Hydrological Processes in Hill Slopes:
Tender Foot, Montana

Contact Information
Brian McGlynn
Department of Land Resources $ Environmental Sciences
Montana State University
334 Leon Johnson Hall
P.O. Box 173120
Bozeman, MT 59717-3120
Tel: 406-994-7690
Fax: 406-994-3933
bmcglynn@montana.edu
http://landresources.montana.edu/watershed/

Survey Area

The survey area is a box (58 km^2) located 9 km west of Neihart, Montana. This area was flown and completed on September 19, 2005 (Day 262). Figure 1 shows the project boundary and location. The survey was conducted using an Optech 1233 Airborne Laser Terrain Mapper (http://www.optech.ca/) mounted in a twin engine Piper Chieftain (N931SA).

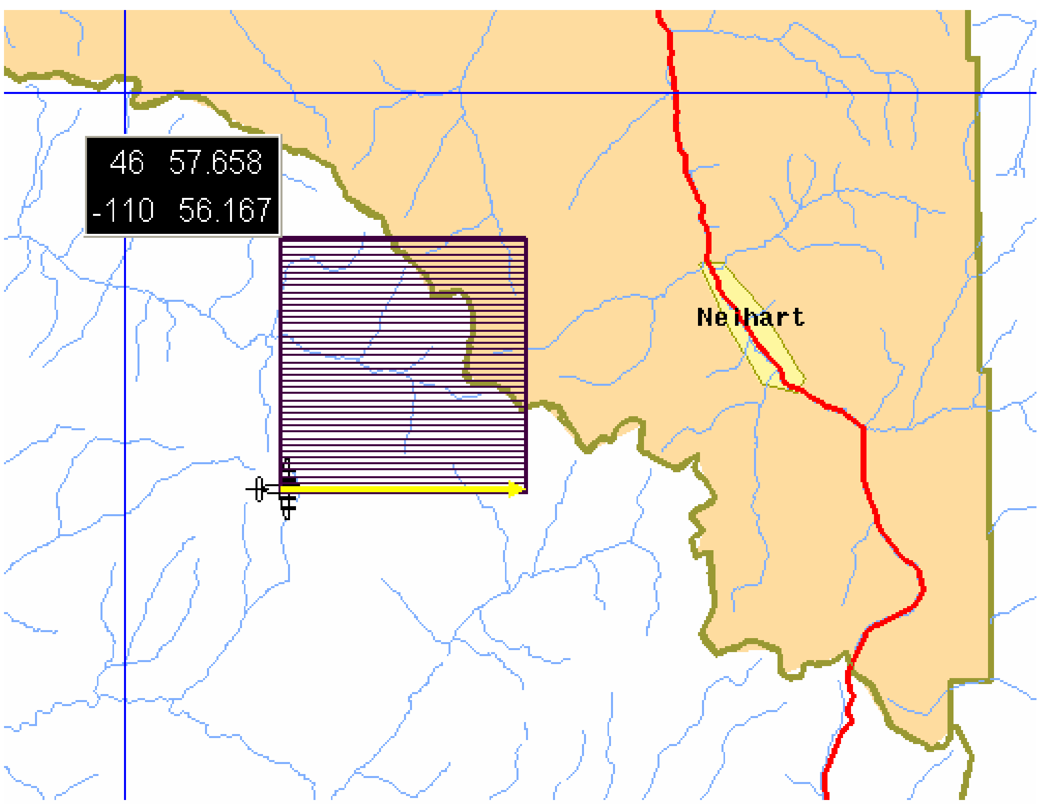


Figure 1. Tender Foot, Montana project shape and location.

Survey Parameters

This project was completed following 40 flight lines oriented east and west (Figure 1). Four perpendicular cross lines and three ground truth lines were flown for field calibration purposes. A total of three flights were made to complete the survey. The laser range was targeted at 600 m above ground level (AGL), but ranged between 600-900 m AGL due to the mountainous terrain. Although the aircraft speed was targeted at 77.2 m/s (150 kts), there was a very strong eastern wind during the survey. The eastern heading (90˚) speed was significantly higher than heading west (270˚) by approximately 40 m/s (80 kts). Figure 2 shows the flight planning parameters.

