3D VISUALIZATION MODELS AS A TOOL FOR RECONSTRUCTING THE HISTORICAL LANDSCAPE OF THE BALLONA CREEK WATERSHED

by

Christopher Scott Beattie

A Thesis Presented to the
FACULTY OF THE USC GRADUATE SCHOOL
UNIVERSITY OF SOUTHERN CALIFORNIA
In Partial Fulfillment of the
Requirements for the Degree
MASTER OF SCIENCE
(GEOGRAPHIC INFORMATION SCIENCE AND TECHNOLOGY)

December 2014

DEDICATION

To my parents.

ACKNOWLEDGMENTS

I thank Esri’s Geoff Taylor and Walt Disney Animation’s Brett Achorn for their assistance with CityEngine’s .cga code.

I thank all of the Spatial Sciences Institute faculty who made my experience at University of Southern California exceptional, especially my committee members Dr. Yao-YI Chiang and Dr. John Wilson. I also thank Dr. Travis Longcore (Committee Chair) for his willingness to share his expertise on the Ballona Creek watershed, his trust in me to push the boundaries of GIS, and his guidance throughout my academic journey.

I thank all my friends, especially Ben, Brittany and Matt, for their constant encouragement and interest in my thesis. I also thank all the members of my family, Denise, Scott, Gregory, and Blake, for being the driving force behind my collegiate success.

Most importantly, I want to thank Zahabiya — I am forever grateful for your support and love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
ADM	Automated Design Module
CAD	Computer-aided Design
CGA	Computer Generated Architecture
CSUN	California State University Northridge’s
DEM	Digital Elevation Model
DTM	Digital Terrain Model
FTP	File Transfer Protocol
GIMP	Graphics Manipulation Program
GIS	Geographic Information Systems
OBJ	Object File
PCC	Playa Capital Company
PDF	Portable Document Format
PNG	Portable Network Graphic
RGB	Red Green Blue Color Model
SCCWRP	Southern California Coastal Water Research Project
TIF	Tagged Image File
TPL	Trust for Public Lands
USGS	United States Geological Survey

ABSTRACT

Ever-increasing demand on Earth's finite natural resources and land requires environmental planners to employ informed and successful management of environments. Historical resources enhance environmental management by providing information to compare past landscapes to contemporary, urbanized states. In this study, heterogeneous historical resources were converted into GIS datasets to reconstruct the Ballona Creek watershed in Los Angeles, California as a three-dimensional (3D) model. To develop the 3D terrain, contour lines were extracted from early 20th century United States Geological Survey (USGS) topographic maps. Transforming contour lines into a Digital Elevation Models (DEM) enabled creation of 3D models to visualize the terrain of the Ballona Creek watershed before the region was heavily urbanized. To increase the effectiveness and functionality of these models, 3D vegetation and hydrography features were also added to the terrain to "paint a picture" of the historic extent of the Ballona Creek watershed. The historic 3D topography allowed calculation of elevation changes occurring over the last century to the Ballona Creek watershed and provided visualizations of previously reconstructed historical habitats. These visualizations and associated analyses comparing historic and current conditions provide a historical perspective for environmental planners to identify landscape changes and current trajectories of urbanized landscapes. These results suggest that 3D visualizations models, synthesized from an array of historical resources, can effectively deliver information about past landscapes to environmental planners, decision makers, and the public.

CHAPTER 1: INTRODUCTION

Environmental management relies on contributions from biology, ecology, information systems, and many other fields to mitigate humanity's impacts on Earth's finite natural resources and land. Furthermore, it synthesizes and informs a wide spectrum of viewpoints, from academia to the government, to better understand how human societies interact with their environment and optimize the protection of ecosystem services and restoration and conservation of natural resources. Geographic information systems (GIS) have contributed to environmental management's already wide lens the practice of spatially enabled environmental management. GIS improves restoration and conservation efforts by providing modeling and analyzing tools to demonstrate the value of such projects, therefore encouraging a deeper understanding of its specific importance in environmental management. Specifically, GIS enables environmental planners to compare heterogeneous historical resources, such as old maps, photographs, and written accounts, to current environments, guiding conservation and restoration projects.

1.1 Environmental Planning

Draining wetlands for farming or relocating a meandering stream to improve an irrigation system are common examples of environmental management techniques utilized by past and present societies. These examples demonstrate that, historically, environmental planning has been concerned with developing practical uses for Earth's natural resources and land. In contrast, environmental management now focuses on collaboration between interdisciplinary experts to make informed, responsible decisions about the best practices for environmental management. The decision-making process of environmental planning encompasses social, economic, and urban development at the city, regional, and global level (Marsh 2010). Demands for resources and land in one part of world create environmental challenges in another. A burgeoning human population forces governments, scientists, and businesses to addresses these challenges with a sense of urgency and responsibility. Environmental planning is a comprehensive approach for finding solutions to these problems that encompasses social, cultural, and political factors (Marsh 2010).

The exponential growth of human populations, rapid industrialization of developing countries, and competition over finite resources have made environmental planning, once considered a luxury, a necessity (Scally 2006). Balancing the quality of human life and protecting and preserving the natural environment, however, comes with an economic cost. Technological approaches to environmental planning provide a solution for reducing the costs of environmental management. Diverse and scalable environmental issues require transparent and participatory communication between the public, environmental planners, and policymakers about the objectives of environmental management and the methods that should be used to reach them.

1.1.1 Spatial Enabled Environmental Planning

GIS are computer-based systems that are capable of creating, storing, editing, analyzing, and displaying spatial data. Spatial data are made up of geographic information that represents the geometry of objects, known as *features*, and their position on Earth. Integrating spatial data into a geodatabase specifically designed for GIS data promotes creation and management of spatial datasets that represent real-world features. Such datasets can be used to measure, analyze, and model Earth's phenomena, such as changes in topography.

Greater computational power and mobile devices' improved GPS capabilities and locational services have lead to an explosion of spatial datasets. Free, open-source datasets encourage the sharing of spatial datasets throughout the world. Spatial datasets enable real-world objects and functions to be replicated for environmental planning purposes. For example, the complex and diverse hydrography and habitat types of a watershed are represented by polygons and polylines, providing tools for modeling and analyzing the watershed in its current condition. Basemap layers are used to represent the actual surface where the ecosystem services and features exist. A topographic map is a common basemap type that provides a landscape's elevation information. Topographic maps are also beneficial because they can be converted into Digital Elevation Models (DEMs). Based on elevation data, DEMs interpolate elevation information to represent the surface of a terrain.

The environmental planning decision-making process relies on interdisciplinary models that integrate biology, ecology, biology, and hydrology. The complex relationships and functions of different environments can be well represented in GIS by using its diverse toolboxes. GIS have modeling, analysis, and publication capabilities that can help understand the structure and interactions of ecosystems. GIS can effectively manage multiple types and layers of landscape data, including hydrography, topography, and habitat datasets. Furthermore, fundamental ecosystem relationships and processes, which are key components in environmental management, can be replicated to understand how humanity influences environments. Advances in spatial data collection are beneficial for ecosystems that are intact today, but are ineffective in collecting data about the past.

Reconstructing past ecosystems and their historical environments is more challenging. To create historical GIS datasets, historical resources must be synthesized and converted into georeferenced raster and vector digital files. Heterogeneous historical resources, including maps, images, and written accounts, are used to estimate and reconstruct past ecosystems. Historical resources integrated into GIS enhance environmental planning by providing context on how historic environments functioned and looked in the past (Grossinger et al. 2007, Stein et al. 2007, Stein et al. 2010, Dark et al. 2011). Reconstructing the aesthetics, functions, and relationships of historical environments provides a perspective of what habitats environments supported, how degradation has changed the environment, and the value of preserving and conserving environments (Stein et al. 2010, Mattoni and Longcore 1997). GIS creates a workflow for the entire decision-making process in historical habitat reconstruction, from data conversion to providing tools for environmental management. As valuable as historical resources are in providing information about the past, the conversion of their information into formats that are compatible with GIS presents significant challenges.

1.1.2 Visualization Models

As the conflicts between humanity's natural resources needs and those resources' protection increases, environmental planners are responsible for integrating industry-leading technology solutions for environmental management. For example, diverse types of visualizations outputs have been incorporated into GIS in order to communicate environmental assessments to a broad audience, including the government and public (Bishop 1994). Furthermore, 3D models are proving to be valuable GIS visualization tools and becoming a common method for communicating environmental issues (Appleton 2003). 3D visualizations allow users to detect intuitively the information they would otherwise have to derive from assembling individual 2D map components, such as symbology and scale (Reed 2000).

1.2 Research Question Problem

Environmental planning protects existing ecosystem services and restores impacted habitats to ensure future human generations are provided with natural resources and land. Restoration benefits from assessing historical resources by illustrating how damaged habitats once looked (Mattoni and Longcore 1997). Furthermore, historical analysis provides a perspective for understanding ecosystems that are so impacted by urban developments that there are no traces of the ecosystems’ existence (Mattoni and Longcore 1997, Sanderson 2005, Stein et al. 2010). Historical resources provide a wealth of information but the application of this knowledge to an urbanized environment depends on the restoration objectives and current status of the landscape (Dark et al. 2011). Environmental planning tools that encourage discussion and a deeper understanding on how to use historical resources to guide and demonstrate the value of restoration efforts are a necessity.

1.2.1 Limitations of Reconstructing Historical Resources

Historical resources provide information about the landscape and functions of environments prior to its degradation or destruction. Unlike environmental planning datasets that were created with their GIS intentions in mind, historical resources could not have contemplated integrating with GIS at the time of their creation (Stein 2010). For example, extraction of elevation information locked in historical topographic maps is challenging due to the coloring and age of the maps (Leyk and Boesch 2010). Although the coloring was helpful at the time it was created, it exacerbates the topographic maps conversion to digital vector and raster forms. A multitude of software platforms must be integrated, including graphic editing, GIS, and modeling to convert historical resources into digital vector and raster datasets. Often this requires learning a new set of skills to prepare, convert, and store the historical resources. Also, heterogeneous historical resources, such as hand-drawn maps, photographs, and descriptions may have inaccuracies and differences that present challenges in synthesizing resources.

1.2.2 Limitations of 2D Outputs

2D images and maps provide large amounts of information about a historical environment’s extent and appearance. However, the viewer has to rely on map legends, scale, and other information to envision the historical environment. 2D images lack the inherent clues that a wide spectrum of viewers can intuitively detect compared to 3D visualizations (Reed 2000).

1.2.3 Limitations of 3D Visualization Tools

Integrating rich 3D graphics with spatial datasets merges the gap between graphic design planning and geospatial modeling within environmental management. However, there are several factors that limit the effectiveness of 3D visualization tools. First, there are modeling tradeoffs that must be evaluated. For example, increasing details will reduce the user’s ability to interact with the visualization (Appleton 2003). Enhancing the detail also increases the cost of creating the 3D model, restricting the number of historical landmark features generated (Maïm et al. 2007). Specifically, to reduce the cost of the model, only prominent historical landmarks are generated while the remaining features may be “stock” or “generic” models not based on real world descriptions or appearances. Second, the GIS dataset used to guide the 3D visualization’s detail will typically require modifications prior to importing into a 3D modeling software; this may require new skills outside of traditional GIS manipulation (Appleton 2003). Third, 3D models may lack the geographic context to make them effective beyond being an aesthetically pleasing visualization. Allocating too much time and effort to creating “beautiful” features threatens the model’s balance of functionality and realism; although richer, realistic graphics are tempting, they severely reduce a user’s ability to navigate through the model and use analysis tools.

1.3 Research Question Solution

This study aims to design an efficient and robust workflow for accurately converting heterogeneous historical resources, such as topographic maps, past photographs, and written accounts into digital vector and raster GIS datasets. The 2D GIS data will be used to guide the generation of a 3D landscape model that visualizes the historical extent and appearance of the Ballona Creek watershed. The 3D model will serve as a valuable tool for environmental planners to detect temporal changes in the topography, identify unknown historical features, and to encourage decision makers and the public to participate in understanding the importance of conservation and restoration.

CHAPTER 2: LITERATURE REVIEW

2.1 Currents Trends

Technological advances in environmental planning have improved the usefulness of 3D visualization models in project planning. This subsection outlines three case studies that utilize 3D visualizations in environmental management and planning: 1) The Mannahatta Project, 2) CityEngine: Procedural Pompeii, and 3) Geodesign and Wildlife Corridor: ADM.

2.1.1 The Mannahatta Project

The Wildlife Conservation Society's "Mannahatta Project" from 1999–2009, compared Manhattan, one of the five boroughs located within New York City, to its historical habitat. Despite Manhattan's diverse ecological history, it is now part of the most densely populated county in the Untied States, New York County. The New York Stock Exchange, Broadway Theater District, and Chinatown, which are internationally known urban landmarks, are all found in Manhattan. These features make living in Manhattan desirable, as shown by the 2013 Census' estimates: over 1.5 million residents were living in Manhattan's 22.96 square miles.

Dr. Eric Sanderson of the Wildlife Conservation Society recreated the ecological history of "Mannahatta," which means "Island of Many Hills" in the native language of the Lenape people, or better understood as Manhattan. Dr. Sanderson utilized heterogeneous historical resources and spatial analysis to reconstruct the history ecology of "Mannahatta" (Sanderson 2005?). Extracting the information locked in historical resources, such as maps, written descriptions, and drawings, the topography, hydrology, and land cover of Manhattan were reconstructed by the Mannahatta Project. The project suggested that in the 17th century Manhattan Island was a diverse landscape and comprised of over fifty different ecological communities, which is a stark contrast to the 3% found today (Sanderson & Brown 2007).

The Mannahatta Project overlaid the geographic reconstructed habitat layers onto the 21st-century topography of New York City to compare the extent of Manhattan's urbanization. The powerful visualization provides insight into the possibility of restoration efforts. This transformation of heterogeneous resources into a historical ecology GIS dataset guides restoration by producing a benchmark that can be used to restore a damaged ecosystem and encourage public interest and participation in restoration (Sanderson & Brown 2007). It is difficult to imagine places with extensive urbanization, such as Manhattan, as healthy ecosystems, but reconstructing historical ecology provides a "glimpse" of the past. Seeing where past habitats once existed reminds people, decision-makers, and scientists of the importance of understanding the consequences of development by demonstrating the extensive changes humanity has caused to the environment (Figure 1).

Figure 1. An example of the Mannahatta Project's historical ecology layer overlaid onto the current extent of Manhattan, New York; image from mannahatta2409.org.

2.1.2 CityEngine: Procedural Pompeii

CityEngine is a modeling program owned by Esri that specializes in creating visualizations for urban planning, architecture, and design. It enables planners to create realistic 3D models, from large cities to individual buildings, integrating spatial datasets to assist project design. Furthermore, CityEngine provides environmental planners with an opportunity to simulate cities' functions before they are built. It provides a greater understanding of how to build sustainable environments by creating functioning, realistic 3D virtual models.

CityEngine is primarily used for developing future cities but has capabilities for reconstructing cities and environments of the past. The "Procedural Pompeii" project reconstructed the entire city of Pompeii prior to its destruction by the volcanic eruption in 79 AD (Figure 2). The project also enables a user to "cyberwalk" throughout the ancient city on a mechanical treadmill. 3D modeling projects are usually limited to reconstructing only vital landmarks of an ancient city due to high costs (Maïm et al. 2007). CityEngine, however, integrates GIS datasets to guide an automated process of reconstructing entire buildings and cities. GIS data such as population density, land usage, street networks, and building footprints were used as rules to design the buildings of ancient Pompeii (Maïm et al. 2007). Furthermore, heterogeneous historical resources such as building remains, archaeological data, and paintings were used to derive the buildings' geometries. For example, historical data converted into GIS data enabled large-scale models to be generated with the appropriate type and style of building. The entire city of ancient Pompeii was reconstructed using historical resources and the powerful rule guided, mass-modeling techniques of CityEngine.

The reconstruction of Pompeii using historical resources shows the benefits of being able to visualize and navigate within a 3D model. Although 2D maps or images provide information, 3D models allow a user to operate within the environment, enhancing their understanding of the place. The Pompeii example would improve by refining and adding by additional resources to the model. For example, buildings were designed using the CityEngine rules, but their location was not based on historical resources. Only the location of the temple of Jupiter was derived from known archeological information from verified excavation sites. Additionally, the terrain of the Pompeii city is flat in the model; it did not use a Digital Terrain Model (DTM) to correctly model the 3D terrain of the study area.

Figure 2. Pompeii reconstructed in CityEngine. Image from esri.com.

2.1.3 Geodesign and Wildlife Corridor: ADM

As pressures for greater land usage and development forces societies to degraded ecosystems, critical wildlife habitat is being destroyed (Perkl 2012). Specifically, habitat fragmentation, which occurs when areas of habitat are disconnected by human development, structures, or is destroyed, threatens species diversity and populations (Perkl 2012). Wildlife corridors preserve habitat parcels to connect fragmented habitats, encouraging species to migrate and disperse throughout a developed environment.

Wildlife corridors are vital tools for preserving precious habitat for species. Although corridor models are helpful to determining boundaries, they often fail to address and represent deeper wildlife planning issues (Perkl 2012). For example, a wildlife corridor must provide the correct plant species and vegetation patterns to be an effective parcel of land for animal migration. Without site-specific information such as vegetation functions wildlife corridor models are inefficient (Perkl 2012). Perkl combines a hybrid of planning components, visualizations, and geospatial analysis to evaluate the functions and relationships of an environment. This approach is known as geodesign, "a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic contexts" (Flaxman 2010).

Perkl developed a new tool, the Automated Design Module (ADM), created using Esri's Spatial Modeler, a modeling tool part of the ArcGIS suite. To determine the native vegetation that would populate a corridor in the Sonoran desert, the ADM determines the capability of the landscape to host various vegetation species. Each species is evaluated at the raster cell-level by using a selection algorithm to correctly align a vegetation species with each cell in the corridor. The final output of ADM is wildlife corridor that includes the native plant species and their respective patterns, promoting the success of migration for species (Perkl 2012). Furthermore, the model produces a 3D visualization of the modeled wildlife corridor that is capable of analyzing and portraying the functions of the corridor (Figure 3). Utilizing GIS to design, create, and implement successful techniques for environmental management, the ADM is an exceptional example of a functional model that provides visualization and analysis tools. The ADM synthesizes diverse GIS datasets to recreate degraded habitats in 3D, portraying the appearance and functionality of an environment.

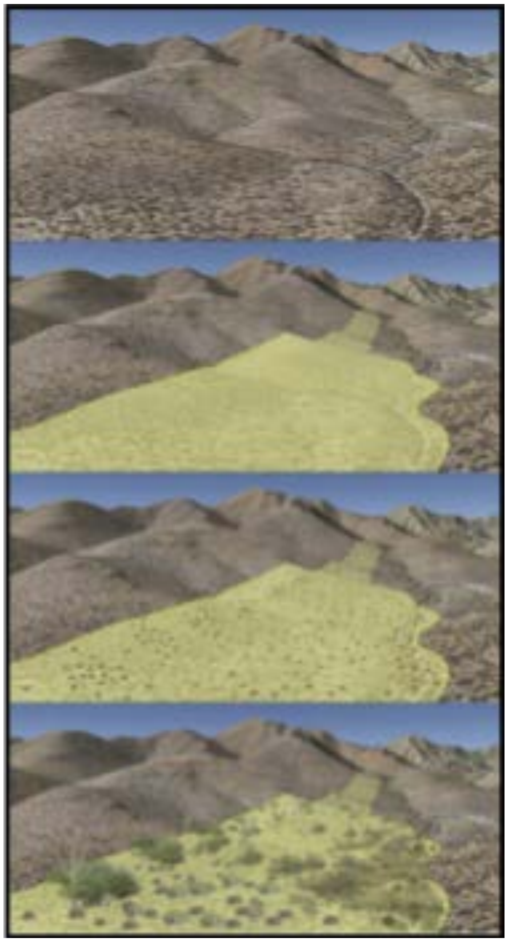


Figure 3. An example of a wildlife corridor designed by the ADM functional wildlife corridors; image from esri.com.

2.2 Extracting Data from Topographic Maps

Conversion of scanned raster maps to vector formats is important for the generation of DEMs. Topographic maps contain large amounts of data, often only in paper or raster form (Chiang 2014). Topographic maps illustrate elevation information by contour lines. Using these lines, generalization about the terrain’s elevation and landforms can be conceptualized (Vitek 1996). However, the process of extracting the contour lines and converting them to vectors forms is difficult. According to Khotanzaed et al (2003) four major challenges are faced in extracting contour lines from topographic maps: 1) aliasing caused by scanning the map into digital raster form; 2) difficulties in determining closely-spaced features; 3) introducing false colors from poor scanning; 4) contour lines intersecting or overlapping with other features. Chen el al. (2006) outlines the four steps in extracting contour lines:

Step 1) digitization of the original paper map by scanner;

Step 2) color image segmentation and filtering noisy pixels;

Step 3) thinning and pruning the binary image;

Step 4) raster-to-vector conversion of the resulting thinned lines.

Ample research describes automating the tedious and time-consuming process of extracting features from topographic maps, such as roads. For example, Chen and Lu (2002) describe color image segmentation to make topographic more suitable for extracting information. In another example, Khotanzad and Zink (2003) used a RGB color histogram and a multitude of algorithms to extract map features.

2.3 Creating Historical 3D Visualizations

Three-dimensional visualizations are highly effective in communicating complex spatial data to diverse audiences. Often, according to Reed (200), 3D visualization models encourage users to detect visual clues and details with greater ease compared to 2D maps. Also, visualizations provide users with a unique perspective of reconstructed historical places by enabling them visualize changes in 3D. For example, Shimizu and Fuse (2003) rubber sheeted historical maps to create a visualization that compared land use changes in Tokyo. Relatively little research has been devoted to reconstructing 3D visualizations of historical habitats. This study’s purpose is to advance current trends in historical modeling to include reconstructing past habitats with accurate and realistic landscape features.

CHAPTER 3: METHODOLOGY

3.1 Study Location

In the early 19th century, the 14,149-acre Ballona Creek watershed was a diverse watershed (Figure 4), featuring “freshwater ponds, vernal pools, wet meadows, freshwater marshes, and numerous springs” (Dark et al. 2011). The Los Angeles River once flowed through the Ballona watershed and lagoon before 1825, but several years of heavy rains and major earthquakes caused the river to permanently discharge in the San Pedro area (Dark et al. 2011). The Ballona watershed continued to support its complex and diverse wetlands habitats through freshwater springs, despite the shift of the Los Angles River (Dark et al 2011). The unique topography of the Ballona Creek watershed was formed from geologic factors, such as the Newport-Inglewood Fault (Dark et al. 2011). Several notable features were created from the geology of the Ballona watershed, including the “Baldwin Hills and other outcrops, aeolian beach-derived sand deposits” (Dark et al. 2011). Diverse habitats flourished in the niches created from the topography, including a large wetland complex formed along the base of the east side of the Baldwin Hills. Seasonal rainfall and the various courses of the Los Angeles River allowed the region to support diverse wetland ecosystems, including the most prominent wetlands, the La Cienega wetlands and the Ballona Lagoon (Dark et al. 2011).

The Ballona Creek watershed was, however, extensively modified to create flat ground for agriculture as development moved away from ranching (Stein et al. 2007, Dark et al. 2011). Furthermore, oil was discovered in West Los Angeles in the early 1900s and the topography dramatically changed as oilrigs were erected in the watershed to drill for it. Attempts to use the region for recreational developments, such as a fishing pier, hotels, and a hunting lodge, were repeatedly destroyed by the dynamic and diverse watershed. As a result, one of the prominent features of the Ballona watershed, the Ballona Creek, was dredged and cemented.

Soon after the cementing of the Ballona watershed features, Howard Hughes, an eccentric businessman, developed an extensive manufacturing facility in the wetlands' upland area in the 1940s. The construction of Marina del Rey in the 1960s, destroying over 900 acres of the northern wetlands and displacing approximately 2.5 million cubic yards of the construction's dredge soils throughout the remaining wetlands (Hall, Jr. 2012).

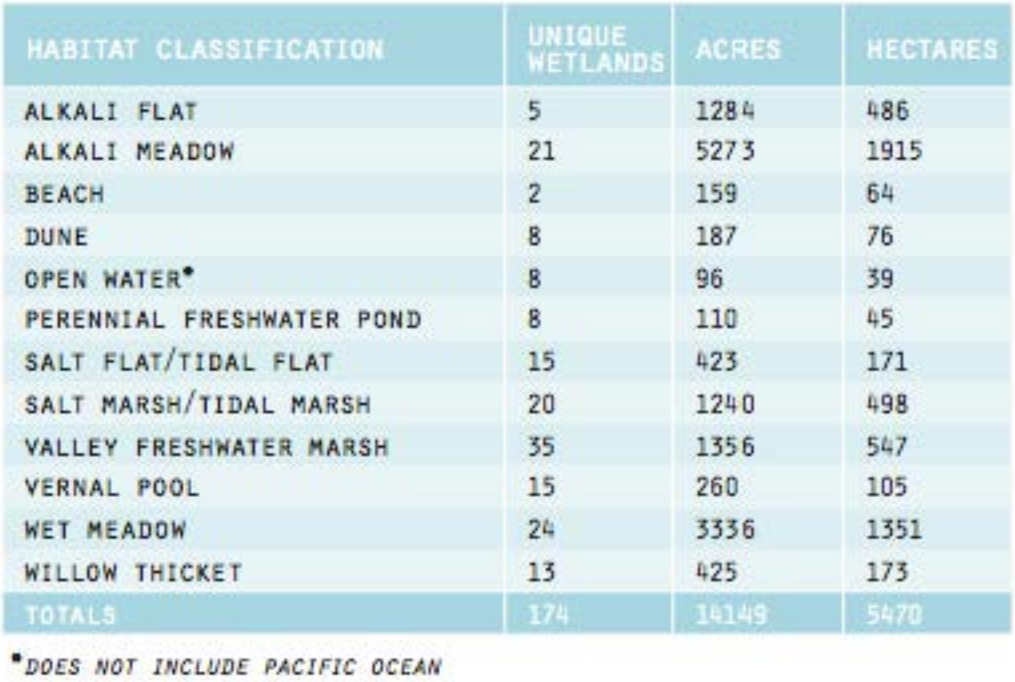
The California Department of Fish and Wildlife (DFW) manages the remnants of the Ballona lagoon and watershed (Figure 5). Known as the Ballona Wetlands Ecological Reserve, it started down the path to becoming state property on August 8, 2001, when Playa Capital Company (PCC) granted Trust for Public Lands (TPL) an option to purchase the 600 acres of Ballona Wetlands. On August 22, 2003, the State, PCC and TPL came to terms to transfer ownership of the Ballona Wetlands to the State of California.

