Greg Pohll, Ph.D.

TECHNICAL MEMORANDUM

To: Walt West, P.E., Washoe County Community Services District

From: Greg Pohll and Chris Garner

Date: December 4, 2017

Re: A Landsat-Based Stage Chronology of Swan Lake, Washoe County, Nevada

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This technical memorandum details the development of a Landsat-based chronology of Swan Lake from 1984 to 2017. This information can be used by Washoe County staff to estimate the historical water balance, frequency of inundation, and assess the risk for re-flooding of Swan Lake.

3585 Bluejay Court
Reno, NV 89509
(775) 813-0610
greg.pohll@gmail.com

Introduction

Swan Lake is a terminal lake basin located ten miles north of Reno, Nevada in the East Lemmon Valley hydrographic basin (Figure 1). Swan lake is fed primarily by runoff from Peavine mountain to the southeast. Surface water and groundwater contribute to intermittent flooding of the playa. The background imagery in Figure 1 shows the flood extent for March 11, 2017 in Swan, Silver and White lakes. Although Swan Lake and adjacent low-lying areas are designated by the Federal Emergency Management Agency (FEMA) as a high (1 percent) flood hazard zone, little is known about local hydrology that controls flooding in this area. There are no stream gages monitoring discharge to the lake, climate monitoring stations in the upper portion of the watershed, or historical stage measurements on Swan Lake. During the flooding event of 2017, emergency managers did not have basic information on the potential for flood waters to increase or recede following initial flooding. The purpose of this project is to reconstruct Swan Lake stage measurements from the historical Landsat imagery archive. This information can be used by Washoe County staff to estimate a local water balance, frequency of inundation, and assess the risk for re-flooding of Swan Lake.

Methods

A Landsat-based chronology of Swan Lake stage was developed from the National Aeronautics and Space Administration (NASA) Landsat imagery archive and an AutoCAD topographic elevation model provided by Washoe County. The approach applies Landsat imagery to identify the shoreline location along a transect of elevation points and translates that location to a spot elevation from the topographic model.

Multiple elevation transects were investigated for use in the analysis but ultimately one was chosen that represented a gentle slope. The transect originated at the lowest point of the lake and followed a gently-sloping elevation gradient to maximize sensible changes in elevation (Figure 2). The spot elevation dataset is shown as black crosses, and the selected elevation transect points are shown in red beginning at zero feet as indicated in Figure 2. The profile along the elevation transect ranges from 4913.8’ to 4927’ (Figure 3). The topographic model indicates the lake is dry at 4913.8 feet.

The shoreline location for each Landsat scene was estimated by extracting the reflectance values in the shortwave infrared (SWIR) channel (1.55-1.75um) for each transect point using Google Earth Engine image processing capabilities (Gorelick et al., 2017) for Landsat missions 5, 7, and 8 over the period 1984 to November 2017. Figure 4 shows the total annual Landsat scene count available for the analysis.

The pixel values at each elevation point represent the reflectance of energy in the SIWR spectrum as recorded by the satellite at the top of the atmosphere. Figure 5 shows the reflectance returns for the transect points on May, 27 1984 from Landsat 5. The reflectance can range from zero for total absorption to one for total reflection. Water is strongly absorbing in the SWIR channel so values near zero indicate water, and higher values may indicate dry land, clouds, or snow. Figure 6 shows a map of the SWIR band for a Landsat 5 scene of Swan lake for the same date.

An algorithm was developed to automate the post-processing of transect reflectance returns from Google Earth Engine and identify the shoreline of the lake in each scene. Using Figure 5 as an example, the algorithm initially examines the first three points of the transect near zero to determine if they show reflectance values of water (i.e. high absorption). Water pixels were defined to have threshold reflectance less than 0.05. If the first criterion is met, the scene is processed, otherwise the scene is omitted. If the reflectance is indicative of water (i.e. below the threshold), the reflectance values of the remaining points of the transect are sampled until a rapid increase in reflectance occurs signifying the shoreline. This is seen in Figure 5 at point ID 35. The last value with a reflectance below the threshold is assumed to represent the shoreline location. The elevation for the estimated shoreline location is simply read from the Washoe County topographic elevation model transect. In this example, the elevation was estimated to be 4915.9 feet. This was a first level processing and filtering step of the scenes. Due to cloud cover, snow, shadows, and haze, additional manual filtering of scenes was performed to reduce noise introduced by these factors. Dry lake scenes were also visually identified in the secondary post-processing step.

