The method used can have a significant bearing on the outcome of the project and quality or timeliness of the services and data rendered. Common sense, good judgment, and verification of qualifications are prerequisites to a successful procurement.

REQUEST FOR PROPOSALS (RFP)

A request for proposal is an invitation for offerors, often through a bidding process, to submit a proposal on a specific commodity or service. RFPs often dictate the structure and format of the offeror's response. They are a price-based solicitation meaning that the offerors bidding on the project must include pricing information with the proposal.

An RFP can very clearly describe the specifications of a project: budget, benchmarks, expected outcomes, standards, etc. Offeror proposals provide a basis for choosing among seeming equals. But are they equals? Are they equally qualified to perform the services and deliver the data as you requested when you requested? Is one offeror's proposed methods superior or more likely to produce the required deliverables than another's very different methods? When procuring professional services, using RFPs may not always be the appropriate tool.

Professional services are not commodities. They are designed and prescribed to fit the specific needs of the stakeholders. They are often unique and tailored to a specific scenario. They cannot be purchased at Ace Hardware or off-the-shelf. Additionally, the taxpayer and other stakeholders need some measure of confidence that the services or data meet important quality and safety standards and that the services or data were delivered by qualified professionals not just by anyone that won the bidding contest.

The major drawback to this approach when procuring professional services is that the stakeholders have been unable to leverage the expertise of the professionals in the firms so the project design is optimal and designed to deliver maximal value to the stakeholders using the wisest mix of technology and methodology. Instead, the RFP may dictate exactly what deliverables were needed and when. The bidders often propose very different methods to meet those specifications. This then leaves the review board (often populated with few members qualified to assess the technical or practical merits of a proposal) in the position of deciding which method has maximal value and makes the most sense except by comparing price which is often the an unreliable indication of competence or quality.

QUALIFICATION-BASED SELECTION (QBS)

Selecting qualified geospatial professionals is a key ingredient to a successful project. The project design will determine the costs, financial and functional feasibility and the operation and maintenance costs during the life of the project. QBS is an objective, flexible, and fair process to select professional engineers, photogrammetrists, land surveyors and GIS technicians based on the professionals' experience and credentials. Only after qualified-firms have been identified and selected is "pricing" negotiated. The pricing is often negotiated after consultation with the firm about the application of best practices to meet the needs of the stakeholders. The cost of services plays no role in the initial selection of qualified firms.

Fifty states impose strict educational and registration or licensing requirements for surveying professionals, and many include mapping in such licensing laws. The high standards established by organizations for their members exemplify the professional nature of their work. These standards are designed to protect the public health and safety during and after contract performance. Some states even prohibit licensed professionals from engaging in competitive bidding.

The Brooks Act (Public Law 92-582), passed in 1972 rejected idea of price competition for architectural and engineering services and enacted the federal Brooks A-E Act. Surveying and mapping activities are included in the definition of A-E services defined by the Brooks Act. The FAR Act [(FAR) 48 CFR 36.601-4(a)(4)] specifically includes surveying and mapping activities as services subject to section 36.601 of this act and must be procured using QBS. Since that time many states have implemented similar legislation commonly referred to as "mini-Brooks Acts".

QBS protects those procuring professional services by ensuring that only the most qualified firms can be awarded the project. It minimizes the probability (although does not guarantee) that unqualified or poor performing professionals perform the contracted services. All bidders' qualifications are assessed independent of price and un- or under-qualified firms are discovered and eliminated before contract award. Using price bidding procedures, however, the low bidder wins regardless of their "fitness" or qualifications for delivering the professional services.

The entity procuring professional services often does not have the expertise required to adequately define the scope and operational methods to accomplish project objectives. This can lead to misunderstandings and misinformation about the project scope and expectations and ultimately to deliverables that may not meet the needs of the stakeholders.

For a more thorough explanation of this subject please see:

- "Quality Based Selection for Professional Mapping Services," Appendix A of this document.
- "Detailed Workbook for Qualifications-based Selection," American Council of Engineering Companies (ACEC), November 2004, http://www.qbs-mi.org/pdf/2004_QBS_workbook.pdf (accessed January 5, 2010).
- American Institute of Architects, *Qualifications Based Selection: A Process for the Selection of Architects by Public Owners* (January 2006).

PROCUREMENTS USING A MIX OF PRICE AND QUALIFICATION

When QBS is not the legislated procedure for procuring professional services, solicitation procedures can be used that balance the tension between price and quality. Often this process may use an RFP but request that pricing be submitted in separate sealed envelopes. Then the RFP review board selects one or more proposals based on their references, experience, the quality of the proposal, and the aptness of the methods. Only after this decision on the firms most qualified to perform the services are the price quotations of the qualified firms reviewed and a selection made.

The major drawback to this type of approach is similar to that of the RFP process. When the insight and skill of geospatial engineers and professionals are not used to design an approach to the problem that best matches the need of the stakeholders, the qualifications of the firm, and the merits of existing technology, the safety of the public and value to the taxpayer can be compromised. Be-

Licensing Data

Licensing Data

If licensed, the data can often be procured at less expense because the licensor is able to sell or lease the data to multiple parties.

Licensed data is data not wholly owned or controlled by the licensee. All or part of the ownership and control of how the data is used resides with the licensor. The licensor grants the licensee certain rights and privileges for using the data. Frequently, the data may not be resold or used by entities other than those listed on the license.

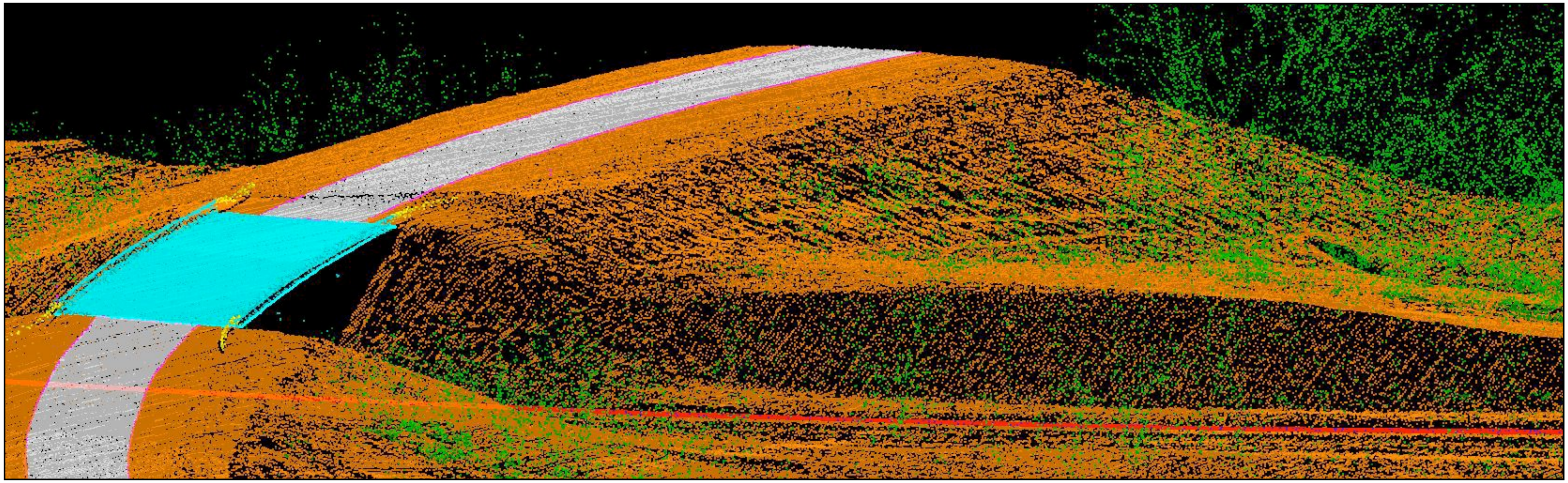
License terms are many and varied. Some of the more common or most discussed include the Creative Commons license, the Open StreetMap license, and ODC Open Database License (ODbL). There are a number of legitimate reasons why data procured using public monies should and should not be available without cost to the public which are fascinating but beyond the scope of this discussion.

Once the data for a geospatial project is procured, will it be licensed or wholly owned by you? If owned by you, how will you control its distribution? Will you require some type of payment for costs associated with requests for the duplication of the data? Will you allow others to make derivatives from the data? Can others obtain copies and resell it?

If licensed, the data can often be procured at less expense because the licensor is able to sell or lease the data to multiple parties. Conversely, there are added costs associated with managing the license that should be carefully considered. Licensed data often includes flexible terms such that any government agency (and related agencies and contract personnel) is allowed unrestricted internal use of the data. If licensed, how will access to the data be guaranteed if the licensor is purchased, sold, or goes out of business? Who will need access to this data? How will the data need to be used: streamed, downloaded, processed? What uses of the licensed data are allowed? Can the data be resold by me or others? Are other agents for our organization (e.g., subcontractors or associates) allowed to use the licensed data? These and many other questions should be answered before agreeing to purchase licensed data.

Paper or Digital Submissions

Classified LiDAR

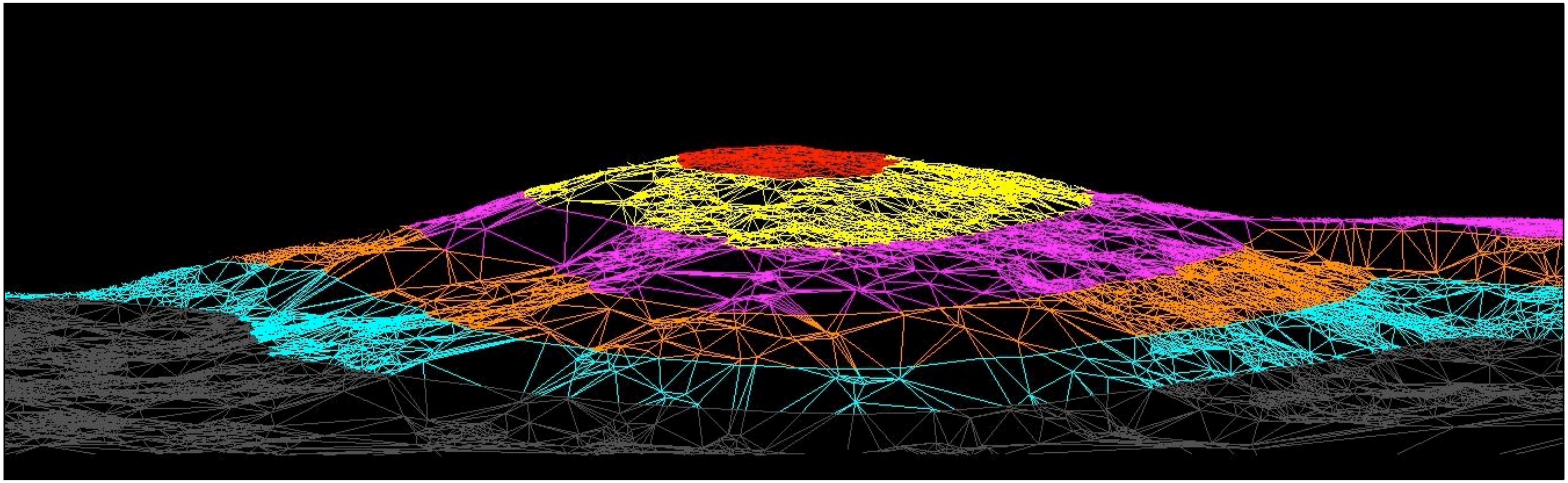


Files may define the classification as ground and unclassified while another user prefers to see the unclassified further classified to additional levels, including vegetation, buildings and water.

Will the project proposal and qualification materials be required as bound paper or digital submissions? Procurements are often released that require multiple bound paper copies even when digital copies would be less expensive and facilitate more rapid dissemination among contracting officers and other staff. Requiring hard copy submittals may be convenient for some, but is often more costly and cumbersome.

Bid Bond

Triangular Irregular Network (TIN)



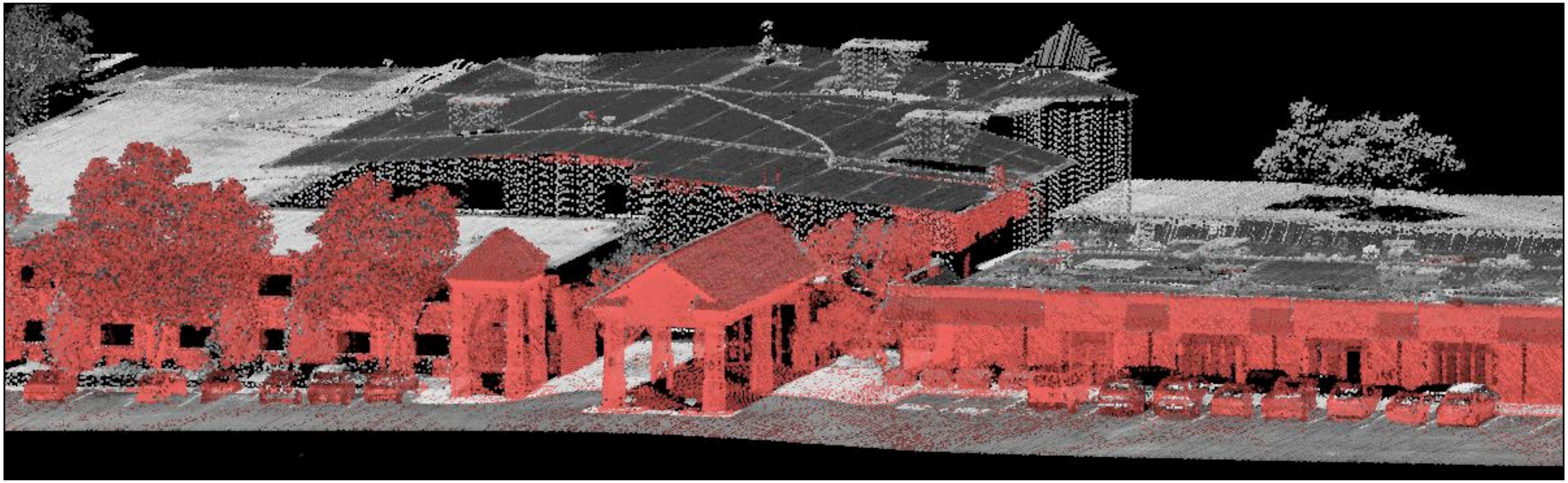
A TIN is a vector-based model which represents geographic surfaces as contiguous non-overlapping triangles. The vertices of each triangle are known data points (x,y) with values in the third dimension (z) taken from surveys, topographic maps, or digital elevations models (DEMs). The surface of each triangle has a slope, aspect, surface area, and continuous, interpolated elevation values.

A bid bond (or surety bond) is a financial guarantee ("insurance" issued as part of a bidding process) to the project owner, to guarantee that the winning bidder will undertake the contract under the terms at which they bid. The bid bond protects the purchaser against financial loss if the bidder withdraws its bid or does not, within the time required, enter into a formal contract.

Bid bonds are an unnecessary expense if the professional services are procured using QBS and other methods that ensure only firms with demonstrated qualifications and performance are contracted. If QBS or similar contracting procedures are not used, then bid bonds may bring a measure of confidence that the services will be rendered but not without added cost. A bid bond does nothing to ensure that the services procured will be from quality professionals.

Deliverables

Mobile & Airborne LiDAR



Mobile and Airborne LiDAR data can be merged to create a full three-dimensional picture of a any location. In this example, the red data points represent mobile LiDAR acquisition and the white points were acquired using an aircraft.

When procuring professional services it is important to enlist the technical expertise of those professionals most knowledgeable about those services. These are usually experts working with the firms that will be competing for the procurement. It behooves the contracting officer to engage these experts to the maximum extent possible to help define deliverables using the best technology and best practices so the value and utility of the procured services are maximized.

Technology changes rapidly. Recent advances in technology may make one type of deliverable or method of delivery more expensive or less important than one in common use previously. Some qualified firms may have procured new equipment or discovered superior methodologies that the contracting officer could not be aware. Therefore, it is important that contracting officers consult with qualified firms and discuss the fundamental needs of the end users and exploit the professionals' expertise to define the deliverables and methodology used to create and deliver them.

If deliverables are defined in the solicitation without this expertise it may likely create unwelcome tension with "best value". If professional services are procured as "lowest price" this can often deflate the utility of the final product to the end user, at best, and at worst create public hazards.

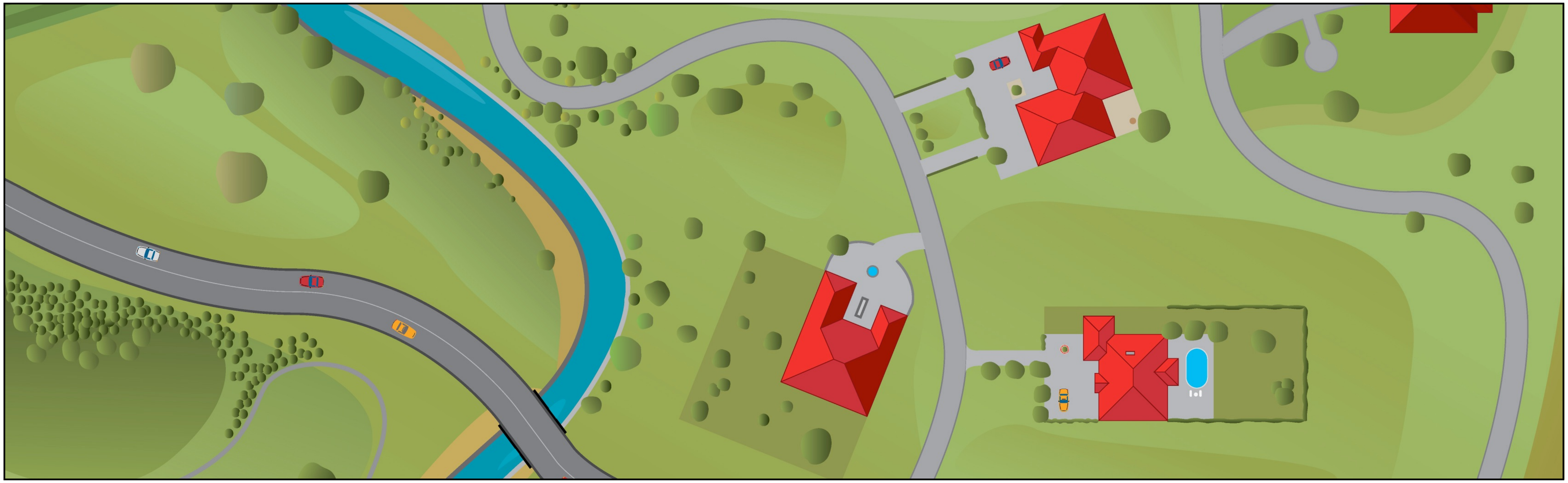
It can at times be advantageous to allow contractors to propose additional deliverables (or different formats) if that would improve the final product or enhance production efficiencies. Contracting officers should also be cognizant of the fact that deliverables cost money and if unnecessary reports or other deliverables are required, it takes funds away from the actual intent of the project.