Although the Ballona Creek watershed is now only a fraction of its historical size, there is still tremendous value in restoring the ecosystem's functions, especially the coastal wetlands and natural springs. Converting heterogeneous historical resources into modern datasets provides an opportunity to understand the historical functions of the wetlands. Human activities have greatly altered Ballona and similar wetlands around the world, making understanding and envisioning their natural processes extremely processes (Stein et al. 2010.)

Through the comparison of historical and contemporary resources, Ballona Wetlands provides a unique opportunity for insight on the effects of highly urbanized areas on ecosystems as well as the potential for restoring degraded ecosystems. This study builds on previous work to depict the historical habitats in the Ballona Creek watershed in two dimensions (Dark et al.

2011), portraying them in 3D with a historically accurate topographic layer. This study provides a tool for visualizing the dramatic changes in the Ballona watershed's landscape to encourage a deeper understanding of the effects of urban development, to challenge the status quo of the wetlands, and most importantly to show the value of 3D models in restoration and conservation of ecosystems. The wealth of historical resources, such as topographic maps, historical photographs, and written accounts, and previous studies (Dark et al. 2011), enabled synthesizing heterogeneous data sources to produce a glimpse of the past and motivation for the future.

Table 1: Historical habitat types (Dark et al. 2011). Open water does not include the Pacific Ocean.



HABITAT CLASSIFICATION	UNIQUE WETLANDS	ACRES	HECTARES
ALKALI FLAT	5	1284	486
ALKALI MEADOW	21	5273	1915
BEACH	2	159	64
DUNE	8	187	76
OPEN WATER*	8	96	39
PERENNIAL FRESHWATER POND	8	110	45
SALT FLAT/TIDAL FLAT	15	423	171
SALT MARSH/TIDAL MARSH	20	1240	498
VALLEY FRESHWATER MARSH	35	1356	547
VERNAL POOL	15	260	105
WET MEADOW	24	3336	1351
WILLOW THICKET	13	425	173
TOTALS	174	14149	5470

*DOES NOT INCLUDE PACIFIC OCEAN

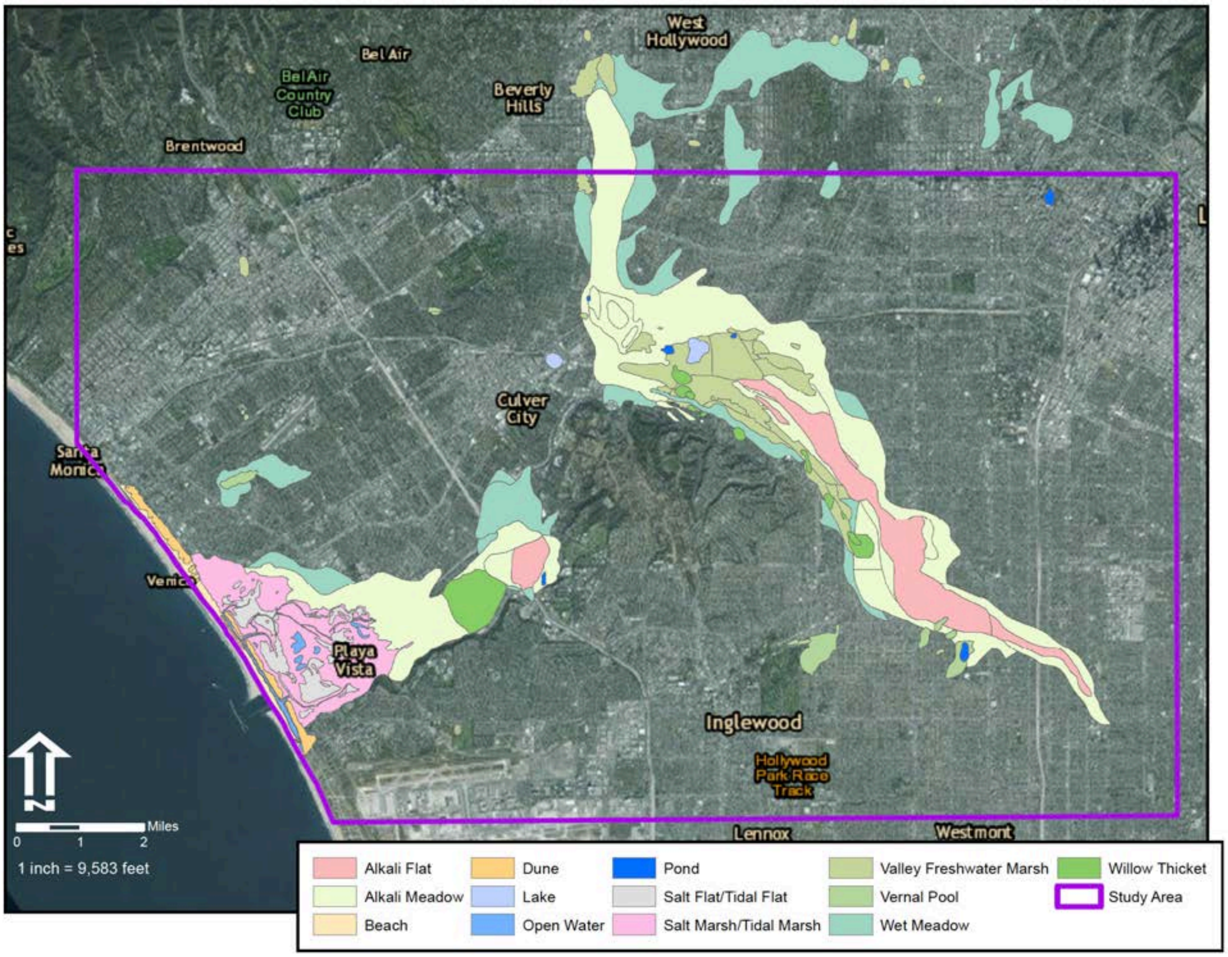


Figure 4. Historical wetland habitat types of the Ballona Creek watershed from Dark et al. (2011) and the study area extent.

Figure 5. The current extent of the Ballona Wetlands Ecological Reserve managed by the California Department of Fish and Wildlife.

3.2 Conversion of Historical Maps to Digital and Raster Data

The methodology workflow (Figure 6), was converting heterogeneous historical resources, such as maps, images, and written accounts, into vector and raster digital data (Table 2) that could be transformed into 3D models. The primary elevation resources were two USGS topographic maps, 1894 Redondo (Figure 7**)** and 1902 Santa Monica (Figure 8). High-resolution versions of the topographic maps were downloaded from the USGS National Map website. Georeferenced versions of the Redondo and Santa Monica maps were borrowed from the California State University Northridge (CSUN) archives to spatially adjust the contour lines to their correct location. Additionally, CSUN provided US Coast Survey topographic sheets known as “T-sheets” and historical photographs used in the production of Dark et al. (2011). Two maps were needed to cover the historical extent of the Ballona Wetlands. The Redondo topographic map contained the southwest portion of Ballona while the Santa Monica map provided the northwest portion.

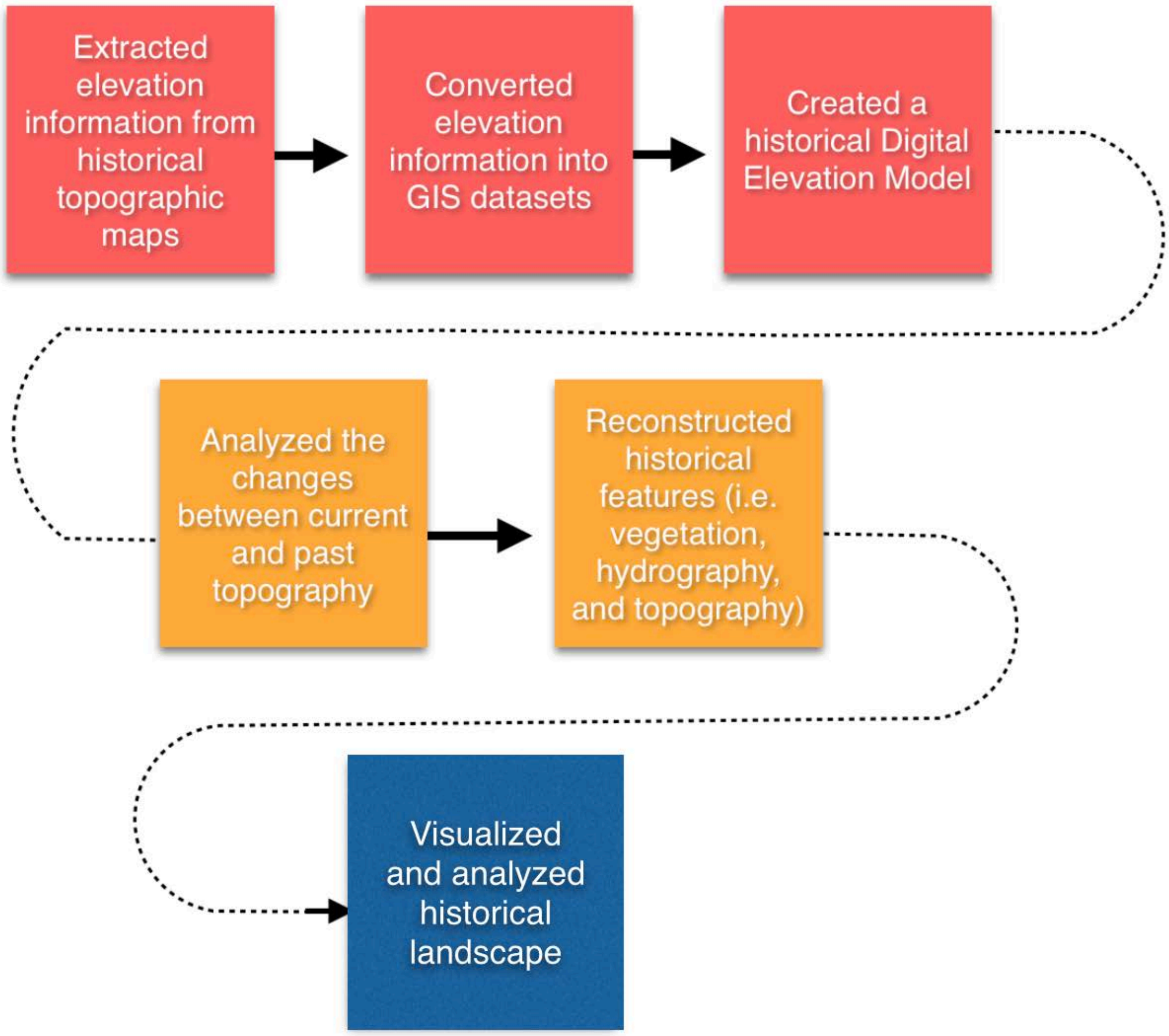
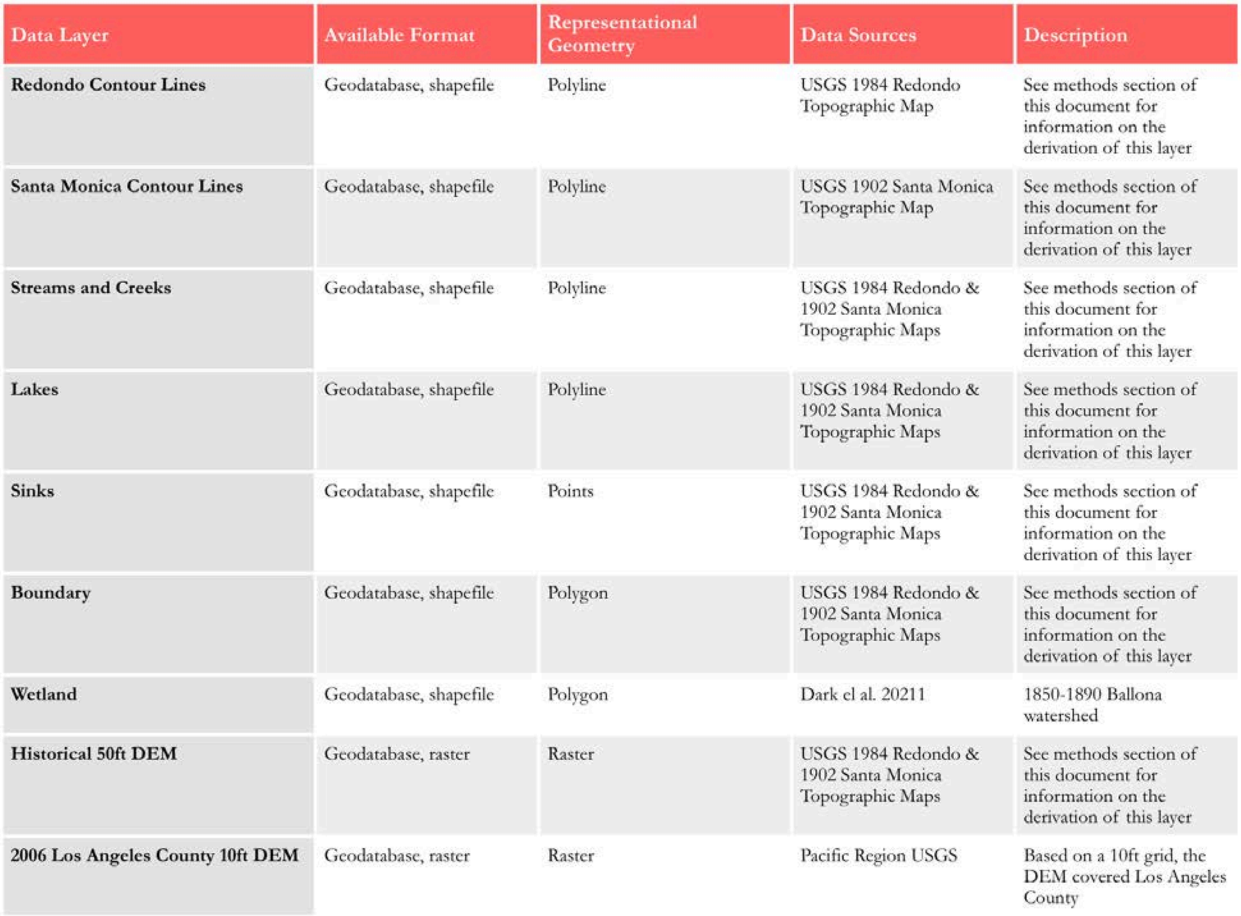


Figure 6. A flowchart documenting the workflow of the methodology.

Table 2. Data products created and used in reconstructing the historical landscape of the Ballona watershed.



Data Layer	Available Format	Representational Geometry	Data Sources	Description
Redondo Contour Lines	Geodatabase, shapefile	Polyline	USGS 1984 Redondo Topographic Map	See methods section of this document for information on the derivation of this layer
Santa Monica Contour Lines	Geodatabase, shapefile	Polyline	USGS 1902 Santa Monica Topographic Map	See methods section of this document for information on the derivation of this layer
Streams and Creeks	Geodatabase, shapefile	Polyline	USGS 1984 Redondo & 1902 Santa Monica Topographic Maps	See methods section of this document for information on the derivation of this layer
Lakes	Geodatabase, shapefile	Polyline	USGS 1984 Redondo & 1902 Santa Monica Topographic Maps	See methods section of this document for information on the derivation of this layer
Sinks	Geodatabase, shapefile	Points	USGS 1984 Redondo & 1902 Santa Monica Topographic Maps	See methods section of this document for information on the derivation of this layer
Boundary	Geodatabase, shapefile	Polygon	USGS 1984 Redondo & 1902 Santa Monica Topographic Maps	See methods section of this document for information on the derivation of this layer
Wetland	Geodatabase, shapefile	Polygon	Dark el al. 20211	1850-1890 Ballona watershed
Historical 50ft DEM	Geodatabase, raster	Raster	USGS 1984 Redondo & 1902 Santa Monica Topographic Maps	See methods section of this document for information on the derivation of this layer
2006 Los Angeles County 10ft DEM	Geodatabase, raster	Raster	Pacific Region USGS	Based on a 10ft grid, the DEM covered Los Angeles County

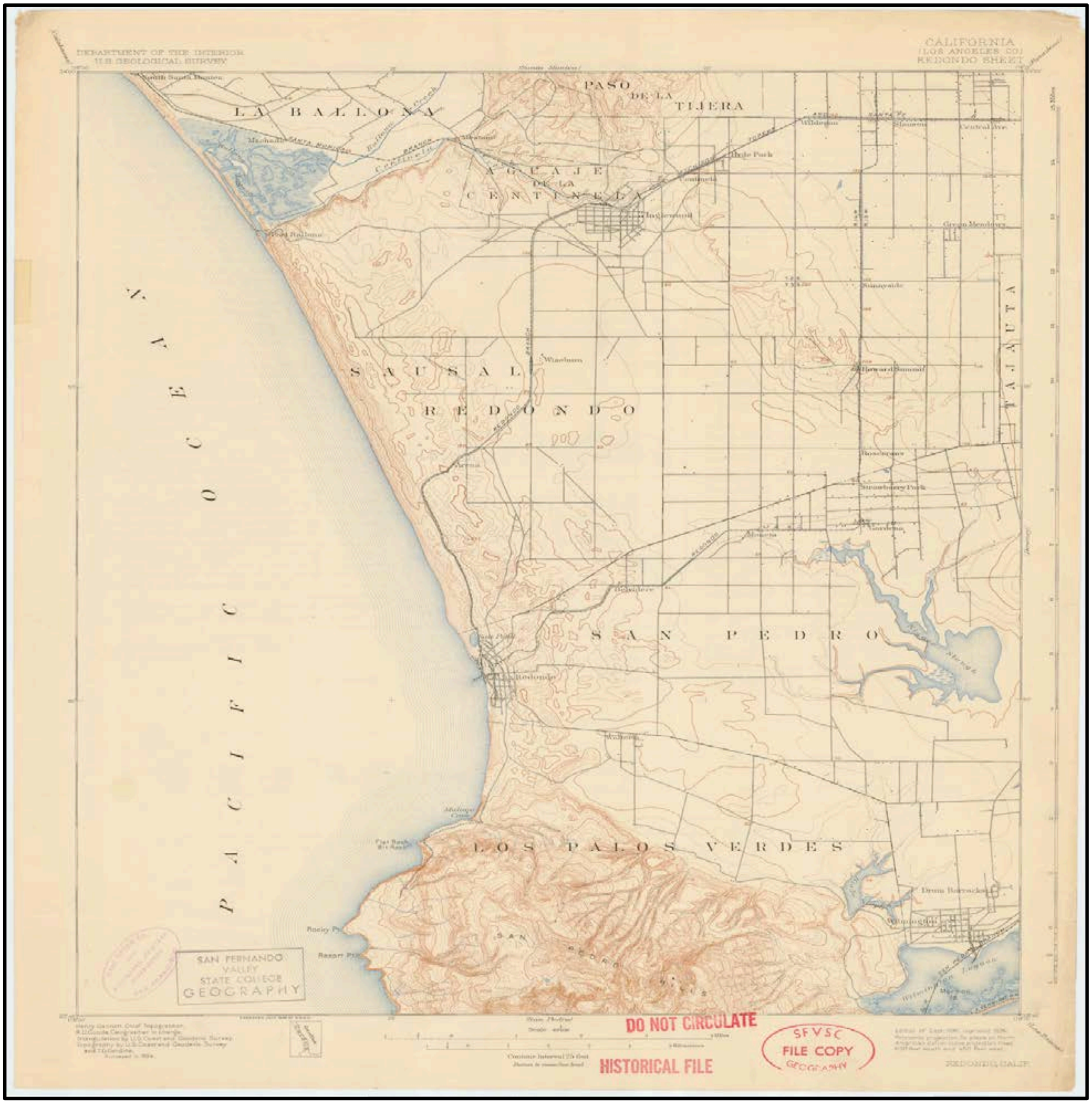


Figure 7. USGS Redondo 1894 topographic map georeferenced by CSUN (Dark et al. 2011).

Figure 8. USGS Santa Monica 1902 topographic map (prepared by Dark et al. 2011).

3.2.1. Topographic Maps

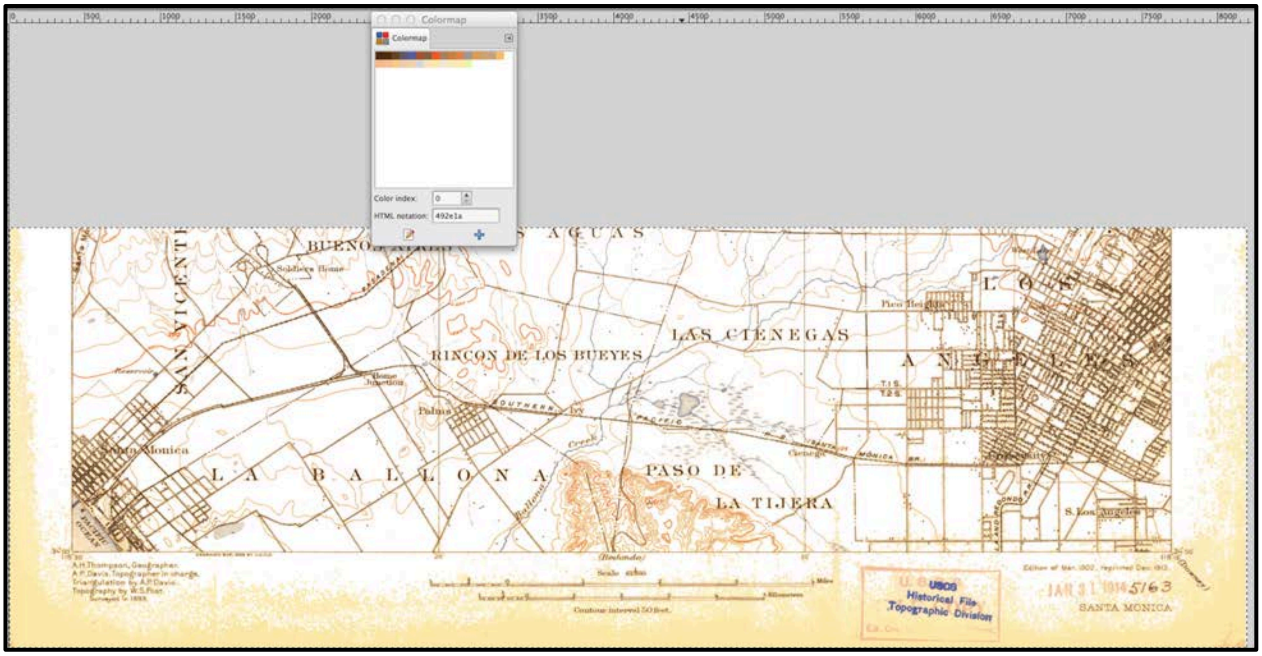
John Wesley Powell urged Congress to systematically map the United States on December 4th-5th of 1884. Shortly after, the Unites States Geological Survey began making topographic maps. Initially maps were at a scale of 1:250,000 for 1-degree areas and 1:125,000 for 30-minute areas, but shifted to 1:62,500 for 15-minute areas in 1894, which was when the this study's first map, Redondo 1894, portray the shape and elevation of an area

was created (Usery et al. 2009). The majority of the USGS mapping occurred in the Western United States and required grueling and costly traveling for the first mappers. Topographic maps were made from crude surveying and mapping instruments, and used the planetable surveying techniques. Climbing to an area's best vantage point, a topographer relied on a planetable, a portable drawing board and a sighting device set on a tripod, to map seen and measured features from the field (Usery et al. 2009). Geographic features included natural and manmade works, ranging from lakes and mountains to boundaries and railroads. Contour lines, the distinguishing feature of topographic maps, portrayed the 3D shape and elevation of an area on a 2D surface.

Geographic features were represented by foreground and background colors that made extracting individual features from the topographic map difficult (Chiang 2013). Because this study only needed contour lines to extract the elevation data, all additional information was removed to make it easier to identify the contour lines. Before extracting topographic lines from USGS topographic maps, the files were converted from Portable Document Format (PDF) to Tagged Image File (.tif).

