TITLE OF PAPER

Paper # 1884
Modeling River Water Surfaces Using LiDAR Technology and ArcGIS Spatial Analyst

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ABSTRACT

LiDAR (Light Detection and Ranging) is a powerful technology for creating very accurate Digital Terrain Models (DTMs). However, developing an aesthetically pleasing representation of the topography, particularly where it involves variably inclined water surface features like rivers or canals, is a significant cartographic challenge. LiDAR returns (reflections) from water surfaces are known to be of suspect accuracy, having a large standard deviation about the true (mean) value, and their injudicious use can produce unexpected results–like water flowing uphill. Because water generally flows downhill, and for mapping purposes can be deemed to have a flat surface (at least locally), it is desirable to have contour lines crossing the water surface at the appropriate interval where the water elevation corresponds with terrain elevation on either side of the stream. This paper describes the methodology for extracting suitable LiDAR points from the dataset and using them to derive accurate elevations for sloping water surfaces in order to integrate them seamlessly with the surrounding terrain.

INTRODUCTION

DTMs have become a popular GIS construct for visualizing the earth's panorama in three dimensions. LiDAR currently is the most advanced technology available for accurately recording *xyz* coordinates for large expanses of the earth's surface and consequently LiDAR derived DTMs can represent the earth's surface with unsurpassed reality. However, LiDAR is *not* so good at representing the hydrosphere, and where the latter interfaces with the lithosphere that accuracy can diminish. Things are not too bad where the cartographer wants to represent the surface of a lake, where for most purposes the surface can be deemed to be flat and the water's edge can easily be defined. However, when dealing with rivers or canals, we know that water generally flows down hill, and because the surface of the water is seamlessly continuous with the surface of the earth, we need to develop a smooth water surface in order to derive cartographically acceptable contours (topography).

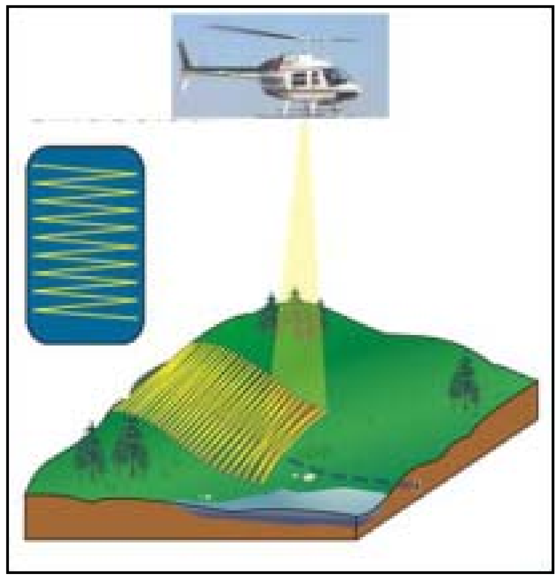
This paper takes the form of a tutorial and describes the steps to model a water surface using a real life example. It assumes the reader has a working familiarity with ArcMap and Spatial Analyst (SA). It describes briefly the minimum software requirements and the principles governing the collection of LiDAR; how it is processed and used within ArcMap to produce a DTM and contours for the topographic map.

MINIMUM SOFTWARE REQUIREMENTS

Although the processes described in this paper could probably be reproduced in ESRI® 's ArcView 3.x, the writer has not attempted to do so and thus cannot state with assurance that it can be done. ArcInfo Workstation provides all the functionality required, but the project described was first completed using ArcMap 8.3; Spatial Analyst and some of the routines provided in ETGeoWizards 8.7, a set of vector tools developed by Ianko Tchoukanski to bring some ArcInfo functionality to the ArcMap platform.

LIDAR

First developed in the 1960's, LiDAR has become a mainstream technology made possible by the availability of high precision time interval meters (TIM), military grade inertial navigation systems (IMU), numerous satellites signals for highly accurate differential global positioning systems (GPS) and relatively inexpensive computer processing units, recording, and storage devices. LiDAR instrumentation can be installed in fixed or rotary wing airborne platforms; for the type of river survey described here, a helicopter is probably superior. The IMU measures aircraft pitch, roll and yaw while the GPS is used for positioning, flight path and altitude navigation and control.