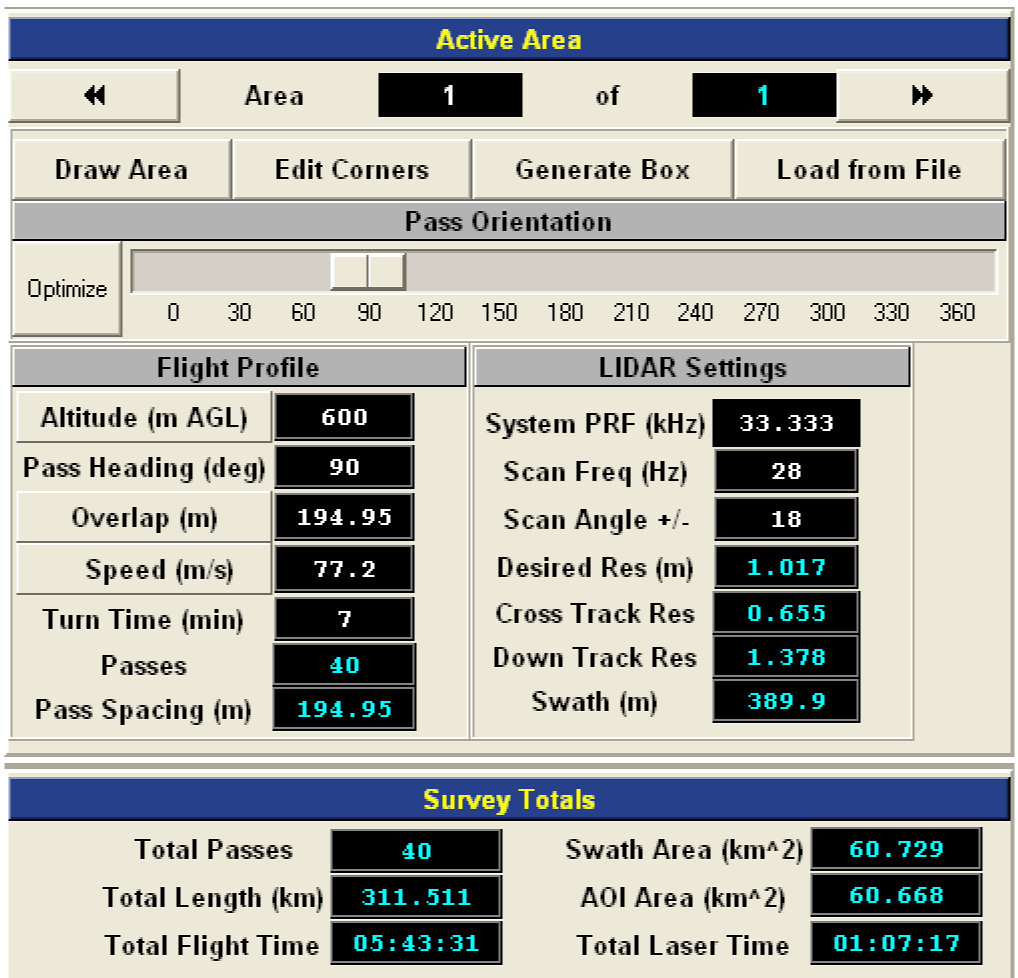


Figure 2. Tender Foot, Montana flight planning parameters.

GPS Reference Stations

Two GPS reference station locations were used during the survey. One receiver was placed on a newly set mark GO99, just off Highway 89 located 2 miles NE of the NE corner of the project, and one receiver was placed on a newly set mark MNCH at the junction of Highway 89 and Highway 427 two miles north of Monarch, MT. All GPS observations were logged at a 1-second rate and submitted to the NGS online processor OPUS. Final coordinates for reference stations GO99 and MNCH were based on these OPUS solutions (http://www.ngs.noaa.gov/OPUS/). For more information on the CORS network, refer to http://www.ngs.noaa.gov/CORS/. Ground equipment included ASHTECH Z-Extreme receivers and choke ring antennas (Part #700936.D) mounted on a 1.5 m fixed height tripod.

Navigation Processing

The airplane trajectories for this survey were processed using KARS software (Kinematic and Rapid Static) by Dr. Gerry Mader of the NGS Research Laboratory.