3.2.2 Editing Topographic Maps in a Graphics Editor

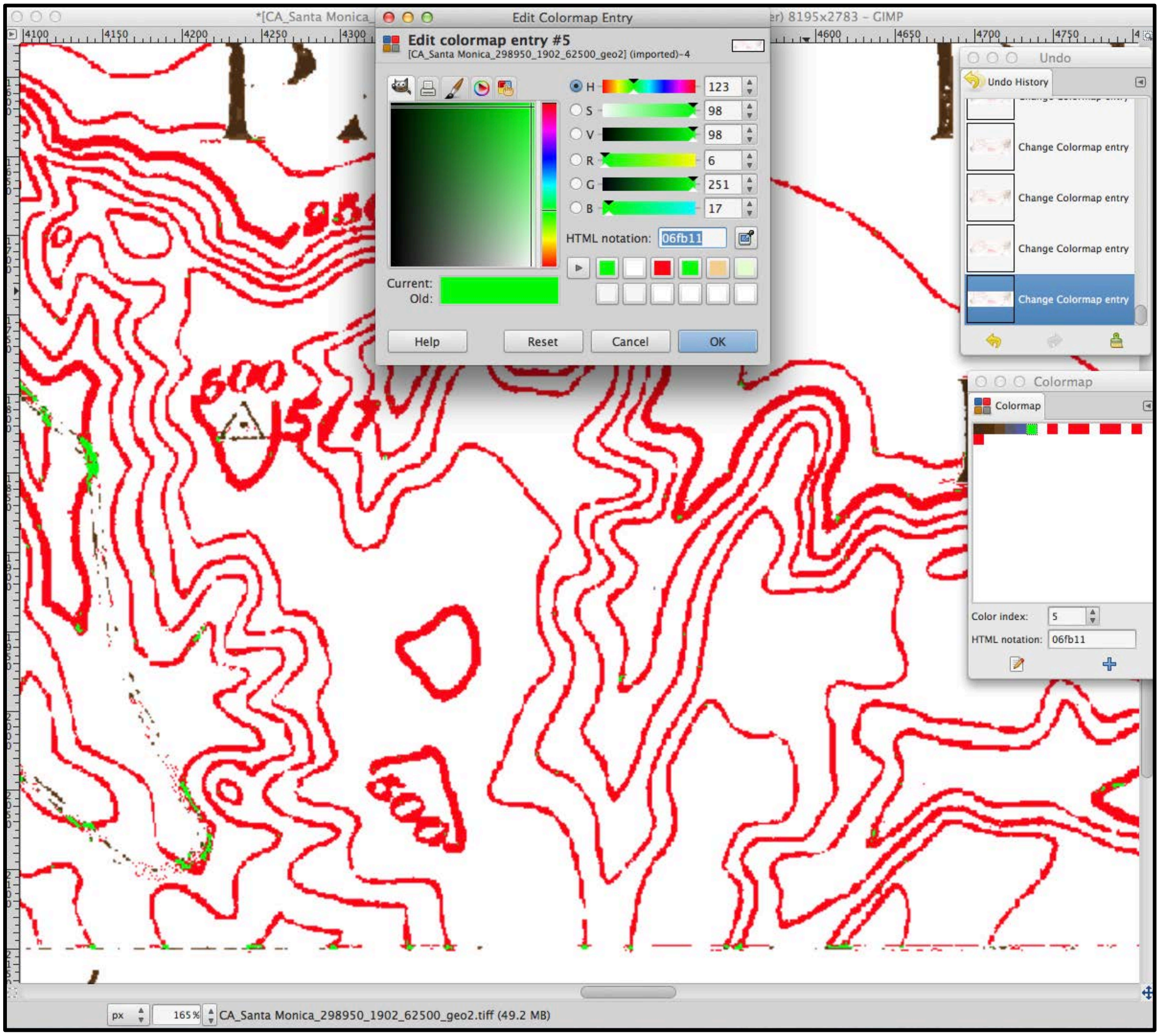
Maps were then uploaded individually into the graphics editor GNU Graphics Manipulation Program (GIMP). Once in GIMP, each map was cropped to their respective extent and converted from the Red Green Blue color model (RGB) to a 256-color size indexed image. By indexing the raster image, GIMP generated a color palette, an array of colors. Each pixel in the topographic map was represented by a number and unique color, which corresponded to the color palette. Using the topographic indexed image's color palette all unnecessary map information (background) was replaced with a “white” color” (see Figure 10). Each map’s color palette was reduced to two colors: white (background) and red (contour lines). Every color in the color palette was tested with a green color to determine if the feature color should be replaced with white (not needed) or red (contour lines) (Figure 11). This process was repeated until both maps, Redondo and Santa Monica, only had contour lines and background visible. Upon completion of eliminating all unnecessary features, large portions of the maps’ contour lines were blurred together and were indistinguishable as individual lines (Figure 12). The contour lines were cleaned up in GIMP by manually connecting gaps or holes (Figure 13), and the two maps were separately exported as .tif files.



Color index: 0

HTML notation: 492e1a

Figure 9. Each pixel in the color palette, shown at the top of the image, was replaced with a white value to remove all non-elevation information from both maps. This example used the cropped version of the Santa Monica topographic map.



H 123

S 98

V 98

R 6

G 251

B 17

HTML notation: 06fb11

Color index: 5

HTML notation: 06fb11

165 %

CA_Santa Monica_298950_1902_62500_geo2.tiff (49.2 MB)

Figure 10. An example of how pixels were tested to determine if they were contour lines or another feature. The pixel value in question was replaced with a bright green color to compare it with the contour lines.

Figure 11. An example of contour lines too close to distinguish as individual lines.

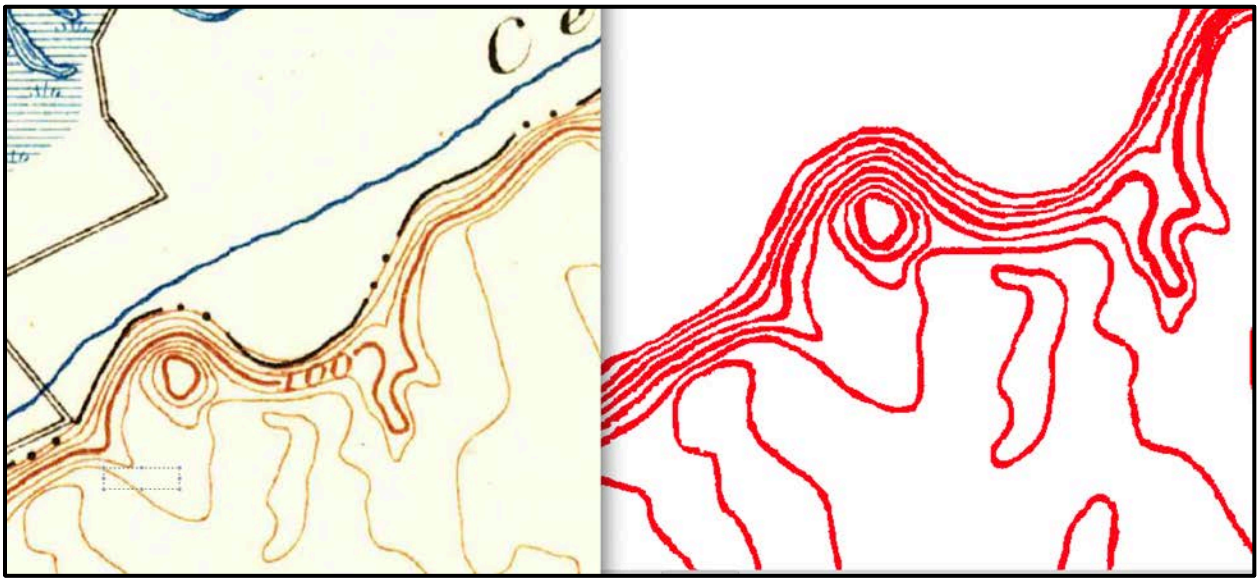


Figure 12. An example of manually cleaning contour lines in GIMP.

3.2.3 Extracting Contour Lines from Topographic Maps

The Tiff images were uploaded into Adobe Illustrator, a vector graphic editor, which provided a “Live Trace” tool that traced the raster images. The “Live Trace” prepared rasters

(TIF images) to be converted into vectors by adjusting a raster image's contrast, blurring the jagged lines created by pixels, and drawing vector paths. Using the "Live Trace" tool, the contour lines in each topographic map were traced and selected (Figure 14). Illustrator's "Live Paint" tool converted the traced objects into vector lines. The vector contour lines were exported from Illustrator as .dwg, a vector file, used in Computer-aided design (CAD) software, as shown in Figure 15.

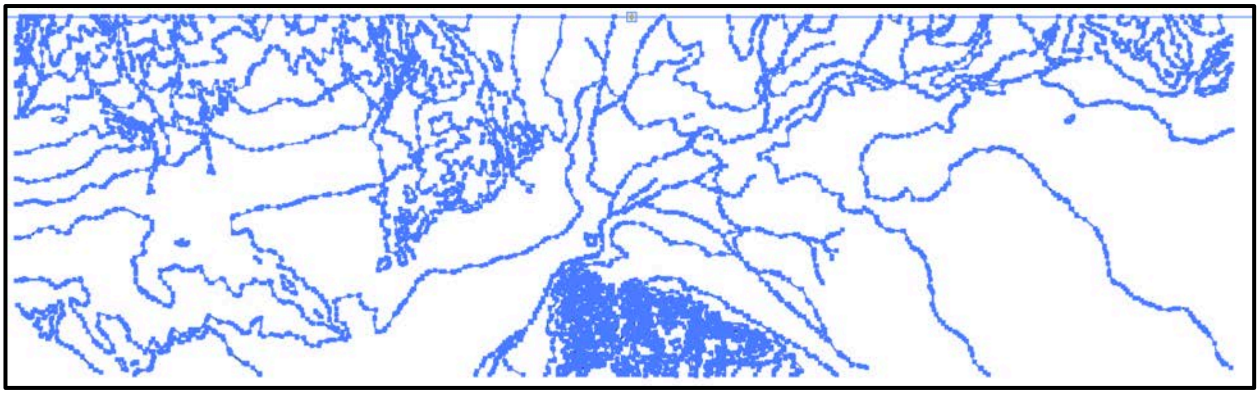


Figure 13. The "Live Trace" Adobe Illustrator tool selected the contour lines from the raster image.

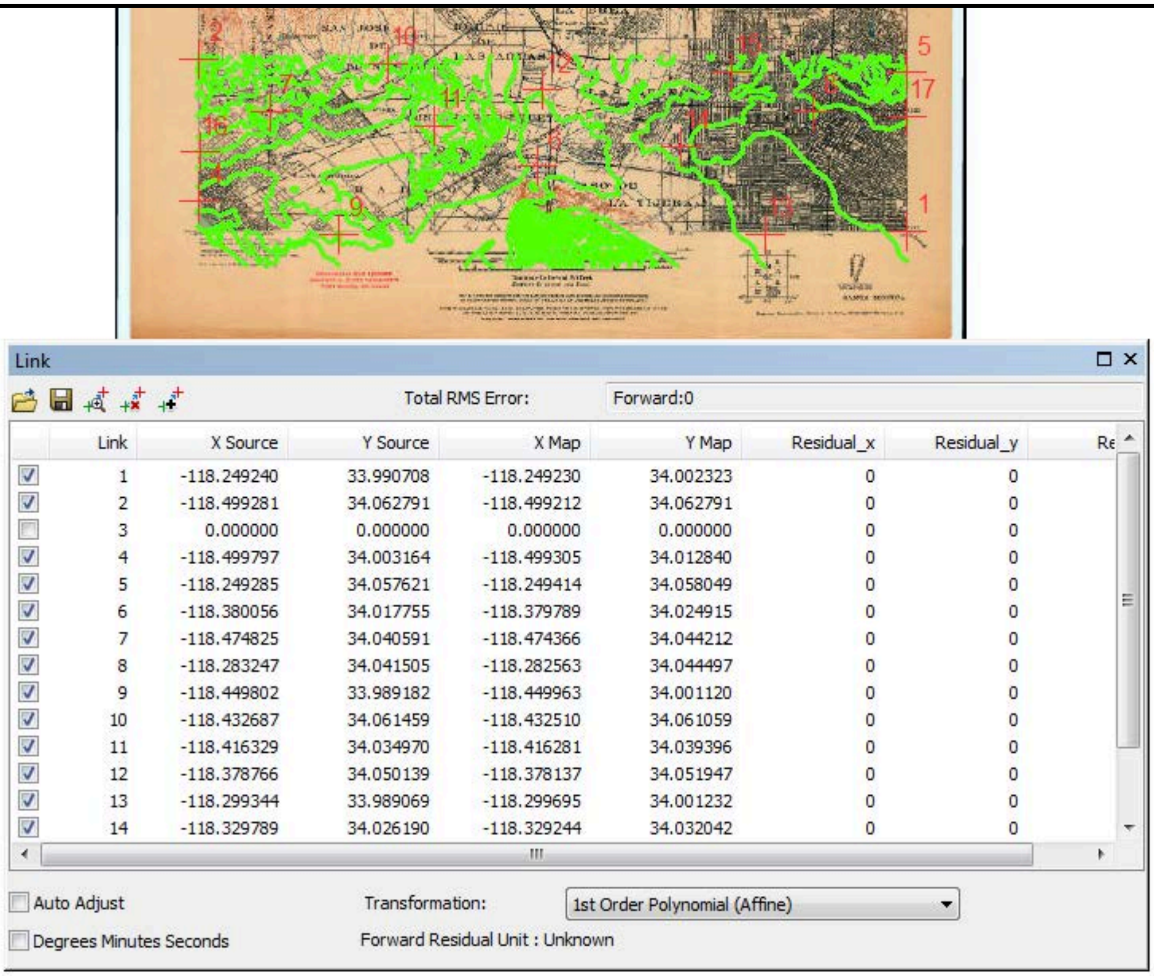
Figure 14. Vector contour lines, as a .dwg file, derived from the Santa Monica topographic map.

3.2.4 Contour Lines

3.2.4.1 Editing Contour Lines

Esri’s ArcMap, a product from the ArcGIS suite, was capable of importing the CAD file .dwg. The .dwg files were uploaded into ArcMap and converted to an Esri feature class, polylines, using the “CAD to Geodatabase” tool. Additionally, an elevation field was created for the feature class to store the elevation information as an attribute. All of the contour lines, however, were connected as a polyline rather than individual contour lines. Using the ArcMap “Multipart to Singlepart” tool, the contour lines were separated into singlepart polylines.

The contour lines contained multiple errors, such as individual lines merging together or having gaps between continuous lines. Using the ArcMap “Spatial Adjustment” tool, a tool for aligning geodatabase data to real-world GIS coordinates, the contour lines were georeferenced to the topographic maps (see Figure 16). Once correctly georeferenced, the contour lines were edited with ArcMap’s “Editor” to remove two types of errors: gaps and incorrect locations of vertices. First, polylines were digitized to bridge the “holes” or “gaps” found between continuous contour lines (Figure 17). Second, the vertex points in the contour lines were moved to correctly represent the contour lines found on the topographic map (Figure 18).



Total RMS Error: Forward:0

	Link	X Source	Y Source	X Map	Y Map	Residual_x	Residual_y
☑	1	-118.249240	33.990708	-118.249230	34.002323	0	0
☑	2	-118.499281	34.062791	-118.499212	34.062791	0	0
☐	3	0.000000	0.000000	0.000000	0.000000	0	0
☑	4	-118.499797	34.003164	-118.499305	34.012840	0	0
☑	5	-118.249285	34.057621	-118.249414	34.058049	0	0
☑	6	-118.380056	34.017755	-118.379789	34.024915	0	0
☑	7	-118.474825	34.040591	-118.474366	34.044212	0	0
☑	8	-118.283247	34.041505	-118.282563	34.044497	0	0
☑	9	-118.449802	33.989182	-118.449963	34.001120	0	0
☑	10	-118.432687	34.061459	-118.432510	34.061059	0	0
☑	11	-118.416329	34.034970	-118.416281	34.039396	0	0
☑	12	-118.378766	34.050139	-118.378137	34.051947	0	0
☑	13	-118.299344	33.989069	-118.299695	34.001232	0	0
☑	14	-118.329789	34.026190	-118.329244	34.032042	0	0

☐ Auto Adjust

Transformation: 1st Order Polynomial (Affine)

☐ Degrees Minutes Seconds

Forward Residual Unit : Unknown

Figure 15. The "Spatial Adjustment" links between the Santa Monica contour lines and the georeferenced topographic map. The source point from the contour lines was selected first then the destination point from the topographic map.

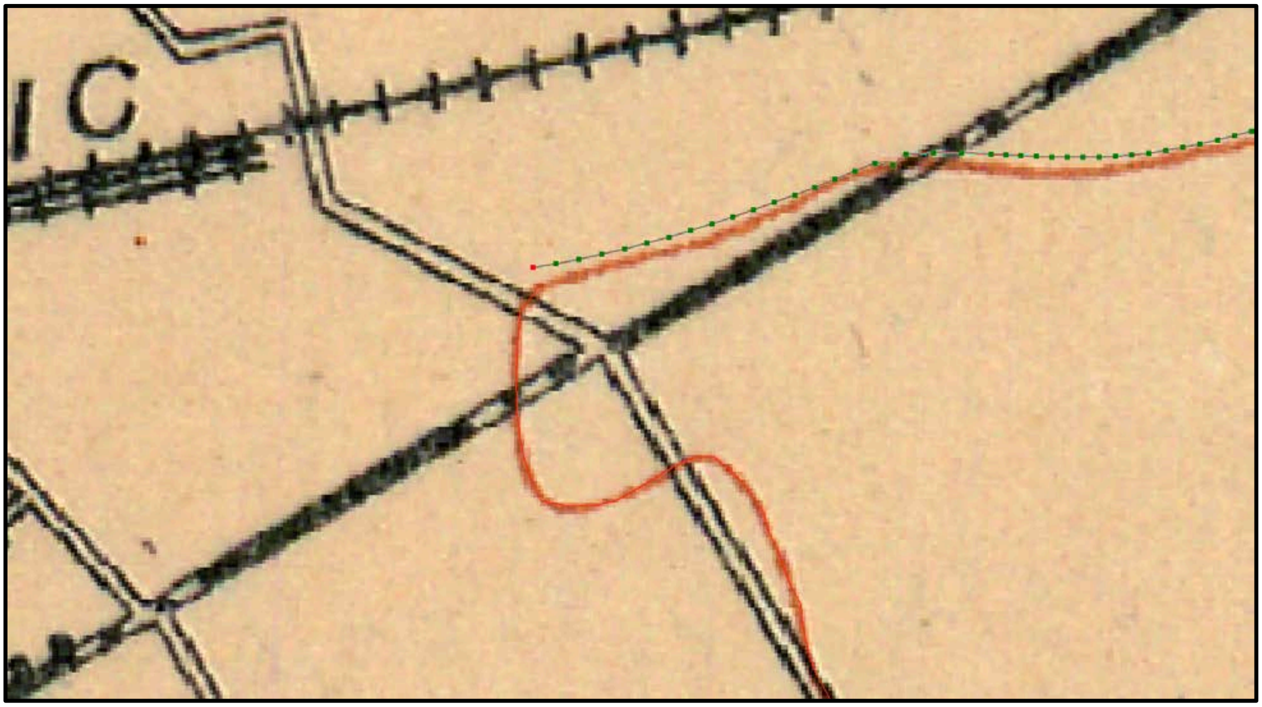


Figure 16. An example using the ArcMap tool “Editor” to bridge a gap in a continuous line.

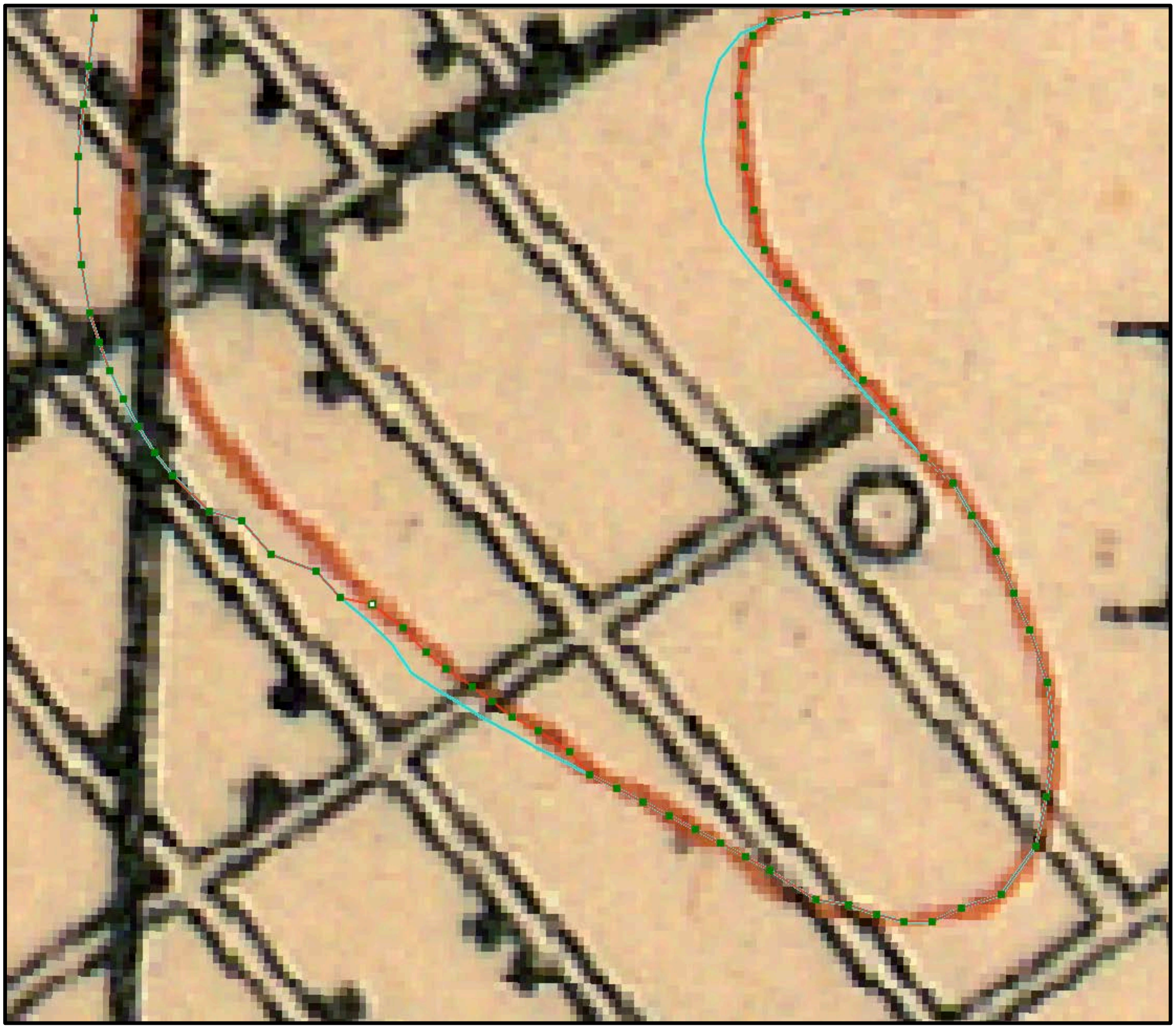
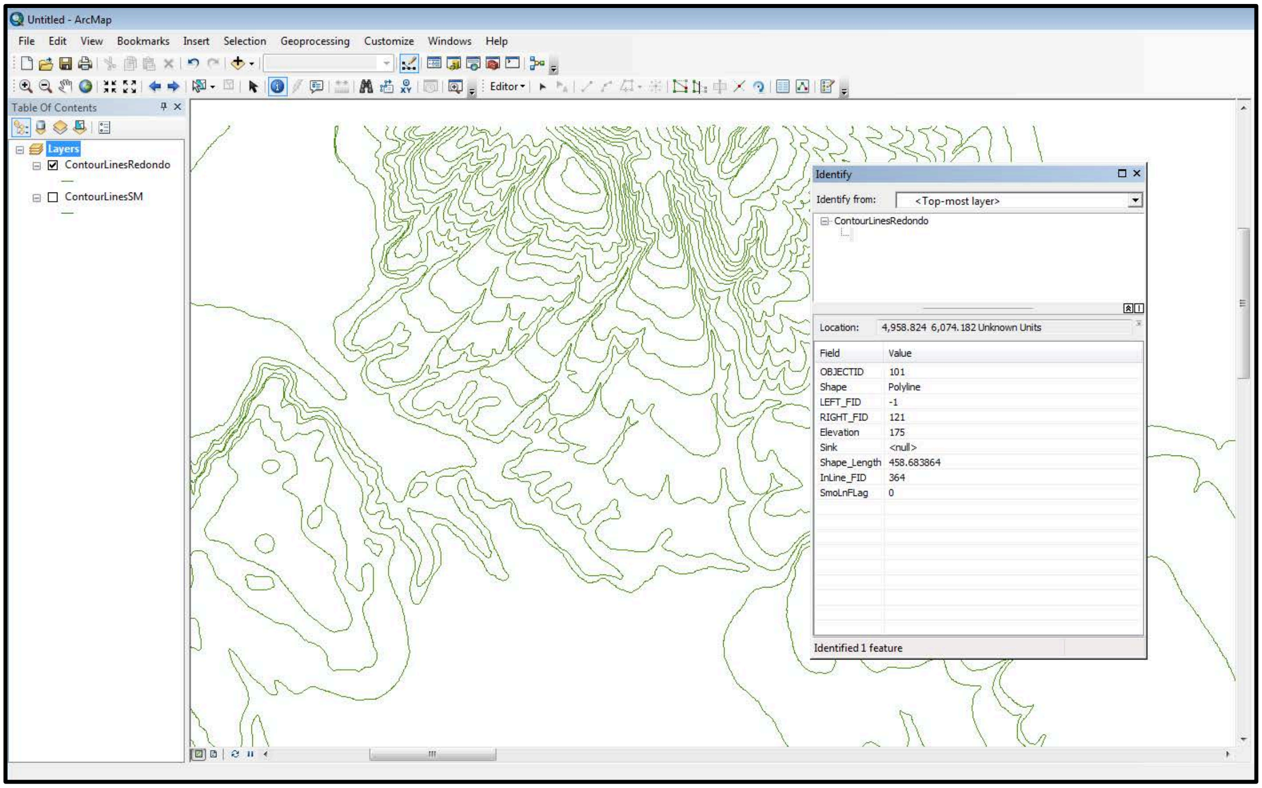


Figure 17. An example of moving the contour lines vertices to match the georeferenced topographic map.

