



Terrain Elevation Difference Analysis 1968 to 2007

for

City of Sausalito

By

**Towill, Inc.
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August 2009

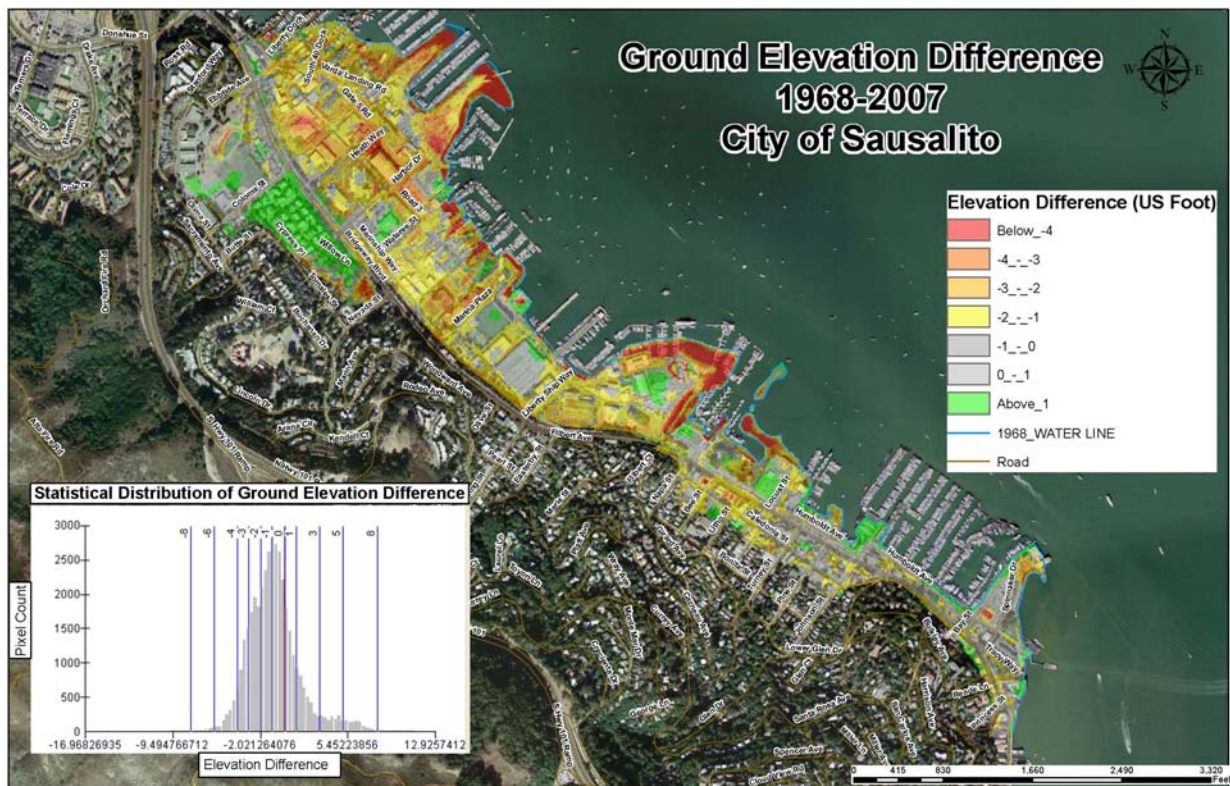


1. Executive Summary

Towill, Inc. was commissioned to locate existing terrain data from 1968 to the present and analyze the changes occurring between elevation 0.0 and 20.0 from the North end of Sausalito to the ferry terminal. Horizontal and vertical coordinate datums were determined for each data set and all data was converted to horizontal datum NAD83 and vertical datum NAVD88.

Several data sets were reviewed, and this analysis is based on a set of photo contour maps at 1"=100' scale with 2' contours created by Towill, Inc. in 1968 and a set of LiDAR data created for FEMA in 2007. Additional data sets were reviewed, but either the accuracy did not meet requirements for this project or the date of the data was not sufficiently different to determine a trend.

A color coded map was prepared to display the results of the analysis. Areas that compared within one foot are colored grey to indicate the two data sets are virtually equal within the accuracy tolerances expected. Areas that computed more than one foot higher in 2007 were colored green, and areas that computed lower in 2007 were colored in one foot increments from yellow to red, with red containing all areas greater than four feet lower in 2007 than in 1968.





2. Data Sources

The 1968 data consists of nine photo contour maps at 1"=100' with 2' contours created by Towill, Inc. The original mylar maps were scanned by the City of Sausalito and supplied to Towill as source materials for this project. The maps did not have either the horizontal or vertical datum documented, but they did include a coordinate grid at 1000' intervals. A coordinate transformation between NAD27 and NAD83 was performed and the road network was compared to current mapping known to be on NAD83 datum. The horizontal correspondence was very close, within 2', so we concluded the 1968 maps were compiled using NAD27 horizontal datum.