Results

The estimated time series of Swan Lake stage is provided in Figure 7. A Microsoft Excel file containing a record of the scene dates and estimated stage is also included. Black dots in Figure 7 represent estimated Swan lake elevations derived from Landsat scenes. The blue line is a linear interpolation between the points for ease of interpretation. The time series has a step function shape where rapid changes in stage are followed by short periods of relatively constant stage. In 1984, the lake is declining from an earlier period of flooding in 1983 that was unfortunately not available in the Landsat archives. The remainder of the stage record clearly shows the relationship between wet years and sequential wet years when the lake is maintained higher for extended periods. For example, 1986 to late 1988, the late 1990s, and 2005 to 2007. The magnitude of the lake stage after the 2017 flood events (approximately 4922.5 feet elevation) quantifies the exceptional nature of this event relative to the previous years included in this analysis. Dry periods in the early 1990's, in the early 2000's, and the recent 2012-2015 drought are also clearly defined. In general, the lake is maintained more consistently under persistent wet conditions, reflecting the importance of sequentially wet years. Antecedent soil and groundwater storage are likely also significant contributors to maintaining the lake more consistently over time and cannot be overlooked. Mid-winter atmospheric river events which produce rain-on-snow precipitation are associated with the highest estimated stages (e.g. 1986, 1997, 2017).

Conclusions

The approach implemented in this study proved to be effective at reconstructing the changes in Swan lake stage over time. A first level filter of the scenes based on reflectance was adequate to remove a majority of the problematic scenes and estimate the stage, but visual inspection and manual filtering was required to eliminate noise associated with other factors. The location of the transect was adequate in terms of its overall gradient, however, several local minima contributed to outlier stage estimation. Further, due to limitations associated with the Landsat pixel size, the tendency of unidentified contaminated scenes to produce erroneous elevations, and the coarseness of the elevation model, we estimate the uncertainty in this product to be on the order of half a foot. Transitional states in the lake stage are also likely to be uncertain as some of the estimated drops in the lake stage occur too rapidly. Despite these issues, the resulting time series will allow water managers to investigate the patterns and changes in the lake stage relative to other components of the water budget to better understand the potential for future flooding.

References

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R., 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*.