After all errors were corrected, each contour line was assigned an elevation value using the ArcMap “Editor” (Figure 19). Elevation information was derived from the marked contour lines on the topographic maps and their contour intervals.



Identify from: <Top-most layer>

ContourLinesRedondo

Location: 4,958.824 6,074.182 Unknown Units

Field	Value
OBJECTID	101
Shape	Polyline
LEFT_FID	-1
RIGHT_FID	121
Elevation	175
Sink	<null>
Shape_Length	458.683864
InLine_FID	364
SmoLnFLag	0

Identified 1 feature

Figure 18. An example of a contour line that has been assigned elevation information.

3.2.4.2 Contour Lines Topology Rules

Geodatabases enforce topology rules on feature classes saved with the geodatabase. Two topology rules were created to check for errors for the contour lines: 1) Must not intersect (with other contour lines), 2) Must not self-intersect. The topology was validated in ArcMap and all identified errors were corrected.

3.2.5 Generation of DEM

ArcMap Spatial Analyst includes a tool called “Topo to Raster.” This tool was ideal tool for this study because the input elevation data can be either contour lines or contour points. According to Esri’s tool description, the “Topo to Raster” tool is based on a program, ANUDEM 5.3, which was developed by Michael Hutchinson (1989) for generating hydrologically-correct DEMs. Esri’s interpolation process generates a DEM raster while enforcing rules that connect the surface’s watershed drainage features (streams). This study, however, is focused on creating a historical DEM for 3D terrain modeling rather than drainage modeling. The “Topo to Raster” tool has multiple options for data inputs for generating the interpolated elevation raster. For this study, the contour lines, streams, lakes, boundary, and sink inputs were used to create the early 1900s historical DEM.

3.2.5.1 Contour Lines

The Redondo and Santa Monica contour lines were combined into one polyline feature class called “Ballona_Contour_Lines” using ArcMap’s “Editor.” This enabled the contour lines to be input into the “Topo to Raster” tool as the primary source for elevation information. Once input, the tool required selection of the name of the attribute field in the feature class that contains the elevation data.

3.2.5.2 Streams

The streams’ input data for the “Topo to Raster” tool were polylines digitized using ArcMap’s “Editor.” A new feature class was created in ArcCatalogue and the stream features were digitized from the CSUN georeferenced topographic maps in ArcMap (Figure 20). No field selection options are available for streams in the “Topo to Raster” tool.

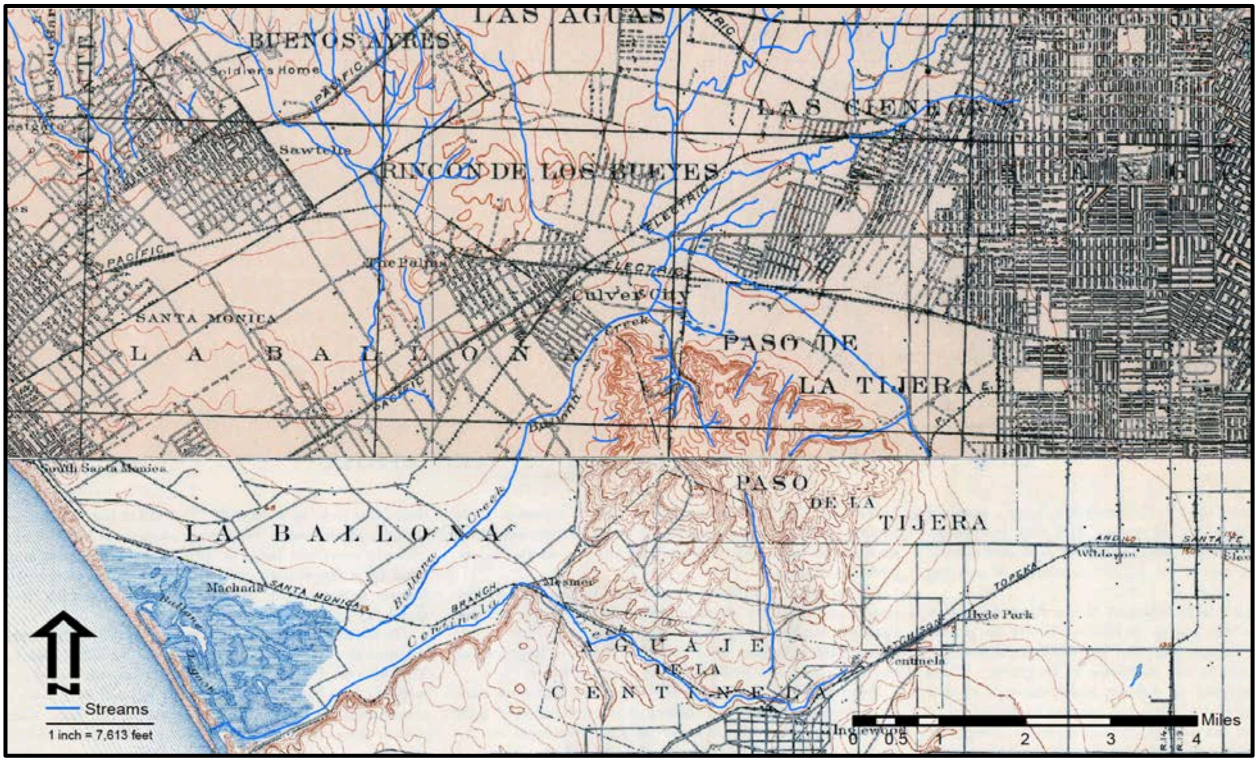


Figure 19. The “streams” feature class inputted into the “Topo to Raster” tool.

3.2.5.3 Lakes

Using the Editor in ArcMap, lakes from the topographic maps were digitized as polygons and saved to the feature class created in ArcCatalog (see Figure 21). The “Topo to Raster” tool ensured that the elevation data for each lake is comparable to its neighboring features (streams). The tool also guaranteed that the lake’s interior elevation remained less than the terrain’s. Similar to the stream input data, there was no need to select an elevation data field.

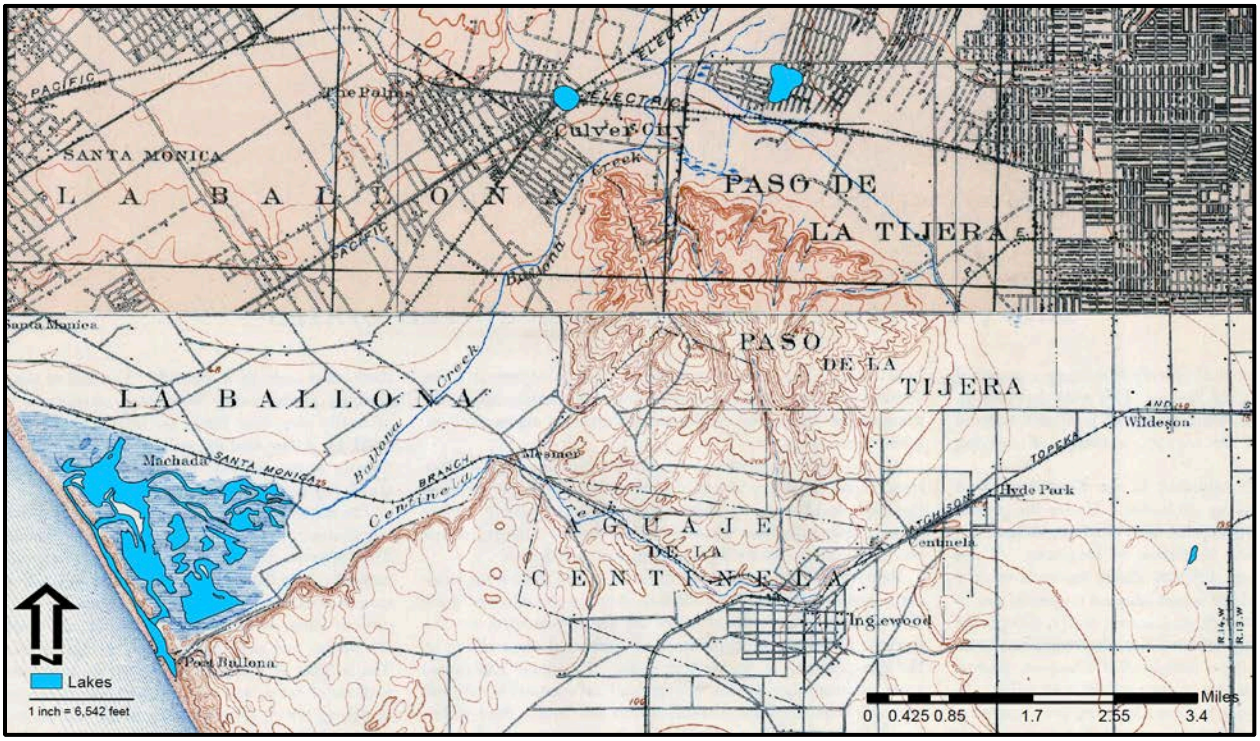


Figure 20. The “lakes” feature class inputted into the “Topo to Raster” tool.

3.2.5.4 Boundary

A new boundary feature class was created in ArcCatalog and the extent of the historical DEM was digitized using ArcMap’s “Editor.” This process eliminated the ocean areas in both topographic maps. The boundary input defined the extent of the output DEM.

3.2.5.5 Sinks

After a sinks point feature class was created in ArcCatalogue, the sinks, or topographic depressions, were digitized in ArcMap using the “Editor” tool as shown in Figure 22. The point feature class contained an elevation attribute field that store the elevation of the sinks. This field was selected in the “Topo to Raster” tool to correctly align the elevation of the known sinks to the cells in the DEM. It was important to manually identify the sinks because the “Topo to Raster” tool removed unidentified sinks to preserve the drainage flow of the DEM. According to

Goodchild and Mark (1987), sinks are generally rare to find in the topography so it is best to remove them from a DEM to maintain proper drainage.

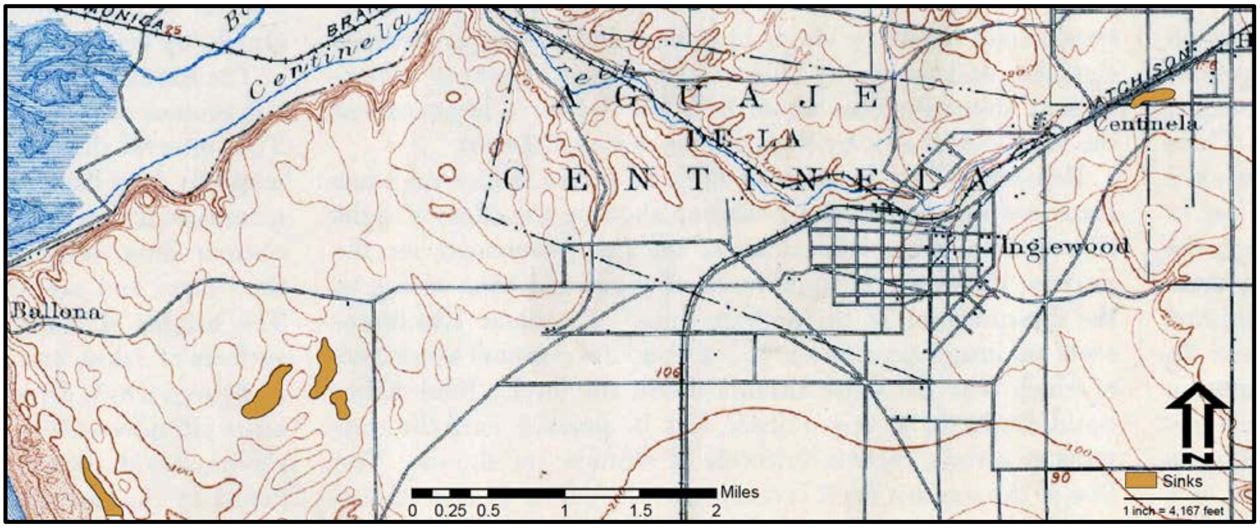


Figure 21. The “sinks” feature class input into the “Topo to Raster” tool. The furthest left, bottom sink was cut in half because a portion of it was outside the DEM’s extent.

3.3 3D Visualization Models

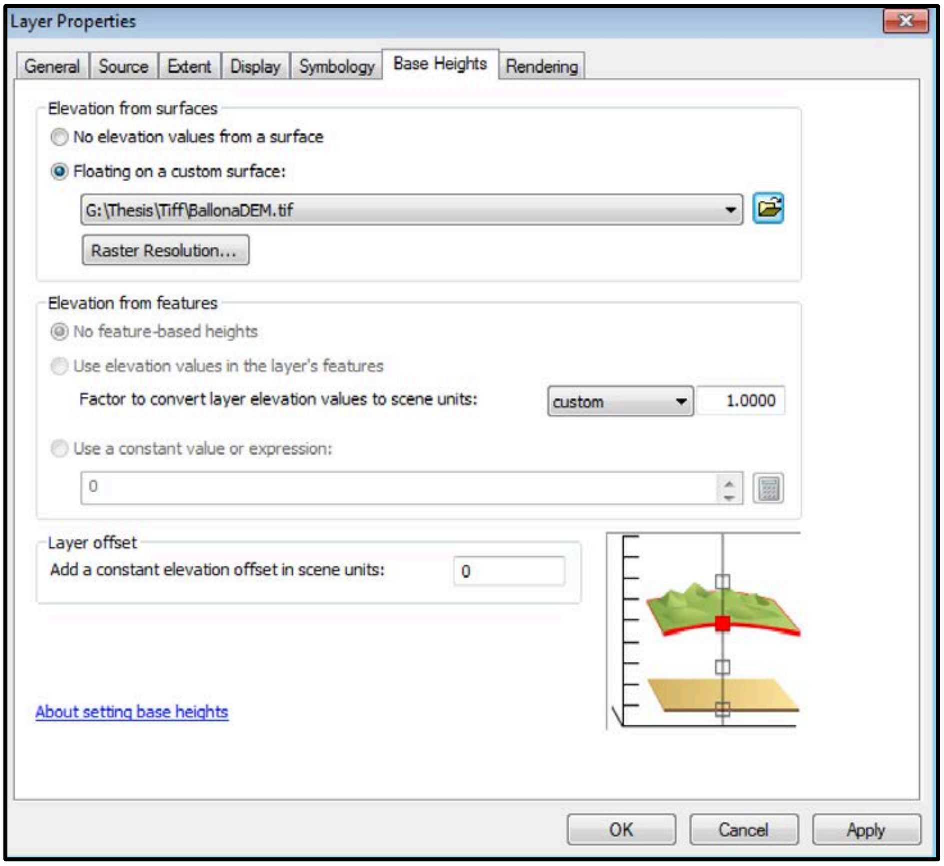
Two case studies were designed to explore the transformation of 2D GIS into 3D models using Esri’s ArcScene and CityEngine. The first case study used ArcScene to explore the topographic maps in 3D and compare the topography changes over the last century. The second case study reconstructed the historical terrain and vegetation by visualizing the features with CityEngine.

3.3.1 Case Study One: ArcScene

Esri’s ArcScene was used to create four models of the study area that analyzed the changes in topography of Ballona Wetlands. First, the USGS topographic maps, Redondo 1894 and Santa Monica 1902, were draped over the historical 3D terrain. Second, a change in elevation raster was draped over the historical 3D terrain. Comparing the historical DEM to the 2006 Los Angeles County DEM created the change in elevation raster (in feet). Third, the change in elevation raster was converted into a 3D model and overlaid onto the 3D historical terrain. Fourth, the change in elevation 3D model was overlaid with the location of historical habitat features.

3.3.1.1 Topographic Maps

The first model visualized the topographic maps in 3D terrain by draping the maps over the DEM’s 3D terrain. The historical DEM was uploaded into ArcScene and assigned a base height to transform the 2D DEM into 3D terrain. Within the layer’s properties there was a Base Height tab that was used to apply the elevation information of the DEM to a 3D terrain model. By enabling the “Floating on a custom surface” button it enabled the DEM to represent its elevation data in a 3D form (see Figure 23). To “drape” the two topographic maps over the 3D terrain, the topographic maps had to be clipped to the extent of the historical DEM. Working in ArcMap, two separate boundaries polygons, one for each map, Redondo and Santa Monica, were used to crop each map. ArcMap’s “Clip” tool cropped the two georeferenced maps to their respective extents. Using the “Merge Rasters” tool in ArcMap, the two georeferenced raster clips were merged together to form the extent of the DEM. The clipped topographic map was added to the scene that contained the historical 3D terrain. Similar to the DEM, the base height information was accessed from the layer’s properties. Selecting “Floating on a custom surface,” the DEM was used as the base height for the topographic maps.



Elevation from surfaces

○ No elevation values from a surface

● Floating on a custom surface:

G:\Thesis\Tiff\BallonaDEM.tif

Elevation from features

● No feature-based heights

○ Use elevation values in the layer's features

Factor to convert layer elevation values to scene units: custom 1.0000

○ Use a constant value or expression:

0

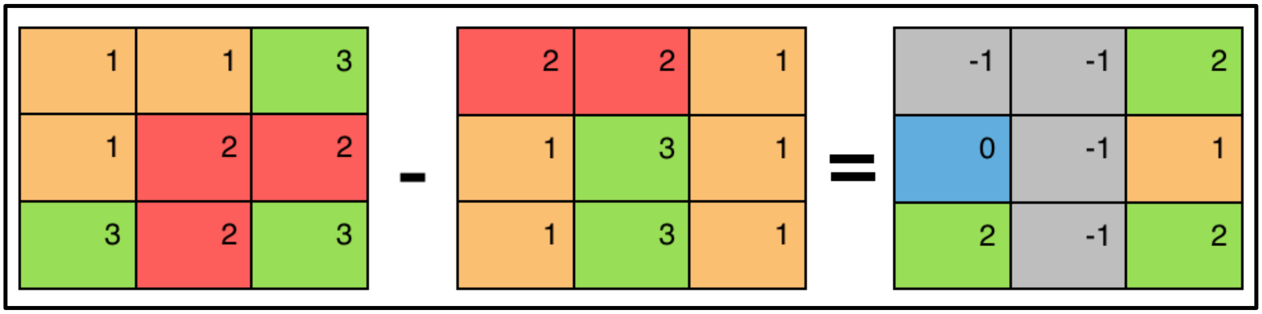
Layer offset

Add a constant elevation offset in scene units: 0

Figure 22. The Layer Properties' Base Height tab for assigning an elevation from a surface. This is an example of assigning the historical DEM to the topographic map.

3.3.1.2 Topography Changes Rasters

The 2006 Los Angeles County DEM was downloaded from the Los Angeles County's GIS FTP server. Using the "Clipped" ArcMap tool, the Los Angeles County DEM was reduced to the extent of the historical extent. Two different elevation ArcMap tools were used to assess the topography changes between the two DEMs. First, the "Cut Fill" tool calculated if groups of pixels' net elevation volume was increased, decreased, or unchanged. Second, the "Minus" tool subtracted the historical DEM's elevation from the Los Angeles County DEM to calculate the change in elevation, in feet, between the two DEMs (see Figure 24).



1	1	3
1	2	2
3	2	3

-

2	2	1
1	3	1
1	3	1

=

-1	-1	2
0	-1	1
2	-1	2

Figure 23. An example of how the elevation pixels are subtracted to calculate the change in elevation for feet.

3.3.1.3 Elevation Change Raster Draped over the 3D Historical Terrain

In ArcScene, the base height for the elevation change raster was set to the historical DEM. The 3D terrain was the historical DEM, but the surface was the symbology from the elevation change raster.

3.3.1.4 3D Elevation Change Raster Overlaid onto the 3D Historical Terrain

The base height for each raster, the elevation change and historical DEM, were set to their respective base heights in ArcScene. The 3D elevation increases appeared above the 3D terrain of the historical DEM while the decreases appeared below the surface of the terrain.

3.3.1.5 3D Elevation Change Raster Model

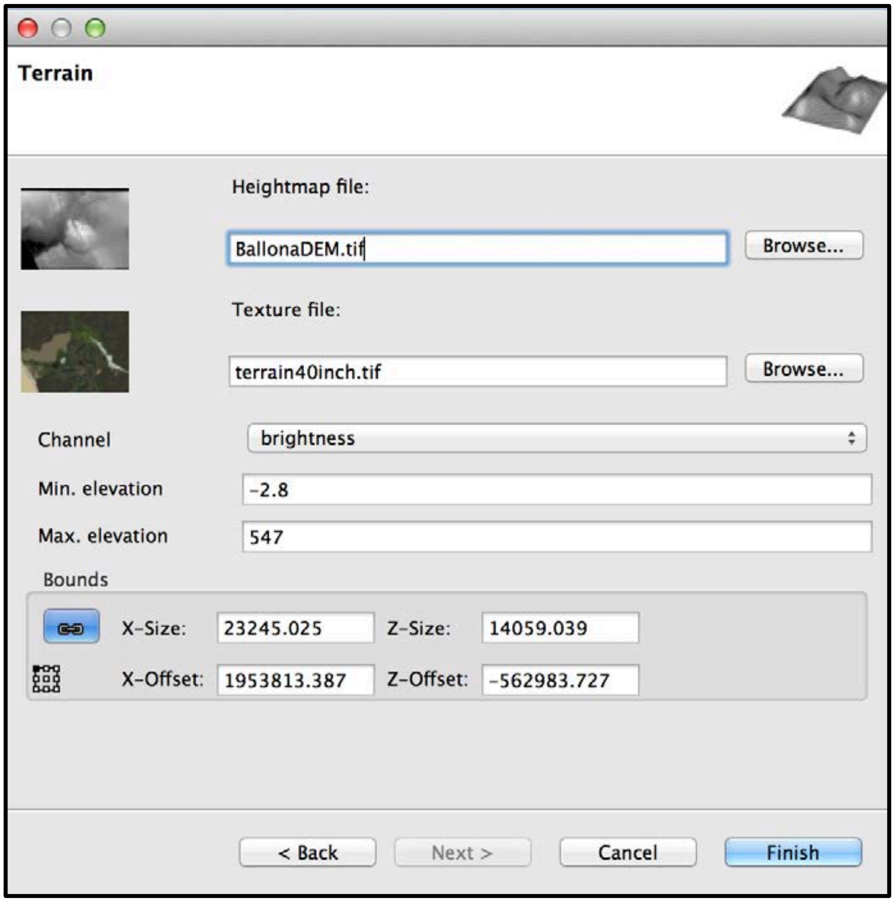
In ArcScene, the base height for the elevation change raster was set to itself, creating the elevation changes in 3D. The 3D terrain and symbology were represented by the elevation change raster.

3.3.2 Case Study Two: CityEngine

Using a combination of graphics-editing software and Esri’s CityEngine, the historical topography and vegetation of Ballona Wetlands was reconstructed with realistic 3D models. Since there was no imagery available to drape over the 3D terrain, a custom image was created to texture the surface. 3D native vegetation models and water features were designed using the Computer Generated Architecture (CGA), the grammar-based modeling language of CityEngine. The entire 3D scene was exported to a CityEngine WebScene that allows users to explore and navigate throughout the historical Ballona Wetlands.

3.3.2.1 Terrain map

CityEngine did not support the usage of DEMs; instead it required a greyscale terrain image or “Heightmap” that used elevation data from the DEM image to create a terrain layer. Therefore, in ArcMap, the DEM was exported to a CityEngine accepted file type, tif. The .tif was converted into a heightmap by using the “New map layer” tool in CityEngine and selecting the “Heightmap” map layer option. This assigned the .tif as the heightmap for the terrain layer (Figure 25). A “texture file” was draped over the heightmap to stylize the 3D terrain’s surface.



Terrain

Heightmap file: BallonaDEM.tif

Texture file: terrain40inch.tif

Channel: brightness

Min. elevation: -2.8

Max. elevation: 547

Bounds

X-Size: 23245.025 Z-Size: 14059.039

X-Offset: 1953813.387 Z-Offset: -562983.727

Figure 24. Adding the historical DEM as a heightmap generated a 3D terrain in CityEngine. A texture was draped over the 3D to terrain make the surface features.

CityEngine allowed a "texture" file, such as a portable network graphic (.png) or TIF image file, to be draped over the heightmap. Since no historical imagery exist to drape over the heightmap, an original texture file was created to suggest how the landscape features might have looked. Creation of the texture file required graphic editing knowledge since CityEngine provided no guidance on producing a texture file. Producing the texture file required creativity, graphic editing "tricks," and an array of software.

ArcMap was used to design the texture file by converting the historical habitat shapefile, created by Dark et al. (2011) and available for download at www.ballonahe.org, into raster images using the "Feature to Raster" geoprocessing tool. Similarly, the boundary polygon of the historical DEM was also converted into a raster image. The resulting image (Figure 26) was exported as TIF image and uploaded in the graphic editing program Adobe Photoshop CS6.