After GPS processing, the trajectory and the (Inertial Measurement Unit) data collected during the flight were input into APPLANIX software POSPROC which uses a Kalman Filter to produce a final navigation solution (aircraft position and orientation) at 50 Hz, in SBET format (Smoothed Best Estimated Trajectory).

Calibration and Laser Point Processing

A total of three flights were made for this project – 262a, 262b and 262c. The calibration was done individually for each one of the datasets generated by the three flight passes, using cross lines flown for each individual flight.

The SBET and the raw laser range data were combined using Optech's REALM processing suite to generate the laser point dataset. A small calibration site containing crossing flight-lines was initially extracted and used for relative calibration with TerraSolid's TerraMatch software. This application measures the differences between laser surfaces from overlapping flightlines and translates them into correction values for the system orientation -- easting, northing, elevation, heading, roll and/or pitch. . After obtaining adjustments to calibration values using TerraMatch, laser point processing was re-done and the calibration rechecked.

Results are shown below in TerraMatch output format:

For 262a:

```
Laser project:
D:\Projects\Tenderfoot_05\TerraScan\laser\calib_262a.prj
Trajectories:
D:\Projects\Tenderfoot_05\TerraScan\trajectory\calib_262a\
No known points
Observe every 1th point
```

```
Intensity not used
Solution for whole data set

Starting average dz:    0.2003
Final average dz:       0.0473

Standard error of unit  0.0206

Execution time: 587.1 sec
Number of iterations: 22

Points       1132731
H shift      +0.0104    Std dev  0.0021
R shift      -0.0590    Std dev  0.0009
P shift      +0.0169    Std dev  0.0020
Scale       -0.00616
```

For 262b:

```
Laser project:
D:\Projects\Tenderfoot_05\TerraScan\laser\calib_262b.prj
Trajectories:
d:\projects\tenderfoot_05\terrascan\trajectory\calib_262b\
No known points
Observe every 1th point
Intensity not used
Solution for whole data set

Starting average dz:    0.2748
Final average dz:       0.0582

Standard error of unit  0.0260

Execution time: 943.7 sec
Number of iterations: 25

Points       2060629
H shift      -0.0063    Std dev  0.0020
R shift      -0.0591    Std dev  0.0007
P shift      +0.0164    Std dev  0.0016
Scale       -0.00735
```

For 262c:

```
Used loaded points
Trajectories:
d:\projects\tenderfoot_05\terrascan\trajectory\calib_262c\
No known points
Observe every 1th point
Intensity not used
```

```
Solution for whole data set

Starting average dz:    0.2055
Final average dz:       0.0508

Standard error of unit  0.0227

Execution time: 196.2 sec
Number of iterations: 29

Points         500971
H shift       +0.0187    Std dev  0.0037
R shift       -0.0548    Std dev  0.0015
P shift       +0.0215    Std dev  0.0028
Scale        -0.00703
```

After calibrating each of the three individual datasets, overlapping areas from adjacent dataset were loaded in TerraScan and inspected for consistency. No further calibration was needed.

No absolute ground calibration was performed on these data. Ground truth was collected and checked against the LiDAR elevations for the BigSky project flown the following day with the same equipment and set-up and a bias of only 6mm was found.

The laser point data was extracted by flight strip using the updated calibration parameters using Optech's REALM software.

All coordinates were processed with respect to NAD83 and referenced to the national CORS96 network. The projection for the 9 column output is UTM Zone 12, with ellipsoid heights, and units in meters. The last return data was extracted from the 9-column format and the heights reprojected to orthometric heights in NAVD88, computed using NGS GEOID03 model with the Corpscon v6.0 software (Corps of Engineers Coordinate Conversion).

The most complete output format is nine-column ASCII (space delimited), one file per flight strip. The nine columns are as follows:

1. GPS time (seconds of week)
2. Easting last return
3. Northing last return
4. Height last return
5. Intensity last return
6. Easting first return
7. Northing first return
8. Height first return
9. Intensity first return

Note that in these 9-column files no geoid model has been applied - height values are ellipsoid heights and these height values will NOT match orthometric heights (elevations) found in the 3-column files or in the 1-meter DEM grid nodes.

During processing, a scan cutoff angle of 1.5 degrees was used to eliminate points at the edge of the scan lines. This was done to improve the overall DEM accuracy (points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements). Points with very low intensity values were also filtered out (intensity values less than 7), because these points also tend to be the least accurate. This is due to the fact that very weak return pulses yield the noisiest range measurements. These points represent a very small percentage of the total number of points, usually in the neighborhood of a few hundredths of one percent.

