Introduction

In September 2002, the lower reach of San Pedro Creek in Pacifica, California was restored as a part of a Wetland Restoration and Flood Control Project to improve the flood capacity of the creek and the adjacent floodplain. As a part of the flood control project and wetland restoration, a small estuary was created north of the mouth of San Pedro Creek (Figure 1). The estuary was created in 2002 by excavating the existing sediment (Figure 2) to restore the natural hydrology of the site and by planting the area with riparian and wetland vegetation characteristic of similar reference sites along the central coast of California (Lee 1999). The goals for the restoration design were to expand the flood capacity of the creek, to restore the natural hydrology of the stream channel that had been removed with channelization of the creek in the 1960’s, and to reestablish native riparian and wetland vegetation in the area. However, there is currently no existing data on the geomorphic characteristics of this system. No elevation surveys have been conducted to establish baseline conditions to evaluate geomorphic changes in this system over time.

Purpose

The purpose of this project was to develop a method for collecting and processing elevation survey data in order to create a Triangulated Irregular Network (TIN) elevation model. The data was collected using standard sight level operating procedures, processed using Excel, and imported into Arc Model Builder to generate a TIN elevation model for the San Pedro Creek estuary.
Figure 1: San Pedro Creek Estuary After Restoration September 2004

Figure 2: San Pedro Creek Estuary Before Restoration, August 2001
Methodology

Location: The San Pedro Creek Wetland Restoration and Flood Control Project is located in the southern most section of Pacifica, CA, located approximately 10 miles south of San Francisco. The San Pedro Creek estuary is bordered on the north by the city of Pacifica pump station, on the west by Pacifica State Beach, on the south by Pedro Point Shopping Center, and on the east by San Pedro Rd. and Hwy 1.

Site Characteristics:

The physical characteristics of the site consist of a large open water area covered with aquatic vegetation, a depositional bar to the north of the mouth of San Pedro Creek, and a large berm on the east and south side of the estuary. The depositional areas are covered with numerous grasses, forbs, and ferns; the berm and upland areas are inhabited by riparian and scrub species, and the transitional zones consist of emergent wetland plants. The water level of the estuary varies seasonally with the highest levels occurring in the winter during the rainy season and the lowest levels occurring in the summer during the dry season. Visual surveys of the estuary indicate that the high flows of San Pedro Creek in the winter deposit sediment in the estuary that accumulates on the bottom of the open water areas and on the sediment bars adjacent to the creek mouth (Vasey 2004).

Materials:

- Sight level and tripod
- Stadia rod
- 2 compasses
- 100m measuring tape
- GPS Unit
- Camera
- Data notebook
- Hip waders
- GIS software
- 2 way radios
Methods:

The San Pedro Creek estuary was surveyed using standard leveling procedures as outlined by Harrelson, et al. (1994). A stadia rod and Sokkisha automatic level were used to determine the vertical elevation and horizontal position of 153 points that represented major breaks in slope and the boundaries of the estuary. The measurements were used to establish x, y, and z coordinates for each point location and the data was imported into ArcMap Geographic Information System (GIS) software and processed using Arc Model Builder. This software was used to create a model of the topography of the estuary by generating a TIN elevation model.

Optimal locations for survey points were determined from site visits, site sketches, engineering plans used to construct the estuary, and aerial photographs. The level was initially set up in the most efficient position in order to conduct a backsight to the United States Coast Guard (USCG) Geodetic Survey benchmark located on the Highway 1 Bridge, immediately east of the study site. The elevation of the benchmark, 30ft, was used to establish the vertical elevation control for the survey. The geographical coordinates of the USCG benchmark were determined using a Garmin Global Positioning System (GPS) receiver, which showed an accuracy of 4m. The Universal Trans Mercator (UTM) coordinates for the benchmark location were used to establish the horizontal control for the survey, Easting = 54398 and Northing = 4160967.

Elevation readings were taken by level sighting to the stadia rod in metric feet with a precision of 0.01ft. The elevation survey was conducted using a backsight to the benchmark established from the USCG benchmark and foresights to each of the survey points. Height of the instrument (HI) was determined by adding the backsight to the known benchmark elevation. The elevation of each survey point was determined by subtracting the foresight to that point from HI.

Horizontal distance (HD) from the level to the rod was estimated from the distance between calibrated crosshairs on the level scope. The lower cross hair reading was subtracted from the upper reading and the difference multiplied by 100 to calculate the horizontal distance between the level location and the rod. Circle direction readings were taken from the sight level with each survey point in order to establish the geographical coordinates of each reading. The circle readings from the level were
oriented to magnetic North by using a Suunto compass and adjusted to true North by adding the local declination adjustment of +15.5° (Davis 2004). The adjusted readings established the azimuth from the level to the survey point. The x and y offset for the horizontal position was then determined for each point by calculating

\[ \text{X}_{\text{offset}} = \sin(a) \times \text{HD} \quad \text{and} \quad \text{Y}_{\text{offset}} = \cos(a) \times \text{HD}, \]

where \( a = \) azimuth and HD = horizontal distance.

These offset values for x and y where then added to the geographical x and y coordinates for the level position. The geographical position for the level was determined by using the above equations with the azimuth reading from the benchmark to the level and the HD between the level and the benchmark to calculate offset values. The x and y offset values for the level position were then added to the x and y coordinates measured for the benchmark location to determine the geographic coordinates for the level position.