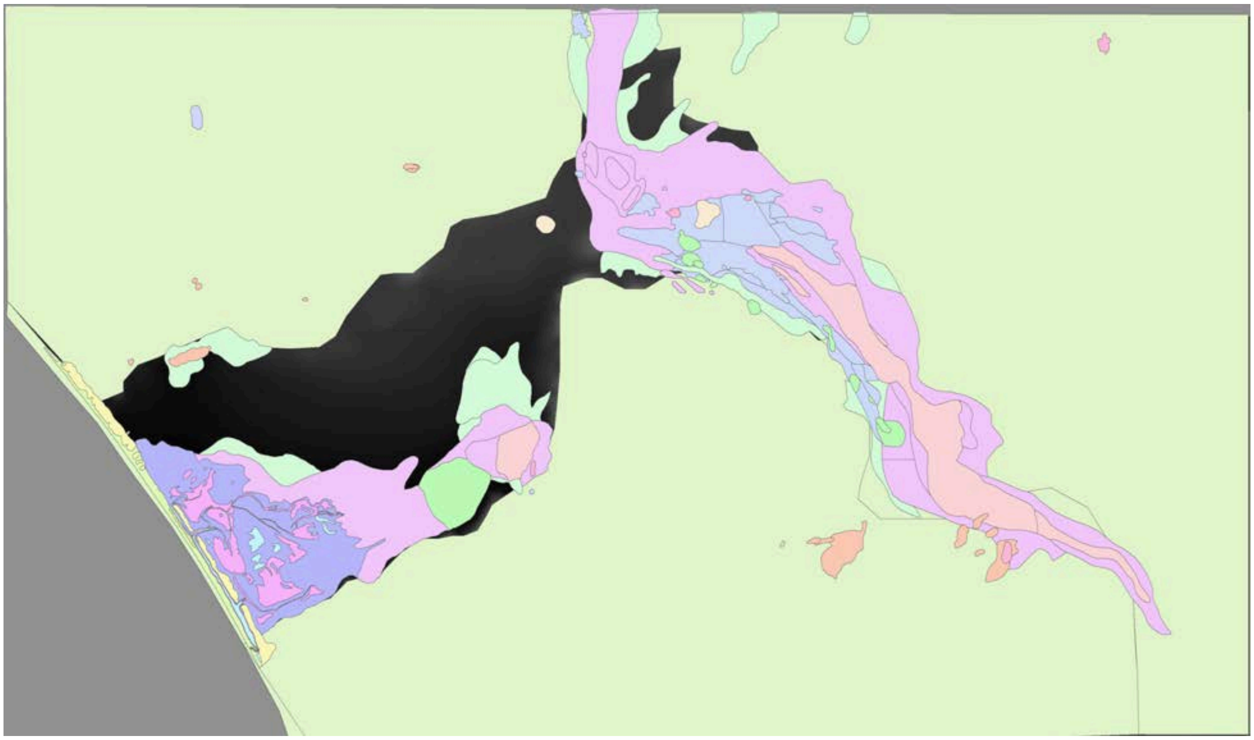


Figure 25. The historical habitat shapefile (Dark et al. 2011) was converted into a raster image.

In Photoshop, each habitat type was saved as individual layer and differentiated by a color scheme. To stylize the texture file, current locations that matched the habitat type and elevation of the each historical habitat type were found on Google Earth. These images were extracted from Google Earth, and edited in Photoshop to isolate desired habitat imagery. Each habitat was assigned an imagery file that was placed above the habitat layer in Photoshop in the layers' list. This order allowed the usage of the "Create Clipping Mask" tool in Photoshop, which clipped by the imagery by each habitat shapes (see Figures 27 and 28). This process was repeated until all of the imagery layers were transformed into the shapes of the historical habitats. Regions that were not differentiated by Dark et al. (2011) were also clipped with the appropriate imagery from similar habitats and elevation based on the author’s knowledge of the area. The final texture file was exported as TIF image from Adobe Photoshop CS6.

Figure 26. An example of the “Create Clipping Mask” tool that was used to drape the imagery over the habitat shapes. In this example the salt marsh layer is being clipped by the purple salt marsh habitat layer in Photoshop.

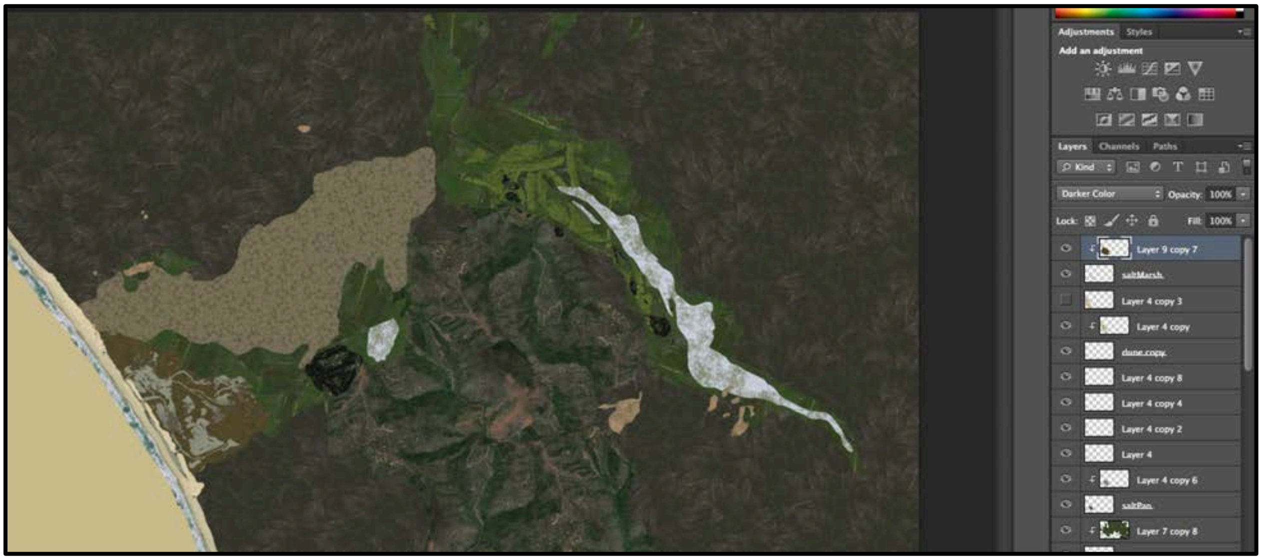


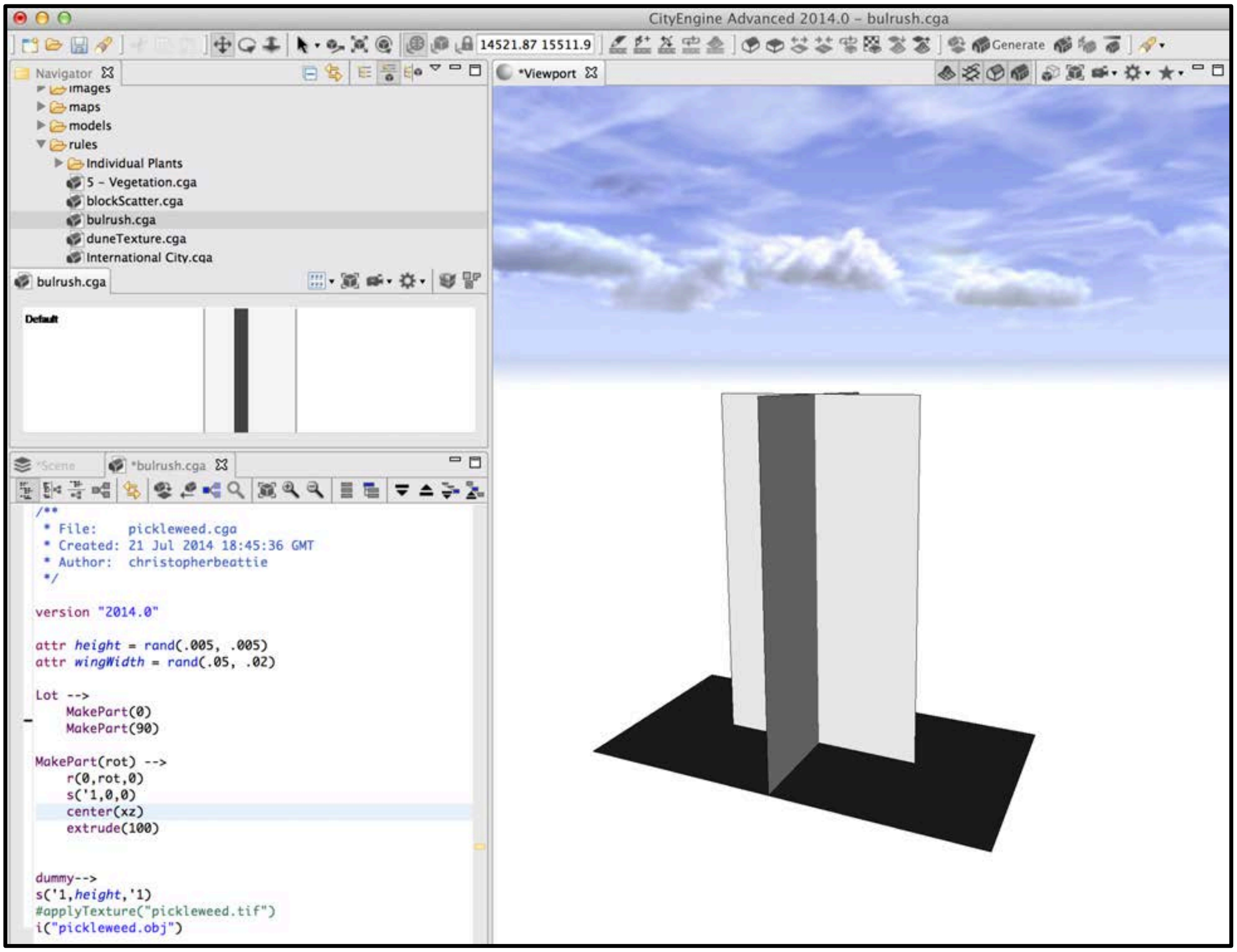
Figure 27. After the salt marsh imagery was clipped to the shape of the salt marsh habitat layer.

3.3.2.2 3D Vegetation Content

Computer Generated Architecture (CGA) is the programming language used within CityEngine. Simple shapes, such as a 3D square, are transformed into complex models by adding additional architectural 3D detail through CGA rules. Using this process, shapes were manipulated to create 3D content, such as plants and streams. CGA was vital for the creation of custom vegetation models for species that were native to the Ballona Wetlands. CityEngine comes equipped with a vegetation library, Plant Factory, which contained one hundred and thirty different plant species models. Plant Factory, however, lacked the necessary wetland species historically native to the Ballona Wetlands. To make the 3D City Engine visualization model realistic, this study created a native plant library using Photoshop and CityEngine.

CGA code was written to create cardstock 3D models of the historical vegetation species. Cardstock models are shapes that are intersected at a minimum of 0 and 90 degrees, to create a fan model with 3D-likeness of a plant species (Figure 29). Each side of the cardstock model was textured with an image of the plant that has a transparent background. To obtain images of the native plants, with transparent backgrounds, pictures of the desired plants were taken at Ballona Wetlands Ecological Reserve. Pictures of the plants were taken in the field against a white poster board, to reduce the amount of background pixels (Figure 30). The twelve images of different species were uploaded in Adobe Photoshop CS6 to remove the white background pixels. Using the “Color range” tool in Photoshop, all of the white pixels in an image were selected. Next, the “Inverse” tool selected the opposite of the current selection (the white pixels). After this process, the entire plant is selected without any background and saved to a new Photoshop layer that has transparent background (Figure 31`). This image was exported as a TIF image with the transparent background.

Texturing a shape with the Tiff image created an outline of the plant's shape while the transparent areas were removed from the square. Intersecting two or more TIF images created a "fan-like" 3D plant model.



```
/**
 * File:    pickleweed.cga
 * Created: 21 Jul 2014 18:45:36 GMT
 * Author:  christopherbeattie
 */

version "2014.0"

attr height = rand(.005, .005)
attr wingWidth = rand(.05, .02)

Lot -->
    MakePart(0)
    MakePart(90)

MakePart(rot) -->
    r(0,rot,0)
    s('1,0,0)
    center(xz)
    extrude(100)


dummy-->
s('1,height,'1)
#applyTexture("pickleweed.tif")
i("pickleweed.obj")
```

Figure 28. An example of creating a 3D "fan" model in CityEngine. Two rectangular shapes were intersected at 0 and 90 degree as shown by the .cga code on the bottom left of the image.

Figure 29. A picture of a *Salicornia virginica* (pickleweed) at Ballona Wetlands against a white poster board.

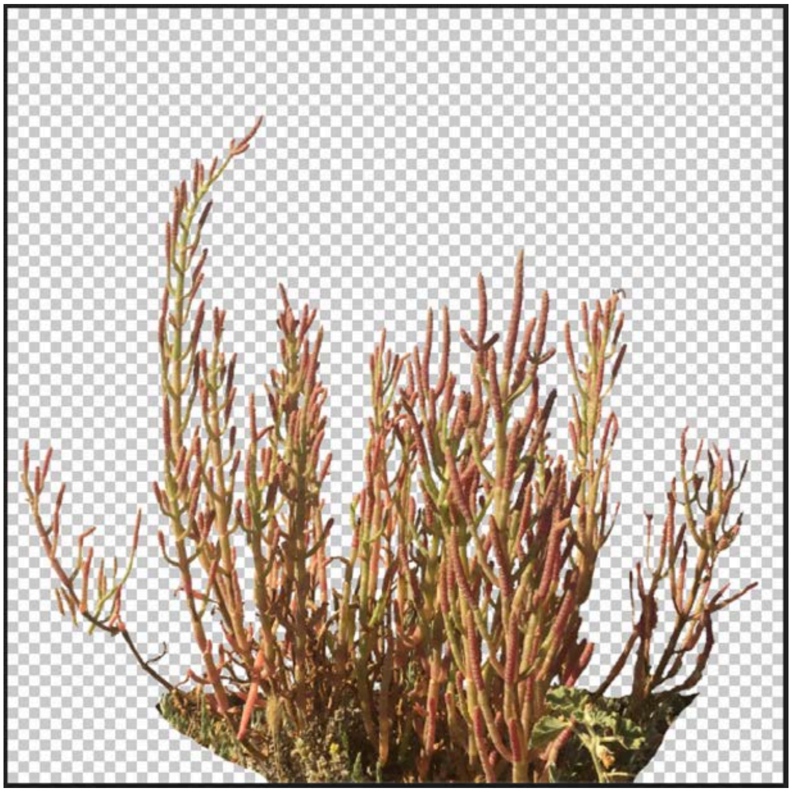
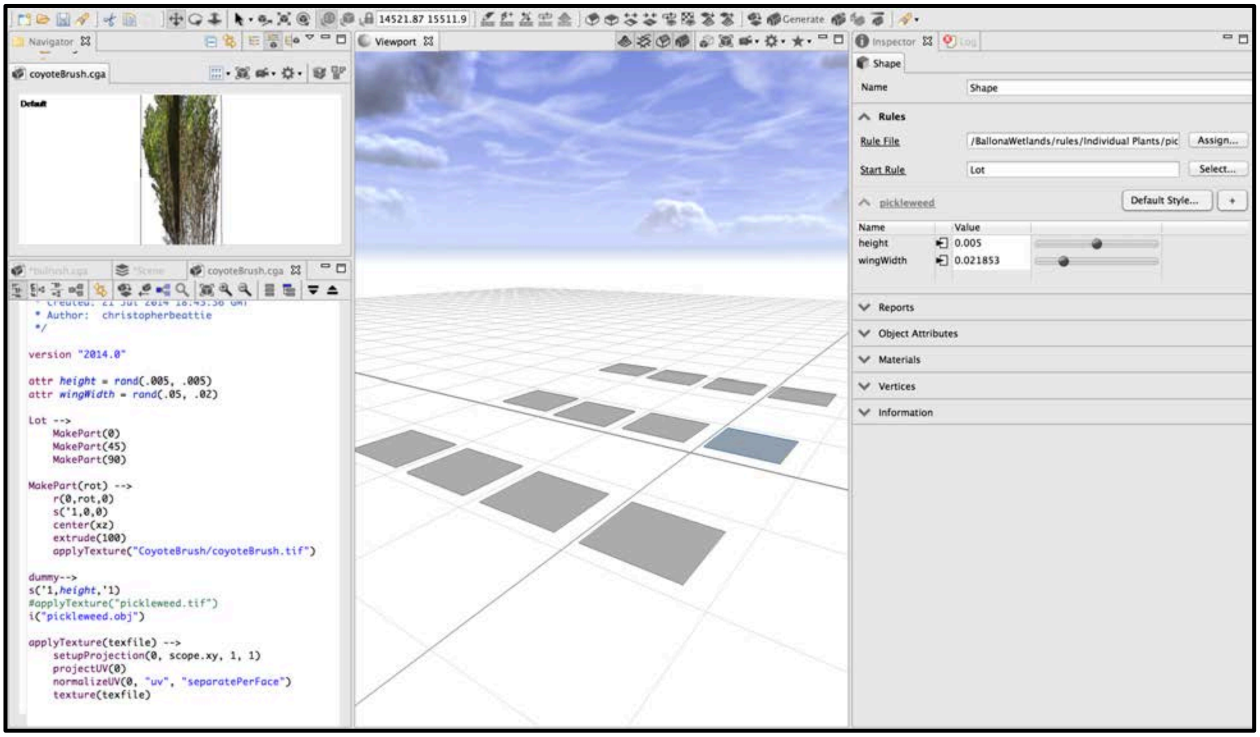


Figure 30. A *Salicornia virginica* (pickleweed) against a transparent background. Once imported into CityEngine, only the plant will be visible, not the surrounding square.

In CityEngine, individual CGA plant rules were created to generate the 3D shapes that used the TIF images of each species (Appendix A). As previously mentioned, .cga rules are applied to basic shapes to transform them into more complex models. Twelve squares were drawn and each square was assigned a different plant species (see Figure 32). When the .cga code for each square was executed, it generated the particular species of plant that was assigned to the square. Each individual plant's shapes were exported as an objects file (.obj), a type of geometry file, for representing the polygon vertexes and textures used to make a 3D model object. The plant .objs were needed for the final .cga code, the "Vegetation" rule (Appendix A). When applied, this rule provided the option to select a particular species and height to assign to the shape (Figure 33).



```
 * Author:  christopherbeattie
 */

version "2014.0"

attr height = rand(.005, .005)
attr wingWidth = rand(.05, .02)

Lot -->
    MakePart(0)
    MakePart(45)
    MakePart(90)

MakePart(rot) -->
    r(0,rot,0)
    s('1,0,0)
    center(xz)
    extrude(100)
    applyTexture("CoyoteBrush/coyoteBrush.tif")

dummy-->
s('1,height,'1)
#applyTexture("pickleweed.tif")
i("pickleweed.obj")

applyTexture(texfile) -->
    setupProjection(0, scope.xy, 1, 1)
    projectUV(0)
    normalizeUV(0, "uv", "separatePerFace")
    texture(texfile)
```

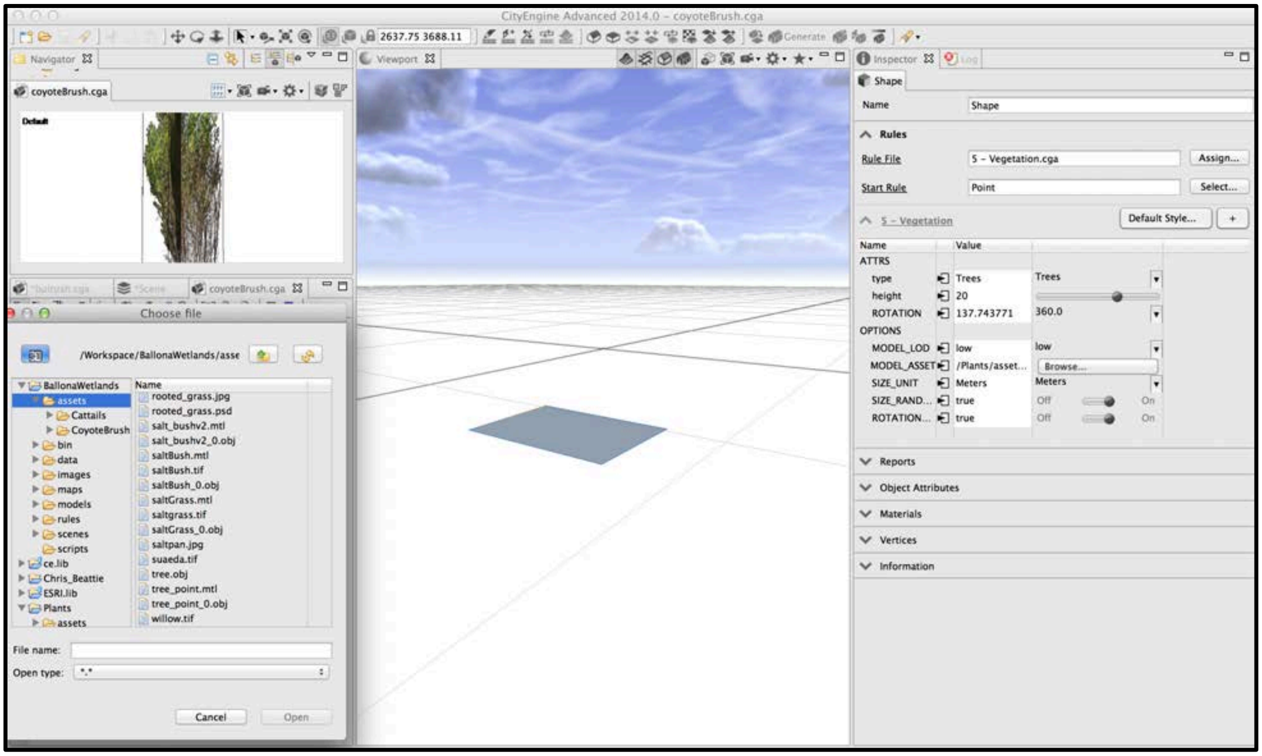
Name: Shape

Rule File: /BallonaWetlands/rules/Individual Plants/pic

Start Rule: Lot

Name	Value
height	0.005
wingWidth	0.021853

Figure 31. The blue square was selected and in the upper right corner, the Coyote Brush rule was selected and assigned to the shape. The coyotebrush.cga is shown at the bottom left. Above the code, a preview of how the basic square was going to be transformed.



Name: Shape

Rules

Rule File: 5 – Vegetation.cga

Start Rule: Point

5 – Vegetation

Name	Value	
ATTRS		
type	Trees	Trees
height	20	
ROTATION	137.743771	360.0
OPTIONS		
MODEL_LOD	low	low
MODEL_ASSET	/Plants/asset...	Browse...
SIZE_UNIT	Meters	Meters
SIZE_RAND...	true	Off On
ROTATION...	true	Off On

Figure 32. An example of the vegetation rule applied to a basic shape. In the “OPTIONS” section the ability to select the plant .obj was available. In the “ATTRS” the plant’s height was selected.

3.3.2.3 Mass Modeling

CityEngine had the ability to mass model thousands of shapes with explicit control over their design. Attributes, applied using CGA rules, can be selected randomly or uniformly to accurately represent features as they would in the real world. The CGA rule “pointsScatter” was written to uniformly distribute points across a shape (Appendix A). Assigning the “pointsScatter” rule to a particular shape enabled the selection of the number of points to generate from the attributes field. However, these shapes initially “hovered” above the assigned rectangular shape. Converting the models to shapes, with “Convert models to Shapes” tool, allowed the usage of the “Separate Faces” tool (Figure 34). This tool separated, or unlinked, the original rectangular shape from the point shapes. The rectangular shape was deleted and the point shapes were brought to the surface of the model, rather than hovering above, with the "Align Shapes to Surface" tool.

The "Vegetation" CGA rule was applied to the aligned points shapes. Using the rules attributes, the desired species .obj and height were selected to generate the plant models. At each shape point a plant species model was generated (Figure 35). Importing the historical habitat shapefile into CityEngine enabled this process to be applied to individual habitat shapes. Based on the habitat type, the appropriate plant species were assigned and generated.