Four vertical datums were tested in areas above 20' elevation where the ground could be considered to be fairly stable during the study period. These datums are NGVD29, NAVD88, MLLW, and a local datum. NAVD datum was ruled out because it was not defined at the time of the mapping. A local datum is very unlikely and would make this analysis less reliable because we would need to assume some areas did not change and adjust the local datum to match the 2007 datum in these areas. NGVD29 was considered as the most likely vertical datum since most mapping used NGVD in the 1968 time frame. However, a comparison of many elevations on probably solid ground indicated the elevations on the 1968 maps were closely matching MLLW datum values. Since MLLW datum is only 0.06 feet below NAVD88 and NGVD29 datum is 2.69 feet above NAVD88 we came to the conclusion the 1968 maps were created on MLLW datum. MLLW (Mean Lower Low Datum) is often used by coastal communities and USACE (United States Corps of Engineers). With only 0.06 feet difference between MLLW and NAVD88 we decided to use the elevations as shown on the 1968 maps rather than change them to NAVD88 for the analysis.

The scanned maps were brought into AutoCAD by performing a least squares scaling + rotation + translation based on all grid ticks found on the maps. Typically 6-8 grid ticks were used and residuals were less than 2'. A composite map was created and the contours and spot elevations were digitized. Breaklines were compiled by inferring their locations based on the shape of the contours. The breaklines are important to ensure interpolation between contours is done correctly. Finally a Digital Terrain Model (DTM) was created from the compiled contours, spot elevations, and breaklines. This data is contained in file *Towill_1968_NAD83_NAVD88.dwg* on the attached CD.

The 2007 LiDAR (Light Detection and Ranging) data was supplied by the City of Novato along with a text file attributing the data to a FEMA Flood Insurance Rate Map Modernization Project performed by Dewberry and Davis, LLC. The data included both masspoints and breaklines which were easily converted to a DTM. The accompanying text file also identified the horizontal datum as NAD83 and the vertical datum as NAVD88. This data is contained in file *FEMA_2007_NAD83.DWG* on the attached CD.

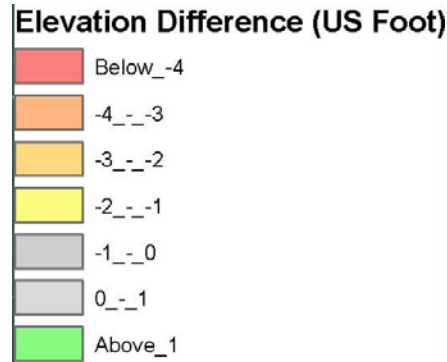
Additional data sets were reviewed, but either the accuracy did not meet requirements for this project or the date of the data was not sufficiently different to determine a trend. The 1997 MarinMap data created by Towill has only 5' contours so both the accuracy and density of data would be insufficient to detect differences of one foot or less. The 2004 MarinMap data created by Vargis has 2' contours, but major anomalies were discovered at the north end of Sausalito where the maps show Bridgeway rising nearly 5' from Gate 5 Road to Hwy 101. A close



analysis of the data showed breaklines did not model curb heights and breaklines and spot elevations did not agree with one another nor the contours generated from them.

3. Analysis

ArcGIS 9.3.1 with 3D Analyst was used to compute the elevation differences between the 1968 and 2007 terrain data. The 1968 and 2007 terrain models were subtracted and differences were grouped into polygons with one foot increments. The legend shown below describes the colors used to indicate each grouping of differences.



The results appear to indicate the data sources are accurate and consistent. Most roads show a difference of less than one foot. The differences form reasonably contiguous polygons and very little random differences are seen. If the data sets had random errors larger than one foot, it would be likely the differences would show a much more random distribution. Areas with large settlements are typically on unimproved land near the shoreline and areas with large fills are typically on land where improvements have been added since 1968. A statistical distribution chart of all data in the study area is shown on the delivery product that indicates a bell shaped distribution centered to the negative side and weighted significantly heavier on the negative (settlement) side.

4. Delivery Products

A compact disk (CD) is attached to this report. The files on the CD are described as follows:

Elevation_Difference_Analysis (folder)

Elevation_Difference.dwg.....AutoCAD 2004 file with polygons showing color coded elevation differences

Elevation_Difference.pdf.....A PDF plot of the AutoCAD file

Elevation_Difference.kml.....A Google KML file plotted from the AutoCAD file

CHART.tif...The statistical distribution chart of elevation differences over the site

Orthophoto (folder)

Sausalito_2004.sid.....A MrSID composite of the MarinMap color orthophoto dated 2004

Sausalito_2004.sdw...A georeference file for the MrSID image

Report (folder)

Sausalito_1968-2007.pdf.....This report

Sausalito_1968-2007_tra.pdf.....A delivery transmittal

Source_data (folder)

FEMA_2007_NAD83.DWG.....Breaklines and Masspoints from 2007 LiDAR

Towill_1968_NAD83_NAVD88.dwg.....Contours, spot elevations, and breaklines from 1968 photo-contour maps

Towill_1968_NAD83.TIF.....A composite of the 1968 photo-contour maps

Towill_1968_NAD83.tfw.....A georeference file for the 1968 photo-contour maps