The elevation readings and the geographical coordinate measurements were used to establish vertical elevation readings (z) in meters and geographical position measurements in UTM coordinates (x,y) in order for the data to be synthesized in ArcMap. The data collected during the survey was converted to the above coordinates using Excel. The spreadsheet used to convert the field data into x, y, and z coordinates is included in Appendix 1. The equations used to convert the survey data are also included in Appendix 1.

After the raw data was converted to x, y, and z coordinates, the coordinates were copied in a new Excel worksheet and the worksheet was saved as a *.dbf file type (DBASE IV). This *.dbf file was then converted to a shapefile (*.shp) using ArcCatalog. This shapefile was then used as the input data for the Survey Data to TIN ArcModel (Figure 3) that was created to process the survey data. This model includes two identical models one used to process the raw survey data and the other used to process corrected survey data. This was necessary because the raw survey data produced a TIN with several inaccuracies. Several correction points were added to the data set based on knowledge of the topography of the site and field notes. The model allows both sets of data to be processed and compared.
The model shown above takes a shapefile with x, y, and z coordinates as an input and uses the data to generate a TIN model. The model also converts the TIN to raster and creates a hillshade layer, slope layer in degrees, and 1M Contours for the survey data. Some of the outputs of this model are displayed in Figures 4-7.
Results

The TIN model created from the uncorrected survey data for the estuary is shown below in Figure 4. This model displays the geomorphic features of the study site and displays elevation in graduated colors.

Figure 4: TIN Model Created from Raw Data
The above model does not accurately show the geomorphic features of the site, because it was created using survey points on the bridge. The inclusion of the bridge points inaccurately represents a slope on the southern portion of the map and obscures the creek channel on the southeastern part of the map. Additionally, the northern edge incorrectly shows a rise in elevation. This results because TIN models create a convex hull when points are connected. The connection of the two points on the corners creates a false slope on the northern edge. The image displayed below in Figure 4 has correction points derived from field notes and the physical features of the site. The added points correct the false slope on the northern edge and remove the bridge points from the analysis. The figure below more accurately represents the geomorphic features of the site.

Figure 5: Corrected TIN with Contour Lines

Corrected TIN with Contour Lines
The figure below displays the same corrected image as above, although this image includes TIN lines to better represent the connection of survey points that was done by ArcMap when creating the TIN model.

Figure 6: Corrected TIN with TIN Lines

Corrected TIN with Lines
The figure below again displays the corrected data and shows some of the major features with labels (i.e. stream channel and upper berm). The area of uncertainty ellipse represents points that show an inaccurate representation of the geomorphic features of the site, because not enough data was collected at these points.

Figure 7: Corrected TIN with Text

Corrected TIN Model
The figure below shows a slope model that was created for the site from the TIN model. This slope surface model was created in ArcMap using the TIN generated with the Survey Data to TIN Model.

Figure 8: Slope Model from Corrected Data

Slope Model from Corrected Data
Figure 9: Photograph of Estuary Facing South
Figure 10: ArcScene 3D Image of Estuary Facing South

Figure 11: Photograph of Estuary Facing North
The accuracy of the horizontal distance readings made with sight level was verified by comparing the measurements with slope distance measured using a 100m tape. The results of this comparison are shown below in Table 1.

Table 1: Comparison of Slope Distance (SD) to Horizontal Distance (HD)

<table>
<thead>
<tr>
<th>SD (ft)</th>
<th>HD (ft)</th>
<th>(SD-HD) (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>5.2</td>
<td>0.8</td>
</tr>
<tr>
<td>29.5</td>
<td>29</td>
<td>0.5</td>
</tr>
<tr>
<td>69.5</td>
<td>68</td>
<td>1.5</td>
</tr>
<tr>
<td>78</td>
<td>77.5</td>
<td>0.5</td>
</tr>
<tr>
<td>109.3</td>
<td>106</td>
<td>3.3</td>
</tr>
<tr>
<td>149.3</td>
<td>148</td>
<td>1.3</td>
</tr>
<tr>
<td>181.2</td>
<td>180</td>
<td>1.2</td>
</tr>
<tr>
<td>236.8</td>
<td>235.5</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Average 1.3

The results of this comparison indicate that slope distance was slightly greater than horizontal distance. The slope on which these measurements were taken was gradual and slightly greater slope distance measurement would be expected. The range of the difference values was 0.5 ft – 3.2 ft, and the average difference was 1.3 ft. This indicates that the HD measurements were accurate to at least 1.3 ft.
Conclusion

The survey was successful at creating a digital elevation model of the San Pedro Creek estuary. The shape of the model approximates the actual estuary and appears to capture changes in geomorphic features that are present in the estuary. Comparisons of the model to photographs of the site also indicate the model’s similarity to the natural features of the site. The model establishes baseline conditions for the estuary that can be used in future monitoring to track changes in geomorphic conditions. The digital model will also provide a base map for future mapping of vegetation species present in the estuary.

Some possible threats to the validity of this model are the limited number of points collected in the northern portion of the estuary and in mid-slope areas of the upper berm. The model would have been more accurate if more points were collected along the creek channel under the bridge, in the open water areas, and outside the boundaries of the estuary to better establish the elevation for the surrounding area. The methodology for this study could be improved in the future by first conducting a GPS track survey to help identify boundaries and the general shape of the estuary before conducting the level survey. This study should be repeated quarterly to assess changes in geomorphic features of the survey site.

References

Davis, Jerry. 2004. Personal communication with the author. San Francisco State University. San Francisco, CA.


Vasey, Mike. 2004. Personal communication with the author. San Francisco State University. San Francisco, CA.