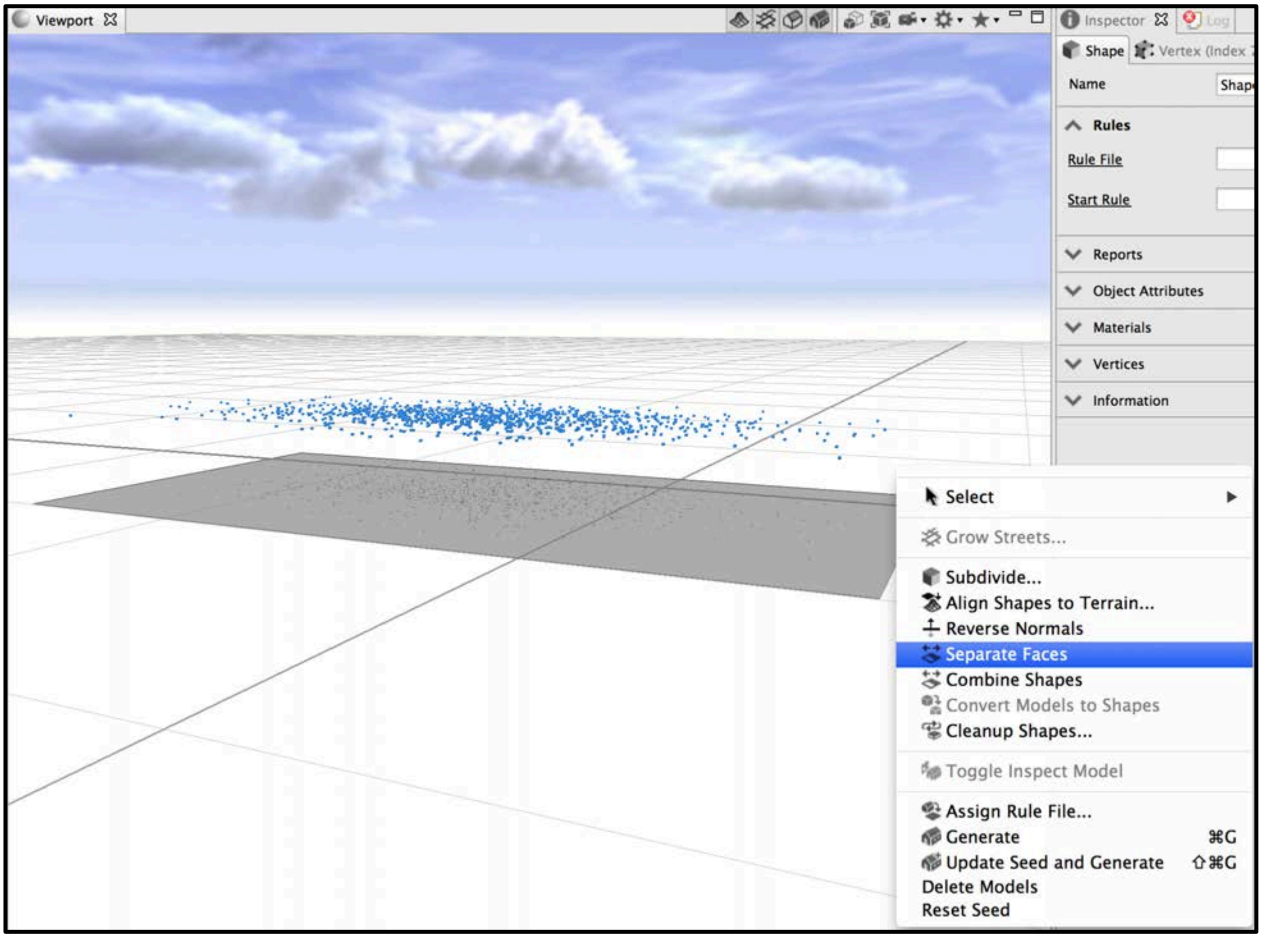
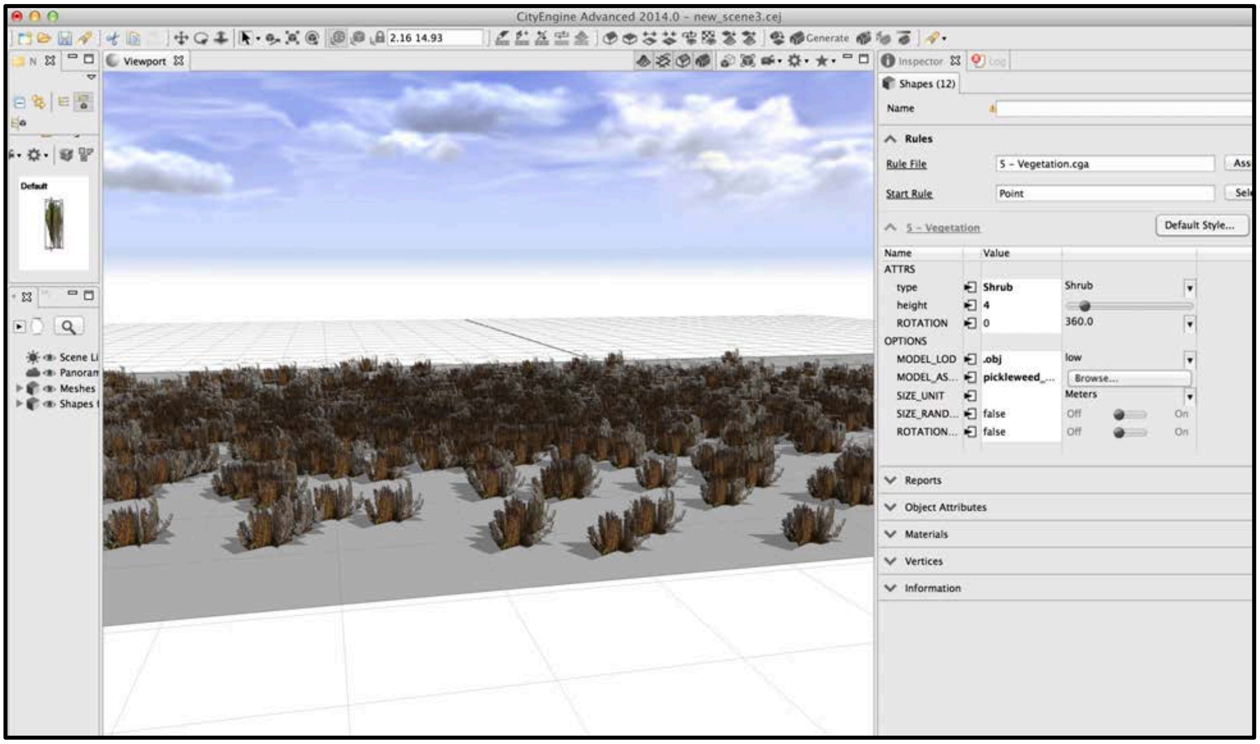


Figure 33. An example of mass modeled shapes and their separation from the larger gray, rectangular shape below the point shapes.



Rules
Rule File: 5 – Vegetation.cga
Start Rule: Point

5 – Vegetation

Name	Value	
ATTRS		
type	Shrub	Shrub
height	4	
ROTATION	0	360.0
OPTIONS		
MODEL_LOD	.obj	low
MODEL_AS...	pickleweed_...	
SIZE_UNIT		Meters
SIZE_RAND...	false	Off On
ROTATION...	false	Off On

Figure 34. An example of point shapes that were aligned to the surface and assigned the "Vegetation" rule. In this example, the pickleweed plant was selected and generated at each point shape.

3.3.2.4 3D Hydrology Content

The historical habitat shapefile, which included open water, ponds, lakes, and vernal pools, and the historical stream shapefile, derived from the topographic maps, were imported into the CityEngine. An "ocean" feature class was created in ArcCatalog and the Pacific Ocean's extent in each of the topographic maps was digitized. This was also imported into the CityEngine. All of the hydrography shapes were adjusted to overlay directly on top of the terrain map by using the "Align Shapes to Terrain" tool. To create 3D, moving water in CityEngine, the layer that contained water features, such as the ocean, was renamed simply renamed to "Sea__water". All of the hydrology layers and their shapes were transformed into 3D, moving bodies of water.

3.3.2.5 Exporting to a CityEngine WebScene

To view an entire scene, for example the terrain, hydrography, and vegetation, as a WebScene, all features must be selected. Next, the “Export Model” tool in CityEngine was used to export the model as a CityEngine WebScene. This allowed the CityEngine model to be explored as a 3D model in a web browser.

CHAPTER 4: RESULTS

This chapter provides the results of transforming heterogeneous historical resources, including topographic maps and images, into GIS datasets in Section 4.1 and the 3D visualization models created in Esri’s ArcScene and CityEngine in Section 4.2.

4.1 Historical Resources

The heterogeneous historical resources were carefully manipulated in graphic editing software to improve the accuracy of extracting the elevation information. The elevation information was converted into GIS datasets, such as shapefiles and rasters files.

4.1.1 Historical Topographic Maps

It took eighty hours to replace all pixels with a white value except for the contour lines, red value, and streams, blue value, for the edited versions of the USGS Santa Monica (Figure 36) and Redondo (Figure 37) topographic maps. Both maps were exported as TIF images, a readable file in ArcMap.

Figure 35. The results of replacing all other pixel values, such as roads, background colors, or text, with a white value in the USGS 1902 Santa Monica topographic map.

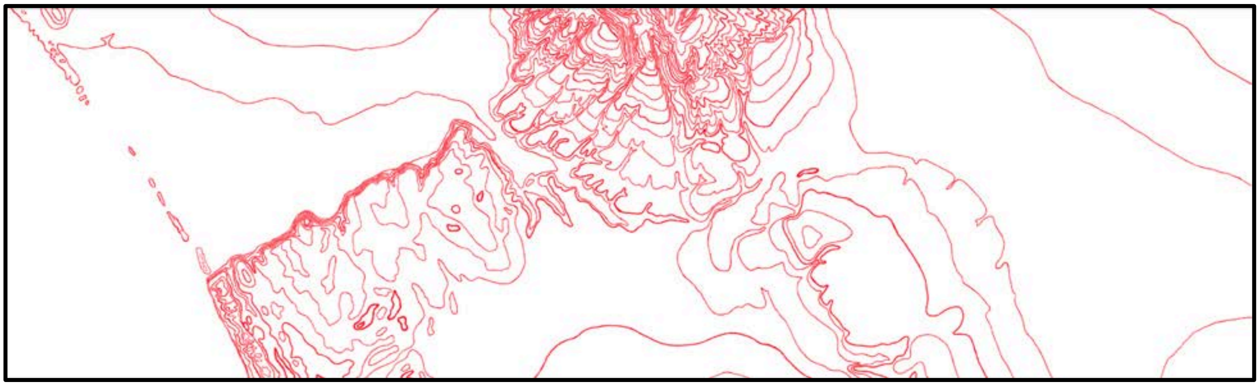


Figure 36. The contour lines shown were a TIF image, a type of raster dataset that was uploaded in Adobe Illustrator to extract the contour lines vector lines.

4.1.2 Contour Lines

The spatial adjustment of the contour lines took twenty hours. The contour lines were spatially adjusted to their respective georeferenced CSUN USGS topographic map. The Redondo contour lines were at 25-foot contour intervals (Figures 38 and 39), while the Santa Monica contour lines had a 50-foot interval (Figure 40 and 41).

Figure 37. The extracted Redondo contour lines derived from the georeferenced USGS Redondo 1896 topographic map.

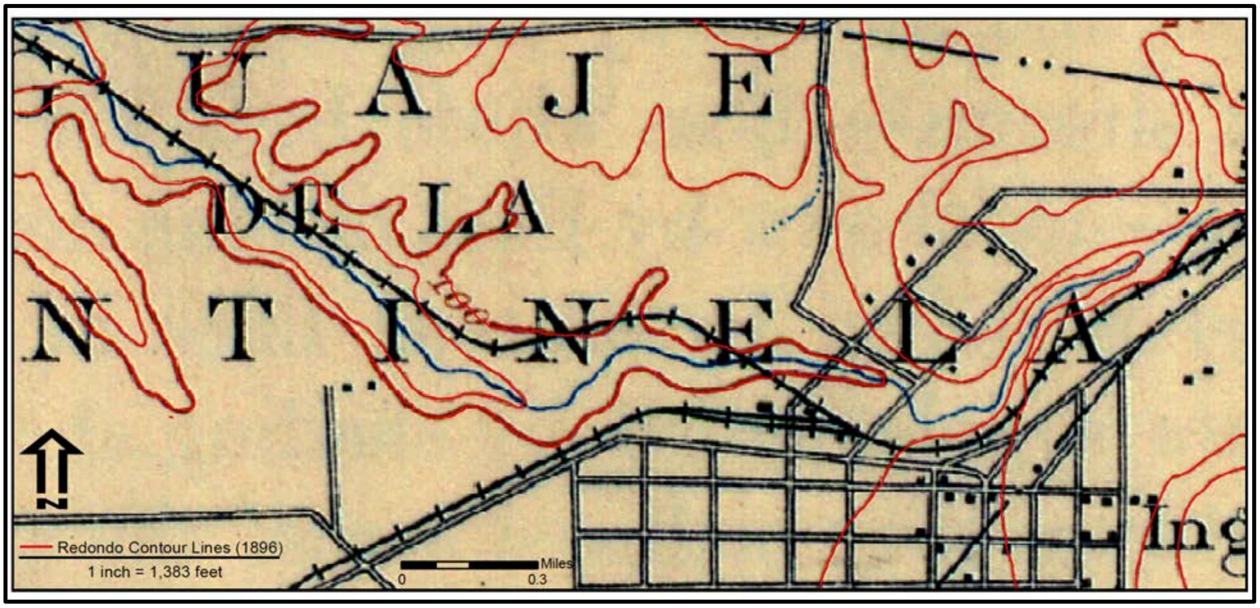


Figure 38. The Redondo contour lines, at a scale of 1:16,000, showing accuracy of digitized polylines from their georeferenced topographic map.

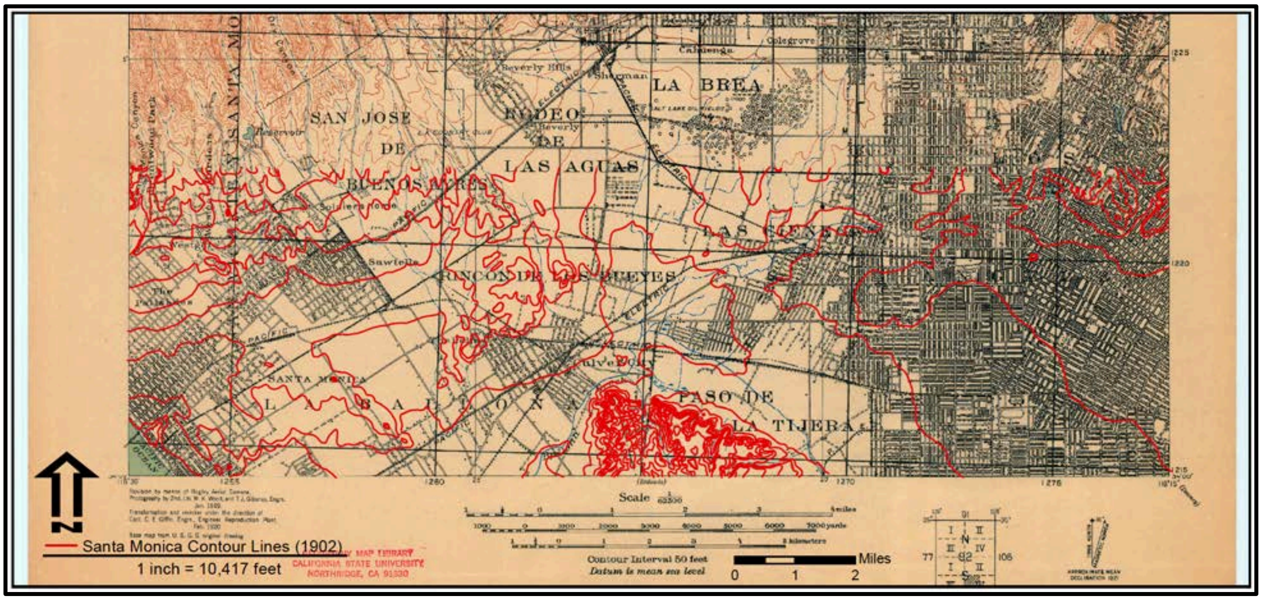


Figure 39. The extracted Santa Monica contour lines derived from the georeferenced USGS Santa Monica 1902 topographic map.

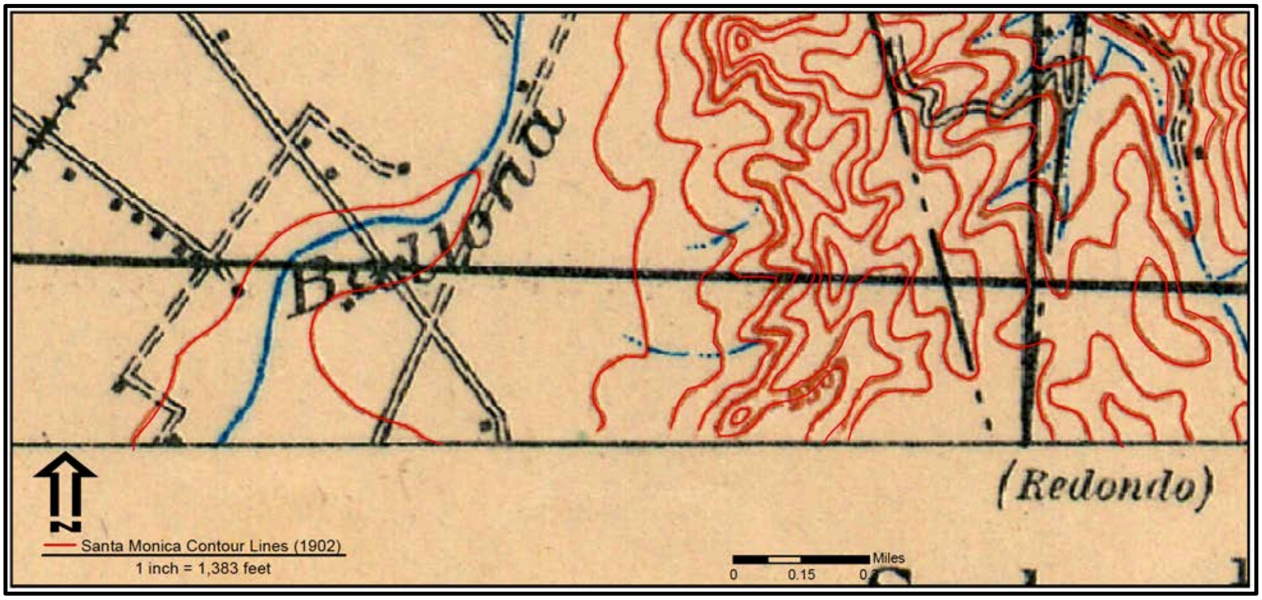


Figure 40. Similar to the Redondo contour lines, the Santa Monica contour lines were spatially adjusted and edited in ArcMap for gaps or holes in the polylines.

4.1.3 Digital Elevation Model

The historical DEM covers an area of 111.22 square miles (Figures 42 and 43). The DEM’s resolution is 10 feet by 10 feet (Figure 44).

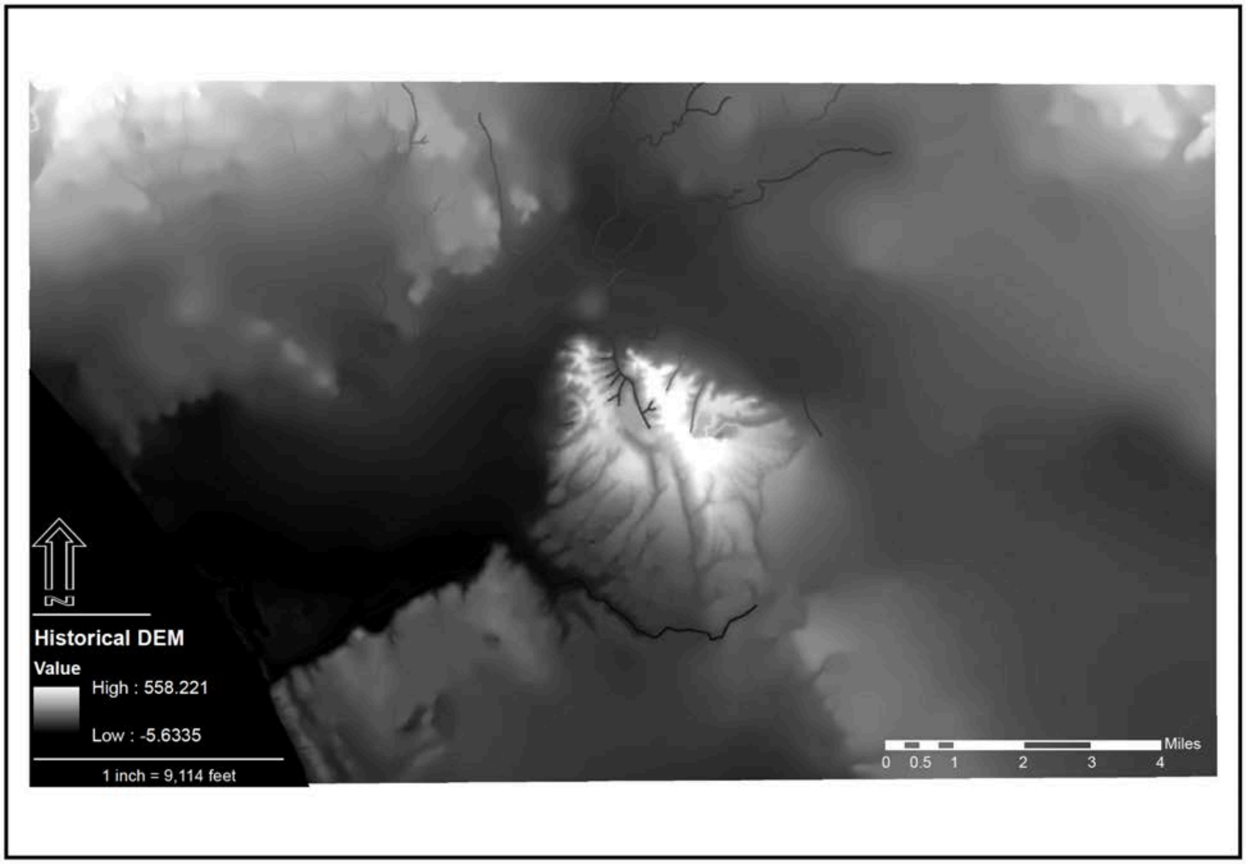


Figure 41. The final output, a digital elevation model (DEM), from the ArcMap "Topo to Raster" tool. It used hydrography data from Dark et al. (2011), and elevation information from the USGS 1896 Redondo and 1902 Santa Monica topographic maps, to generate a hydrologically-correct DEM.

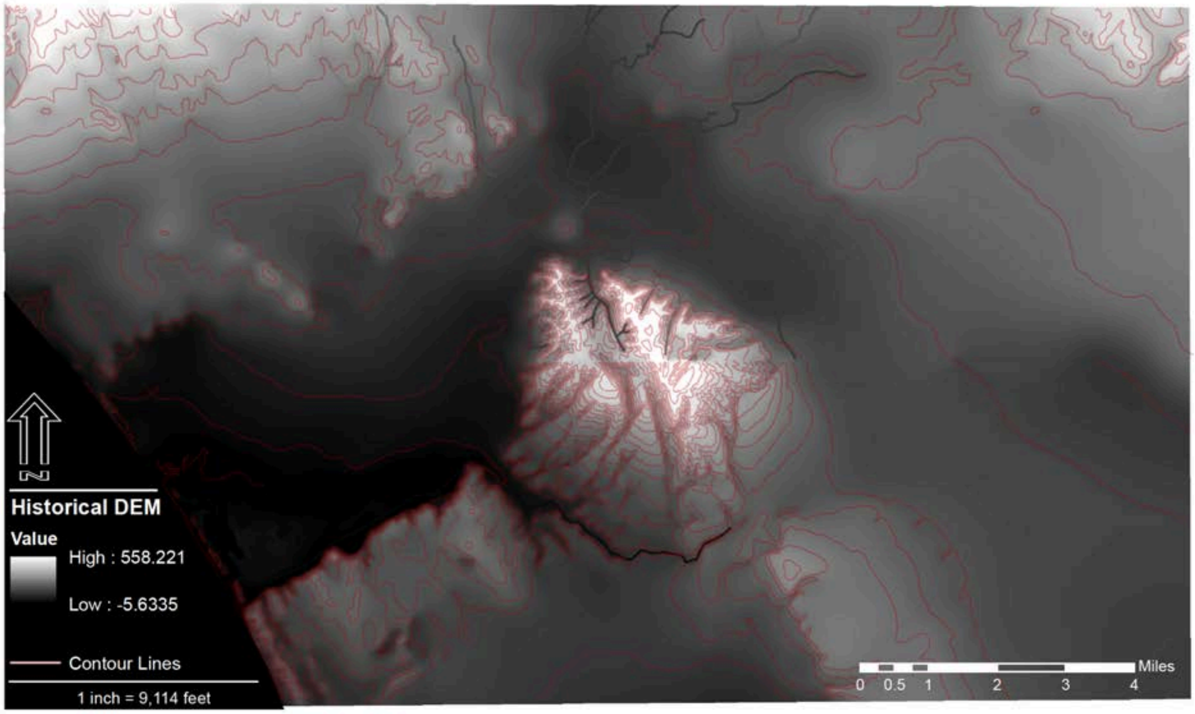


Figure 42. The 25-foot contour interval of the Redondo contour interval, which contributed to the southern half of the DEM, created a finer raster resolution than the northern half's 50-foot contour interval.