Figures

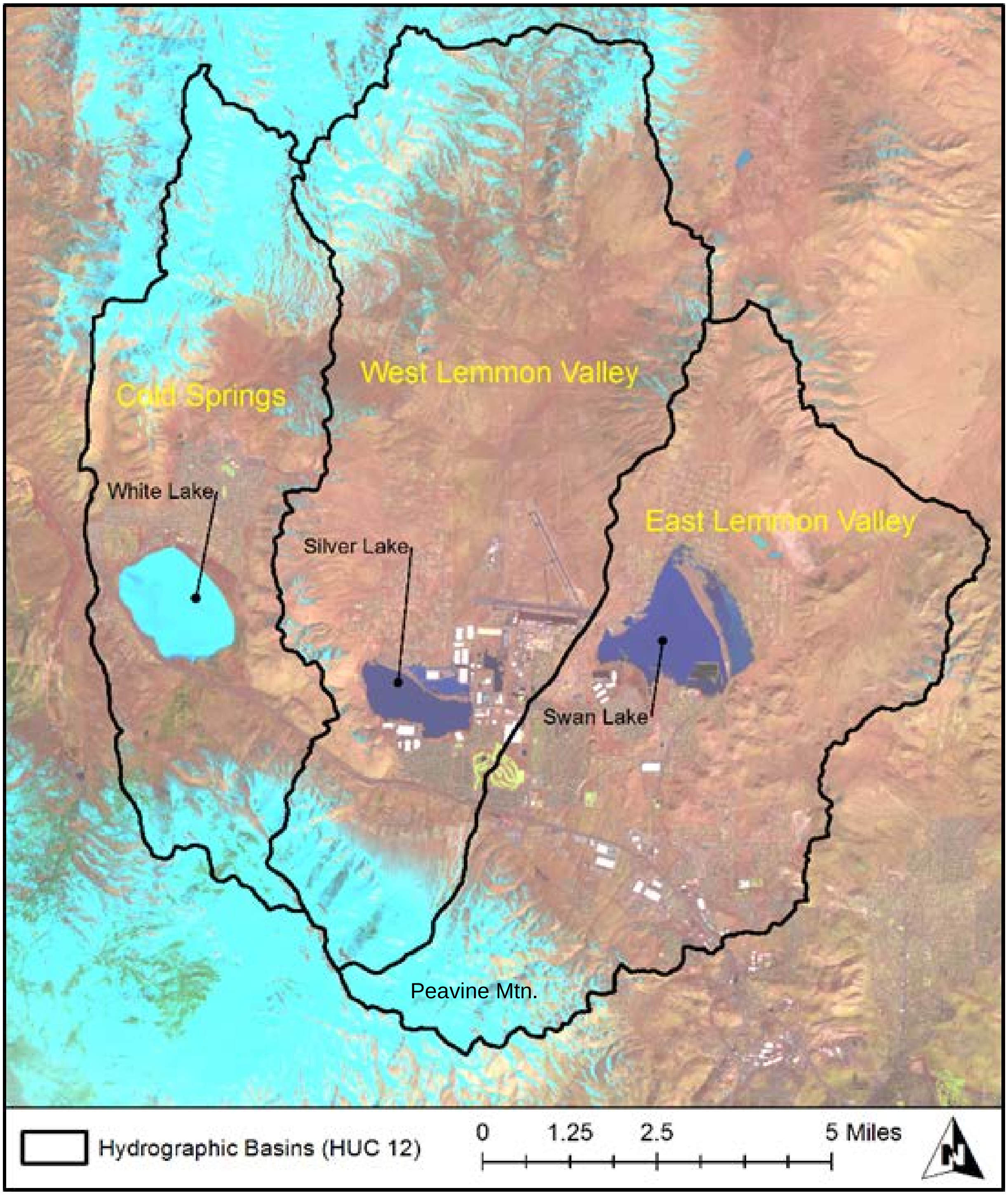

Figure 1. East Lemmon Valley, West Lemmon Valley, and Cold Springs hydrographic basins and Swan, Silver, and White lakes. Background imagery is for March 11, 2017.