LiDAR is an active sensing system that uses its own energy source and works by emitting an eye-friendly laser beam that scans rapidly from 10-70,000 pulses per second, generally in a sinusoidal pattern perpendicular to the aircraft flight path. The "ranging" of the reflecting object is based on the recorded time difference between light emission and reflection as recorded by the TIM. Using the constant speed of light (299,792,458 m/s), the time lapse is converted into a slant range distance. Knowing the exact position and orientation of the sensor, and azimuth and declination of the LASER pulse, the *xyz* coordinate of the reflective surface can be calculated. For each single light pulse emitted, as many as five reflections may be detected: the first may be from the top of tree canopy, the second may be from a branch, the last is assumed to be from the ground. By subtracting the first from the last, vegetation "cover" can be removed to create a "bald earth" surface.

LIDAR is used in the study of atmospherics, flood plains, forest canopy density, agriculture and geology, but the commonest application by far is for the construction of DTMs. However, LiDAR fails badly when it comes to returning reliable elevation values for water surfaces. This is because water has a number of physical properties that vary tremendously and make it a poor reflector of light. Sometimes it acts like a mirror and no reflection at all returns to the sensor (which converts light photons into electrical signals); sometimes the LASER penetrates the water and is just absorbed. However, there is an exception to this generalization and that when pulses emitted at nadir – pulses that strike the water surface at very close to the perpendicular – will usually return an acceptably accurate signal. Thus if we have the flight path provided by the LiDAR vendor, we can identify in the GIS those pulses that fall on or close to the flight path. We will use this characteristic to determine the water surface in the steps that follow.

The DTM in Fig.1 will be used to illustrate the derivation of our water surface model. Note the reservoir on the western end held back by a weir, over which water spills down into a gorge and then exits to a slightly wider section of the river as it flows eastward. The drop in elevation is nearly 100 feet.

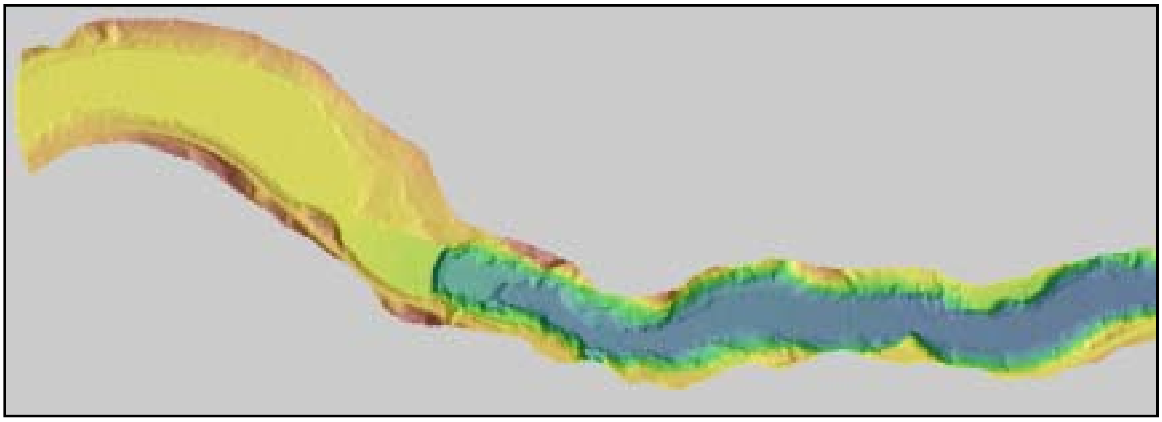


Fig: 1 DTM derived from LIDAR points. Note "stippled" water surface

Contours can be derived directly from this DEM, but because the water surface is irregular, modeling is impossible. Notice the how the 1 foot interval contours appear chaotic in the graphic below.