The discussion below lists many of the most important factors that should be considered with a specific type of deliverable in a mapping project. The importance of each to the scope, cost, and complexity of the project is also indicated using a "star" rating system. Because end-user needs and technology are in constant flux this cannot be an exhaustive list. But given the state of technology and business today, the factors listed below, if understood and carefully considered with geospatial professionals, should contribute to a more successful procurement.

Opinion: How NOT to Procure Professional Services

By Mike Tully, President & CEO Aerial Services, Inc.

Professional Services, Not A Simple Commodity



As professionals procuring "stuff" we are accountable to others for the money we spend and the things we buy. But professional services are not "widgets". Your health is not a widget. Your tooth extraction is not a commodity item. Building a bridge or acquiring a useful digital terrain model (DTM) is not the same as hiring someone to service your photocopier or replace your oil filter.

I love amazon.com. Knocking off my Christmas list by finding the cheapest price for all is glorious. Reading real customer reviews about the product ... priceless. By using Amazon-like tools, I am fairly certain that the best price is happening. Procuring professional services can't and shouldn't be procured as if they are widgets.

We all want a "deal". This economic freedom of downward pressure on "price" and upward pressure on value by encouraging innovation and performance is what has driven America to be the most incredible economic engine with the most personal liberty the world has ever known.

As professionals procuring "stuff" we are accountable to others for the money we spend and the things we buy. But professional services are not "widgets". Your health is not a widget. Your tooth extraction is not a commodity item. Building a bridge or acquiring a useful digital terrain model (DTM) is not the same as hiring someone to service your photocopier or replace your oil filter. There is value in how the dentist extracts my tooth, manages my pain and treats me when I'm in his office or being billed. There is value in how a DTM is acquired and produced. Its accuracy and timely delivery add value. There are better ways to procure professional services than simply "lowest price".

So as our profession works through another "procurement" season and many RFPs for professional services hit the streets, here are ways NOT to procure professional geospatial services.

How NOT to Write a Solicitation

1. Cut & paste specifications into your proposal from others if they are "pretty close" to what we want. A little ambiguity is ok.
2. Be unclear in specifications because we don't mind comparing apples or oranges. What's wrong with bidders making wild assumptions about what we really want and how we will score their proposals.
3. Go ahead and use terms you don't fully understand, e.g. topo, aerial, geoid, DEM/DTM. That's what everyone else says is needed.
4. Don't ensure all the technical requirements are sufficiently described. It's not really important to us to differentiate between acceptable and unacceptable bids or discover a "better approach" among the proposals.
5. Don't have the RFP final draft reviewed by knowledgeable professionals to ensure it is clear and aligned with our actual needs. We love to answer dozens of questions from respondents about the same puzzling specification.
6. Use the same specs as last year. Technology and innovation never occurs.
7. Set the minimum acceptable technical and performance requirements good and low so everyone can bid.
8. Specify the actual flights heights from which you want your imagery and lidar acquired. After all aren't all sensors the same. I know I'm not an operator of that sophisticated equipment, but I do "know" how best to acquire it.

Professional geospatial services are, by definition, complex. Every procurement is unique. It's not like making "frisbees". Weather, stakeholder demands, equipment performance, and a variety of other factors contribute to a project's complexity. Further, professional standards of accuracy and quality continue to evolve as technology advances. Don't recycle ambiguous, unneeded RFP language. Technical specifications need to align with unique stakeholders' needs. It is imperative those writing the RFP understand the relevant technology and how to clearly define specifications. The writers need not be experts but they must understand the basics. If not, get help from those service providers or other neutral third parties. They should not dictate "how" the work should be done, but instead, simply define what the deliverable needs to be. Don't ask for more quality or accuracy than your stakeholders really need or you're just wasting good money and losing "value".

If specifications and minimum acceptable requirements are too low then marginally acceptable bidders become candidates for contract award, low price becomes the determining factor, and the risk of project failure, threats to the public and low quality deliverables are more likely and “value” declines. Setting good minimum standards also protects the client and providers from positive bias toward those bidders who are able to far exceed those minimums. For example, the smaller company with less but acceptable experience, for example, still "passes" the threshold and can compete on equal footing with the larger firm. A small firm's innovation and responsiveness can win them a seat at the table and ultimately bring additional value to the stakeholders.

Not all projects can have clear specifications at the outset because of their complexity or novelty. Sometimes new technology is being used and no provider has tons of experience using it and “how to do it" and its associated costs are simply unknown. In these cases, specify a pilot project. This will help the client and provider work out these details and set a reasonable price based on real world experience doing the needed work. Some of the approaches that can be taken to mitigate these risks when writing an RFP are:

- Set related project experience specifications. Require a minimum number of similar projects to have been completed in the last 12 months to demonstrate familiarity and experience with the work.
- Require key project personnel to meet minimum experience and education thresholds. That said, don’t make these too arbitrary. You don't want qualified bidders disqualified simply because a proven project manager didn't have a Master's degree in Geography, for example.
- Set technical standards such that inferior or marginal equipment cannot be used.
- Set clear and appropriate positional accuracy standards so sub-par work is not allowed and "quality" can be objectively measured in the deliverables. I can't count the number of times I've seen RFPs and talked with stakeholders that express a sincere desire for "accuracy", but their RFP criteria fail to set meaningful, measurable standards for accuracy.

Lowest Price Solicitations

1. Go low bid! We love sub-par contract staffing, marginal technical accomplishment, late deliveries, and cost overruns. Let's go low bid!
2. Go low bid so contractors are encouraged to pay the lowest possible amount to the least qualified staff, cut corners, and keep unemployment high.
3. Go low bid and enjoy adversarial relationships with our providers as their performance slides and our [unrealistic] expectations of timeliness and quality erode.
4. Go low bid because we love explaining to our board why more money is needed to get the job done or the deliverables we received are sub-par.
5. Go low bid because you don't really want to have any confidence that the geospatial data received really is "fit" for its intended use.
6. Go low bid because we don't care about the "best" way, just the cheapest.

"Lowest price" bidding is inappropriate for professional services. Lowest price technically suitable RFPs are not suitable for procurements with complex services or uncertain performance risk. When the client applies this strategy to unsuitable procurements, both the client and the providers lose. When the client is a government entity, we all lose because our taxes are being wasted on inefficient, unsafe, and possibly unneeded services. Generally, as price is pushed downward, performance risk goes up. At the end of the day, the lowest bidder's reputation suffers, their fiscal health is probably hurt because of low or negative profitability, and the client is criticized for cost and schedule overruns and for failing to manage their program correctly. In the end, everyone loses and the initial satisfaction of saving a few thousand bucks is often overshadowed by the burden of poor contractor performance.

Qualifications-Based Selection (QBS)

When clients use qualifications-based selection (QBS) or Best-Value procurements (where price is not a consideration until after the most qualified firms has been identified), they recognize that there is value in non-cost factors such as public safety, public welfare, technical approach, management plan, and past performance, to name a few. These tradeoffs give the client the latitude to award a contract to other than the lowest priced offeror because of that added value.

The Brooks Law, adopted by Congress in 1972, was amended in 1989 to add that qualifications-based selection procedures apply to the professional services of surveying and mapping. QBS is simple.

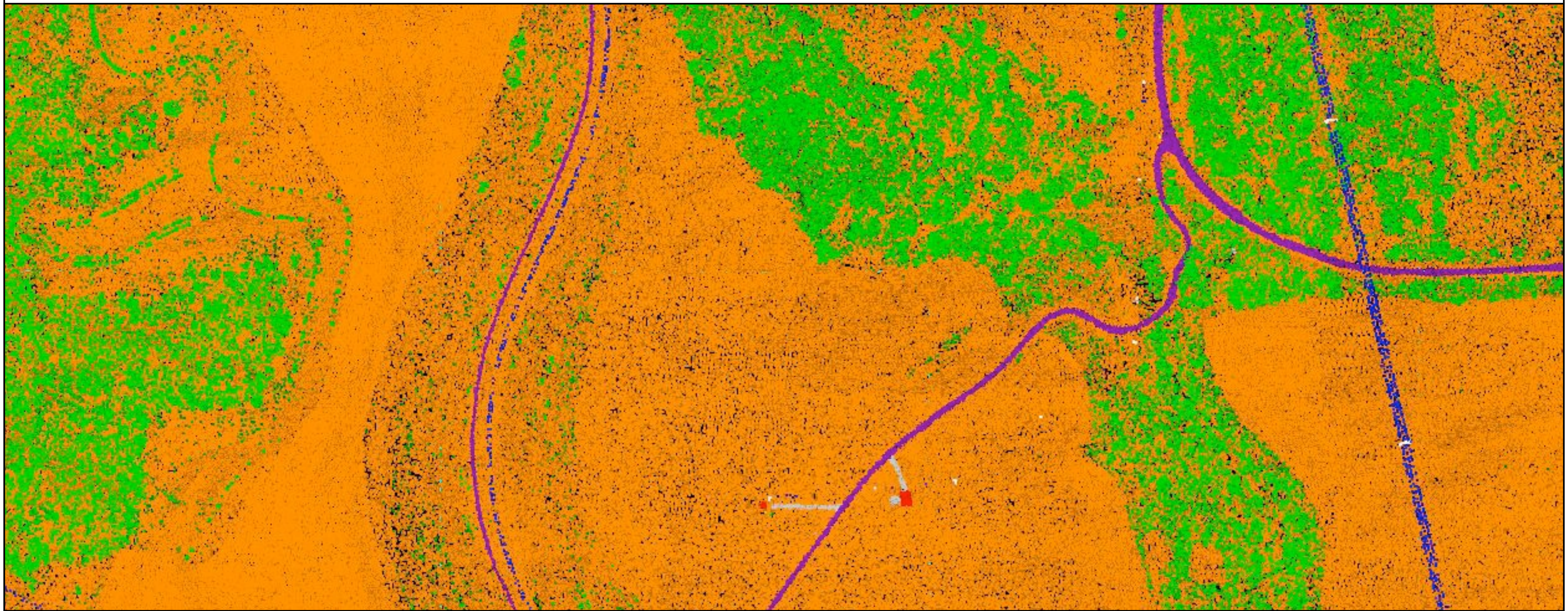
1. Write the RFP clearly, setting minimum selection criteria.
2. Select the Most Qualified Firm.
3. Define the Scope of Services that optimizes "value" to all stakeholders.
4. Negotiate the price with the most qualified provider.
5. Retain the geospatial firm.

If an acceptable price cannot be negotiated with your first pick, move on the second most qualified firm. The beauty of this contracting approach is that the second and third firm on the list are both qualified. The good specifications and project approach devised in consultation with the experts have minimized the risk that the client will get an unqualified firm or sub-standard performance.

So as you gear up to procure professional geospatial services for 2014, be smart. Get the best deal with the most value for your stakeholders. The contracts with the most value are seldom found among the bottom feeders. Professional services should not be contracted as if they were simple widgets. Unlike widgets, every geospatial project is unique and requires skill, careful management, sophisticated technology, and the balance of a thousand other factors. Find the best value for your projects by writing solicitations clearly and selecting firms based on qualifications not price.

CHAPTER 2

Mapping: Scale & Standards



“Every deliverable mapping product has some level of accuracy (at any scale) whether good or bad. This desired project specification should be clearly described and mapping products should require a statement about the accuracy and the intended use of the material.”

Mapping Scale

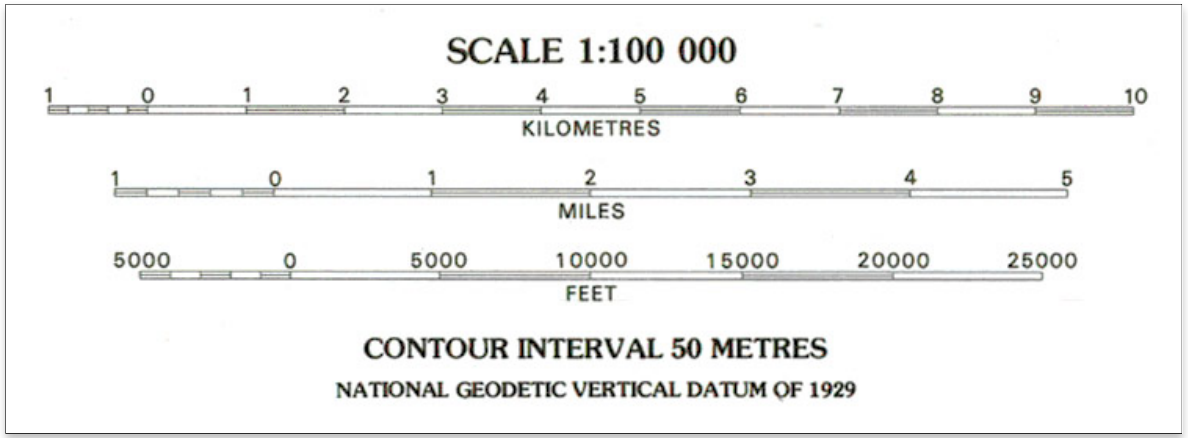
Aerial Imagery Overlay

Aerial orthoimagery can be overlaid onto terrain models (often created via LiDAR) to create a realistic view of the earth's surface.

Today in the digital age where map scale can be changed simply by hitting a zoom button, a geospatial deliverable's positional accuracy is no longer directly related to the scale of a map as it was when all mapping was based on analog techniques. Modern digital map-making techniques minimize the loss of accuracy throughout the entire map production cycle. For this reason, map scale is of much less importance than ground sample distance (GSD).

Every deliverable mapping product has some level of accuracy (at any scale) whether good or bad. This desired project specification should be clearly described and mapping products should require a statement about the accuracy and the intended use of the material. For example, is the data suitable for engineering, planning, or general-purpose mapping?

Mapping is usually classified as either "large-scale" or "small-scale". These terms are frequently confused but is easily remembered if one knows that the "largest" possible scale is 1:1 (actual scale). So when map scale is expressed as a unit-less fraction like 1/2400 (where 1 unit on the map equals 2400 units on the ground) or 1/500, the fraction closest to 1.0 is "larger" scale. "Large scale" mapping (generally agreed to be 1:2400 and larger fractions) shows more detail and requires flying at lower altitudes. "Small scale" mapping (1:4800 and smaller fractions) is acquired at higher altitudes and shows less detail.



Large-scale mapping is generally possible when flying close to the earth. Small scale mapping is achieved by flying further from the earth. Measurements of the earth are more accurate as the distance between it and the remote sensing equipment is shortened. The solicitation materials should rarely, if ever, dictate to the service provider the altitude from which remote sensing operations should be performed. Instead, the solicitation should define the needed deliverables and desired positional accuracies. Then the professional service provider can prescribe the methods needed to produce those deliverables to a defined quality standard.

Map Accuracy Standards

Accuracy Has Many Factors

When map accuracy standards are not clearly specified for procurement, it may be difficult or impossible to compare approaches and costs between contractors. Map accuracy is generally the primary driver of cost in geospatial projects.

Few other factors affect the cost and complexity of geospatial solicitations more than positional accuracy specifications. Buyers often leave out or inadequately define these important measures. Map users often use geospatial data without understanding it's accuracy specifications or “intended use”. When map accuracy standards are not clearly specified for procurement, it may be difficult or impossible to compare approaches and costs between contractors. Map accuracy is generally the primary driver of cost in geospatial projects. As mentioned in the GSD discussion, accuracy can be achieved (or not) using a wide array of equipment configurations, flight parameters, and post-processing techniques. Any lack of specificity for map accuracy standards may result in substandard services and will make it virtually impossible to compare different proposals and project approaches.

It is important that the solicitation state that a certified photogrammetrist on staff is a requirement for all firms. These professionals receive national certification from the American Society for Photogrammetry and Remote Sensing (ASPRS) every five years. This professional credential increases the likelihood that the professional has a thorough understanding of positional accuracy specifications, photogrammetric principles and techniques, and mapping project design.

Today there are three common map accuracy standards. The National Map Accuracy Specifications (NMAS) written during the era of hardcopy paper maps when these products had a fixed-scale and is obsolete today because digital map data can be displayed at any scale. Later, in 1990 the American Society of Photogrammetric and Remote Sensing (ASPRS) rewrote the NMAS and adapted them to mapping delivered as digital files, where the map-scale could be changed dynamically. The most recent, and now, most widely used mapping specification, the National Standard for Spatial Data Accuracy (NSSDA), provides a common, scale-independent statistical measure of accuracy allowing users to compare datasets across applications. The NSSDA is not an "accuracy standard" but simply defines how a desired accuracy is to be measured and expressed.

The table on the next page summarizes how the NMAS & ASPRS positional accuracy standards compare with each other. Keep in mind, because these are older standards, photogrammetrists using modern photogrammetric equipment (such as softcopy stereoplotters, autocorrelation, gyro-stabilized aerial camera mounts, and digital cameras) may be able relax these conservative guidelines and still achieve the desired spatial accuracy. More importantly, the table below is based on map scale which has little direct effect on map accuracy. Far more important determinants of map accuracy are GSD and operational factors that may affect resolving power. The table below is included simply as one way to demonstrate the relationship between these different accuracy standards.

Comparison of Horizontal Accuracy Standards: NMAS & ASPRS

Map Scale	Representative Scale	Horizontal RMSE (Feet)		
		ASPRS Class 1	NMAS Accuracy at 90% Confidence Interval	ASPRS Class 2
1"=50'	1:600	0.5	1.7	1.0
1"=100'	1:1,200	1.0	3.3	2.0
1"=200'	1:2,400	2.0	13.3	4.0
1"=400'	1:4,800	4.0	80.0	8.0

The maps scales shown here are commonly used for large scale mapping projects. A 1"=100' scale mapping project compliant with ASPRS Class 1 Standards would have a horizontal accuracy greater than or equal to +/- 1.0 feet.

Spatial accuracy is expensive. Therefore, it is important to identify the potential users' positional accuracy "needs" not "wants". There will normally be tension between the "needed" accuracy and the budget. By balancing spatial accuracy needs with budget realities, you can provide the best value to the geospatial users. Your professional geospatial service provider can help you identify the best value using current geospatial technology.

