MAPPINGMATTERS

YOUR QUESTIONS ANSWERED

The layman's perspective on technical theory and practical applications of mapping and GIS

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QUESTION:

Breaklines for Lidar Data, Do We Really Need Them?

Question: Although today's lidar data is more accurate and denser than previously achieved, and therefore more accurate and reliable in representing the topography of the land, we have some clients who are generating or request we generate contours from dense lidar datasets for different reasons and uses. We always strive to provide our clients with sound approaches that help them make best use of their budgets. Considering the current state of technology, what is your opinion on the following concepts?

1. The idea of generating contours in the presence of a dense and accurate lidar dataset;
2. The need for breaklines to augment the lidar dataset before generating the contours;
3. Lidar-derived contours are more accurate than the contours generated from traditional photogrammetric practices;
4. With U.S. Geological Survey (USGS) Quality Level 2 (QL2) lidar data, is it safe to say, "The contour lines are a visual representation of the lidar data" when we deliver the contours to clients?

Kent Park, Woolpert Inc., Bluffton, IN

Dr. Abdullah: Thank you, Kent, for bringing this very important topic to my attention. The discussion of generating contours from lidar data and whether this process requires breaklines is haunting the industry, and there has not been clear action to settle it. In the hope to inform users and data providers on this important topic and to remove myths surrounding it, I will try to shed some light on the concept of contour generation from lidar and the role of breaklines. The best way to start discussing this topic is to provide the history and evolutionary stages that terrain modeling has experienced over the years. Without understanding the history, it is difficult to devise a way forward.

> **"contours should have no place in today's digital mapping environment"**

Contours

A contour line is a line connecting places of equal elevation. Using contour lines is the most common way of numerically representing land elevation. In the 18th and 19th centuries, land-surveying practices did not allow for the recording of relief across the land, as it was not practical. Only a limited number of spot elevations at survey points were surveyed. That was the practice until U.S. Geological Survey (USGS) topographical survey maps included contour representation of terrain relief. After reflecting on the period that contours were introduced to represent the topography, experts concluded paper maps and other hard surfaces were the only media to document and represent land relief. Even contours generated from photogrammetric methods were scribed on scribe sheet before being printed or reproduced on paper. A scribe sheet is made of a stable plastic base material, coated with a material designed for easy removal using a scribing tool to produce a cleanly cut line. Therefore, the concept of contours to represent topography was

> **Key takeaway about contours:**
> **(1) Contours were the only method available to model terrain elevation numerically on paper media or paper maps. (2) Contours are unnecessary and it should not be used to define a topographic surface in digital form.**

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only developed for paper/hard surface maps. Decades passed before we transitioned to soft copy, digital modeling and representation of land topography. Accordingly, contours should have no place in today's digital mapping environment.

Breaklines

Put simply, a breakline is a three-dimensional line in a digital mapping environment used to represent a sudden or abrupt change or break in the terrain's smoothness. The need for breaklines emerged to help the labor-intensive map-making process using photogrammetric stereo-compilation. It is not economically feasible to trace the ground and generate height information for every single square foot of the land through the 3D digitization process. The industry devised an approach that helped the map-making process and made it more affordable for users. During the early stages of digital map making, terrain topographies were modeled by pulling contours in which the operator fixes the floating mark at certain contour elevations and manually digitizes the terrain where the elevation is equal to the set contour elevation. This process is similar to what the industry used for decades prior to the digital era of map making. However, instead of scribing the contours on the scribe sheet, as described earlier, the contour lines are formed digitally within a digital graphic or CAD file. Later, experts largely replaced this process of modeling the topography by direct drawing of contours with the new practice of generating what some call a Digital Terrain Model (DTM). DTMs usually contain sparse 3D points, sometimes called "mass points," to represent terrain elevation in flat and rolling terrain, and breaklines to represent abrupt changes in the terrain. The mass points and vertices of the breaklines are then later converted to a Triangular Irregular Network (TIN) from which contours and other terrain models are derived in a digital environment. The density and frequency of mass points were in no way close to the density of today's lidar points cloud. The density of compiled mass points depends on map scale and the relief in the terrain. Collecting mass points with post spacing of 50 feet to 150 feet was and still is a common practice when modeling the terrain using stereo photogrammetry. Modeling the terrain with a denser mass point becomes costly, which makes the case for introducing the concept of breaklines. The breakline concept was introduced to avoid modeling the entire project with dense mass points, as it was a manual, labor-intensive process. With coarse post spacing of mass points and with the absence of breaklines, terrain modeling is inaccurate, as it fails to represent the true shape of the terrain.