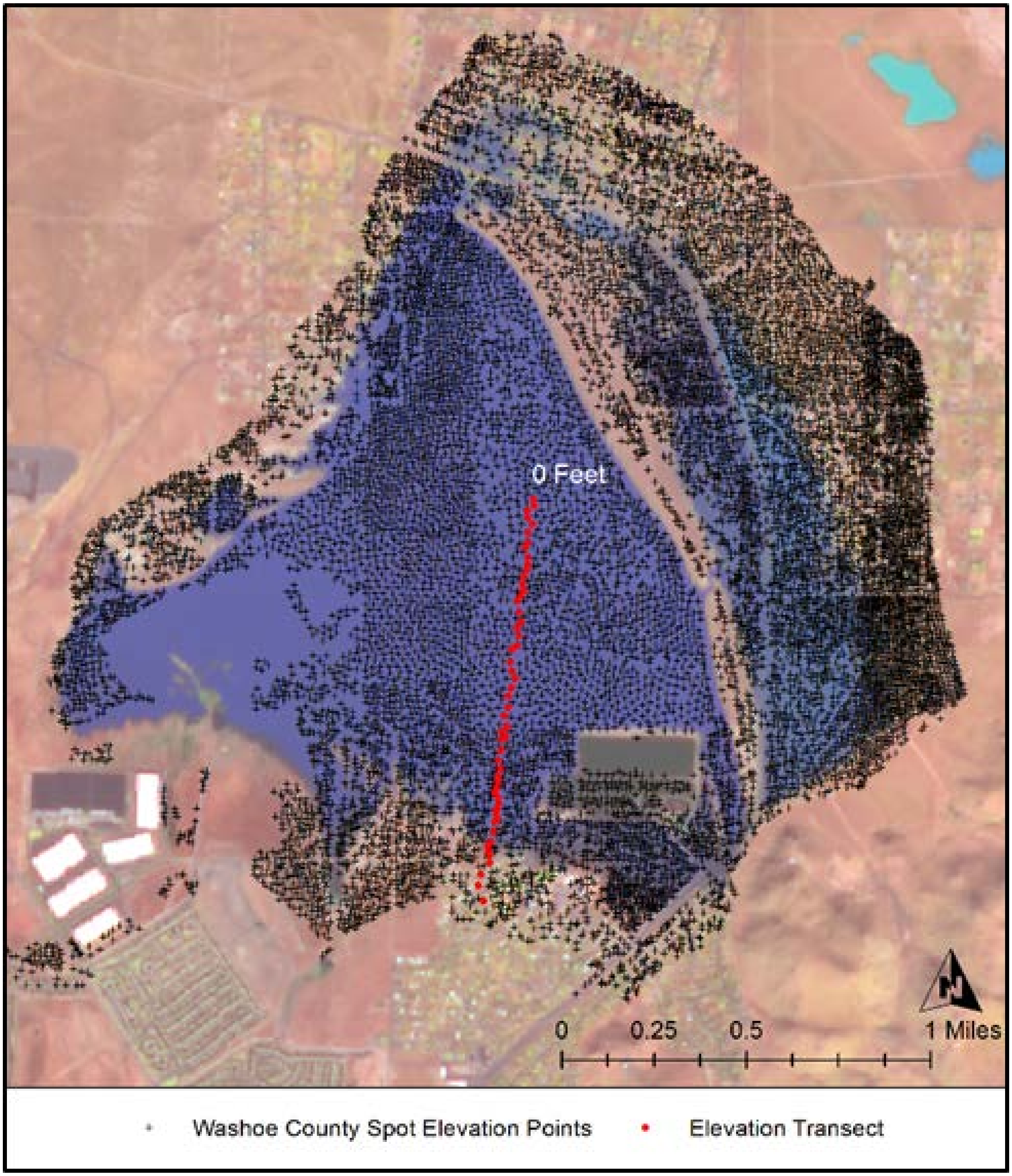

Figure 2. Spot elevation data points from Washoe County AutoCAD topographic model and the transect points used in the stage analysis.