The solicitation should also address how map accuracy is assessed. Will it be "tested" or "presumed" to meet the specified map accuracy standard? A geospatial product can be "tested" by the professional that creates it or independently tested by a third party. Additional testing, however, is more expensive. Those procuring these services are often not qualified to measure and certify positional accuracy. However, they may be able to withhold sufficient ground control from the contractor and use it to verify that their accuracy assessment is reliable. Qualified independent contractors are often used to provide unbiased accuracy assessments. Although this is generally the most costly alternative it will provide the highest level of certainty about accuracy.

Geospatial products with higher accuracy (e.g.,horizontally <= 3 feet to several inches) can be used to represent more features in greater detail. Corridor mapping along pipelines, high voltage transmission alignments, site mapping, and transportation corridors are typical large scale projects with high horizontal and vertical accuracies. Individual features, like fire hydrants, curb heights, cracks in pavement, electrical equipment on towers, one foot contours, etc., can be accurately mapped in space and described in a geographical information system (GIS). Lower accuracy products are often much less expensive and are used for land use planning, orthophotography, environmental modeling, four foot contours, and other similar projects.

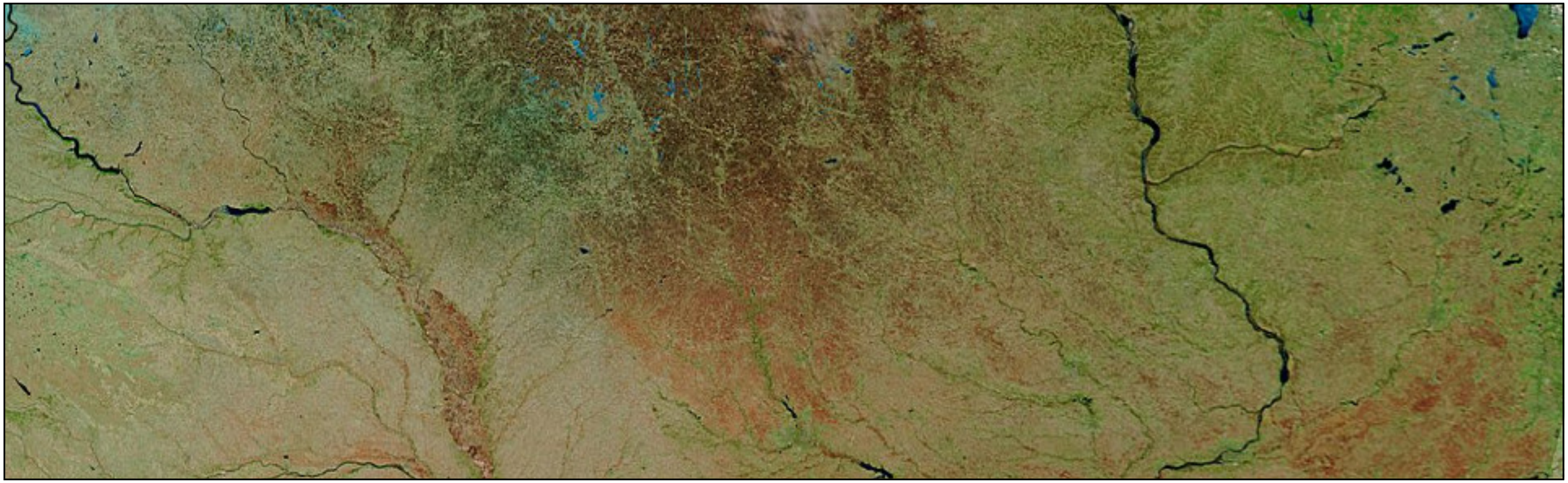
CHAPTER 3

Mapping: Satellite & Ortho Imagery

"A lot goes into making a pretty aerial photo! Sometimes a pretty picture is all we are after. But other times, we must have a beautiful, positionally accurate image."

Satellite

Satellite Imagery, Iowa



Satellite imagery can be acquired via public agencies like NASA or a number of private companies which produce interesting remote-sensing service from space. The above image is via NASA's Terra satellite.

Satellite imagery is available with a dizzying array of technical specifications. They can be an important component of a project or, if used inappropriately, could produce undesirable results. How to determine whether satellite imagery is optimal for use as a base map or supplemental imagery source for a project involves a number of considerations: cost, acquisition window, positional accuracy, cloud cover, whether stereo or orthophotography or both is needed, the intended use of the imagery and what type of data will be derived from the imagery.

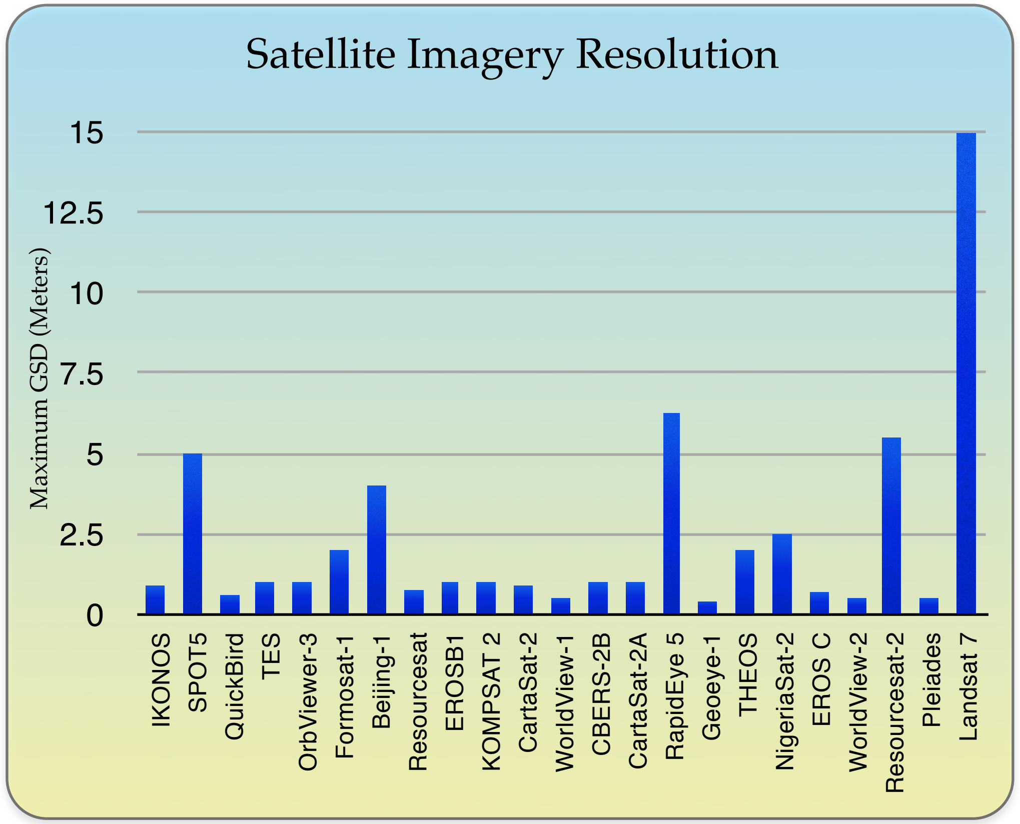
There are a variety of imagery products available from a number of satellite sensors. Some or all may be appropriate for a specific project. Today, most satellite data is licensed and restrictions on use are common. They may or may not be less expensive than acquiring imagery using airborne platforms or purchasing imagery from other sources. Resolution of satellite imagery varies from 40 cm to many meters ground sample distance (GSD). Satellite imagery may have only panchromatic bands or many hyper-spectral bands (visible and invisible). Some sensors have high resolution pan bands and lower resolution color bands. All meet some defined positional accuracy standards but these can vary depending on the number and quality of ground control points used. Positional accuracies are generally much less than those capable using aerial imagery, but if high positional accuracy is not required than satellite imagery may be economical.

Some satellite constellations can be "tasked" and others are configured to photograph any section of the earth every few days. It is important to determine if satellite imagery can be used to meet project specifications and understand the cost implications associated with the acquisition and production of deliverables from the imagery.

Some satellite imagery is available in both stereo and orthophotography, using combinations of panchromatic, color, multispectral and hyperspectral bands. Any 3D feature (containing X, Y, and Z coordinates) extraction must be done from stereo satellite imagery which is often more expensive than satellite orthophotography.

Some satellite sensors can be "tasked", that is, the satellite operator can send commands to the sensor and tell them to "go there and image the earth". This is expensive but can at times be extremely beneficial to a project especially if airborne collection is not an option due to time constraints or geographic location. To image a section of the earth at a specific time in the growing season or immediately after a natural disaster or on a clear day can be quite beneficial.

Satellite imagery may or may not be more cost effective for a given project. It is important to understand the limitations inherent in both satellite and airborne imagery for a given project and choose the image source that will provide the best value to the project and not compromise technical specifications or schedule.



Airborne

Airborne Imagery, Niagara Falls

Airborne imagery can be acquired lower to earth providing some advantages over satellite imagery including higher resolutions, accuracies, etc.

Although best practices when writing performance based Statements of Work generally do not include dictating how the data is obtained, and instead allow the contractors to describe those practices "best" suited to the specifications, it is useful to have a general understanding on how different technical specifications can effect costs. Equipped with this information the Contracting Officer can better understand what is possible within the budget and schedule realities.

Aerial acquisition is a major cost driver for many geospatial projects. The execution of this task is often confined to very narrow windows of opportunity by weather and vegetative conditions. They are often further impacted by equipment failures and other acquisition projects the contractor must complete in the same window. There is always a risk of the acquisition not being completed because of these factors. How can this risk be mitigated? How much of this risk should the contractor versus buyer assume?

The contractor has high incentives to complete the acquisition because payments are often tied to its completion, and further mapping derivatives are seldom possible without it. There are strategies that Contracting Officers can employ to mitigate the risk that the acquisition will not be completed.

First, the contract could allow for imagery collected to lower specifications (later in the season, with more cloud cover, with more standing water, etc.) at a lower cost. Second, when the specifications are written, ensure the maximum possible time is allowed for acquisition. If spring acquisition at leaf off is required, don't unnecessarily constrain the acquisition period by insisting that grass turn green before acquisition can occur unless this is absolutely necessary. Sometimes specifications require "no snow cover" and photography cannot be acquired even if there are a few piles of snow in parking lots. If these piles will not degrade the usability of the imagery for its intended uses, then these specifications are too restrictive.

Third, ensure the contract negotiations are completed well before acquisition is possible. This will ensure all the stakeholders have sufficient time to prepare for the project, e.g., order materials, schedule aircraft maintenance, and deliberately re-prioritize their acquisition schedule to accomplish the project. Contractors are seldom able to organizationally accommodate a project until it has changed from something "possible" to a signed contract.

Fourth, incentives can be paid to the contractor so they give the project priority over other acquisition projects on their schedules. Fifth, large projects that may require a great portion of the contractor's acquisition resources will tolerate fewer interruptions due to weather, equipment malfunctions, or the like. Therefore, consider breaking the acquisition into smaller projects and require more resources from that contractor or additional subcontractors with more equipment be committed to the project. This will increase the likelihood that the acquisition will be completed.

Airborne Aircraft

Aerial Acquisition Aircraft

Aircraft like Aerial Services twin-engine Piper Navajo, fitted with specialized sensor wholes in the fuselage, are ideal for many remote-sensing missons with a good cross-section of fuel economy, speed, and capabilities.

All aircraft manufactured have a service ceiling (maximum altitude above which the aircraft is not rated to fly). Flying above 18,000′ requires more specialized equipment and approvals from government regulators. Airspace above 18,000′ is called "Class A" and is controlled by the FAA Air Traffic Control (ATC), and requires approved flight plans before these areas can be entered. Aircraft flying over 29,000′ must be equipped with reduced vertical separation minimum (RVSM) equipment.

Military Operating Areas (MOS) is airspace over sensitive military areas. These are often the most tightly controlled areas of airspace and can cause considerable delays, and therefore increased costs, of acquisition. These are generally the most problematic areas to operate commercial aircraft.

Projects that require remote sensing above 18,000′ may cost significantly more or be prone to higher costs associated with more complicated access to airspace. If there are ways to accommodate project objectives without requiring acquisition at these altitudes, the project may be less costly and less complex.

Some acquisition authorizations in unrestricted airspace can be difficult to receive because of temporary flight restrictions like Presidential visits in the area, or elevated terror alerts. Sometimes considerable delays are caused by the inexperience or personality of the FAA personnel working the airspace a particular day. These complications are often unplanned and unknowable and may incur considerable costs and delays to a project.

MANNED AIRCRAFT

Today manned aircraft are the predominate commercial option for airborne acquisition of data. Unmanned aerial vehicles are now routinely operated by the government but are not yet allowed for commercial operations.

SPEED

High speed aircraft can be advantageous to enable acquisition over shorter periods of time or in narrow windows of opportunities. Aircraft designed to fly lower often fly at lower speeds but are less costly to operate at those altitudes than high speed aircraft rated for higher altitudes.

ALTITUDE

Aircraft are rated to operate only within certain altitude ranges. Aircraft rated for operation above 27,500' above ground level can normally operate at lower altitude but at higher costs than other aircraft. Aircraft rated for operation below 27,500' cannot be used above this altitude without special modifications. Even if modified, they would often be more costly to operate than others rated for high altitudes.

SPECIAL NOTE

Unmanned aerial vehicles (UAV) are now in common use by the military, government agencies and educational institutions with special authorizations. They are currently not allowed for commercial use. Many government agencies like the Forest Service and Department of Homeland Security now regularly use UAVs for aerial data acquisition. UAVs will be increasingly used for commercial applications in the near future (possibly as early as 2013). New applications for this technology will become important to future geospatial procurements. Many professional services delivered today using manned vehicles may be better served using commercial UAVs when this is permitted by the FAA.

Mobilization

Mobilization Truck with Helicopter

Some systems and equipment, such as Aerial Services Bell 47 helicopter, is mobilized via the ground and then deployed to the air for acquisition. In other cases, such as fixed-wing aircraft, the rig is flown direct from the previous job.

The calendar day(s) and daylight hour(s) that remote-sensed data can be acquired is dependent on a number of factors. The size of this "acquisition window" of opportunity can have a major impact on acquisition costs. If the time that imagery can be acquired is limited to one week in the spring or to only a few hours each morning for a period of two months, then acquisition costs will be much higher than with more flexible acquisition windows. Understanding the remote sensing equipment, the project scope, the intended use of the deliverables, and what factors may limit when an area can be remotely sensed is critical.

The major factors to consider include whether vegetation has foliage or not and how much shading of the ground or features on the ground is permissible. How the imagery will be used will determine which factors are most important. If used for mapping the surface of the earth (e.g., feature extraction or DEM/DTM collection) than a clear view of the earth's surface may be imperative and "leaf off" will be a requirement. However, if the project is for vegetative classification, for example, than it may be important that acquisition be performed during a predetermined period of the growing season with foliage fully expressed.

"Leaf on" or "leaf off" is chiefly a consideration only in temperate parts of the world where deciduous trees can lose their leaves. In these regions, there are generally two seasons, spring and fall, when vegetation is leafless or has minimal foliage. Otherwise, in applications that require foliage, then it is important to acquire imagery when the growth stage of the target vegetative species is most advantageous.

Shading of the ground or important features on the ground is impossible to avoid except in areas devoid of all vegetation. Even during seasons of leaf-less canopies, those parts of the vegetative canopy (grass, trees, shrubs) that are erect obscure incident light and cause shadows and darkening of anything under them. Areas of high relief are often perpetually shaded. The impact of these shadows to the project depends again on the project scope and the needed deliverables. If the surface of the earth or features under vegetative canopies must be accurately mapped than less shadow will be required. It is not uncommon for project specifications to allow that the earth's surface under forest canopies be modeled with less accuracy than other non-forested areas. In these cases, heavy foliage may not be deterrent to the project.

Another important factor to consider is the type of sensor. New digital cameras systems collect high bit depth imagery. This is a distinct advantage over previous camera systems (like film-based cameras) that were far more limiting. The advantage high bit depth brings to the project is that remote sensing interpreters and especially image processing software can "see through" shadows that on film would be solid black and feature-less. With digital sensors, features obscured by shadows (like the ground surface and planimetric features) are visible and measurements can be taken. So, more area covered by shadows and darker shadows are less of a problem.

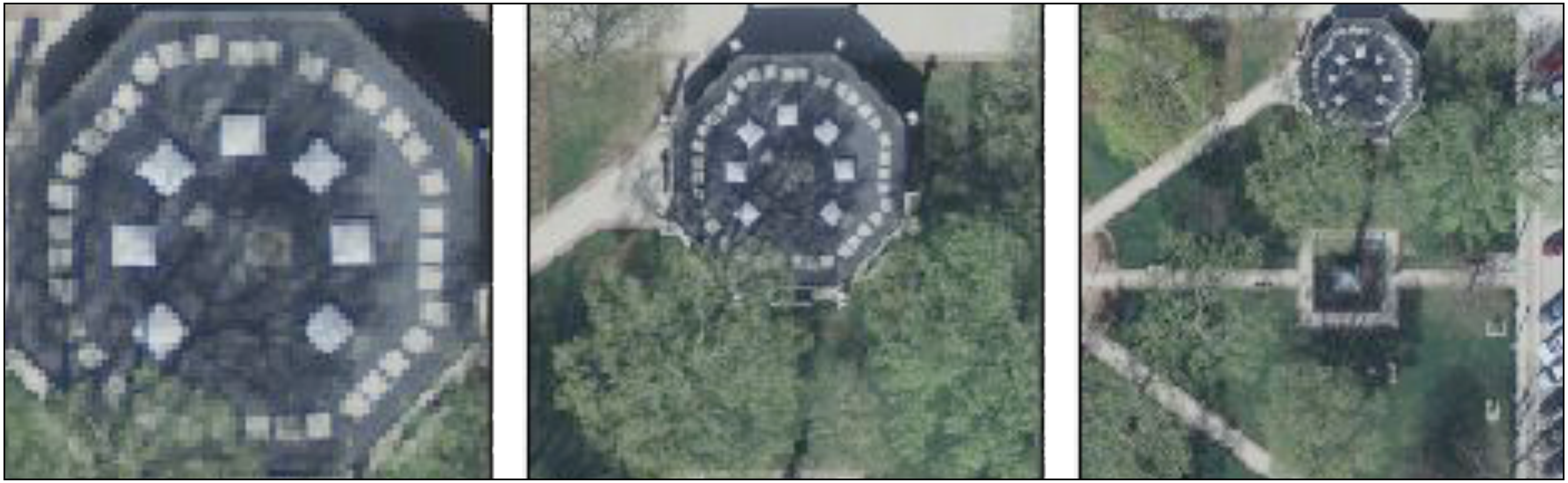
Shadows are also caused by clouds. Most acquisition specifications include some requirement similar to "acquisition must happen with less than 10% cloud cover". Again, because of newer digital sensors, the effect of shadows caused by clouds obscuring features is less important for many applications and more shadows caused by foliage, solar radiation, or clouds can be tolerated. A higher tolerance for shadows means a larger acquisition window. A project with a larger window of acquisition may be considerably less expensive and have a significantly higher chance of being completed. Unnecessarily restrictive acquisition windows are budget busters and make projects more difficult to complete.