> **Key takeaway about breaklines:**
> **Breaklines were introduced to more accurately capture changes in terrain in the presence of coarse mass points, or what we refer to today as points cloud.**

Lidar Dataset

With the familiarity of today's lidar technologies, I will forgo the lidar introduction. When we started using lidar in the mid-1990s, lidar technology was in its infancy, and pulse repetition rate, which contributed to the points cloud density, was very low. Collecting a lidar-based points cloud with a post spacing of 5 meters was a normal practice at the time. A few years later, as lidar technology matured, we transitioned to 2-meter post spacing. This evolved to where we are today—collecting USGS QL2 lidar data with a density of 2 points per square meter and a post spacing of around 0.71 meter (or 2.3 feet), which is the normal practice. Considering the latest advances in lidar technologies, soon Quality Level 1 (QL1) lidar data with a density of 8 points per square meter and a post spacing of around 0.35 meters (or 1.15 feet) will be the norm within the industry. I would like the reader to ponder the fact that a lidar dataset with a post spacing of 71 centimeters or even 35 centimeters is replacing old photogrammetric methods of modeling the terrain with post spacing of 15.2 meters (50 feet) or coarser. This means, with lidar we are able to survey a terrain elevation every 71 centimeters or even 35 centimeters. That is something cost prohibitive even when we perform land-surveying techniques to model the terrain. Field survey for road construction is performed with profiles or cross sections every 30 feet or so, and stockpile volumetric computations are done by surveying minimal spot elevation along the toes and ridges of the pile.

> **Key takeaway about lidar dataset:**
> **Lidar points cloud is the most comprehensive method of modeling the terrain. It provides an elevation post down to every foot of the terrain.**

Now that I've provided some history and background, let us discuss Kent's questions. I will address the concepts proposed in the same order as Kent's submission:

> **"The breakline concept was introduced to avoid modeling the entire project with dense mass points, as it was a manual, labor-intensive process"**

Should you generate contours in the presence of a dense and accurate lidar dataset?

Unless you need contours plotted on a hard copy map for field workers or support, I believe creating contours from a lidar dataset is an unwise practice for the following reasons:

1. You can benefit more from the lidar points cloud, as it is denser and richer in information than contours. Contours are generated by subsampling, (parsing or thinning) dense lidar data to generate less dense data. In other words, it is equivalent to hiding some valuable information about the terrain elevation residing in the points cloud.

2. Generating contours from a lidar points cloud is problematic and, if you want the contours to have the aesthetic look of the contours generated from photogrammetry, takes valuable labor hours. Remember, contours generated from DTM (i.e. breaklines and mass points) are smooth, as the contours are interpolated from mass points (and breaklines, if they exist) with post spacing of 50 feet or more. Such wide spacing of mass points smooth the interpolated contours, as it is less sensitive to the micro changes in elevation across the terrain. On the contrary, lidar points cloud, because of their high density, are very sensitive to changes in elevation, so contours generated from lidar do not look appealing. However, such contours are more accurate in representing the terrain than the photogrammetric contours.

3. Many software applications can handle lidar datasets and can model the terrain in more creative ways than contours.

> **"contours generated from lidar make a better representation of the terrain than the contours generated from DTM"**

Question 2—Do we need breaklines to augment the lidar dataset before generating contours?

Assuming your applications demand the creation of contours to plot on a paper map, the quality and accuracy of the created contours using a lidar dataset depends on the lidar points cloud density and the application at hand. For most applications, when using a USGS QL2 lidar dataset, you don't need to add breaklines due to the high density of the points cloud. Remember that breaklines are only needed in the absence of a dense points cloud, as was the case with the photogrammetric modeling of terrain. Why would anyone need breaklines for terrain modeling when the ground is sampled at a 71-centimeter or even 35-centimeter interval? What would be a better way to define terrain relief than by surveying a spot elevation every 35 or 71 centimeters that lidar data can provide? Some people are concerned about the contours' accuracy with the absence of breaklines. I can assure you that breaklines will not add much to the definition or the accuracy of the terrain model when using a dense lidar dataset. It can result in more appealing contours at road edges and other sharp breaks in the terrain, but again, it will not add to the accuracy or the quality of the contours. Some applications call for breaklines for hydro enforcement, which is another problematic concept. That is mainly due to the limitation of many software applications used in hydro modeling. For down-slope flow modeling, this software expects lidar points not to fluctuate, even within the noise limit or accuracy of the lidar data. That is the only reason massive modeling of breaklines is added to represent linear water feature and to assure a smooth and enforced downhill flow. These modeling software companies or agencies would help the industry and reduce project cost if they would implement a tolerance of elevation fluctuation to within the repeatability of the lidar points cloud, which is specified in the USGS lidar base specifications to be around 6 centimeters. Some specify breakline compilation solely for hydro flattening of water bodies. In my opinion, the latter use of breaklines is a total waste of effort, because most of the time this is done for aesthetic reasons. Users of lidar data should accept the fact that lidar data is very dense, and there always will be an unevenness in the surface due to the random errors in the data represented by the repeatability of lidar data, which in most cases amounts to within 6 centimeters. Lake surfaces do not need to look completely flat and smooth in a lidar dataset. If we accept this fact, we could save hundreds if not thousands of hours flattening such surfaces. Even for volumetric computations, such unevenness of lidar data will not compromise the volume computations' accuracy. Such fluctuation is random and occurs around the mean terrain elevation, assuming all biases are removed from the lidar dataset. We need to recognize that some applications or situations will require the collection of breaklines even with a very dense lidar dataset at least for the time being and until our processes and modeling software changes. Examples of such situations are the following:

1. **Road Design and Engineering:** Most specifications for departments of transportation (DOTs) call for precise delineation of the following:
   a. Edge of pavement
   b. Road crown
   c. Curbs and gutter lines
   d. Top and base of curves
   e. Other elements of the road

Current capabilities of aerial lidar collection do not allow engineers to accurately determine these lines from lidar, therefore manually collected breaklines are needed to complete DOT road engineering activities. In addition, providing breaklines with mobile mapping system (MMS) data allows for the reduction of the size of the delivered data so modeling software can handle it more efficiently. In most cases, full density of the MMS data is used to extract breaklines after which the data is decimated to a 3-foot grid and delivered with the breaklines to be used within the modeling/CAD software. It is worth mentioning here that as computing power and the ability to store and readily access "massive" amounts of data advance, the reliance on breaklines in Road Design and Engineering will also diminish to the point of elimination.

2. **Drainage Lines in Vegetated Areas:** Depending on the density of vegetation, lidar point density in vegetated areas may be reduced considerably. This results in inaccurate drainage modeling if lidar points alone are used to determine the centerlines and boundaries of water bodies. Therefore breaklines, whether from imagery or intensity images, must be compiled to define these obscured or partially obscured hydro features.

3. **Vertical Walls:** Positioning tall, free-standing walls such as sound barriers or retaining walls around bridges approaches.

4. **Other:** There may be additional situations that require the compilation of breaklines.

Finally, if the applications or the end user require breaklines to augment lidar data and if the accuracy requirement allows, there is a less expensive and more affordable approach of extracting contours and that is automated contours. For these type of contours, lidar points cloud and lidar intensity and/or existing imagery are used through image segmentation techniques to extract edges that can be used as breaklines. The process is not perfect yet but we, as an industry, need to pay more attention to this topic in order to advance the technique. Woolpert's latest internal R&D efforts have resulted in a promising quality of breaklines, which also can be utilized to delineate wetlands, vegetation boundaries, roads edges and building boundaries for a variety of applications.

Question 3—Is the lidar-derived contour more accurate than the contours generated from traditional photogrammetric practices?

When contours are generated from elevation posts spaced every 35 or 71 centimeters, the maximum length of the triangular sides of the generated TIN always will be under 100 centimeters. This is not the case with the photogrammetric-derived contours modeled from DTM with triangular sides exceeding tens of feet in length. For that reason, contours generated from lidar make a better representation of the terrain than the contours generated from DTM. They are more accurate. For the same reason, contours generated from a lidar dataset appear jagged because lidar is more sensitive to the changes in terrain. Sometimes, I describe lidar-based contours as "hypersensitive" due to the wealth of elevation details they carry.

> **"with lidar we are able to survey a terrain elevation every 71 centimeters or even 35 centimeters" contours generated from lidar do not look appealing. However, such contours are more accurate in representing the terrain than the photogrammetric contours"**

Question 4—With USGS QL2 lidar data, is it safe to state, "The contour lines are a visual representation of the lidar data," when we deliver the contours to clients?

If you mean that the contours will have the accuracy of the lidar data, then the statement is accurate. Contours generated from QL2 lidar data are derived from a TIN with triangular sides under 100 centimeters in length. Therefore, slight interpolation is performed to generate such contours, and these contours will reflect nearly the actual elevation of the lidar points cloud at the location where these contours are plotted. However, contours in general do not represent the lidar data quality, as the lidar points cloud provides better details about the relief than the contours alone, unless the contours are created with a 5- to 10-centimeter contour interval.

I hope I answered your questions. I also hope that this article benefits many users and data providers who have to follow widely misunderstood specifications about terrain modeling when using lidar data. My humble request from users, especially government agencies who are contracting statewide and countywide lidar projects, is to investigate end users' needs for contours before routinely asking for it. If you have a dire need for contours, then please do not specify breaklines as a routine requirement unless there is a good reason for it. Asking for breaklines, unless generated through automated means, without a good reason does nothing but increase the project budget and delay the final product delivery. Eliminating contours in general and breaklines in particular from any contract is a good practice for the fiscally cautious individual or agency. Even if breaklines are needed to model some features, limiting the number of features that need to be modeled with breaklines can help the project budget and expedite product delivery.

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