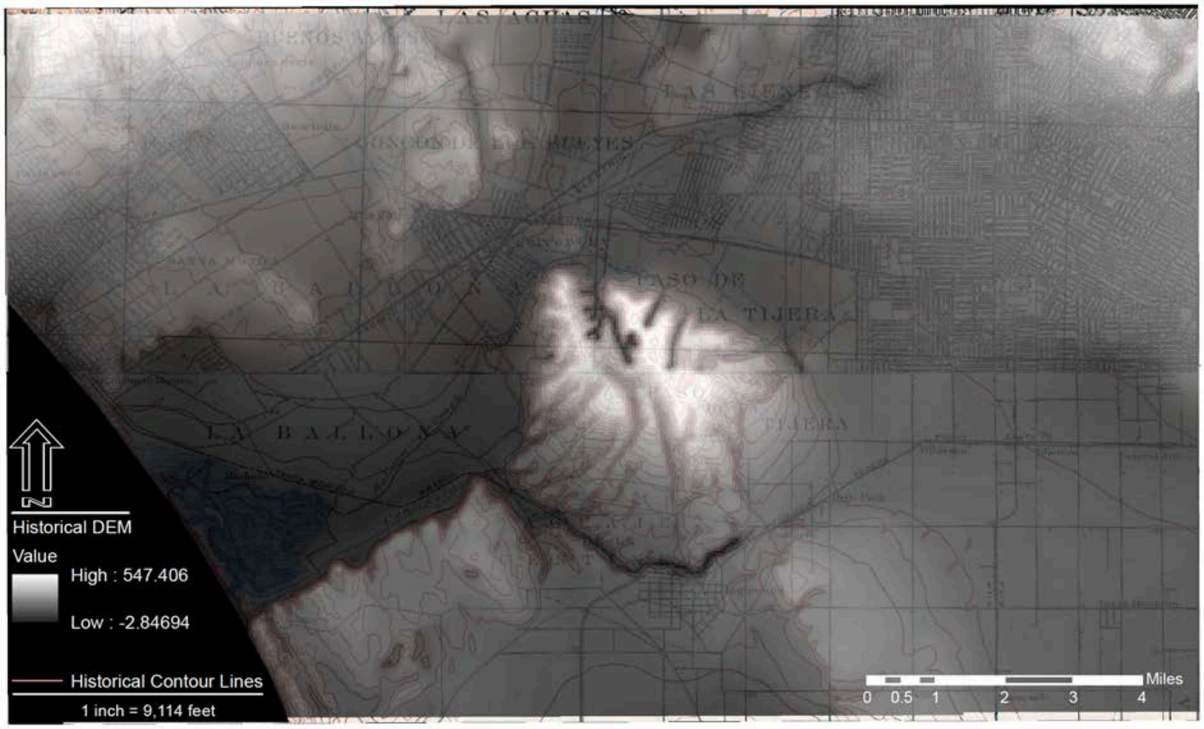


Figure 43. An example of the historical DEM overlaid onto the contour lines and topographic maps.

4.2 3D Visualizations

4.2.1 Case Study One: ArcScene

ArcScene produced two 3D models. The first model used the early 1900s historical DEM for the base height of the model and the two topographic maps, Redondo and Santa Monica, to drape over the 3D terrain. The second model used a combination of the historical DEM and the elevation change raster created in ArcMap to represent the changes in elevation over the last century.

4.2.1.1 ArcScene: Topographic Map Model

The USGS 1896 Redondo and 1902 Santa Monica topographic maps were draped over the 3D historical DEM model in ArcScene. Historic features, such as Ballona’s dunes system shown in Figure 45, are reconstructed to visualize what they would have looked like if they still existed. The resolution of the topographic maps is severely degraded because of the low resolution of the topographic maps, but the visualizations still provide insight as to how the elevation looked in the 3D (i.e. Figure 46).

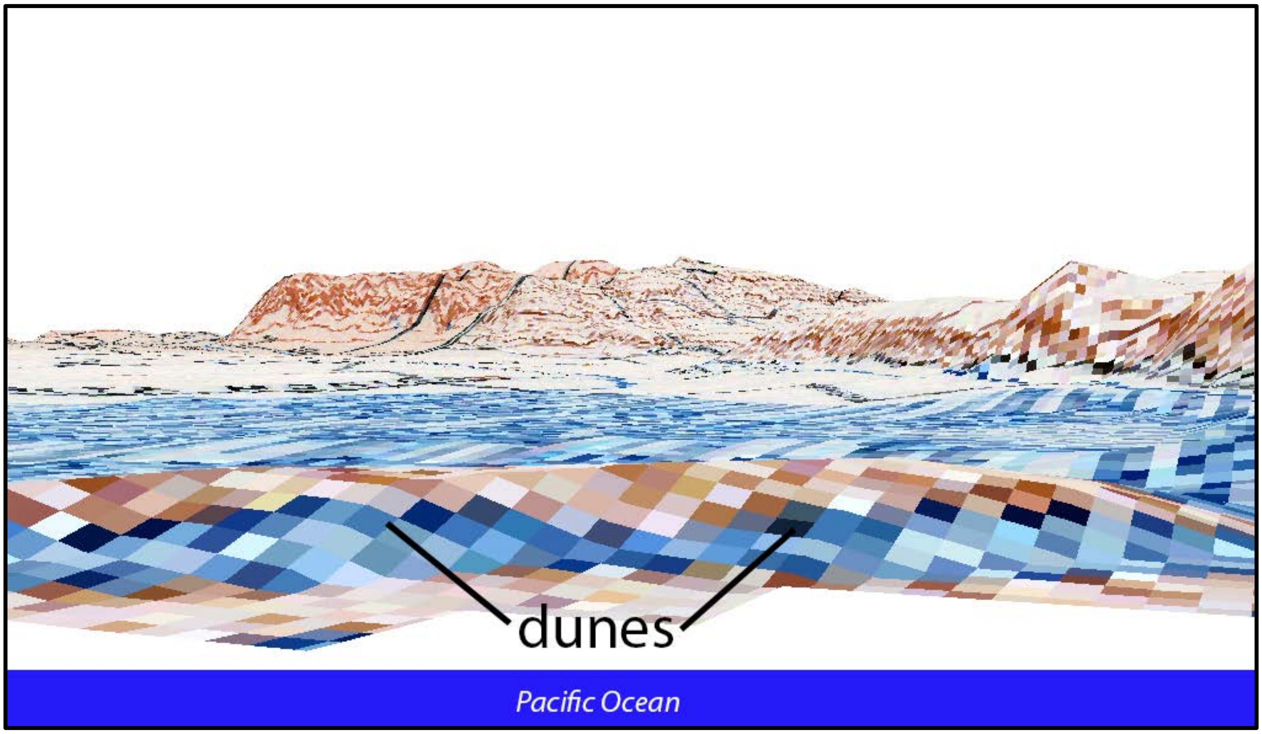


Figure 44. This image was an example of a 3D model that faced west to east, visualizing the historical Ballona Wetlands' dunes, which existed in the early 1900s before they were destroyed.

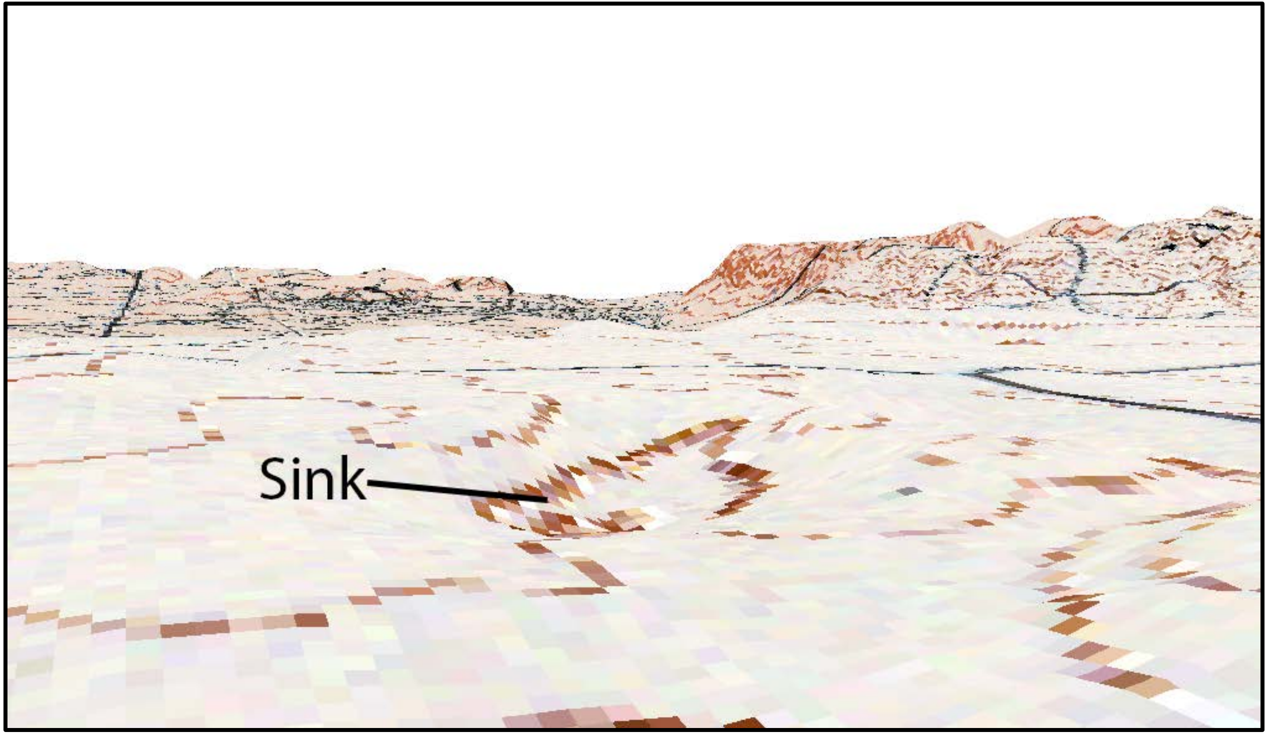
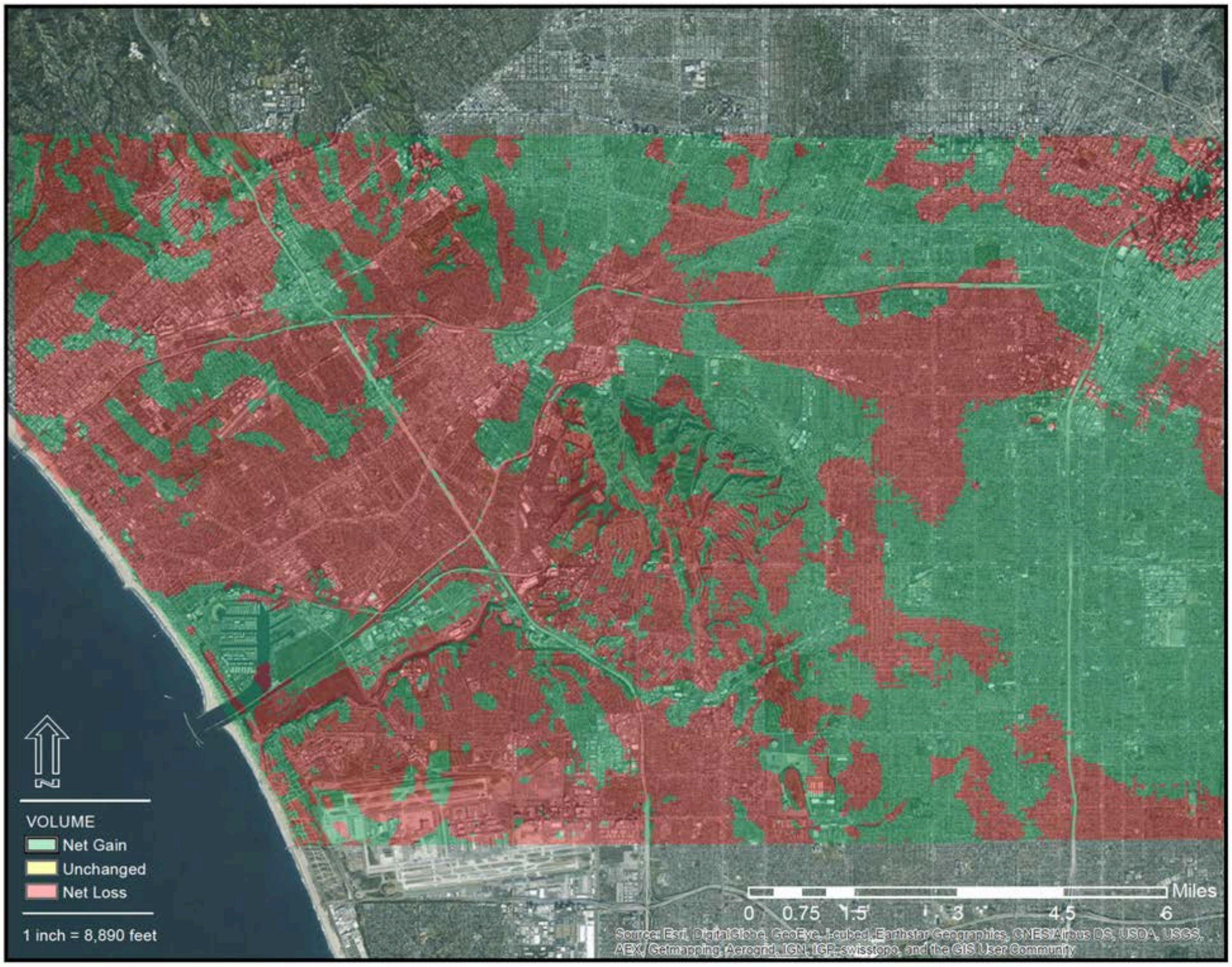


Figure 45. Another example of an image created to visualize a historic sink that existed on the bluffs above the Ballona Wetlands.

4.2.1.2 ArcScene: Changes in Elevation

Two different elevation rasters were created to compare the changes between the early 1900s historical DEM and the 2006 Los Angeles County DEM. The first raster showed areas that experienced an increase, decrease, or no change in elevation volume (Figure 47). This elevation raster was not used in a 3D model.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 46. This is an example of the changes in elevation volume overlaid onto 2013 imagery.

The second type of raster, which delineated the elevation changes in feet, was overlaid onto different types of basemaps, such as imagery (Figures 48, 49, and 50). These maps showed the correlation between the elevation changes and extensive urban development seen in the basemaps.

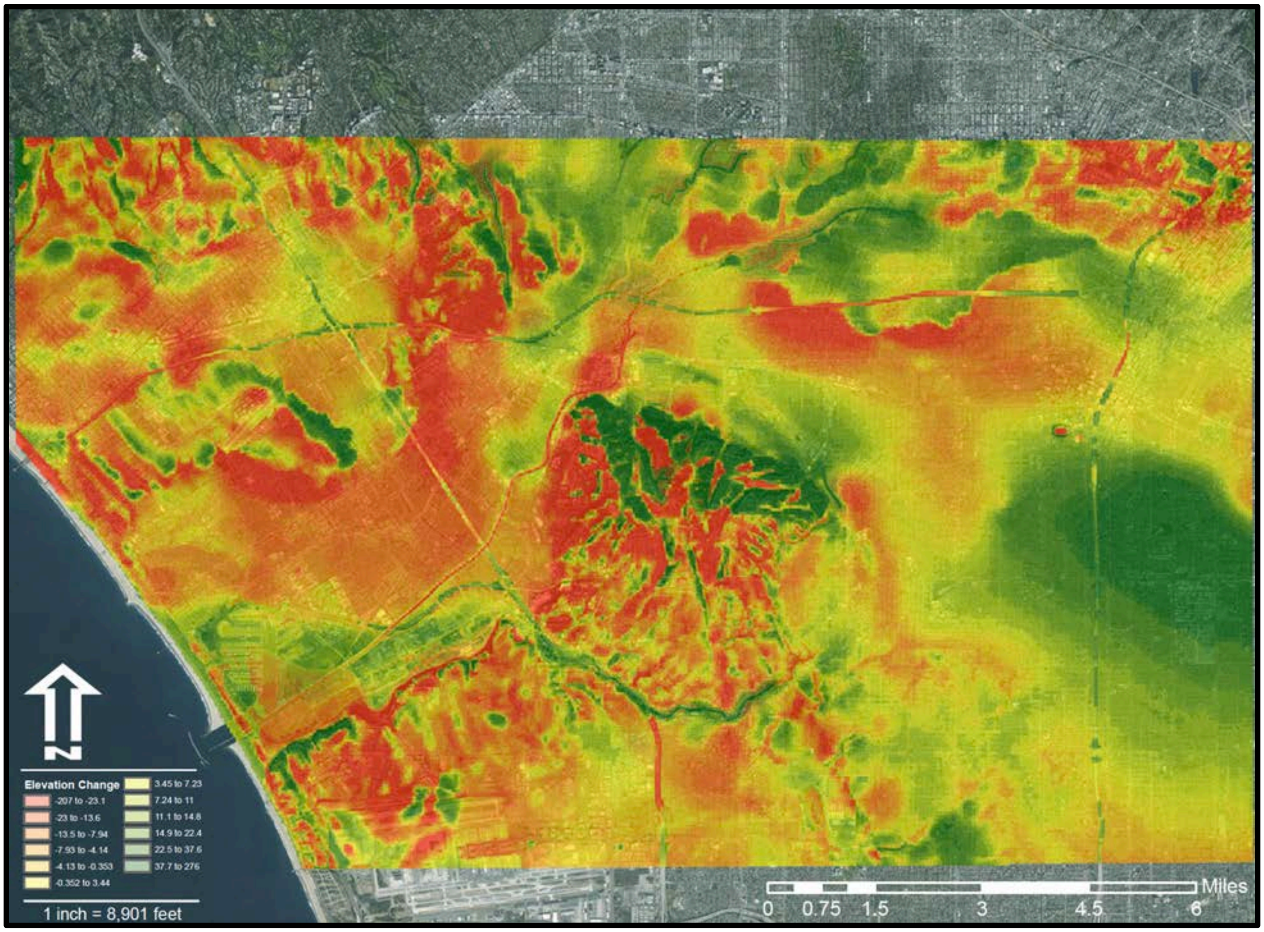


Figure 47. This example showed the elevation change between the 2006 Los Angeles County DEM and the historical DEM, the elevation change raster, overlaid onto imagery.

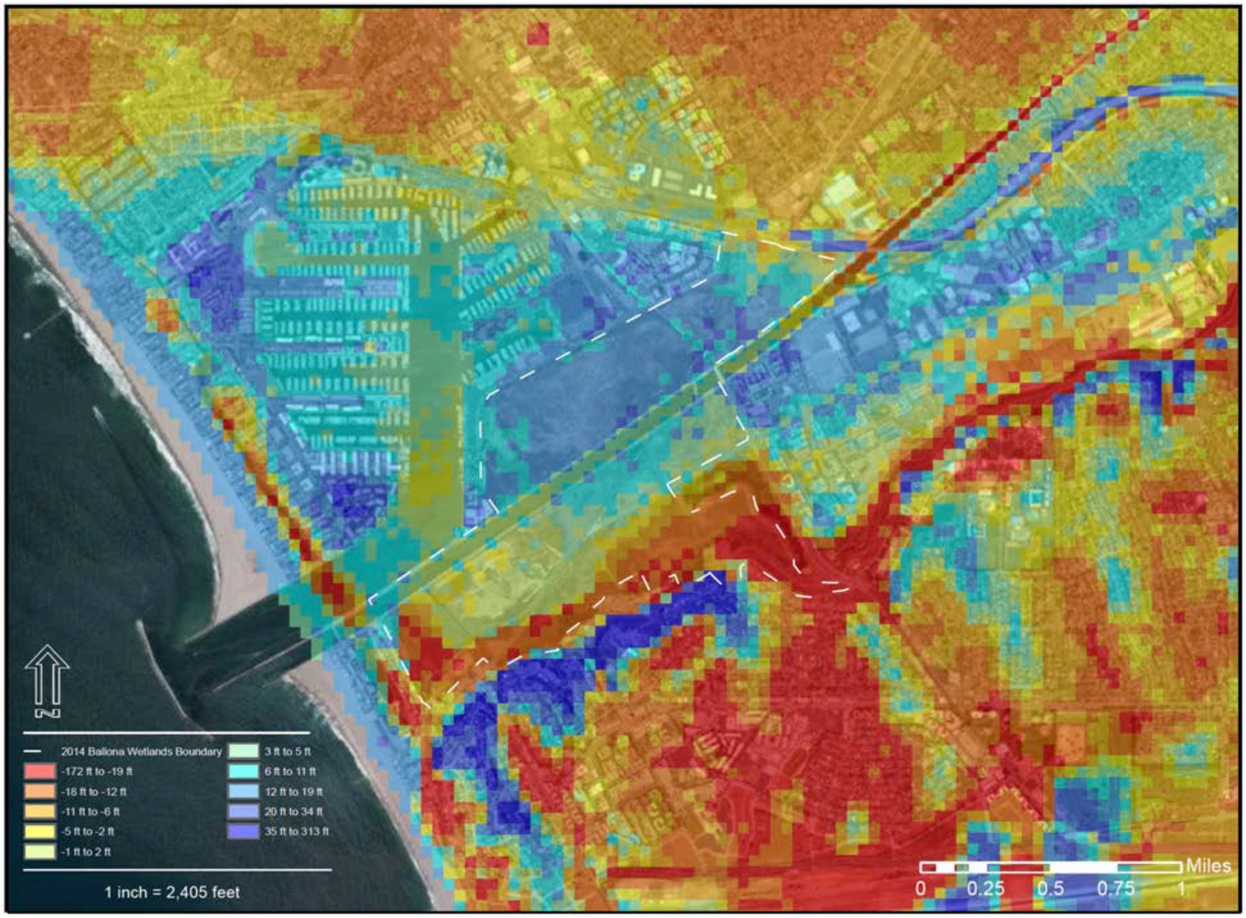


Figure 48 The extensive topography changes are evident in highly developed areas, such as the Marina del Rey, which is located within the historical extent of the Ballona Wetlands.

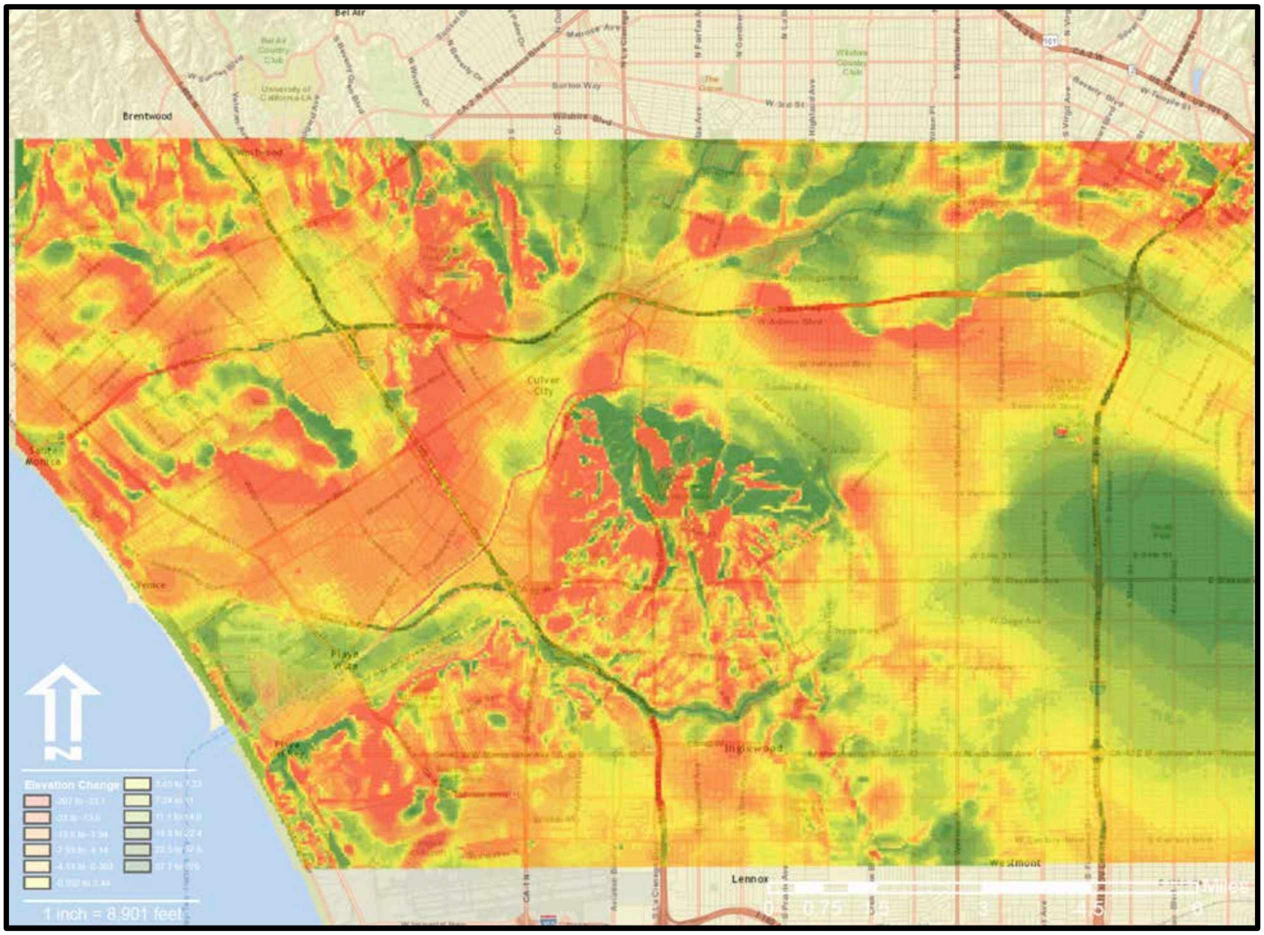


Figure 49. Major development features, like freeways, are distinguishable in the elevation change raster when overlaid onto a "streets" basemap.

Three different types of 3D visualization models were produced from the changes in elevation raster to improve visualizing the changes in feet. First, it was used to drape over the 3D historical terrain to highlight the topography features changed over the last century (i.e. Figure 51). Terrain features that decreased are overlaid with reddish pixels while features that increased are greenish.