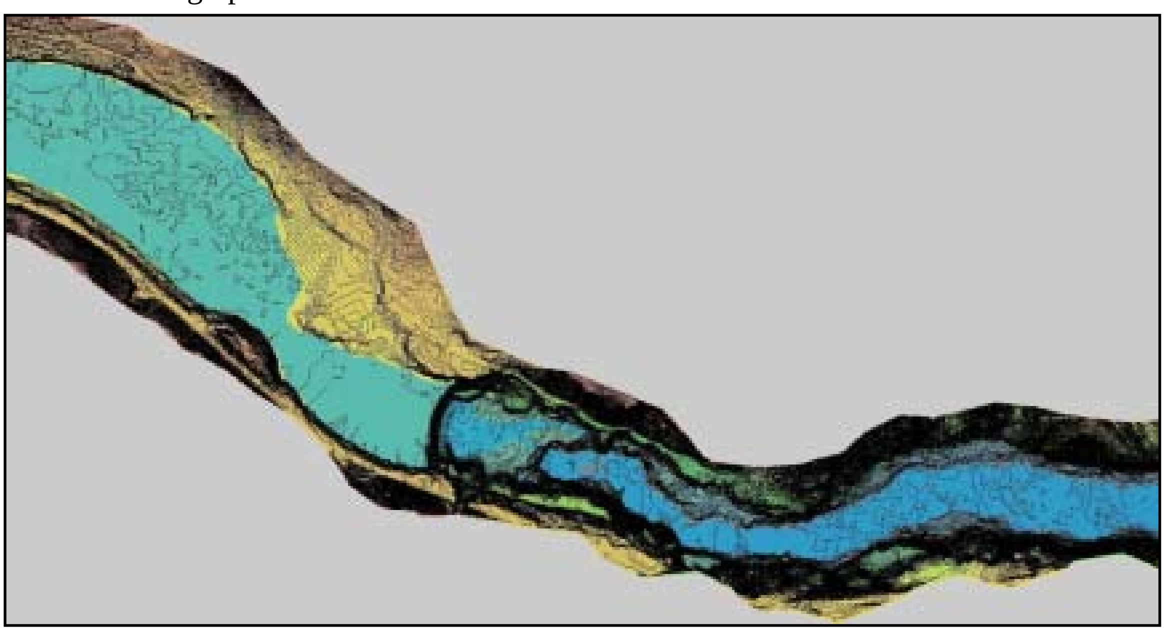


Fig. 2 One foot contours derived from DEM. Notice squiggly chaotic appearance.

STEPS TO CREATING A SMOOTH WATER SURFACE

1) Load the LiDAR data as a comma separated value (csv) file, typically in this format:

```
X,Y,Z
320972.000,5421755.000,284.550        (Often these files will have millions of lines)
320973.000,5421755.000,284.540
320974.000,5421755.000,284.520
320975.000,5421755.000,284.510
320976.000,5421755.000,284.510
320971.000,5421756.000,284.640
```

2) Load the csv into the project, right click and select “Display XY values. This creates an “event” file that displays the xy position of the points.
3) Export the data to create a new point shapefile. Accept offer to add exported data to map.
4) Use Spatial Analyst to convert feature points to raster. The resulting grid is the basic DEM. Create a hillshade of the surface to assist with visualization of features (Fig. 1)
5) Use the resulting DTM (alternatively use orthophotographs, if available) to digitize a polygon representing the wetted area of the river – be as accurate as possible. This polygon will later be used as a “mask” to confine the area of interpolation.
6) Load flight path line feature shapefile to ArcMap.
7) Create a new point shapefile (e.g. control_pts.shp) with both an ID field and an elevation field. Using the flight path line as a guide, strategically locate a number of points along the line and on the water, preferably at bends in the river or wherever sudden elevation changes take place – above or below a rapids, for example. The steeper the elevation change, the closer together the points should be. If the change is very steep, then it is better to create separate models for the water above and below the obstacle.
8) Use control_pts.shp and ‘select by location’ all those LiDAR points within say a 3 meter radius of each individual control point. Open the FTAB and view the selected points.
9) Right click on the elevation column and select ‘statistics’ for the selected elevation points. Note the ‘mean’ value and enter that as the elevation value for each selected control point. Complete this process for all the control points.
10) The ID field is used to identify the correct sequence of points in ascending or descending order. Often an X or Y coordinate field can be used if there is no back-tracking of the river, as is the case in Fig 3. below.