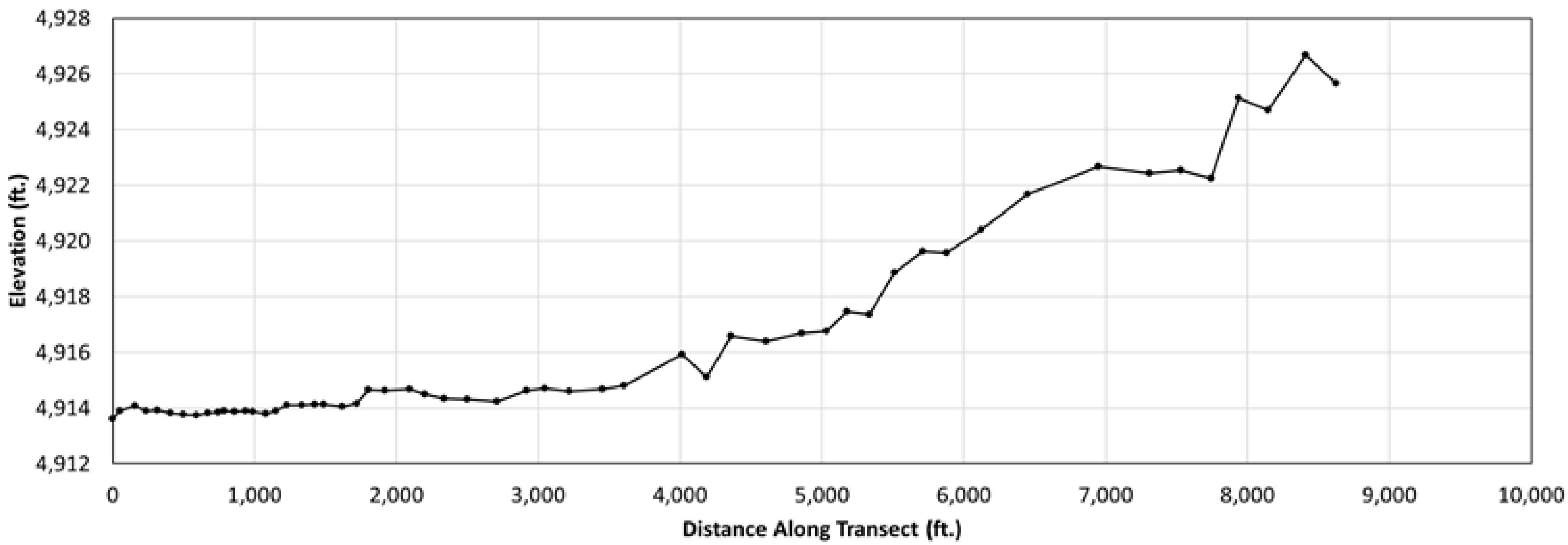

Figure 3. Elevation profile along the transect points used in the stage analysis.