A common imagery acquisition specification that is used to limit the time of day at which acquisition is tolerated is called "sun angle". This is the angle of the sun above the horizon of the earth. A lower sun angle results in longer shadows.

Other factors that may constrain the acquisition window are environmental or climatic factors that obscure the ground, e.g., tidal levels, river levels, snow cover and standing water. Normally, no snow cover is allowed. However, will snow cover in ditches or remnants of snow piles in parking lots be allowed? If a heavy rain occurs during the acquisition window and there is standing water in agricultural or urban areas, will this negatively impact image quality or the accuracy of project deliverables? If so, then they should not be allowed. But waiting until the last snow crystal melts and every puddle dries up from the project area may cause project costs, schedule and complexity to increase dramatically. Seriously consider how these environmental factors affect the project and do not overly constrain the acquisition window.

Resolution

Imagery Resolution



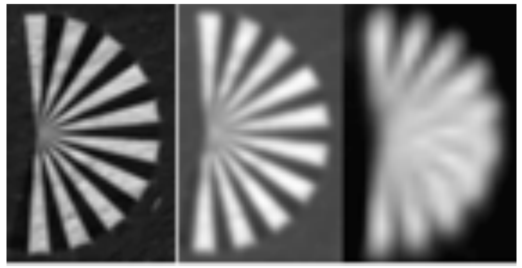
Resolution refers to size of the smallest feature that can be resolved or interpreted in an image. With digital imagery, the GSD is the size of the ground footprint of a pixel and is reported as linear units/pixel, such as 1 meter/pixel, 1 foot/pixel, etc.

A lot goes into making a pretty aerial photo! Sometimes a pretty picture is all we are after. But other times, we must have a beautiful, positionally accurate image. Or maybe, specific features on the ground must be clearly visible and interpreted. A key quality component of digital camera systems is spatial resolution. The pixel size limits the spatial resolution attainable. In practice the nominal resolution of a sensor system is seldom achieved due to blur and noise caused by a variety of factors like optical path quality, electronics, the CCD (charge-coupled device), forward motion compensation, camera mount, camera port glass (if any), flight altitude, flight velocity, exposure, sun angle, air turbulence, visibility, and post processing of the data. Some large-format camera systems create a color "frame" by combining smaller, high resolution, overlapping panchromatic frames then pan-sharpening ("colorizing") them using lower resolution color images. All of these factors can have important effects on the quality of image acquired for your project. For these reasons it is important that each camera system used on a project have a recent field and factory calibration to ensure the system is operating optimally.

One of the key considerations for any imagery acquisition project is ground sample distance (GSD). This statistic describes the size of one image pixel on the ground in meters or feet. Three primary factors affect this: distance from the earth (flight height), focal length of the lens assembly, and CCD size. In simple terms, the further away from a target the camera is positioned the larger the GSD (lower resolution). A CCD with 9 micron pixel size will produce imagery with a larger GSD than a CCD manufactured with 6.5 micron pixels (assuming the same lens is used). Focal length also affects GSD by changing how much ground area is projected onto the CCD surface.

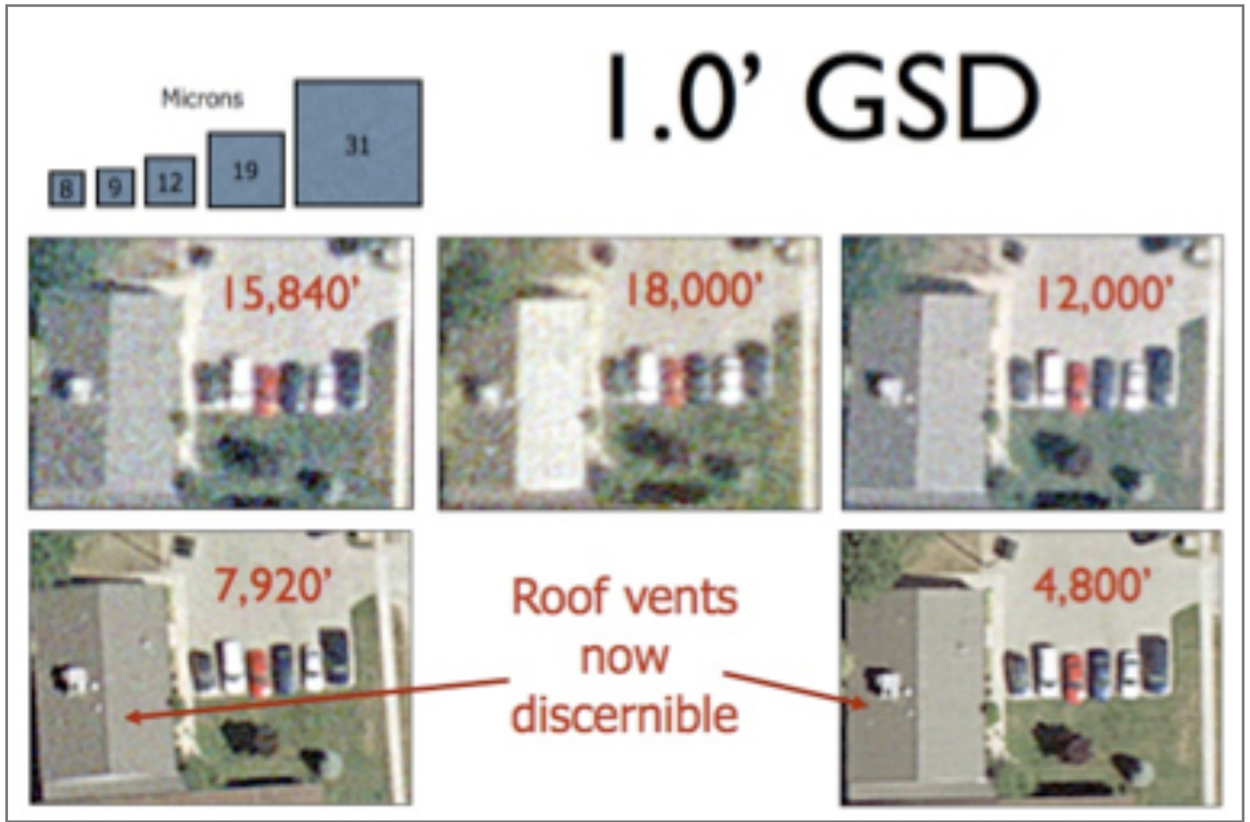
In practice, GSD for a given camera & lens is determined by flight height. Some camera systems allow lenses to be changed so focal length can be adjusted and change GSD at a given altitude. Large-format digital cameras today can produce 1m GSD imagery at flight heights above ground of approximately 10,000 feet.

Higher resolution (small GSD) imagery is more expensive and generally most preferred in many applications. But as GSD declines the costs of acquisition and processing go up. Project planners must determine the maximum GSD (resolution) needed to meet project objectives. However, as desirable as high resolution imagery is to a project, image interpretation (or the resolving power) can be adversely effected. Resolving power is described as a measure of lines per millimeter. The more lines per mm that can be discerned the better the resolving power. Imagine a camera capable of imaging the earth's surface from 10,000′ above ground and producing 1m GSD imagery using 10 micron pixel CCD array. If this camera was put into space and the CCD was upgraded to an amazing 1 micron pixel, the imagery could have the same GSD (1m) as if the flying at 10,000′. The important difference is that small features on the ground, like fire hydrants, are clearly discernible in the image taken at 10,000′. However, the image from space with identical GSD using a higher resolution CCD is much further away from the fire hydrant and it cannot be discerned. So the GSD of each image is identical but the resolving power (the ability to discern features) of each is quite different. For many projects where photo interpretation is important and positional accuracy requirements are high, resolving power of the camera system must be considered.



Siemens star is used to measure the resolving power of a camera system. The same feature captured at different altitudes can be less discernible. Conversely, the same feature captured at identical altitudes by cameras with less resolving power can be less discernible.

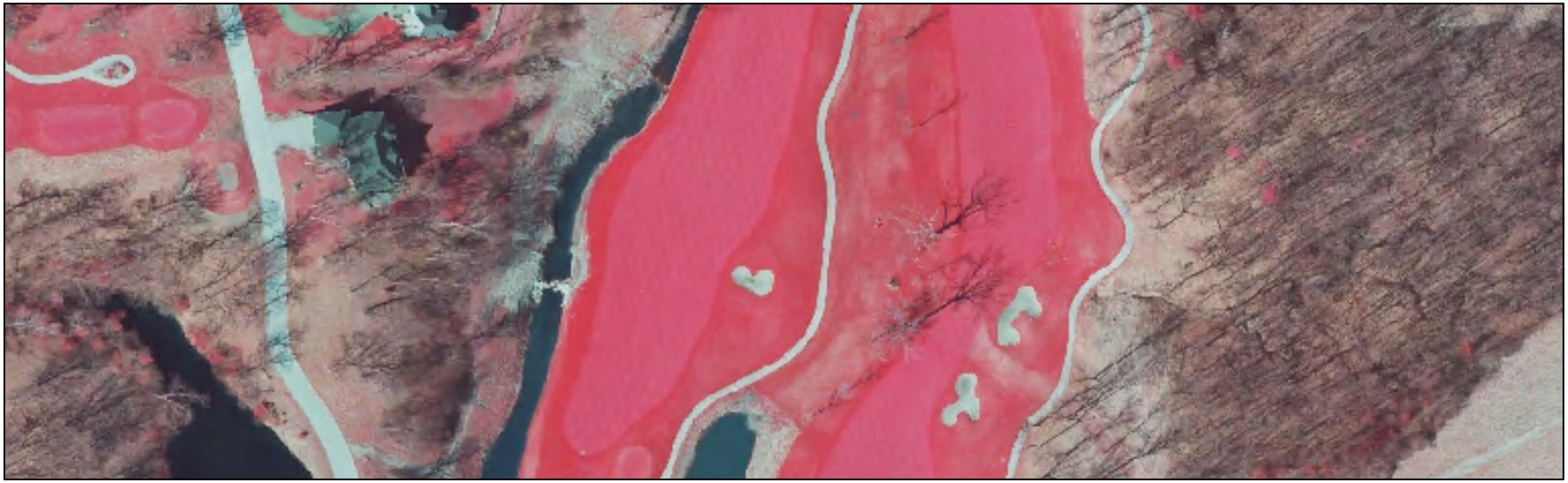
In this age of digital camera systems, there is no longer any reliable correlation between flight altitude and positional accuracy. Pixel sizes of a CCD, focal lengths of lenses, and flight height can all be changed to produce similar GSDs. A high-resolution orthophoto does not have an implicit positional accuracy simply because of its high resolution (small GSD). Additionally, high resolution does not guarantee that small features can be discerned. To ensure that remote sensed data will be dependable and consistent and that positional accuracy, GSD, and resolving power can be defined reliably reliably it is generally recommended that only "metric" cameras be used.



The importance of accuracy will vary based on the intended use of the deliverables. Specific accuracy requirements should be defined. In many cases actual accuracy should be tested after the deliverables are received. Increased accuracy generally means increased cost. Therefore, it is important to not over-engineer the project requiring excessive accuracy and waste project budget dollars for higher accuracy that is not needed. In summary, the positional accuracy of remote sensed data is dependent on a large number of interrelated factors and professionals that understand photogrammetry, equipment, and production procedures should be consulted when designing a project.

Image Band & Depth

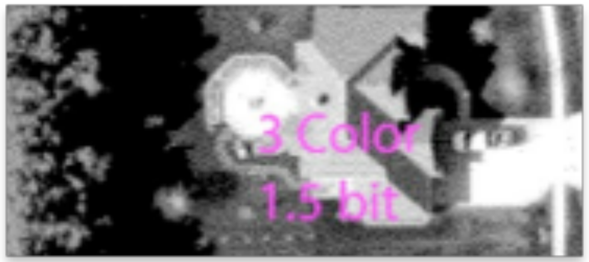
Near-Infrared



A number of imagery bands can be collected during remote-sensing acquisition. Near-Infrared, as pictured above, gives an excellent view of vegetation, pictured in the red tones. The blue-grey ares in this band can also be useful to determine impervious surfaces.

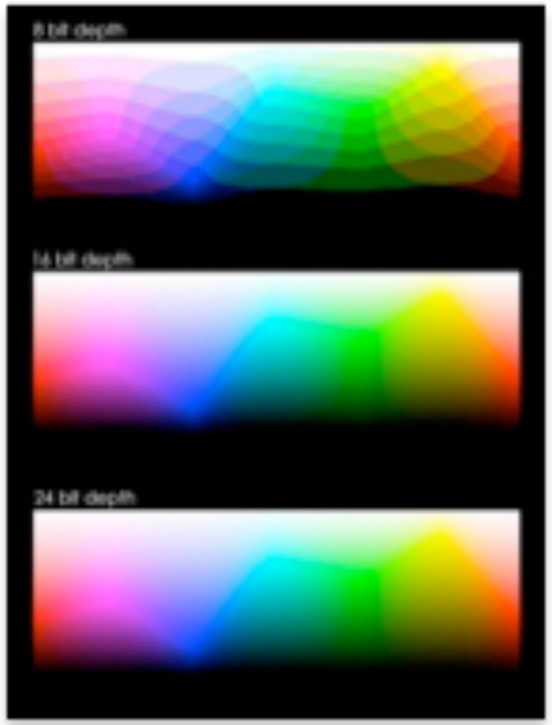
Sensors are capable of sensing and recording electro-magnetic energy. Satellite and aerial cameras typically image in the visible light and infrared parts of the electro-magnetic spectrum. Other sensors can image well beyond this slim slice of the electro-magnetic spectrum. Sensors that record red, green, and blue (full color) plus infrared are referred to as multi-spectral. These are commonly used on projects that require land classification. The infrared bands are used to differentiate vegetation and even paved areas. Sensors that record more than 4 bands are generally referred to a hyperspectral and are used for a variety of specialized needs.

Most remote sensing projects today require only full color imagery. However, many digital camera systems are designed to capture both full color, panchromatic (black & white) and near infrared bands. It costs virtually nothing extra to collect these additional bands. However, requiring additional bands of imagery as deliverables may incur higher fees because additional image processing is required.



Bit depth quantifies how many unique colors are available in an image's (or image sensor's) color palette in terms of the number of 0's and 1's, or "bits," which are used to specify each color. This does not mean that the image necessarily uses all of these colors, but that it can instead specify colors with that level of precision. For a grayscale image, the bit depth quantifies how many unique shades are available. Images with higher bit depths can encode more shades or colors since there are more combinations of 0's and 1's available. Equipment manufacturers often use the term "bit depth" in confusing ways. The bit depth for each primary color is termed the "bits per channel." The "bits per pixel" (bpp) refers to the sum of the bits in all three color channels and represents the total colors available at each pixel. Confusion arises frequently with color images because it may be unclear whether a posted number refers to the bits per pixel or bits per channel. Using "bpp" as a suffix helps distinguish these two terms. For image processing bits per pixel is the important consideration and today's digital camera systems routinely acquire imagery with 10 to 12 bit depth and store it in 16-bit files.

Our printers and monitors are unable to display more than 8 bits per pixel so we are unable to perceive the extra 2-4 bits of color captured with today's digital camera systems. However, these extra bits are important for a number of reasons because they can be "seen" by algorithms that read and process the imagery. One application that benefits tremendously from the higher bit-depth of this imagery is image correlation. This is the computer process that matches a small patch of pixels in one image with the same area in other images. In a 8-bit image, for example, shaded areas are black. That is the pixel value is 0 and no detail can be discerned in these areas. However, in a 12-bit image, there are many more shades of gray in the shadow areas meaning features are much more likely to be discerned in these areas. This enables much more accurate correlation of DEMs using the imagery.



Bit depth determines how many color values are possible with each pixel. The more bit depth, the finer the gradations of colors.

Camera System Type

Leica ADS80 Sensor with PAV80 Gyro-Stabilized Mount

Modern sensor systems today, such as Aerial Services Leica ADS80, are marvels of technology. These systems allow for accurate measurement of the earth by combining photogrammetric techniques, the newest algorithms, and computer advances.

Cameras rarely acquire imagery today independent of an array of associated equipment. Today, the quality of remote sensed data is determined by the camera or LiDAR (Light Detection and Ranging) “system”. Each component of a camera system (for example, aircraft, airborne GPS, inertial measurement systems, cables, computer system, antenna, forward motion compensation, operational personnel training), can have a major impact on the quality of information produced. It is important to access the entire camera system and not only the camera.

Camera systems are further defined as “metric” (calibrated) or “non-metric” (not calibrated). A metric camera enables geometrically accurate reconstruction of the scene. They will deliver accurate, stable, and repeatable results when operated appropriately. The stability, accuracy and repeatability of a non-metric camera by definition unknown. Most geospatial projects are best served using metric camera systems operated by qualified personnel. Film camera systems were, for the most part, very uniform and could be calibrated by a single USGS lab dedicated to this task. These systems were generally calibrated once every three years. Today, however, digital camera systems are comprised of many components and there are many different unique camera systems generally characterized as "frame-based" or "push-broom" sensors. Frame-based cameras take a series of "frames" of photography. Push-broom sensors are more similar to scanners and take single continuous exposures over long distances and produce "strips" of imagery instead of frames. There are significant pros and cons with each camera type that the stakeholders should understand. Because there are many diverse digital camera systems today (and the number and diversity continues to increase) the USGS no longer performs digital camera calibrations. Instead, calibrations are performed periodically by the operator and camera manufacturer. The general expectation is that a digital camera system be calibrated once each 1-2 years by the manufacturer. Field calibrations may be performed by the operator as often as each project.

Project specifications should request that camera calibrations be current. These should be reviewed carefully. The old adage that beauty is only skin deep aptly applies to remote sensed imagery. Making pretty pictures is the easiest part of remote sensing and the easiest thing to sell. Making pictures accurate and useful for the intended purposes is by far much more challenging.