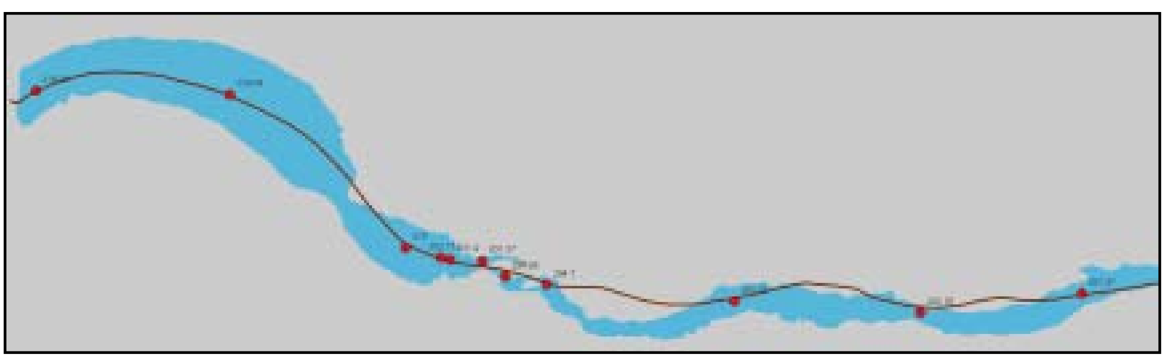


Fig 3. shows the digitized water polygon, the flight path, and control points with elevation labels

11) The next step is to convert (connect) the elevation control points to a polyline_z file. Note that this line will likely cut across bends in the river so the next task is to edit the line and stretch it so that it follows the 'thread of the river' (Fig. 5.)

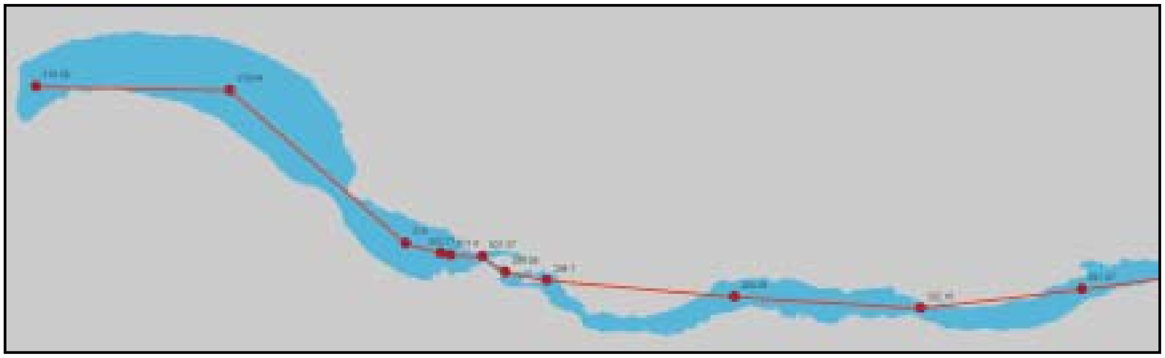


Fig 4. Shows the initial polyline_z after conversion from the control points

12) This step involves the insertion of vertices along the polyline_z so that each segment is a straight line of sight along the river from one control point to the next. Insert a sufficient number of vertices that the z-line runs approximately down the middle of the waterway. Note that these vertices take on the elevation value of the z-line at each vertex location.

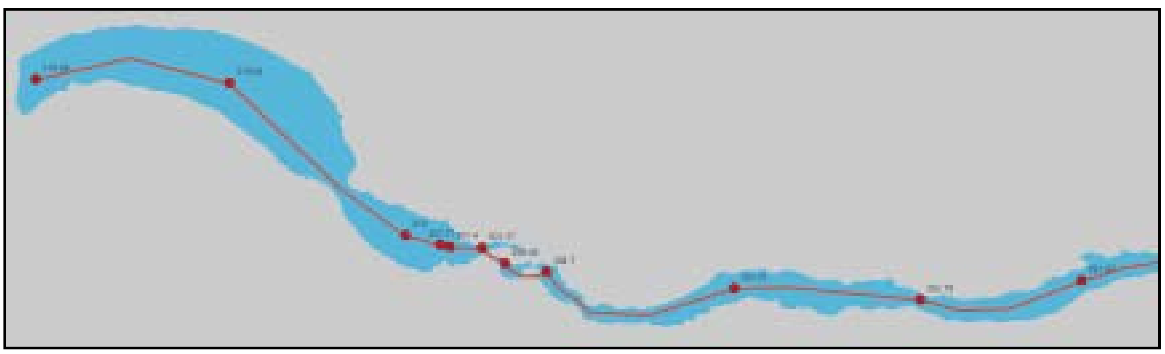


Fig5. Shows the realigned polyline_z after insertion of vertices at points of inflection.