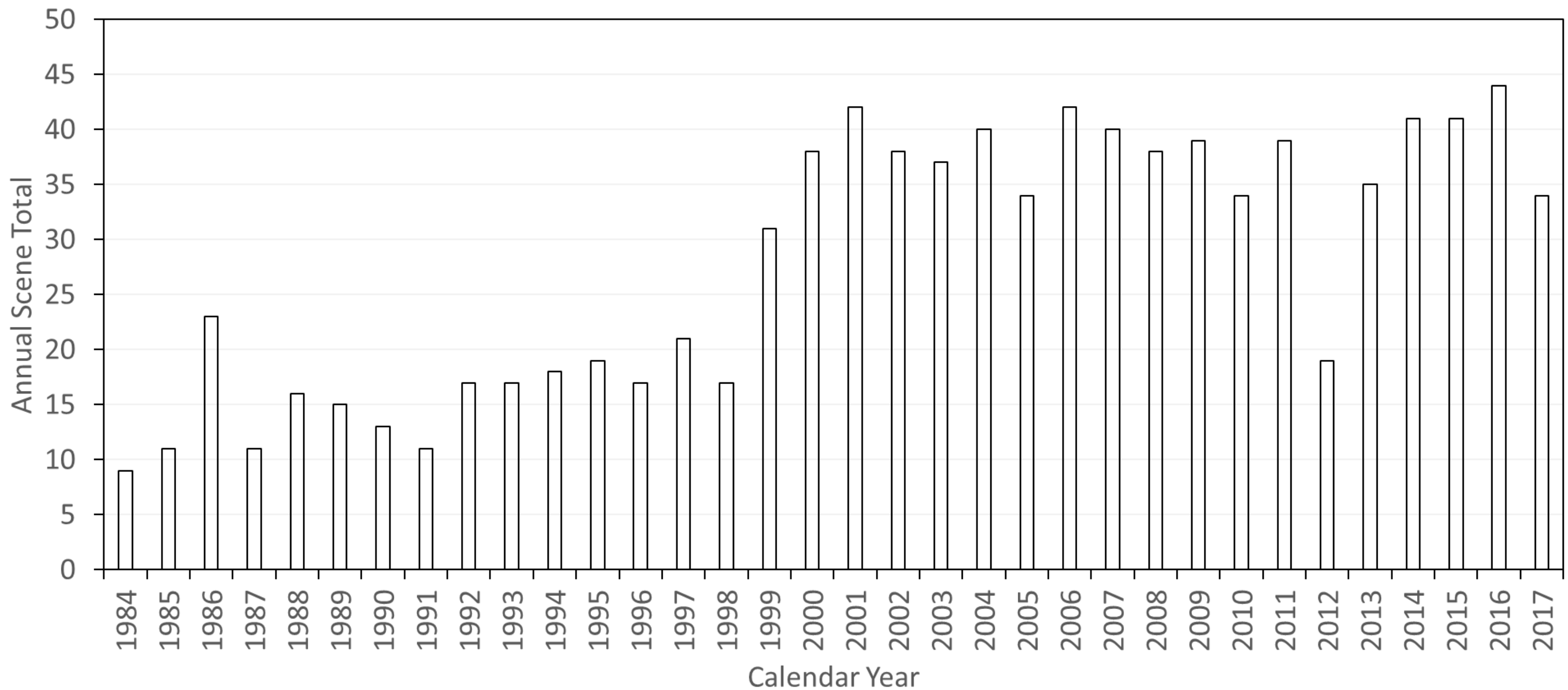

Figure 4. Total Landsat scenes available on Google Earth Engine for each year over the analysis period. From 1984 to 1998, Landsat 5 was the sole satellite. With a return interval of 16 days, complete acquisition results in 23 scenes per year. From 1999 to 2001 Landsat 5 and Landsat 7 were acquiring concurrently corresponding to a complete set of 46 scenes. In 2012 Landsat 5 was decommissioned and Landsat 7 was the sole imaging satellite. Landsat 8 came online the following year (2013) which is reflected in the scene counts up to 2017.

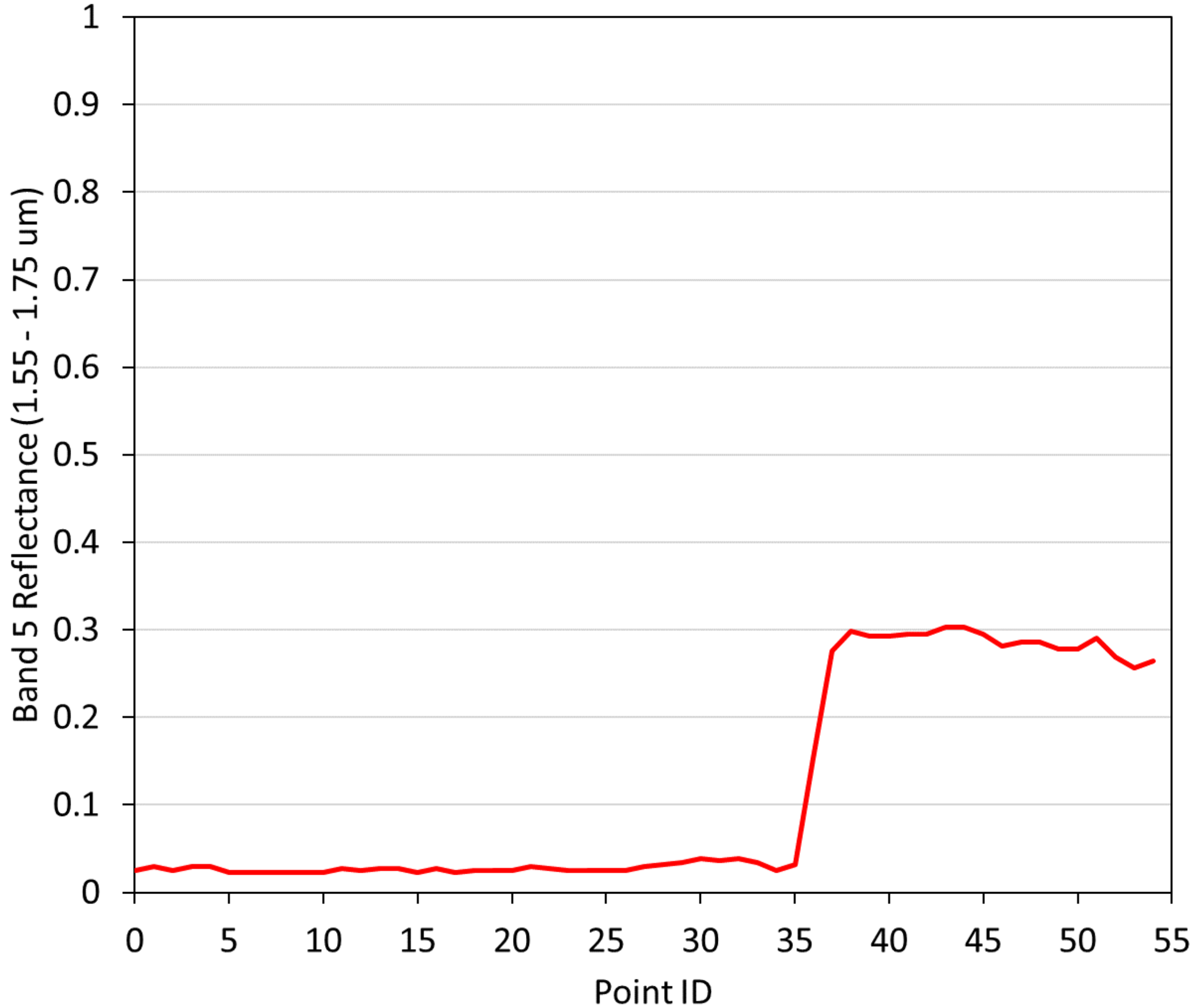

Figure 5. SIWR reflectance values along the transect for May 27, 1984.