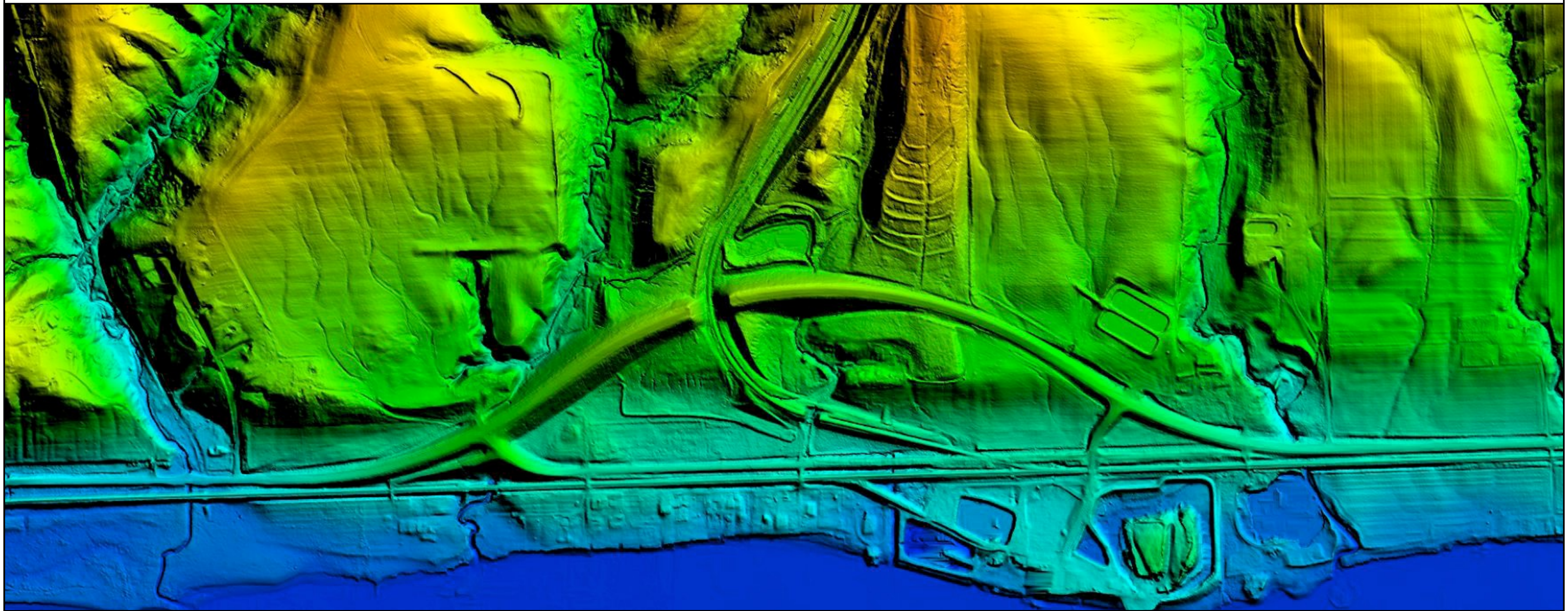
Film camera systems are still in use today and provide very good imagery. Many project specifications can easily be met using film systems. Projects should not exclude film cameras just because they are older technology. Some projects may be more affordable hiring a contractor using film contractors than others using digital cameras. This will become more difficult as the film cameras and photogrammetric scanners age and film is difficult to obtain.

Digital camera systems are generally cheaper to operate than film and produce imagery with greater bit depth and superior image quality. This can accentuate color and positional accuracy. But digital camera systems are generally much more complex, extremely expensive, and require a higher level of expertise to operate. One is not assured of superior imagery simply because it was acquired with a digital sensor. The operation of the sensor and post-processing of the imagery is probably more important to the final quality and accuracy of the imagery than whether it was acquired with a film or digital sensor.

Forward motion compensation is a feature of many camera systems that reduces image blur caused by rapid movement. Satellites and aircraft move across the earth at high speeds. The closer an object is to the sensor at a given speed the more pronounced will be image blur. A camera system equipped with forward motion compensation will dramatically reduce this blur and allow greater accuracy and resolving power. Forward motion compensation used to be a common requirement for photogrammetric projects. However, because of superior optics and electronics of modern digital systems forward motion compensation is not as important and is no longer a required necessity to ensure imagery that will meet project specifications. (Pushbroom sensors require no forward motion compensation, for example.) Image blur increases at a given speed with increasing exposure time. Better optics and electronics in digital camera systems enable shorter exposure times and less image blur.

CHAPTER 4

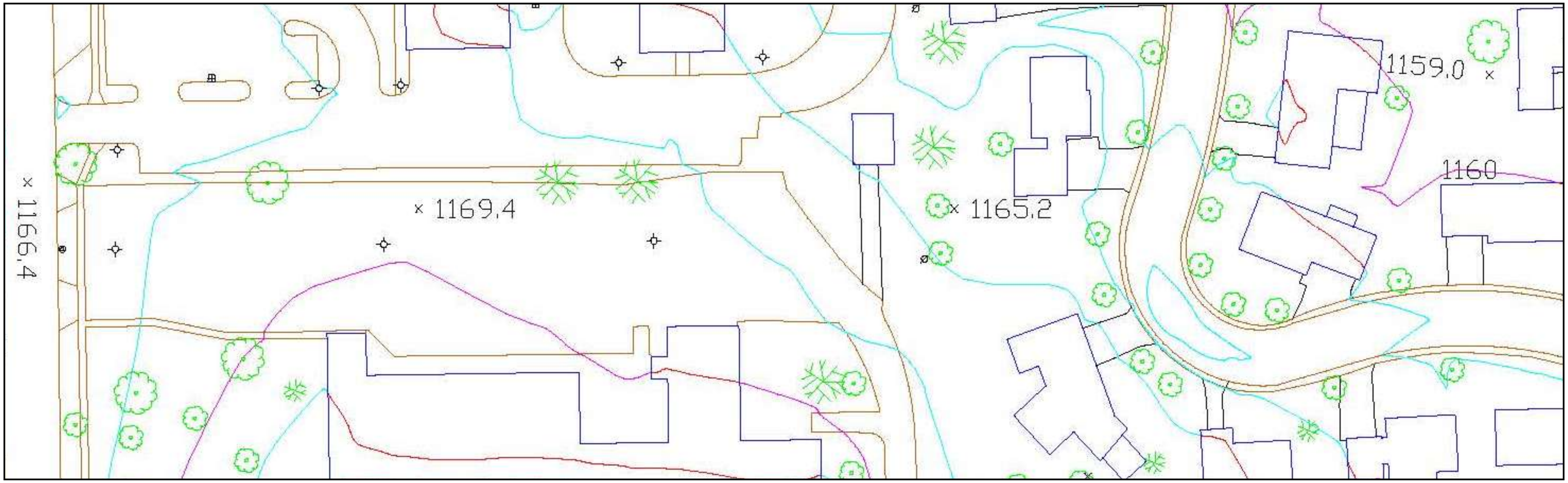
Mapping: Topography, Elevation & LiDAR



"Before writing an RFP or initiating a solicitation for professional services or data, it is important that the author understands the scope of the needs, the stakeholders, and what type of solicitation is required."

Topographic Mapping

Topographic Sample



Topographic maps show the horizontal and vertical locations of natural and artificial features. It is distinguished from a planimetric map by the presence of numbered contour lines.

Topographic (relief) mapping is an important component of many mapping projects. Some type of elevation or surface model is needed. Will the best available model be used or will a new model be created from the stereo imagery or from LiDAR? If "best available" is used, will this be supplied by the client or obtained from a public or other source? If newly created, will it be autocorrelated from stereo imagery, manually digitized, or collected using LiDAR? These are all important considerations and have significant impact on cost, schedule and complexity of the project.

Public sources of elevation models make excellent choices for some projects because they are inexpensive and help reduce the overall cost of the project. The quality and positional accuracy, though, often well described, may not be sufficient for the project. It is important to verify whether they are of sufficient quality and accuracy to meet project specifications or require the contractor to verify their quality and accuracy.

Client-supplied elevation models may be another option. If the solicitation will require the contractor to use an existing elevation model previously compiled on a prior project, was the positional accuracy of that data tested? How old (or current) is the data? What proportion of the data will need revisions? Can areas needing updating be described for the contractor? If the contractor finds the data less accurate than assumed, how will he be compensated to bring that data up to specification? If the project specifications require a defined positional accuracy, then answers to these questions are important to the contractor and have direct bearing on the cost and, perhaps, the schedule of the project.

Creating an elevation model can be one of the most expensive components of mapping. Therefore, if an elevation model from a previous project is available it may reduce the costs significantly. However, if the provided elevation model is of unknown or untested positional accuracy, and the project requires the contractor to meet positional map accuracy specifications, then the elevation model has less value to the contractor because he is unable to assume it meets the accuracy specifications of this project and will have to carefully test and document the elevation model's accuracy. This adds cost of the project. If the elevation model is accurate but dated, which areas and how much area will need to be updated to meet the accuracy requirements?

Sometimes an existing elevation model is not available and a new model must be created from the stereo imagery acquired for the project. Will this new model be derived from the stereo models using autocorrelation. Will it be breakline-enhanced? Will LiDAR be used to collect the elevation model?

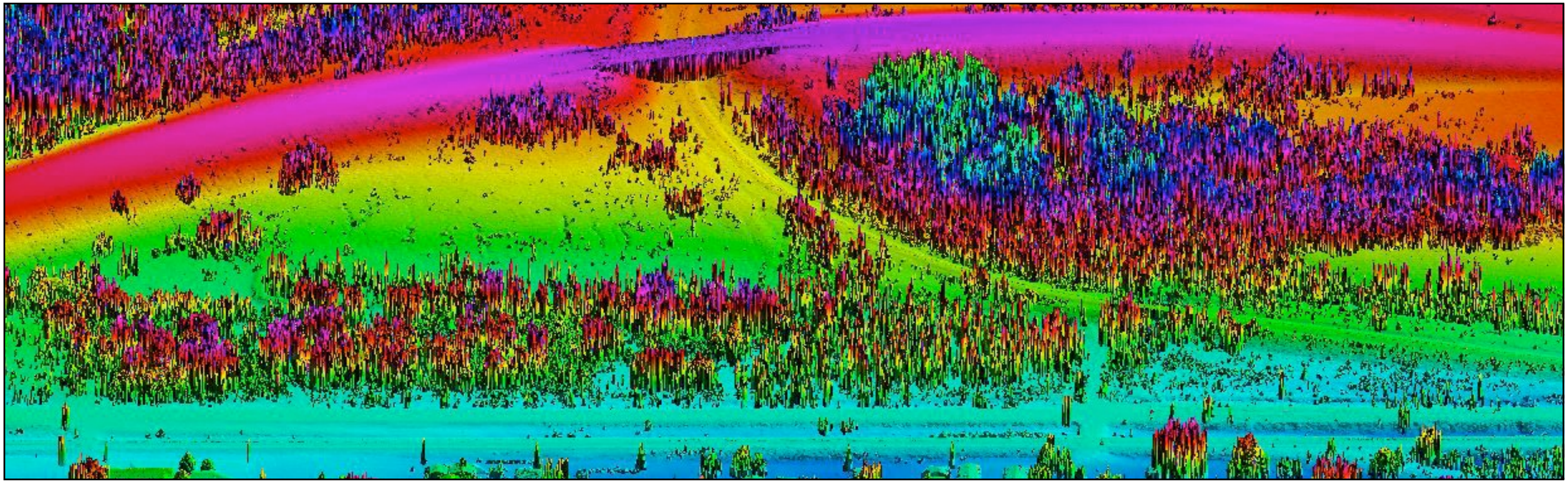
An autocorrelated elevation model is one where elevation measurements are made automatically from stereo imagery on a predefined grid spacing. Most computer systems today perform these operations very rapidly. However, many points are positioned on undesirable objects or inaccurately. Therefore, it is important to determine whether autocorrelated elevation models (or products derived from them, like contours) are edited or systematically tested to ensure they meet positional accuracy specifications.

Sometimes an autocorrelated digital elevation model (DEM) cannot support required positional accuracy requirements and will need to be enhanced with breaklines. Highly accurate breaklines can only be digitized from imagery acquired as stereo models. In these cases, it may be more economical to manually digitize a DEM or DTM or procure LiDAR services.

What is the required point spacing needed to achieve accurate flood plain mapping? Are breaklines needed with the DEM to achieve the accuracy specifications? Will "soft" or "hard" breaklines be needed? Will contours be aesthetically pleasing or topographically accurate? Will they be labeled? How do I know if LiDAR, IFSAR or stereo imagery is needed to create a surface model sufficient to meet my users' needs? These are all important questions that must be addressed in the procurement process and can have a major impact on the project cost. Consultation with a professional services provider before the solicitation is drafted is highly advised so these questions are answered responsibly and the stakeholders understand their impact on price and schedule.

Modeling the Earth's Surface

Shaded Relief Surface Model



Surface models can be created a number of ways, including via traditional photogrammetric techniques or via high-density LiDAR scanners producing an amazing picture of the surface.

The accuracy of a surface model is correlated with the density of measurements made on the surface of the object being modeled. Measurements of elevation spaced in a uniform grid (DEM) along a surface can provide an increasingly accurate model of the surface as their density increases. However, between any two measurements there may be an undetected abrupt change in elevation, e.g., a creek bank or ditch, that will not be modeled. One method of more accurately modeling terrain surfaces is to digitize 3D lines along the tops and bottoms of features similar to these.. These are called “breaklines”. When breaklines and a regular grid of points are present in an digital elevation model (DEM), they are generally referred to as digital terrain models (DTMs). The accuracy of an elevation model is greatly enhanced using breaklines. Although the cost of modeling a surface using a DTM is often higher, a DTM can be a much more useful model of the terrain surface. In fact, the point spacing of a DEM can be significantly decreased with the addition of breaklines and still meet the same positional accuracies.

SURFACE MODELS AND BARE EARTH MODELS

A bare earth model is simply a DEM or DTM that models the bare earth. All elevation points that are on top of non-earth features (vegetation, buildings, etc.) have been removed. Conversely, a digital surface model (DSM) is a DEM or DTM that models the surface of all features under the sensor and includes the tops of vegetation and man-made features.

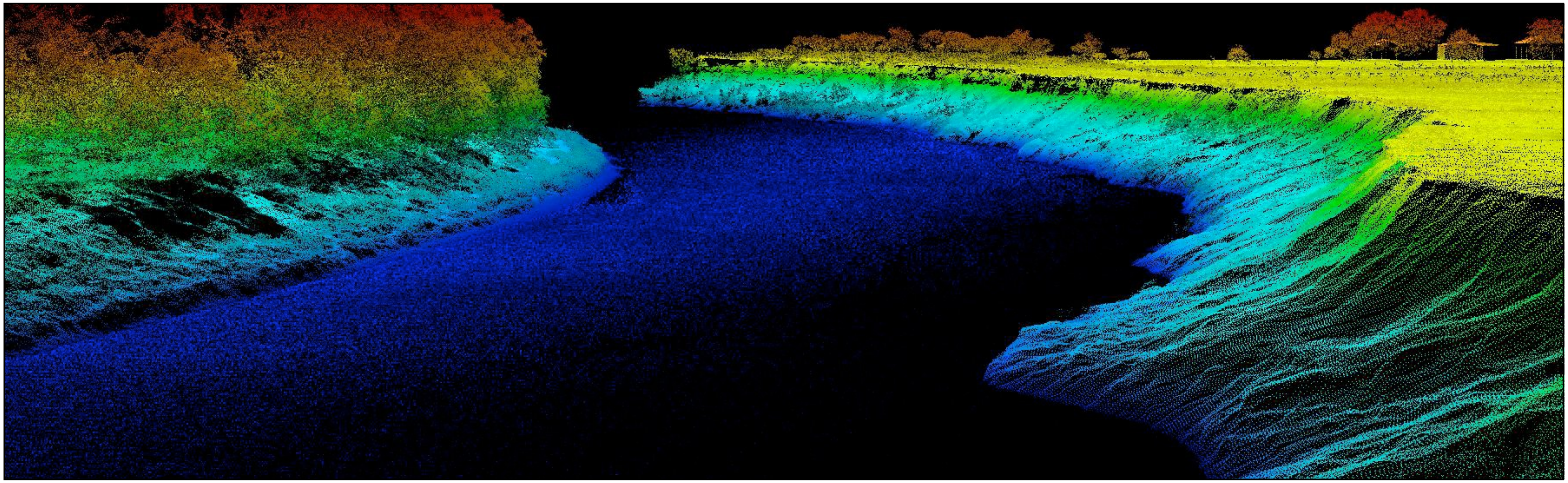
Because this is one of the most expensive components of a geospatial project, it is important to understand this technology and discuss with the service provider which methodology is best suited to meet your project objectives. The technology and methodology used to develop surface models is constantly improving.

CONTOURS

Contours are normally generated from elevation models today and are rarely manually digitized. Depending on the elevation model, the generated contours may be quite accurate but commonly do not look cartographically pleasing. Decisions must be made based upon how the information will be used on whether the contours are “smoothed” and labelled to produce cartographically pleasing features or leave them in their most accurate state, or require both sets as different features that can be used for different purposes.

Elevation - Hydrography

River Scanned with Aerial LiDAR



Typical aerial LiDAR lasers (red) cannot penetrate the waters surface (as seen above), but bathymetric LIDAR lasers (green) can produce accurate models of a water body's depths.

Hydrography is the science of measuring and mapping oceans, seas, rivers and lakes. It is a form of remote sensing, typically relying on sonar or lasers, that has a complex array of factors driving the cost. Types of hydrographic data include bathymetry, side scan sonar imagery and ancillary measurements such as water level, properties of water, currents and bottom type.

The major factors driving the cost of hydrography include the solicitation type, data type requested, resolution and accuracy desired, schedule imposed, environmental conditions, regulatory requirements, project location and specific logistic requirements and the type of deliverables expected. Often the scope or schedule must be adjusted to meet both project goals and budgetary constraints.