13) The next step is to densify this polyline_z with vertices at equal intervals such that the new vertices are approximately the width of the river apart; in this case 50 meters (the "densify function" uses standard ArcObjects methods which are fast and efficient; see ArcObjects Developer Help).

14) Finally, for this preparatory part of the project, we are going to convert this polyline_z back into points, each of which will have an elevation as an attribute derived from the z-line value (Fig. 6.) Note that these points are going to be used to interpolate the water surface so additional points can be inserted where appropriate if the water body is particularly wide, as is the case with the reservoir at the western end of the project. As mentioned earlier, if there is an abrupt break in elevation, as at a waterfall or spillway, it is wise to create separate water

surfaces above and below, and rely on the raw LiDAR to properly model the structures.

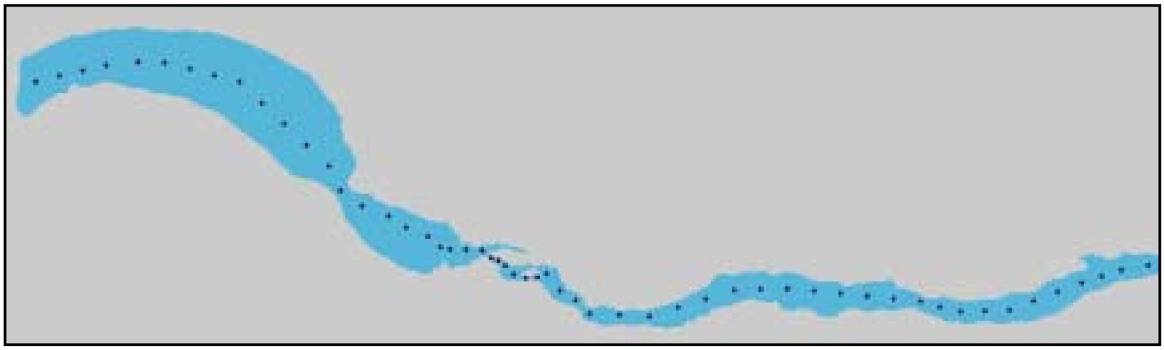


Fig 6. Shows the new set of elevation points derived from the polyline_z.

15) Next, this point layer is used as the input layer for an interpolation routine within SA, where we choose Interpolation, Inverse Distance Weighted, even though the relationship between the points is not inversely related to the distance between them. Under SA Options, remember to use the river outline digitized in (5) above as the mask for this operation. If we use a power of 1, we trick SA into doing a straight linear interpolation between the points. The fixed search radius should be about 20% greater than the distance between the points so that it just finds nearest neighbors. The minimum number of points should be 1; the actual number depends on the search radius. Again, if a waterfall occurs within the interpolated points, use a breakline to prevent interpolation across the discontinuity or create separate surfaces.

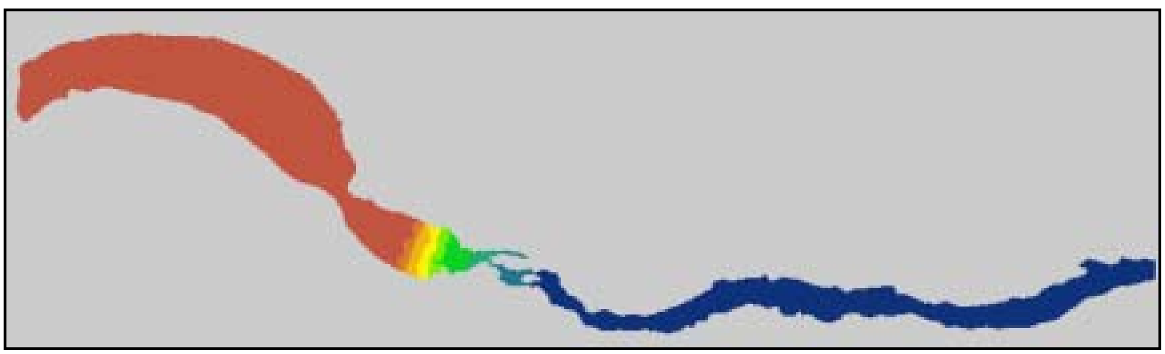


Fig 7. Shows the new raster(DEM) of the water surface – note abrupt change of elevation below the weir.