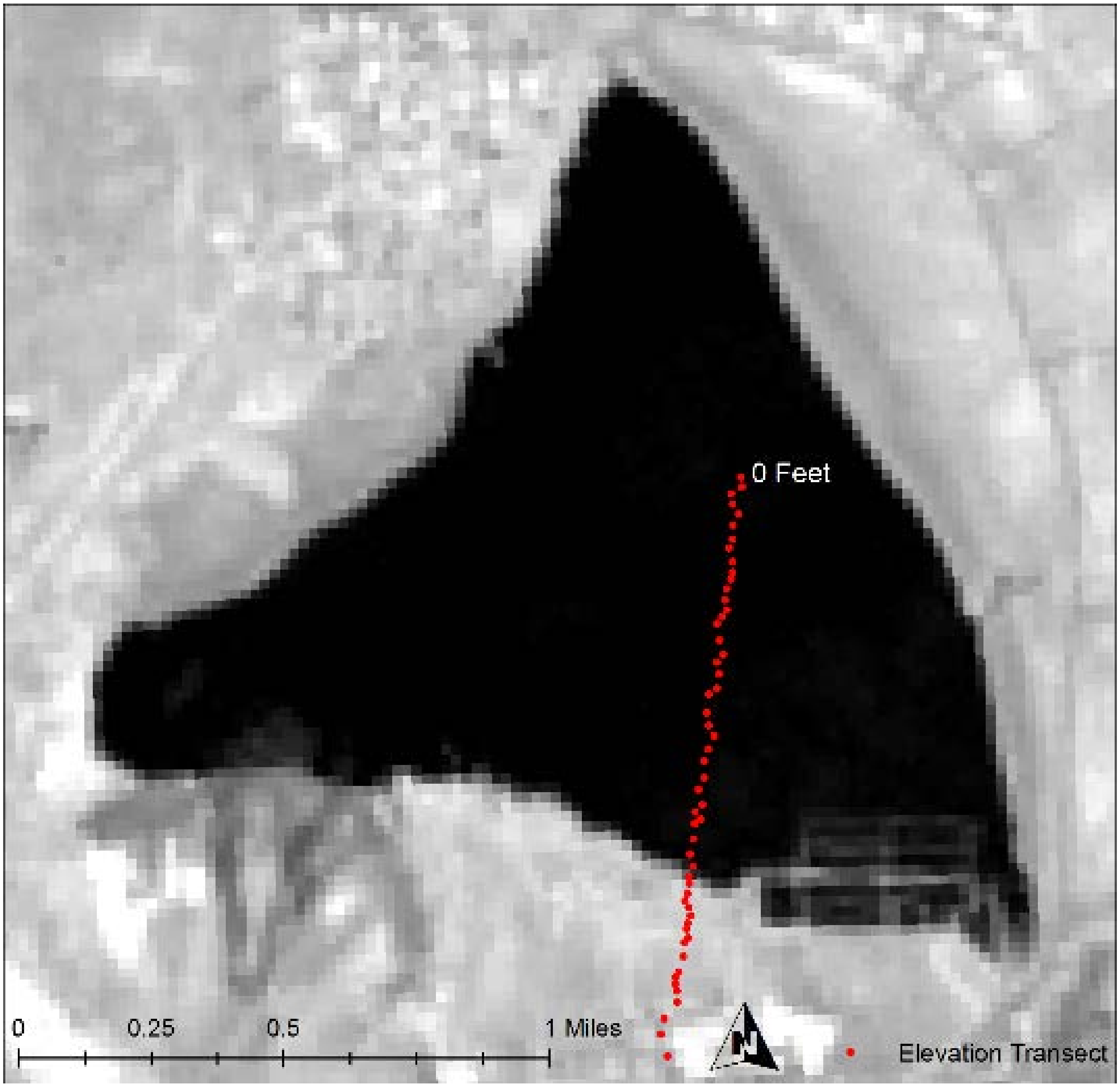

Figure 6. SWIR band Landsat 5 scene of Swan lake and elevation transect for May 27, 1984.