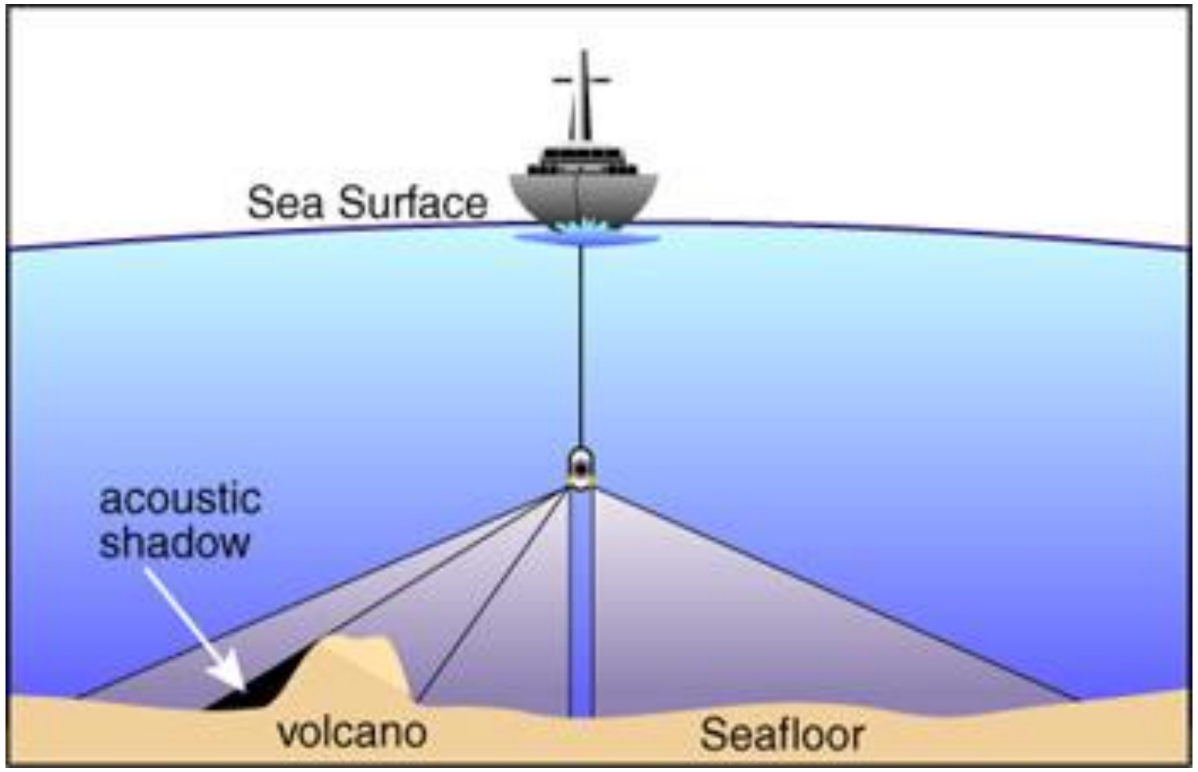
Bathymetry can be collected with Multibeam or Singlebeam sonar or Airborne Bathymetric LiDAR. Each system has advantages and disadvantages and each can be the ideal choice for certain applications.

Multibeam sonar is typically deployed on boats and collects multiple simultaneous soundings to the left and right of the vessel as it travels. The width of the multibeam swath is determined by the system design, sonar frequency and water depth. The boat then runs a pattern that covers the project area with these swaths. Multibeam systems require expensive inertial systems integrated with GPS to measure the position and attitude of the vessel up to a hundred times a second and can generate a considerable amount of data, even over 250,000 soundings per second for some systems and potentially billions of soundings for a project. Although complex, these systems provide a considerable amount of detail and can provide complete coverage of the seafloor ensuring no feature is missed. This is the system often specified when every aspect of the seafloor must be understood such as complex design for construction projects or when searching for hazards to navigation.

Singlebeam sonar surveys are considerably simpler than multibeam surveys. They are also vessel based and the system collects a stream of soundings that are directly below the sensor. If the system is used reasonably calm waters this system can be used without the inertial system required for multibeam surveys and the processing is much simpler. The data volumes are much lower, typically 10 to 20 soundings per second, amounting to sounding volumes thousands or hundreds of thousands. Because this approach does not provide complete seafloor coverage it is appropriate for surveys that measure gross changes such as shoaling and dredging, or for reconnaissance surveys.

Airborne Bathymetric LiDAR surveys differ from the other two major types in that the sensor is a laser and is mounted in an aircraft. The Bathymetric LiDAR sensor differs from terrestrial LiDAR in that it operates on two different frequencies, one that reflects from the surface of the water or land and another that penetrates the water. The data volumes are higher than with singlebeam sonar but typically lower than with multibeam for the same area. One of the commercial systems available produces around 4000 soundings per second and others are similar in their output. Although daily operational costs are quite high for these systems due to the expensive sensor and the aircraft needed to collect data, the systems can cover a tremendous amount of area under the optimal conditions making it cost effective. The depth capable with the systems depends primarily on the turbidity of the water. In ideal conditions such as the clear waters found around the Caribbean Islands depths of 50 meters can be achieved. In poor conditions the system can be unusable in much shallower waters. This type of survey is well suited to hydrography along shorelines that are rocky, shallow or contain numerous reefs but a large survey area is typically required to make them economical.

In addition to bathymetry, data can be collected to search for lost items or hazards or determine the type of material on the bottom using sidescan sonar. Sidescan sonar is a type of system that is towed underwater behind the vessel and while it can resolve small objects or discern differences in the type of seafloor or lake bottom progress can be slow and processing and interpretation can be time consuming. Additionally, it does not provide depths.



The resolution and accuracy of hydrographic data that are necessary and achievable for specific applications are specified in several standards. Some of the best documented are those from the International Hydrographic Organization (IHO), the US National Oceanographic and Atmospheric Administration and the US Army Corps of Engineers. Each organization has multiple standards based on the conditions expected and the goal of the survey. The choice of specification will have a very large effect on the utility and cost of a survey.

The resolution of bathymetric data is varied and is determined largely by both the type of sensor used and the implementation of it. The data density, which largely determines the ability to detect small objects or fine details, is driven by the system chosen and the depth of the water. The farther a given sensor is from the seafloor the less resolution is available. Object detection cannot be achieved unless several soundings hit an object. Specifications for object detection are often listed with the dimension of a cube in a specific depth of water and vary from specification to specification.

The accuracy of the survey is often stated in terms of separate horizontal and vertical accuracies. Although high vertical accuracy is harder to achieve it is generally more important than horizontal accuracy. Bodies of water tend to vary in height over time and all soundings must be reduced to a datum whether in tidal or inland waters. The relationship to the water level is measured either by tracking the water level during the survey or by using very precise GPS and inertial measurements. In either case it must be tied to a known vertical or tidal datum to be useful. Horizontal accuracy is easier to achieve but must still be tied to a defined horizontal datum. The choice of accuracy and datums will have a large effect on the cost of the survey. Converting data between datums after the survey is complete can be problematic and expensive; when possible, it should be avoided by specifying the horizontal and vertical datums before starting so the data can be collected into those datums.

Ancillary measurements for hydrography include the water level, speed of sound or the properties of the water, currents both on the surface and below, and the bottom type. Some of this data is necessary to accurately process the bathymetric data and some is desirable for the project to support later analysis or planning.

Scheduling a hydrographic survey can be a large driver of survey costs. Weather is seasonal and can effect production rates and the cost considerably. Tight schedules require a higher commitment of resources and perhaps higher logistical costs. Fast turnaround of data may require processing in field locations which can raise the cost significantly. If a project allows, relaxed timing allows for scheduling for efficient use of resources. A schedule with flexibility allows for less expensive mobilizations, choice of better weather and office processing.

Environmental conditions such water depths, wind, waves, hazards, tides and currents vary with timing and location and will effect production rates and the choice of equipment. Deeper areas, unreachable with today's LiDAR systems, are generally covered with multibeam more quickly but with lower resolution and with more expensive equipment. Higher resolution can be obtained in shallower areas with less expensive equipment but production rates for Multibeam sonar decrease as depth decrease.

Regulatory requirements can include restricted areas or licensing requirements. In many states, any measurement of land whether above or below water is considered a professional activity that should be performed under the supervision of a licensed Professional Land Surveyor. Also in many areas there are permits required to perform commercial sonar work, the most restrictive being California where the permits can take months to obtain and cost $20,000. Other issues might be restricted areas such as marine sanctuaries, military use areas or areas in proximity to hazards such as dam intakes, locks or high traffic areas where prior permission must be obtained or where timing is critical.

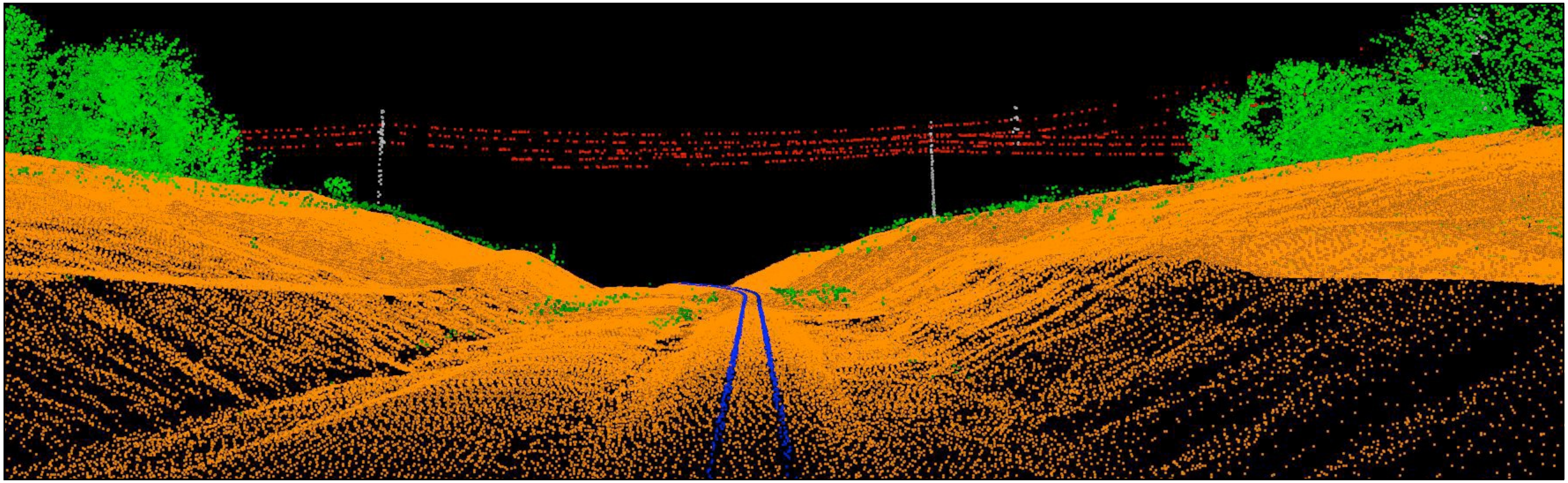
Like any field work, much of the cost of hydrography involves logistics. The project area will need to be accessed by a vessel or aircraft that has the correct equipment installed and crew onboard. Getting the equipment there, managing fuel and parking, accommodations and field offices can be a larger effort than the survey itself but is in fact part of the project. In the case of vessels, the size and range of the vessel is driven by the proximity to support, the duration and type of survey required and the need for spares onboard. Also factored in are safety of crew, delivery of needed items and communications for coordination and emergency response. Larger vessels can work for longer durations in more inclement conditions but are expensive to operate and cannot access shallower areas. Smaller vessels may be handier and cheaper to operate but suffer more weather downtime, can work for smaller durations, and may lack necessary support near the project.

It is very important to specify the desired deliverables early in the process. As with other mapping efforts they may include both paper and digital maps in many forms as well as analysis in support of the project goals. The raw data is often requested even when no ability to make use of it exists. A better strategy may be to require retention of the raw data by the surveyor saving media, storage and delivery costs. Understanding and deciding up front what the needs are should assure that the project goals are met.

Like all mapping activities there are many interlocking aspects to a hydrographic survey. QBS arrangements allow the project owner and hydrographer to work together to choose plans and specifications that address the specific needs of the project for schedule, accuracy, coverage and deliverables to find an approach and budget that achieve the project goals.

Elevation - LiDAR

LiDAR Classified Model



LiDAR can produce millions of points on the ground. This allows for measurement of the service with pinpoint accuracy. The above also includes post-processing to classify the ground (brown), vegetation (green) and man-made features (blue, red, grey).

Light detection and ranging (LiDAR) is an active remote sensing technique providing range (distance) measurements between the laser scanner and the earth topography by measuring the time-of-flight between the emitted and backscattered laser pulse. Direct georeferencing processes turn these distance measurements into 3D point clouds with high accuracy. LiDAR has become an important geospatial tool for remote sensing because point measurements are made at high densities, achieve very high vertical accuracies, are very cost effective over large areas. They can be used during the night or day and under clouds. Additionally, after a pulse is generated it may generate backscatter returns (echoes) and some systems can record up to six echoes for each emitted pulse. Newer LiDAR systems are able to record the signal of the entire backscattered laser pulse and are called full waveform Li-

DAR. The benefit of waveform LiDAR systems is that the user has more interpretive capabilities (intensity, range, and surface structure). The downside is that the processing is more complex and time-consuming. Full-waveform LiDAR data give more control to an end user in the interpretation process of the physical measurement and provide additional information about the structure and the physical backscattering characteristics of the illuminated surfaces.

LiDAR sensors today have a wide range of functionality and associated costs. LiDAR missions commonly generate billions of elevation points that have to be processed and edited to generate a number of useful end products, including "bare-earth" terrain models, "surface" models and contours. The associated costs are related to post spacing (average distance between two points) and point density, and multi-return or waveform processing.

Any specification for LiDAR data should include positional accuracy specifications. It is important to understand that accurate LiDAR points do not necessarily result in a good quality LiDAR surface. Furthermore, a high resolution and high definition LiDAR surface does not necessarily result in high absolute accuracy unless data planning, acquisition, and processing are conducted to a high standard. If very accurate points are widely spaced, then the surface features will lack definition and the elevation model may be much less accurate. Other factors that influence accuracy are the characteristics of ground cover, standing water, and terrain features, and the quality of the classification process. Some project specifications will require breaklines to be added to the LiDAR surface to ensure a higher definition (accuracy) of the surface features.

LiDARgrammetry is a process where LiDAR elevation and intensity data are used to create pseudo stereo pairs using standard digital photogrammetric workstations. This important technology allows mapping technicians to manually digitize 3D breaklines and perform feature extraction from stereo LiDAR intensity imagery. When used on projects requiring feature extraction or the addition of 3D breaklines to meet accuracy specification, it eliminates the cost and technical complexities of acquiring an additional dataset of imagery using a second sensor.

Mobile LiDAR is now commonly acquired to rapidly build surface models along highway, railway, or other corridors. Properly controlling airborne or mobile LiDAR acquisition is extremely impor-

POINT SPACING	VERTICAL ACCURACY (RMSE)	CONTOUR INTERVAL	APPLICATION SUPPORTED				
			Base Mapping	Floodplain Mapping	Natural Resources	Transportation / Utility	Urban Modeling
1 m	0.09 m	1'	✓	✓	✓	✓	✓
2 m	0.20 m	2'	✓	✓	✓	✓	
3 m	0.30 m	3'	✓	✓	✓		
4 m	0.40 m	4'	✓				
5 m	0.51 m	5'	✓				

Note: this table is for example only. Other scenarios are possible and would be defined on a case-by-case basis depending on specific project requirements.

tant and has a significant bearing on achievable accuracy of the datasets. Some projects may benefit from the fusion of mobile and airborne LiDAR datasets. However, this introduces additional technical challenges because each dataset may have different positional accuracy and density.

A number of topographic, meteorological, and technical factors affect the planning and acquisition of LiDAR. For example, mountainous areas usually require flying at multiple altitudes and with greater sidelap to ensure consistent coverage. Heavily vegetated or tight urban canyons required flying with narrower swath widths and greater sidelap. The size and shape of a project area also has a large influence on the cost and complexity of a project. For example, square or rectangular shaped project areas are much more suited to acquire data efficiently; project areas that are irregular require additional flight lines and thus additional collection time; project areas that are broken into small separate areas also will have a higher cost per square mile because of the increased number of flight lines and flying time involved.

Professional assistance is generally needed to determine which of these technologies will provide the "best value" to your project. Modeling the earth's surface using stereo imagery or LiDAR requires detailed knowledge about sensor technology, photogrammetry, surveying, and computer science. These different methods have different financial and technical merits and drawbacks. Because these technologies are changing constantly, the cumulative experience of firms using the technology is invaluable to designing project specifications that will produce the intended benefits.

SYNTHETIC APERTURE RADAR (SAR)

Interferometric synthetic aperture radar (IFSAR) is a remote sensing technology that combines microwave signals collected from two across-track displaced antennae to generate three-dimensional geospatial products. Both orbital and air breathing platforms are available. IFSAR is used, though not as commonly as LiDAR, to collect DEMs over vast areas of the planet. SAR has an advantage over LiDAR in that it operates largely independent of weather conditions (is able to see through clouds), and is quite efficient over expansive geographic areas.

Planimetric Mapping

Planimetric Sample

Planimetric maps show the horizontal positions of the features represented. It does not show relief (elevations) in measurable form (see topographic).

Planimetric mapping is the mapping of man-made features like roads, buildings, fence lines, manholes, etc. Planimetric features are symbolized by symbols, lines, or polygons. The majority of this mapping is still performed manually and is therefore quite labor intensive. Understanding the true needs of the potential user base for project deliverables is important so unneeded features are not specified and the project budget is exceeded. There are many technical factors that contribute to the quality and costs of planimetric mapping. These may be important to define in the project specifications. For example, streams may have to be consistently digitized upstream or downstream, and features that form "networks", like roads and streams, must be physically connected to other features in the network. If not, further analyses of the data may not be possible or severely limited. Project costs can be reduced considerably if planimetric features are delivered with dangling endpoints and crossing features. However, the value of these datasets for many GIS and CAD applications are severely impacted. It is important to discuss these particulars with service providers so GIS analysis is not thwarted and costs are not unnecessarily inflated.

2D OR 3D

Planimetric features should generally be digitized in 3D so every vertex of a particular point, line, or polygon is assigned an X, Y, and Z coordinate value. There is considerable value in 3D datasets because more sophisticated analysis and modeling can be performed and additional costs are minimal.