16) The next step is to replace the existing (uneven) water surface with the new interpolated surface. For that we use the Merge function within the SA raster calculator. Naming the new DEM “final”, the merge expression shows in the raster calculator window as illustrated below. Remember to remove the “mask” in the SA options dialogue and set the extent to “union of inputs”.

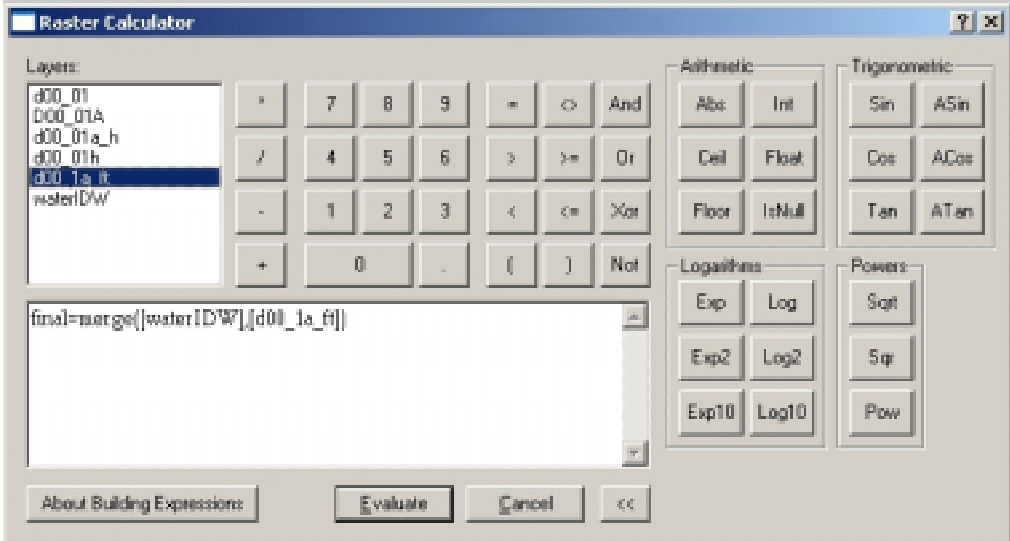


Fig 8. Shows a screen shot of the raster calculation used to merge the 2 DEMs

17) Now we have a merged DEM and can use it to generate a contour layer using SA. Notice that the water surface is no longer "stippled".

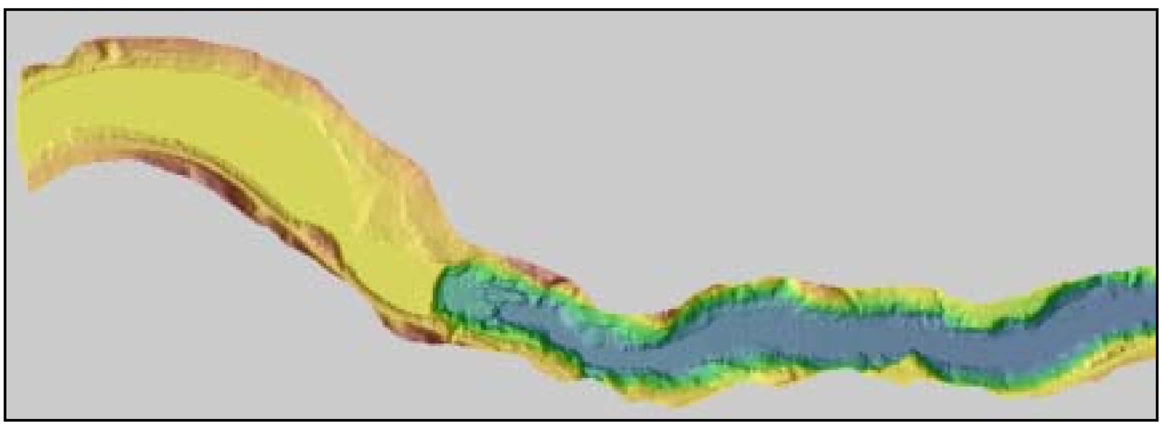


Fig 9. DTM developed from merged land and water surface models.