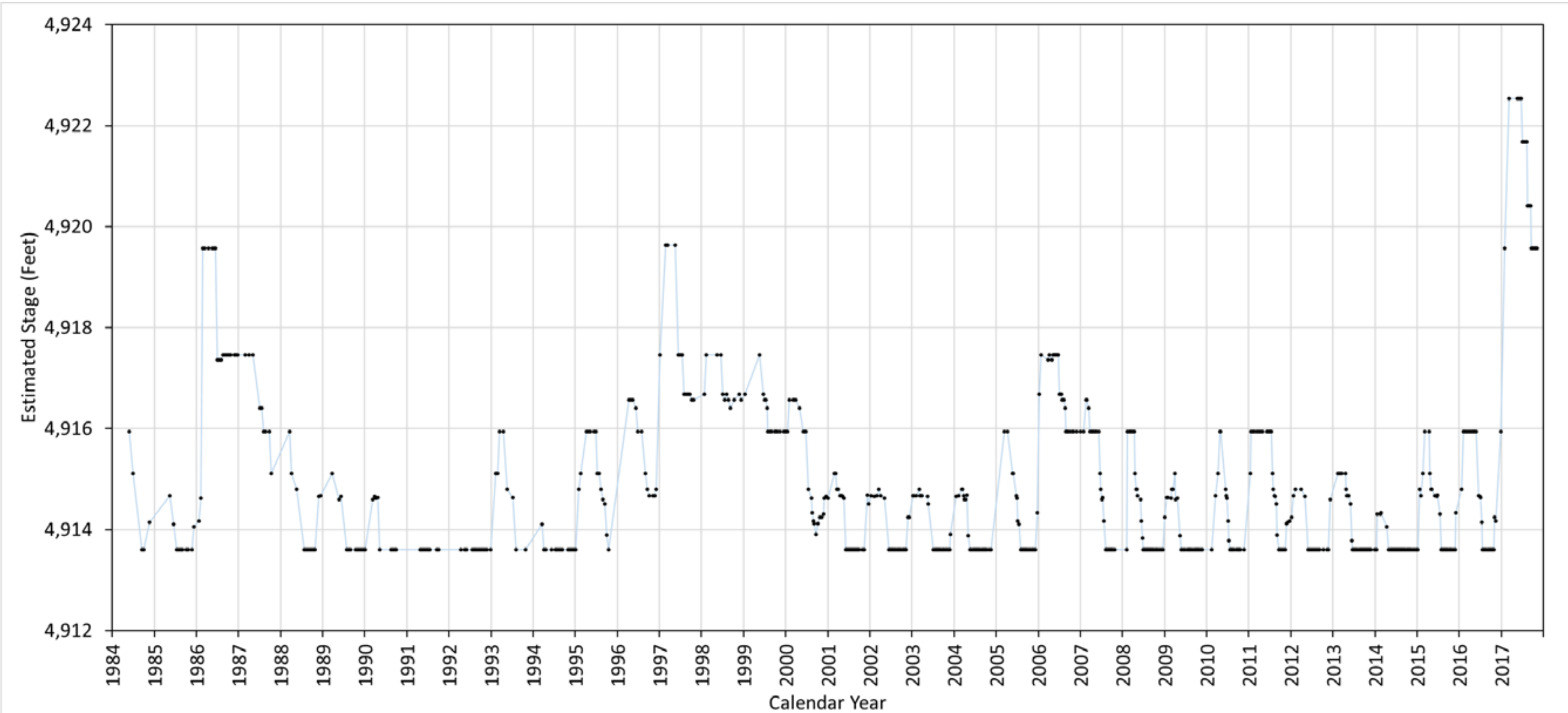

Figure 7. Estimated Swan lake stage using Landsat imagery to identify the shoreline. Black dots are estimated elevations from a Landsat scene. Blue lines are linearly interpolated between scene dates for ease of interpretation.