Filtering and DEM Production

Terrasolid's TerraScan (http://terrasolid.fi) software was used to classify the last return LIDAR points and generate the "bare-earth" dataset. Each of the 7 corridors was processed individually.

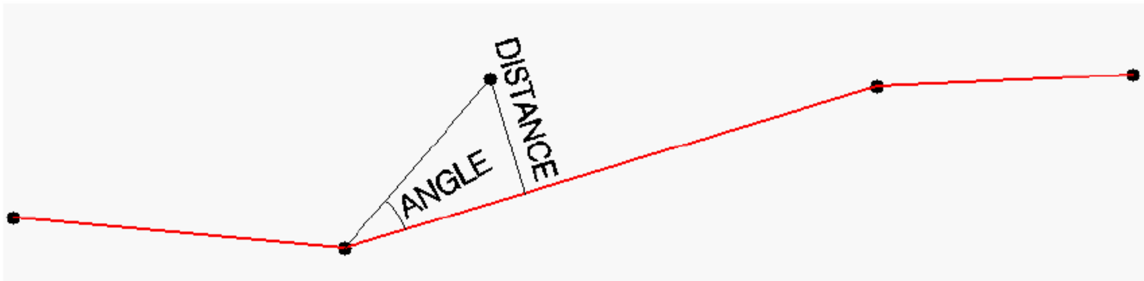
The classification routine consists of two algorithms:

1) Removal of "Low Points". This routine was used to search for possible error points which are clearly below the ground surface. The elevation of each point (=center) is compared with every other point within a given neighborhood and if the center point is clearly lower then any other point it will be classified as a "low point". This routine can also search for groups of low points where the whole group is lower than other points in the vicinity. The parameters used on this dataset were:

```
Search for: Groups of Points
Max Count (maximum size of a group of low points): 6
More than (minimum height difference): 0.5 m
Within (xy search range):  10.0 m
```

2) Ground Classification. This routine classifies ground points by iteratively building a triangulated surface model. The algorithm starts by selecting some local low points assumed as sure hits on the ground, within a specified windows size. This makes the algorithm particularly sensitive to low outliers in the initial dataset, hence the requirement of removing as many erroneous low points as possible in the first step.

   The routine builds an initial model from selected low points. Triangles in this initial model are mostly below the ground with only the vertices touching ground. The routine then starts molding the model upwards by iteratively adding new laser points to it. Each added point makes the model follow ground surface more closely. Iteration parameters determine how close a point must be to a triangle plane so that the point can be accepted to the model. **Iteration angle** is the maximum angle between point, its projection on triangle plane and closest triangle vertex. The smaller the Iteration angle, the less eager the routine is to follow changes in the point cloud. **Iteration distance** parameter makes sure that the iteration does not make big jumps upwards when triangles are large. This helps to keep low buildings out of the model. The routine can also help avoiding adding unnecessary point density into the ground model by reducing the eagerness to add new points to ground inside a triangle with all edges shorter than a specified length.



Ground classification parameters used:

```
Max Building Size (window size): 40.0 m
Max Terrain Angle: 88.0
Iteration Angle: 5.0
Iteration Distance: 1.2 m
Reduce iteration angle when edge length < : 5.0 m
```

After classification the ground points were outputted in 2km x 2km overlapping tiles (60m overlap), ASCII format (XYZI), and gridded at 1m cell size using Golden Software's SURFER ver. 8.01. The tiles need to overlap in order to obtain consistent transitions from one tile to the adjacent ones.

Gridding parameters:

```
Gridding Algorithm: Kriging
Variogram: Linear
Nugget Variance: 0.07 m
MicroVariance: 0.00 m
SearchDataPerSector: 10
SearchMinData: 5
SearchMaxEmpty: 1
SearchRadius: 40m
```

The resulted Surfer grid tile set was exported to ESRI ArcInfo floting point binary format and using an in-house C++ application the overlap was trimmed from each tile. The trimmed tiles were exported to ESRI ArcInfo GRID format and merged into one seamless raster dataset.

A similar process was used to generate the unfiltered seamless grids.