18) Contours generated from detailed land surfaces modeled by LiDAR technology can be extremely detailed and often are very different in appearance from the contours most of us are used to seeing on our maps. They tend to pick out every little bump and hollow and considerable post-processing work is required to effect an acceptable cartographic compromise between the exact representation of the land surface and an aesthetically pleasing set of contours.

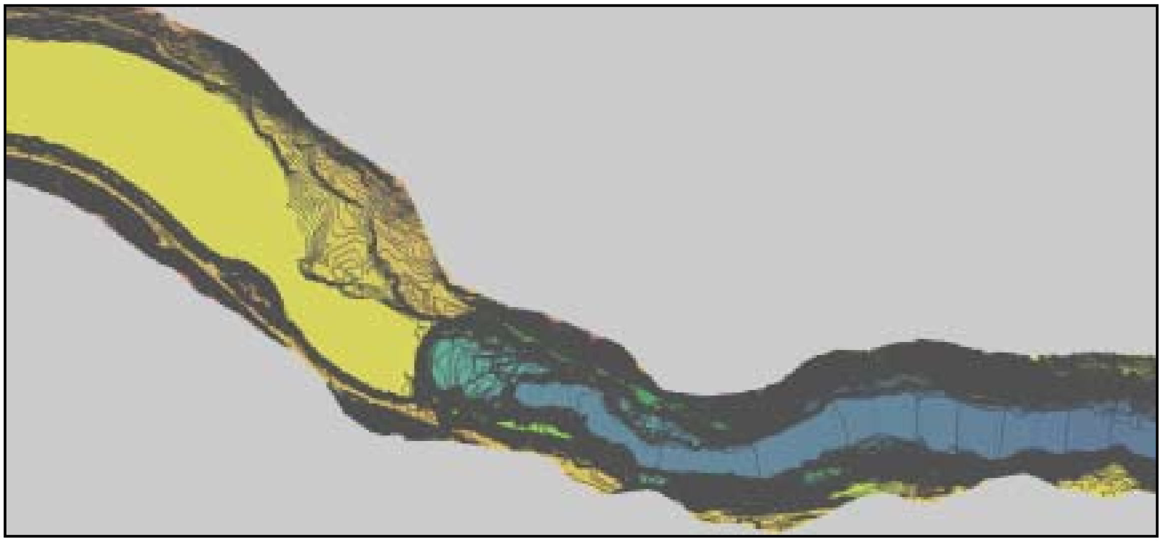


Fig 10. Contours (at 1 foot intervals) now cross the water surface at the appropriate location.

CONCLUSIONS

LiDAR is an extremely powerful tool for modeling the earth's surface and increasingly is being applied for a wide variety of natural resource and engineering applications. Most LIDAR information is used for the study and building of digital terrain models, but it is well suited for many GIS applications because it can be processed rapidly, is intrinsically geo-referenced and can be readily imported into a GIS. The data easily convert to vector format consisting of spatially distributed points. From this topology other GIS formats can be generated, including raster grids, other raster formats and TINs on which various functions may be performed including aggregation, neighborhood / proximity analysis, spatial statistics and contour modeling.

GIS image analysis software increasingly is being used to categorize the points according to their intensity, which is often simpler than categorizing by color. LiDAR data can readily be integrated with other thematic content though scale related issues become apparent as we discover that our existing data sets may not be as accurate as we thought them to be. Evaluation and analysis of 3D models for spatial and temporal changes is becoming me increasingly more important and useful. With tools to model water surface, the earth's topography becomes LiDAR compatible and cartographically complete.

ACKNOWLEDGMENTS

The process described in this paper makes much use of some of the geoprocessing tools available in Ianko Tchoukanski's excellent ETGeoWizards 8.7

APPENDIX

List of acronyms

SA	Spatial Analyst
LiDAR	Light Detection and Ranging
LASER	Light Amplification by Stimulation Emission of Radiation
DEM	Digital Elevation Model
DTM	Digital Terrain Model
TIN	Triangular Irregular Network

END NOTES

REFERENCES

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