USING EXISTING PLANIMETRIC MAPPING

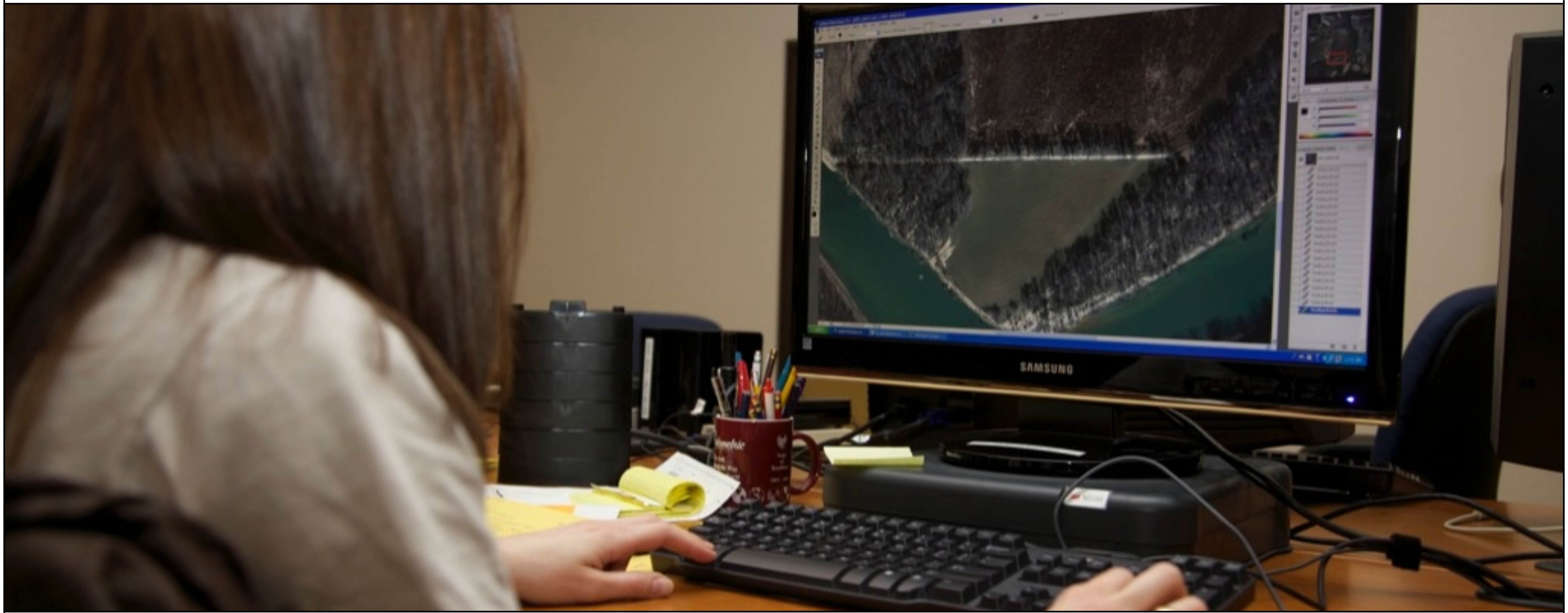
Because planimetric mapping can be very labor intensive to digitize, it may make sense to use existing plan to augment deliverables for the current project. This can save considerable expense if the mapping meets similar quality and positional accuracies of the current solicitation. However, if too dissimilar they may actually increase the project costs because they introduce too many errors and inaccuracies. If existing plan is used, project specifications concerning positional accuracy of the plan should be defined. Additionally, will the plan need to be updated? If so, allow costs for this and decide if information can be provided to the professional that identifies the areas that need updating. If this is not available, then expect costs to increase since all planimetric data will have to be verified to be consistent with the photography or LiDAR. In many cases the existing plan will not have been collected by the same professionals that are updating it. They may discover quality problems with the data. If so, how will they be handled? If the positional accuracy of the planimetric data was not field tested, then who will be responsible to fix and pay for inaccuracies discovered?

URBAN OR RURAL

The number and density of planimetric features specified have a significant impact on cost and schedule. Digitizing all roads in a rural area will take a fraction of the time than those in a urban area. Buildings in an older part of a community may have roof lines that are closer together and more difficult to discern from imagery than ranch style homes in the suburbs. When collecting buildings, is it important that decks be included as part of the “house” feature or as a separate “deck” feature or not at all? Should all buildings be digitized so they are “square” to the adjacent road or appear in their actual orientation on the ground making a less cartographically pleasing map? Are walks required? If so, what about those on private property? Should different types of road surfaces (concrete, gravel, blacktop) be indicated in the roads as they are collected? Should the shoulders of paved roads be symbolized? Should unpaved road shoulders be digitized? All of these questions and many more need to be carefully considered before a solicitation is released. It is important to include geospatial professionals in these discussions so the needs (not wants) of the user community are closely aligned with the procured services and are possible with the project budget.

CHAPTER 5

Quality Considerations



"Every contractor performs some level of quality control and quality assurance for the project. But precisely what is checked and what quality assurance methods are employed by the contractors to ensure quality, repeatable deliverables?"

Ground Control

Ground Control Point, Oklahoma

Measurement and reference to physical points on the ground are necessary to ensure the acquired data "ties" to the ground's surface, creating an accurate deliverable.

Ground Control forms the basis for any mapping or geospatial project and shows the true relationship of features or objects to each other in terms of distance, angle, area, etc. Control is the anchor point, the determining factor in stating the positional accuracy with which a given dataset matches the location at which that dataset occurs in the world.

Control can be many things – a can on the beach marking a starting point for someone to pace off a sand volleyball court, or a precise and highly accurate mark on a geodetic monument disk that has been established with week-long GPS observations. Like many things, control has specialized applications depending on the task at hand and can range greatly in cost.

To be useful, control needs to be more precisely measured and possess a higher degree of accuracy than the mapping or orthophotography. It would do no good to fly imagery for a project and subsequently map it one foot accuracies if the control which anchored all of the mapping work was derived from a U.S. Geological Survey 7.5 Minute Topographic Map with a stated accuracy of 40 feet. The inverse is also true. Control is costly and its measurement needs to be matched to the project deliverables to meet solicitation's budget and schedule.

Control is either paneled as an aerial target, or is collected as a photo-identifiable point. Paneling a point allows you to put control exactly where you want it, but it requires leaving a target, usually painted or identified with plastic strips, to identify where the control point is located and to make it visible to aerial sensors. This has both pros and cons – with plastic, it can be disturbed or destroyed by the farmers cow or by high winds. So panel maintenance becomes necessary to ensure the panels are in place and visible when the aerial photography occurs. This can become expensive and requires coordination between the control and remote sensing crews. If a single critical control point is obscured or destroyed and cannot be seen in the aerial photography or LiDAR, reflights may have to occur. Further, the control targets cannot be removed until after the acquired data has been verified as usable. Removing the targets requires a revisit to the property. This adds another cost to the project.

Photo-identifiable points offer the benefit of being permanent or semi-permanent features in the area of interest clearly visible to the remote sensing equipment, without requiring a panel. Quality, photo-identifiable control is easy in urban areas, but in more remote areas, it can become more difficult to find a suitable feature that has enough contrast, permanency and visibility to act as a stable control point over time.

The source of ground control is important and has direct bearing on the confidence one can place in the accuracy of the base mapping. The value of the very expensive topographic and planimetric mapping and orthoimagery acquired can be significantly compromised without good control. Extreme care and expert advice is needed to ensure adequate control is used for the project. Whatever the source, the ground control must have a "defined, measured" accuracy. It must be collected to a defined set of standards. For example, many photo-identifiable points with latitude and longitude coordinates can be derived from high resolution (15 cm GSD) Google Earth imagery. However, if the positional accuracy of that imagery displayed in that projection has not been defined, then the degree of confidence with which you can use that control for your base mapping project is quite low.

The costs of surveyed ground control can be impacted by a number of factors that need to be considered in the solicitation. Is access to the property possible with or without permission of the land owner? Are the locations of the points accessible or remote? Can they be surveyed safely or will they require special precautions to protect the surveyors? Can the points be accessed using vehicles or will they require other modes of transport?

Control should be obtained using trained GPS technicians and professional surveyors. Many states require professional surveyors to perform this work. For some projects a certified photogrammetrist is qualified to design a project using photo-identifiable control and a professional surveyor is not needed.

COLLECTION METHODS

Professional surveyors are generally needed to measure ground control after the mapping professionals have determined the number and placement of the points needed to meet the mapping accuracy specifications. Because manual labour is involved costs can be quite high. However, they often comprise only a small proportion of the overall project costs and are foundational to the validity and usefulness of all the information built on top of it used by design and GIS specialists.

Existing control may be available and can also be licensed. Some agencies balk at the idea of non-ownership, but when viewed as a commodity such as Microsoft Office, ownership considerations become less important – what is important is the use of the product for the purpose at hand. Licensed control data (in effect “pre-used”) can be more cost-effective than acquiring the control needed for the project.

Quality Control & Assurance

QA/QC Report Grid

Control Surveyed			Tested or Measured			Statistics				
X	Y	Z	X	Y	Z	X	X	Y	Y	XY
		Control			Tested	diff in x	(diff in x) 2	diff in y	(diff in y) 2	(diff in x)2 + (diff in y)2
869389.498	411196.569	701.825	1869389.849	411196.497	701.754	-0.35	0.12	0.07	0.01	0.13
876427.181	414942.456	680.723	1876427.512	414942.279	680.751	-0.33	0.11	0.18	0.03	0.14
873842.676	414185.811	688.948	1873843.062	414185.694	688.772	-0.39	0.15	0.12	0.01	0.16
873865.212	418375.555	742.929	1873865.052	418375.475	742.877	0.16	0.03	0.08	0.01	0.03
870669.276	418132.612	807.629	1870669.35	418132.753	807.367	-0.07	0.01	-0.14	0.02	0.03
869198.123	415985.430	753.525	1869198.256	415985.581	753.303	-0.13	0.02	-0.15	0.02	0.04
877137.221	418092.269	666.047	1877137.41	418092.159	665.809	-0.19	0.04	0.11	0.01	0.05
877240.835	413478.619	697.088	1877241.104	413478.631	697.19	-0.27	0.07	-0.01	0.00	0.07
877289.001	411076.193	819.183	1877289.221	411076.238	819.156	-0.22	0.05	-0.04	0.00	0.05
874289.000	416726.608	718.045	1874289.4	416726.802	717.76	-0.40	0.16	-0.19	0.04	0.20

Accurate reports, like the one pictured, measure all controlled survey points against the final model deliverable. Variances are denoted and in some cases improved upon depending on the contracted specifications.

Every contractor performs some level of quality control and quality assurance for the project. But precisely what is checked and what quality assurance methods are employed by the contractors to ensure quality, repeatable deliverables? How much and what methods of quality control and quality assurance are needed? How much QA/QC can be afforded? Are quality management standards like ISO 9000 important? Should independent contractors be used to certify the quality of deliverables? What measures of quality are important?

The final confidence in the quality of the project's deliverables will be directly proportional to the degree to which the solicitation addresses these concerns.

Quality Control (QC) is a process employed to ensure a certain level of quality in a product or service. Quality assurance (QA) is the process of verifying or determining whether products or services meet or exceed customer expectations. It is prudent to understand what measures the contractor will employ to ensure deliverables meet quality expectations. Quality Assurance is generally performed by the buyer and can be done in-house or contracted to a 3rd party. It is very important that quality assurance procedures and costs be considered while the solicitation is drafted so the project budget accurately reflects these associated costs. The costs of QA typically range from 15%-20% of the project budget.

Deliverable Methods

Aerial Services Server Room

With today's digital services being produced, physical hard drives, web services, backup, and other digital deliverables are the norm.

Geospatial projects continue to grow in size. The total area being imaged or modeled and the volume of data produced and delivered continues has grown to unprecedented levels. Delivery of this information is an important consideration for many projects. Several factors should be considered.

BACKUP COPIES

Is a physical digital copy of the deliverables needed? Generally this is the case if for no other reason than to ensure the data is available if the manufacturers cease to exist, or for other security reasons. If data is a required deliverable the type of media should be specified: tape, external hard drive, or optical. If hard drives are used, will they be USB 2.0, USB 3.0, or SATA interfaces?

WEB SERVICES

It may be advantageous to have data delivered as a web service. The advantages to this include avoiding the high cost of infrastructure and personnel to maintain infrastructure that is needed to host large volumes of geodata internally. Once outsourced, the users may work as usual but the high costs of infrastructure have been outsourced and become a low fixed cost to the organization.

If web services are procured for delivery of project data, project specifications should be drafted that clearly define the following:

- Describe how each type of data will be provided. (Are these services portable to other cloud providers? Are these services scalable?)
  - WMS
  - WMTS
  - FTP
  - Other RESTful services
- Flash or Javascript clients
- Ensure the web services are compatible with the browsers and desktop GIS software that will be used by the user community.
- Clarify data ownership and licensing.
- Clarify where the data is physically located.
- Understand the terms of service.
- Define both the on-boarding (loading data into the web service) and off-boarding (pulling data off the web service) processes and deliverable types
- Define the type of data security in use by the cloud provider and who is responsible for what if the service fails.
- Ensure the billing methods for using the service are compatible with your organization.

CHAPTER 6

Aerial Services Can Help You

Aerial Services, Inc. (ASI) is an integrated team of professionals providing premier Aerial Acquisition, Digital Ortho, Vector Mapping, Terrain & LiDAR services to government, utilities, engineers, and other geospatial clients. Based in the Iowa heartland for nearly half a century, Aerial Services' resilient work ethic, cutting-edge technology, and experienced staff combine to harness the power of geographic information and provide solutions you need.

A Trusted Geospatial Provider

People Matter. Projects Matter.

Aerial Services has been exceeding clients' expectations for nearly half a decade. Their robust toolset of aircraft, remote-sensing equipment, expert employees, and decades of experience ensure the project they do for the people they work for are done right.

Aerial Services, Inc. (ASI) is an established provider of customized geospatial solutions.

- They will **exceed your expectations** while delivering on promises
- Their experience with and mastery of emerging technology ensures your project is **accurate, on-time, and within budget**
- Their **hard-working staff** of professional photogrammetrists, surveyors, computer professionals, GIS specialists, aerial photographers, and pilots are among the best at developing geospatial services
- Many employees have been with the company for **decades**
- Located in the charming Midwestern town of Cedar Falls, Iowa Aerial Services has become a **trusted provider** of geospatial solu-

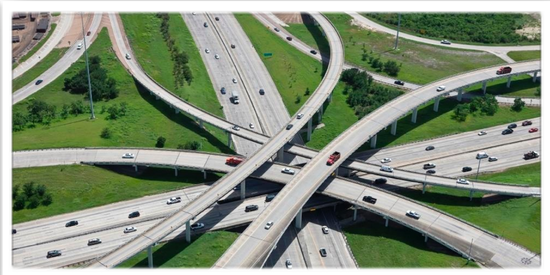
tions, allowing them to provide all of the services of the large geospatial providers with the attention to detail and personal service of smaller operations.

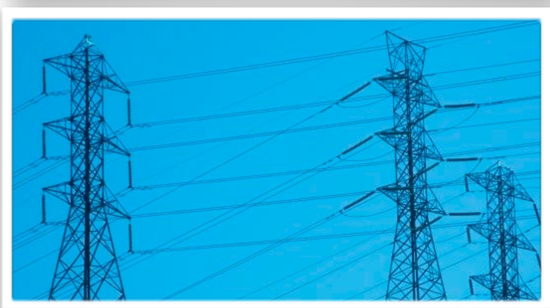
SOLUTIONS

Geosolutions are seamlessly integrated and focused on the critical needs of Aerial Services' customers. We have both standard and custom solutions with foundations in providing excellent value, timely provision of geoknowledge and the ultimate in quality.

Customizable Options For:

- Oil & Gas
- Aggregate & Mining
- Roadway
- Electrical Utility
- Precision Farming
- Resource Management
- Forestry
- Land Management
- Railway





Technology

- Imagery
- LiDAR
- Photogrammetry
- Video
- Metadata
- Ground Penetrating Radar

Visualizations

- Fly Throughs
- Industry Standard Formats
- GIS Files
- GeoPDF
- Paper Maps / Posters

eDelivery

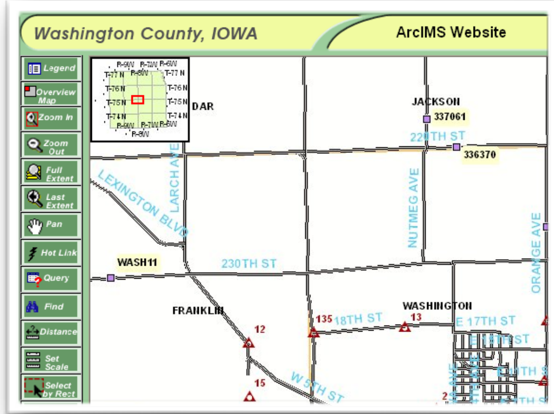
- Hard Drive or USB
- FTP Download
- Web Services

eSolutions

- Spatial Cloud
- eDocs

Accuracy

- GIS Grade
- Engineering Grade



Contact Now

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On Wednesday, December 18, 2013, 3:00 PM (Eastern), AUVSI and MAPPS are hosting special webinar to discuss "Geospatial Mapping Applications Using UAVs". This event will include remarks from Mike Tully, Aerial Services President & CEO, an acknowledged thought leader in the UAS for geospatial discussion.

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Aerial Services, Inc. (ASI) has completed their fall 2013 webinar series. These educationally driven, one-hour events discussed a number of geospatial topics and are free to those interested via recorded video/slides. Each is hosted by Aerial Services

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Volume 7, Issue 4
December 2013

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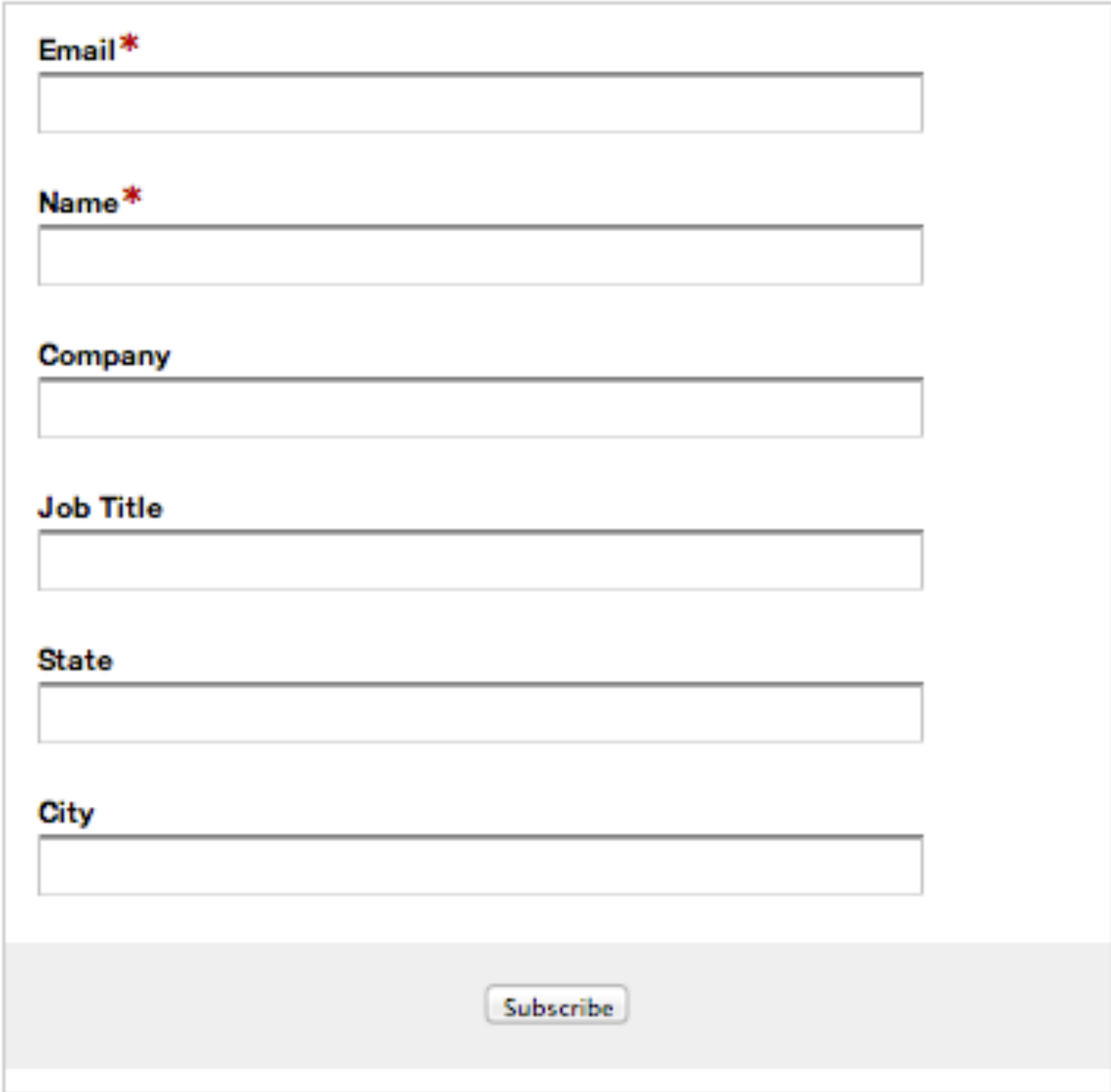

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95% Confidence Level

Accuracy reported at the 95% confidence level means that 95% of the positions or elevations in the dataset will have an error with respect to true ground position or true elevation that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates; GPS-IMU system error, sensor error, processing algorithm error, interpolation error, and final computation of ground coordinate values in the product. Where errors follow a normal error distribution, $Accuracy_z$ defines vertical accuracy at the 95% confidence level (computed as $RMSE_z$ x 1.9600), and $Accuracy_r$ defines horizontal (radial) accuracy at the 95% confidence level (computed as $RMSE_r$ x 1.7308).

A note about Confidence Interval and Percentiles:

The concepts of "95% Confidence Interval" and 95th Percentile sound very similar and can be confusing. But they are quite different and it is important to understand them. For example, we may never want to agree to providing Lidar accuracies in vegetation to a "95% confidence interval", because it may not meet this due to the nature of non-random errors of that dataset. Some specifications may wrongly want this assurance and we need to clearly explain why they should be asking for "95th Percentile" for vertical accuracies of points in vegetation classifications.

95% Confidence Interval defines the Upper and Lower Confidence Limits of your sample mean. If theoretical distribution of sample means is normal, then 95% Confidence Interval defines a PROBABILITY of 0.95 that another sample mean also would fall within the Confidence Limits, if you were to do the experiment again (same sample size).

95th Percentile simply means that 95% of all values lie below that point. That observation applies to all distributions, regardless whether they are normal. It says nothing about the "population" of all measurements. It describes this one sample of observations only.

Related Glossary Terms

95th Percentile

Index Find Term

95th Percentile

Accuracy reported at the 95th percentile indicates that 95% of the errors will be of equal or lesser value and 5% of the errors will be of larger value. This term is used when errors may not follow a normal error distribution, e.g., in forested areas where the classification of bare-earth elevations may have a positive bias. NDEP established guidelines that specifically address LiDAR and the fact that the RMSE process is inappropriate for many land cover categories except for open terrain where there are no valid reasons why errors should not follow a normal error distribution. Vertical accuracy at the 95% confidence level and 95th percentile may be compared to evaluate the degree to which actual errors approach a normal error distribution. See "Issue 37: Quality Control of Light Detection and ranging (LiDAR) Elevation Data in North Carolina for Phase II of the NCFMP".
http://www.ncfloodmaps.com/pubdocs/issue_papers/IP37-phaseII_lidar_qc.pdf

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Related Glossary Terms

95% Confidence Level, Percentile

Index Find Term

Absolute Accuracy

A measure that accounts for all systematic and random errors in a data set. Absolute accuracy is stated with respect to a defined datum or reference system.

Related Glossary Terms

Accuracy

Index Find Term

Accuracy

The closeness of an estimated value (e.g., measured or computed) to a standard or accepted (true) value of a particular quantity. Note: With the exception of GPS Continuously Operating Reference Stations (CORS), assumed to be known with zero errors relative to established datums, the true locations of 3-D spatial coordinates or other points are not known, but only estimated. Therefore, the accuracy of other coordinate information is unknown and can only be estimated.

Related Glossary Terms

Absolute Accuracy, Accuracyr, Accuracyz, Geospatial Accuracy Standard, Local Accuracy, Network Accuracy, Percentile, Positional Accuracy, Precision, Relative Accuracy, Resolution, Root Mean Square Error (RMSE)

Index

Find Term

Accuracy_r

The NSSDA reporting standard in the horizontal component that equals the radius of a circle of uncertainty, such that the true or theoretical horizontal location of the point falls within that circle 95-% of the time. $\text{Accuracy}_r = 1.7308 \times \text{Root Mean Square Error}_r$ (RMSE_r). Horizontal accuracy is defined as the positional accuracy of a dataset with respect to a horizontal datum.

Related Glossary Terms

Accuracy

Index Find Term

Accuracyz

The NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the true or theoretical vertical location of the point falls within that linear uncertainty value 95-% of the time. $Accuracy_z$= 1.9600 x $RMSE_z$. Vertical accuracy is defined as the positional accuracy of a dataset with respect to a vertical datum.

Related Glossary Terms

Accuracy

Index Find Term

Bare Earth DEM (Digital Elevation Model)

A popular acronym used as a generic term for digital topographic and/or bathymetric data in all its various forms, but most often bare earth elevations at regularly spaced intervals in X and Y directions. Regularly spaced elevation data are easily and efficiently processed in a variety of computer uses. A DEM contains elevations at points arranged in a raster data structure, a regularly spaced X, Y grid, where the intervals of ΔX and ΔY are normally in linear units (feet or meters) or geographic units (degrees or fractions of degrees of latitude or longitude). The Z-values in a DEM represent the height of the terrain, relative to a specific vertical datum and void of vegetation or manmade structures such as buildings, bridges, walls, et cetera. The elevation of lakes and rivers in a DEM implies the height of the water surface based on elevation of the exposed shoreline. The observations, or direct measurements, of elevation that comprise the DEM are almost never actually captured on a regular grid; therefore, the elevation for any given point in the grid is normally interpolated from other forms of source data. LiDAR, for example, yields a dense set of irregularly spaced points; interpolation to a grid requires using one of many possible interpolation algorithms, which produce varying results. Linear features, such as streams, North Carolina Technical Specifications for LiDAR Base Mapping Page 23of 74 Adopted January 30, 2013 by North Carolina Secretary of State Elaine F. Marshall drainage ditches, ridges, and roads are often lost in a DEM if the grid spacing is larger than the dimensions of the feature. Furthermore, in a DEM, it is unlikely that the hard edge of the feature will be represented correctly in the terrain model. The DEM, because it is a raster data structure similar to a digital image, is an efficient format for storage, analysis, rendering, and visualization.

Related Glossary Terms

Digital Surface Model (DSM), Digital Terrain Model (DTM), Triangulated Irregular Network (TIN)

Index Find Term

Breakline

A linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line. The two most common forms of breaklines are soft and hard breaklines.

Related Glossary Terms

Contours, Hard breakline, Soft breakline

Index

Find Term

Consolidated Vertical Accuracy (CVA)

The result of a test of the accuracy of vertical checkpoints (z-values) consolidated for two or more of the major land cover categories, representing both open terrain and other land cover categories. Computed by using the 95th percentile, CVA is always accompanied by Fundamental Vertical Accuracy (FVA).

Related Glossary Terms

Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA)

Index Find Term

Contours

Lines of equal elevation on a surface. An imaginary line on the ground, all points of which are at the same elevation above or below a specified reference surface (datum).

Related Glossary Terms

Breakline, Hillshade

Index Find Term

DEM post spacing

Defined as the constant sampling interval in X- and Y-directions of a DEM lattice or grid. This is also called the horizontal resolution of a gridded DEM or the DEM grid spacing. If a DEM is required as part of project specifications the contract must include the desired grid spacing. It is standard industry practice to have: • 1-meter DEM post spacing for elevation data with 1-foot equivalent contour accuracy; • 2-meter DEM post spacing for elevation data with 2-foot equivalent contour accuracy; and • 5-meter DEM post spacing for elevation data with 5-foot equivalent contour accuracy.

Related Glossary Terms

Digital Surface Model (DSM), Digital Terrain Model (DTM)

Index Find Term

Digital Surface Model (DSM)

An elevation model created for use in computer software that is similar to DEMs or DTMs except that DSMs depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth.

Related Glossary Terms

Bare Earth DEM (Digital Elevation Model), DEM post spacing, Triangulated Irregular Network (TIN)

Index Find Term

Chapter 4 - Modeling the Earth's Surface

Digital Terrain Model (DTM)

Data structure is also made up of X and Y points with Z-values representing elevations, but unlike the DEM, these may be irregularly or randomly spaced mass points. Direct observations of elevation at a particular location can be incorporated without interpolation, and the density of points can be adjusted so as best to characterize the actual terrain. Fewer points can describe very flat or evenly sloping ground; more points can be captured to describe very complicated terrain. In addition to mass points, the DTM data structure often incorporates breaklines(further defined below) to retain abrupt linear features in the model. A DTM is often more expensive and time consuming to collect than a DEM, but is considered technically superior for most engineering analyses because it retains natural features of the terrain.

Related Glossary Terms

Bare Earth DEM (Digital Elevation Model), DEM post spacing, Triangulated Irregular Network (TIN)

Fundamental Vertical Accuracy (FVA)

the value by which vertical accuracy can be equitably assessed and compared among datasets. The FVA is determined with vertical checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. FVA is calculated at the 95% confidence level in open terrain only, using $RMSE_z$ x 1.9600.

Related Glossary Terms

Consolidated Vertical Accuracy (CVA), Supplemental Vertical Accuracy (SVA)

Index Find Term

Geospatial Accuracy Standard

A common accuracy testing and reporting methodology that facilitates sharing and interoperability of geospatial data. Published in 1998, the National Standard for Spatial Data Accuracy (NSSDA) is the Federal Geographic Data Committee (FGDC) standard relevant to digital elevation data when assuming that errors follow a normal error distribution. However, after it was learned that LiDAR datasets do not necessarily follow a normal distribution in vegetated terrain, the National Digital Elevation Program (NDEP) published its "Guidelines for Digital Elevation Data" and the American Society for Photogrammetry and Remote Sensing (ASPRS) published the "ASPRS Guidelines: Vertical Accuracy Reporting for LiDAR Data," both of which were published in 2004 and use newer terms defined below as Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). All of these standards, designed for digital elevation data, replace the National Map Accuracy Standard (NMAS) that is applicable only to graphic maps defined by map scale and contour interval.

Related Glossary Terms

Accuracy

Index Find Term

Hard breakline

Defines interruptions in surface smoothness, e.g., to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are 3-D breaklines, they are often depicted as 2-D breaklines because features such as shorelines and building footprints are normally depicted with a series of horizontal coordinates only, that are often digitized from digital orthophotography that include no elevation data.

Related Glossary Terms

Breakline, Soft breakline

Index Find Term

Hillshade

A function used to create an illuminated representation of a surface, using a hypothetical light source that simulates the cast shadow thrown upon a raised relief map. This process is helpful in identifying linear features such as streams and ridgelines. North Carolina Technical Specifications for LiDAR Base Mapping

Related Glossary Terms

Contours

Index Find Term

Local Accuracy

A value that represents the uncertainty in the coordinates of a control point relative to the coordinates of other directly-connected, adjacent control points at the 95% confidence level. The reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point.

Related Glossary Terms

Accuracy, Network Accuracy

Network Accuracy

A value that represents the uncertainty in the coordinates of a control point with respect to the geodetic datum at the 95% confidence level. For National Spatial Reference System (NSRS) network accuracy classification in the U.S., the datum is considered to be best expressed by the geodetic values at the CORS supported by the National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.

Related Glossary Terms

Accuracy, Local Accuracy

Index Find Term

Nominal Point Spacing

Not an appropriate term in LiDAR because a single Pulse can produce multiple points. NPS as used in this standard pertains to LiDAR only and is not intended to pertain to photogrammetry or Interferometric Synthetic Aperture Radar (IFSAR).

Related Glossary Terms

Nominal Pulse Spacing (NPS)

Index Find Term

Nominal Pulse Spacing (NPS)

The estimated average spacing of irregularly-spaced LiDAR points in both the along-track and cross-track directions resulting from: the laser pulse repetition frequency (e.g., 100,000 pulses of laser energy emitted in one second from a 100 kHz sensor); scanrate (sometimes viewed as the number of zigzags per second for this common scanning pattern); field-of-view; flight airspeed, and flight altitude above the terrain. LiDAR system developers currently provide "design NPS" as part of the design pulse density, although the American Society for Photogrammetry and Remote Sensing (ASPRS) is North Carolina Technical Specifications for LiDAR Base Mapping currently developing standard procedures to compute the "empirical NPS" which should be approximately the same as the "design NPS" when accepting statistically insignificant loss of returns and disregarding void areas, from water for example. The NPS assessment is made against single swath first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track pulse spacing should be comparable. When point density is increased by relying on overlap or double-coverage it should be documented in metadata, and the project's reported NPS should not change. The NPS should be equal to or less than the desired Digital Elevation Model grid. NPS is not to be substituted for Nominal Point Spacing.

Nominal Point Spacing = 1 / sqrt(points per sq m)

Related Glossary Terms

Nominal Point Spacing

Percentile

Any of the values in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. Any of those groups can specify a specific percentile, e.g., the 95th percentile as defined below.

Related Glossary Terms

95th Percentile, Accuracy

Index Find Term

Positional Accuracy

The accuracy of the position of features, including horizontal and/or vertical positions.

Related Glossary Terms

Accuracy, Relative Accuracy

Index Find Term

Precision

A statistical measure of the tendency of a set of random numbers to cluster about a number determined by the dataset. Precision relates to the quality of the method by which the measurements were made and is distinguished from accuracy which relates to the quality of the result. The term "precision" not only applies to the fidelity with which required operations are performed, but, by custom, has been applied to methods and instruments employed in obtaining results of a high order of precision. Precision is exemplified by the number of decimal places to which a computation is carried and a result stated.

Related Glossary Terms

Accuracy, Resolution

Index Find Term

Chapter 3 - Image Band & Depth

Relative Accuracy

A measure that accounts for random errors in a dataset. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors (systematic errors and blunders removed) in determining the positional orientation (e.g., distance, azimuth) of one point or feature with respect to another.

Related Glossary Terms

Accuracy, Positional Accuracy

Index Find Term

Resolution

In the context of elevation data, resolution is synonymous with the horizontal density of elevation data points for which two similar terms are used; Nominal Pulse Spacing and Nominal Point Spacing.

Related Glossary Terms

Accuracy, Precision

Index Find Term

Root Mean Square Error (RMSE)

The square root of the average of the sum of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical RMSE ($RMSE_z$), for example, is calculated as the square root of $S(Z_n - Z'n)2/N$, where: Z_n is the set of N z-values (elevations) being evaluated, normally interpolated (for TINs and DEMs) from dataset elevations of points surrounding the X-Y coordinates of checkpoints; and Z'n is the corresponding set of checkpoint elevations for the points being evaluated; -Nis the number of checkpoints; and n is the identification number of each of the checkpoints from 1 through N. Adopted January 30, 2013 by North Carolina Secretary of State Elaine F. Marshall

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Related Glossary Terms

Accuracy

Index Find Term

Soft breakline

Ensures that known elevations, or Z-values, along a linear feature are maintained (e.g., elevations along a pipeline, road centerline, or drainage ditch), and ensures the boundary of natural and man-made features on the Earth's surface are appropriately represented in the digital terrain data by use of linear features and polygon edges. They are generally synonymous with 3-D breaklines because they are depicted with series of Z-Y-Z coordinates.

Related Glossary Terms

Breakline, Hard breakline

Index Find Term

Supplemental Vertical Accuracy (SVA)

The result of a test of the accuracy of z-values over areas with ground cover categories or combination of categories other than open terrain. Computed by using the 95th percentile, SVA is always accompanied by FVA. SVA values are computed individually for different land cover categories. Each land cover type representing 10% or more of the total project area is typically tested and reported as an SVA. SVA specifications are normally target values that may be exceeded so long as overall CVA requirements are satisfied.

Related Glossary Terms

Consolidated Vertical Accuracy (CVA), Fundamental Vertical Accuracy (FVA)

Index Find Term

Triangulated Irregular Network (TIN)

A set of adjacent, non-overlapping triangles computed from the mass points and breaklines in a DTM. TINs also preserve abrupt linear features and are excellent for calculations of slope, aspect, and surface area and for automated generation of topographic contours, which are all important functions to the flood study engineering. Storage formats for TINs are more complex than either DEMs or DTMs, because the relationship of elevation points and triangular surfaces must be preserved within the data structure. A TIN model may be preferable to a DEM when it is critical to preserve the location of narrow or small surface features such as a stream channel or ridge line.

Related Glossary Terms

Bare Earth DEM (Digital Elevation Model), Digital Surface Model (DSM), Digital Terrain Model (DTM)

Index Find Term