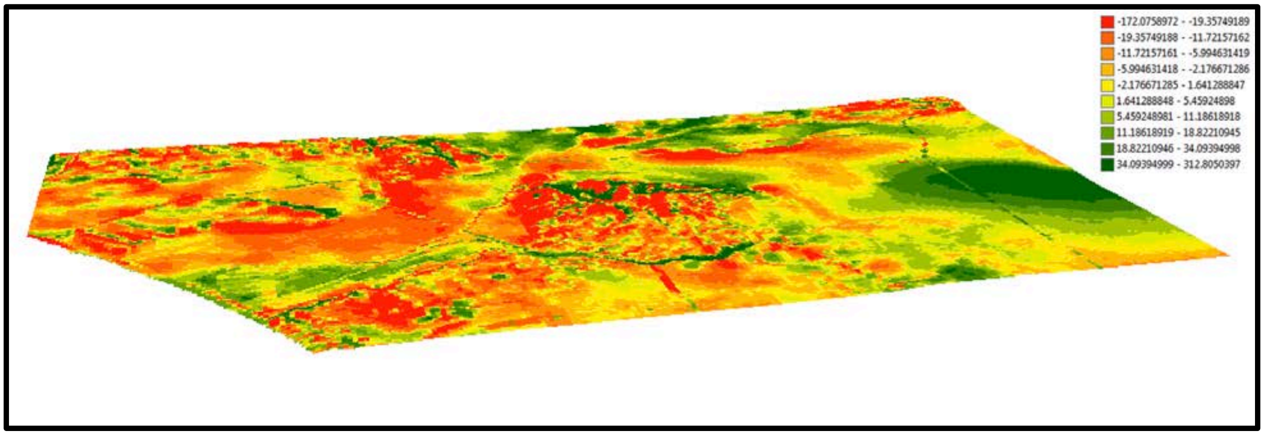
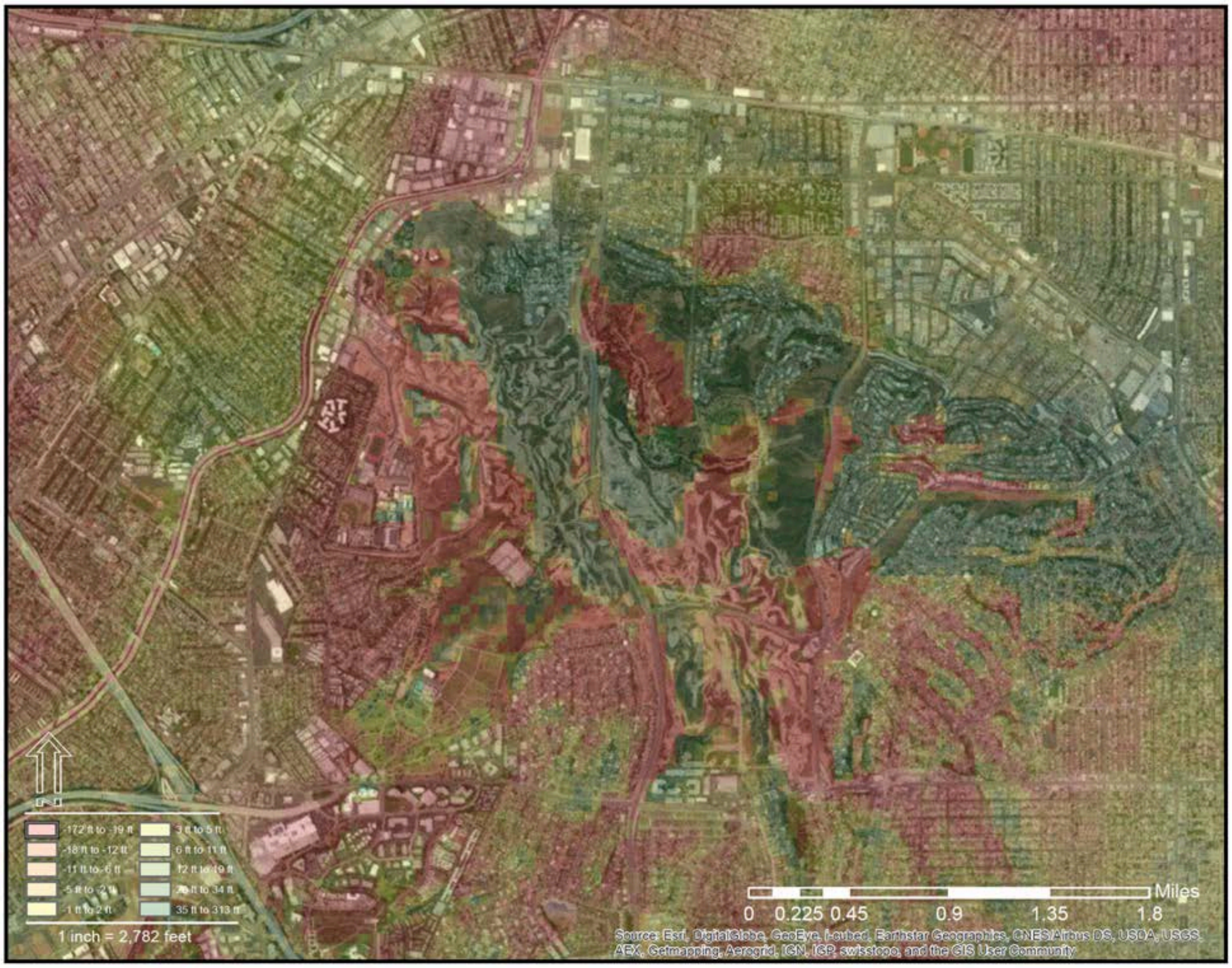


Figure 50. The 3D terrain was generated from the historical DEM while the symbology was derived from the changes in elevation over the last century.

Patterns of red and green pixels in the elevation changes raster suggest that the elevation had been increased and decreased in an attempt to level the surface. The Baldwin Hills are an example of this pattern, demonstrated in 2D (Figure 52) and 3D (Figure 53).



Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 51. The elevation within the Baldwin Hills was drastically changed as shown in the imagery suggested by the elevation change raster.

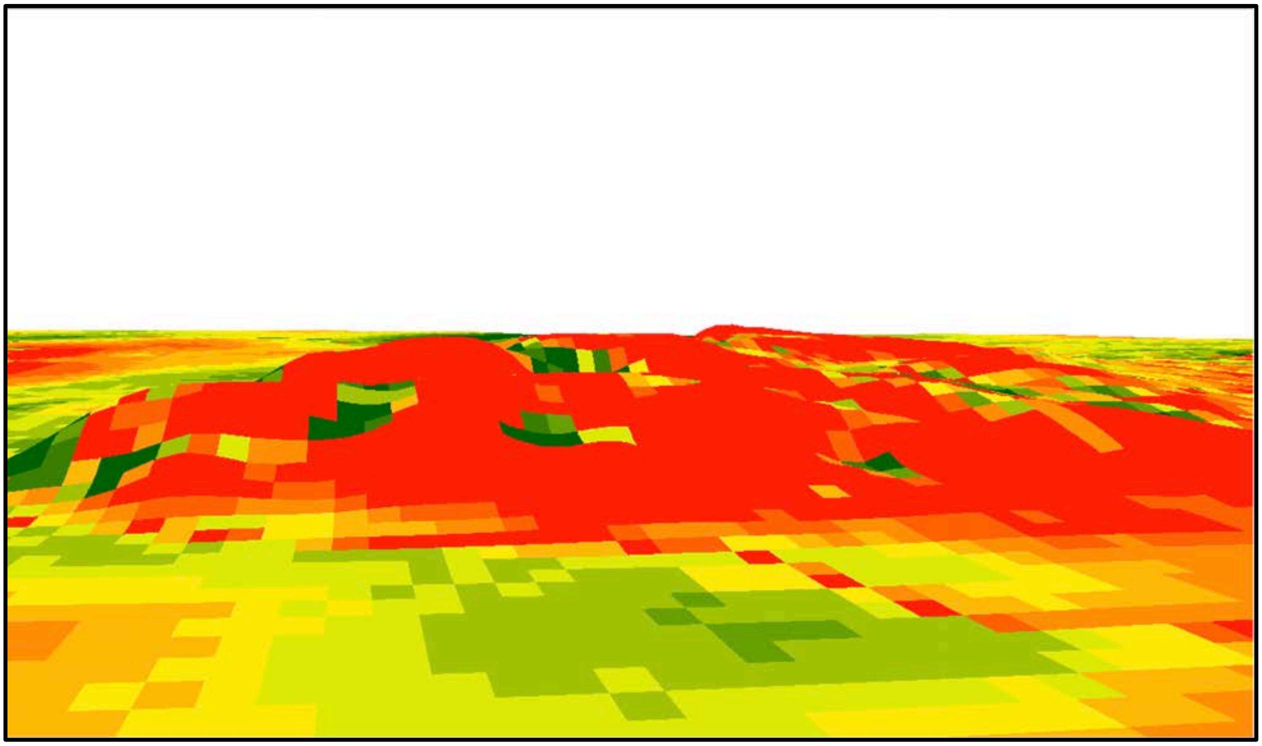


Figure 52. This was an example of visualizing the 3D historical terrain features and the symbology of the elevation changes raster.

Secondly, the elevation changes were displayed as a 3D model and overlaid onto the historical 3D terrain (i.e. Figure 54). Areas of the 3D elevation changes raster where the elevation increased are displayed above the topography of the 3D historical terrain while areas that decreased are below the surface (Figure 55). A comparison of the two types of models displaying a river is shown in Figure 56.

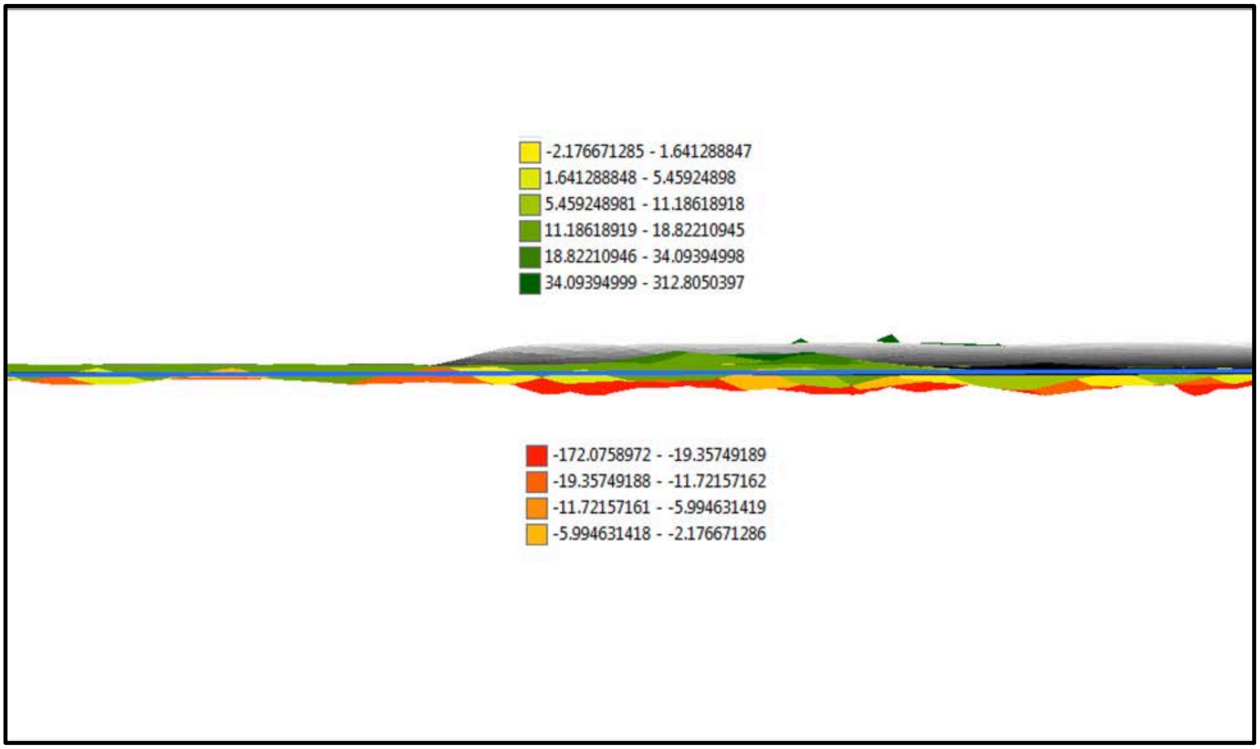


Figure 53. The 3D combination of the historical DEM and elevation changes raster.

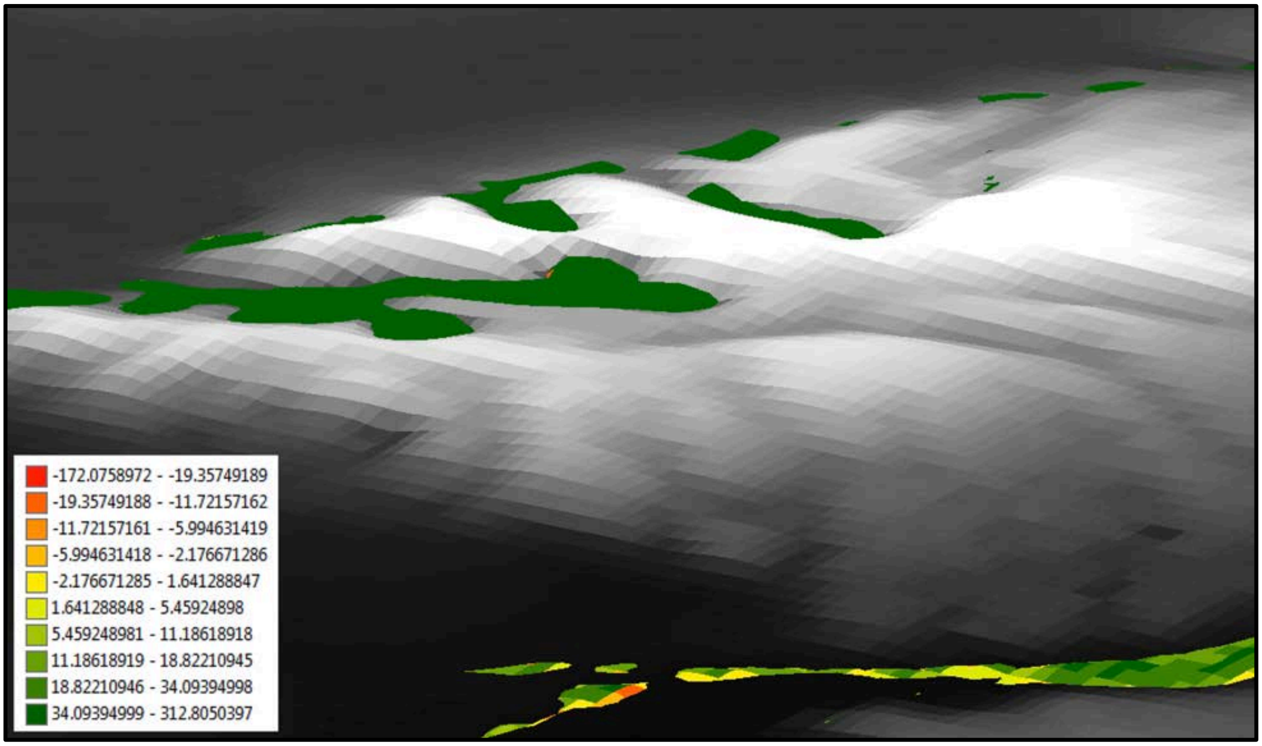


Figure 54. Elevation increases, in feet, appear above the historical 3D terrain as seen when the two 3D models are combined.

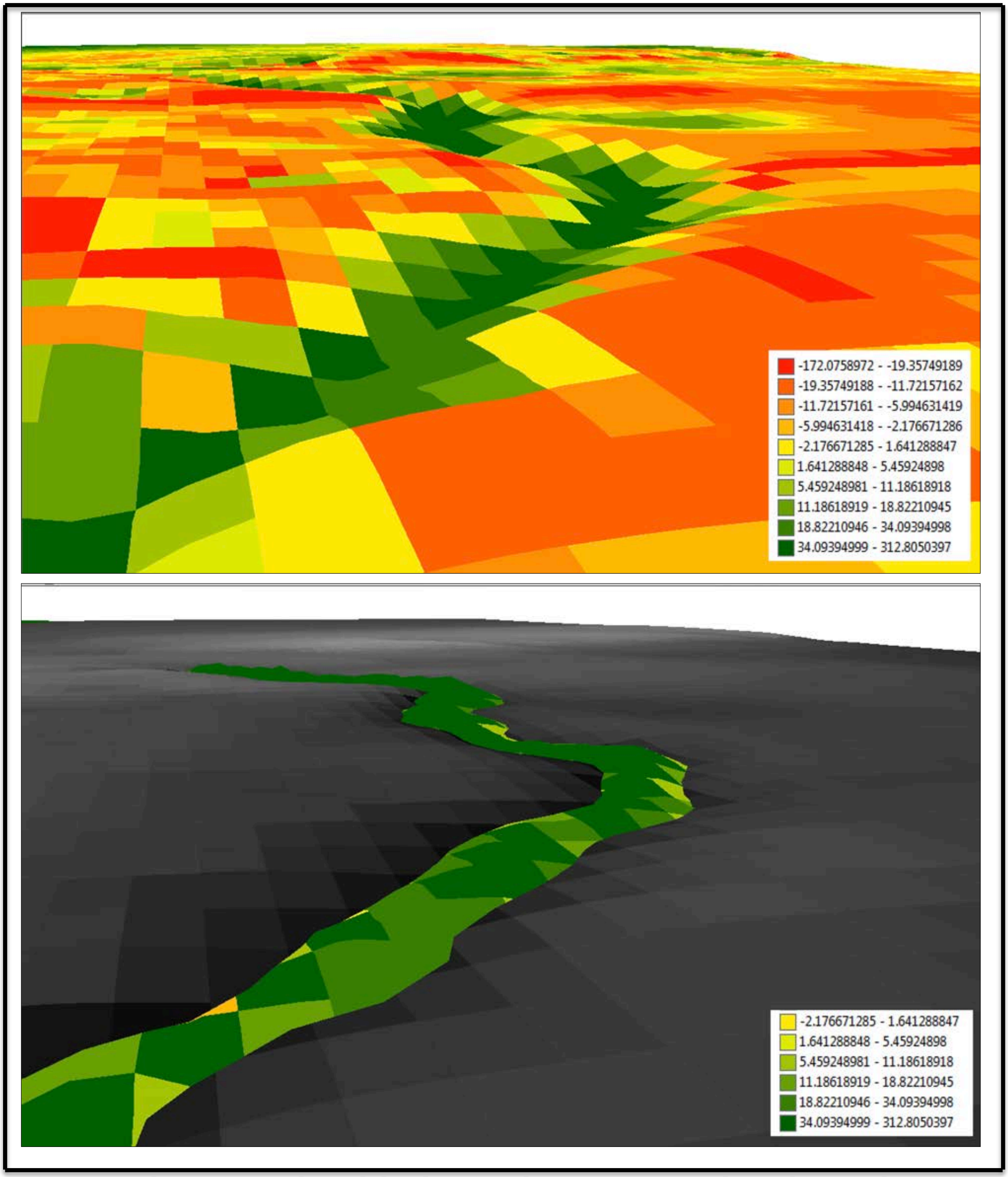


Figure 55. The top image draped the elevation change raster over the 3D historical terrain. The bottom image, of the same stream, displayed both the raster and historical terrain in 3D.

The third type of visualization model featured only the elevation changes raster in 3D. An example of this model combined the historical habitat types and elevation changes raster (Figures 57 and 58).

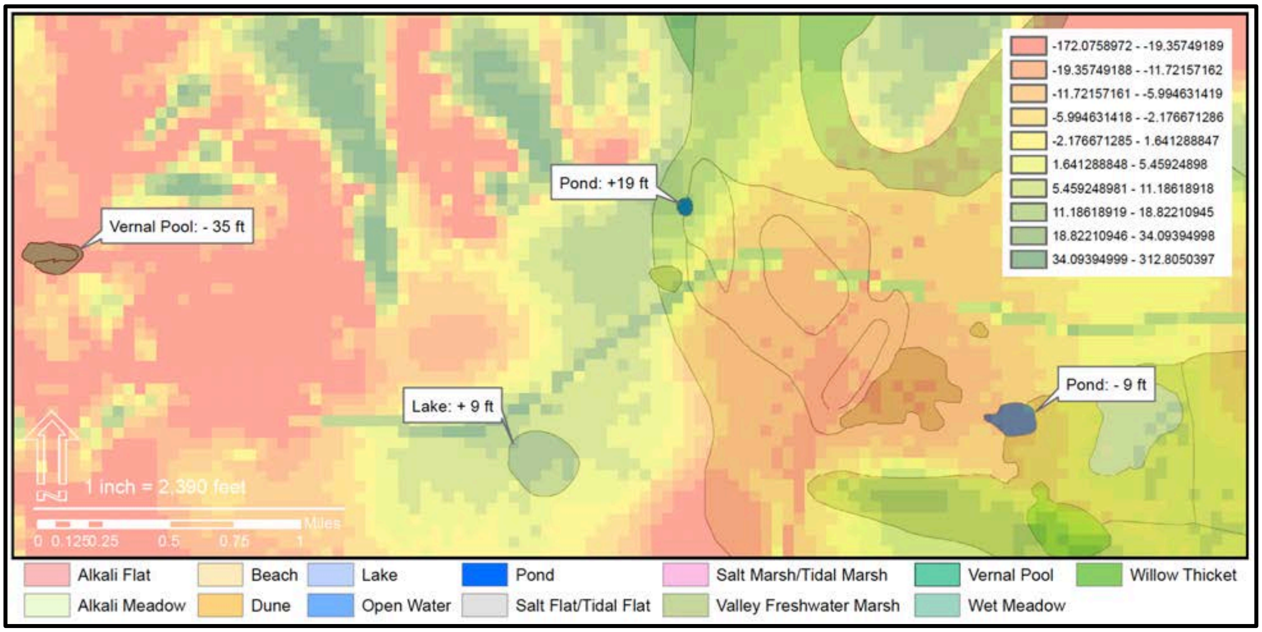


Figure 56. A 2D map of the hydrography habitat layers and their topography changes suggested by the elevation changes raster.

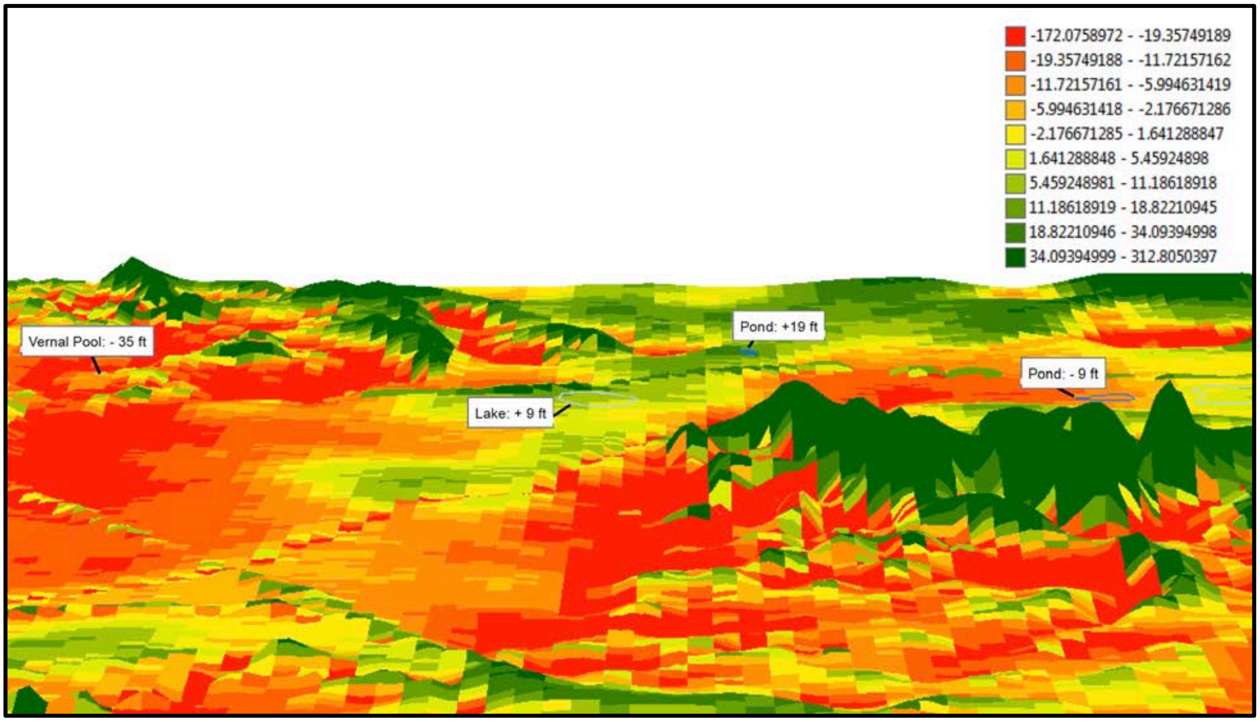


Figure 57. This model is the 3D version of Figure 22. The "z" factor for the elevation has been increased fives times to make the elevation changes more distinct.

4.2.2 Case Study Two: CityEngine 3D Model

CityEngine was used to visualize the historical vegetation and terrain of the wetlands prior to extensive development. The entirety of the historical DEM, 111.22 square miles, was textured with imagery and select places were populated with 3D vegetation models to reconstruct the appearance of the wetlands.

4.2.2.1 CityEngine Vegetation Models

A Ballona Wetlands' nursery of 8 different native plant species (Figure 58) was developed to demonstrate the capabilities of creating custom vegetation in CityEngine. Individual plant species, Figures 59 and 60, were populated and placed in regions where they would have lived based on the historical habitat shapefile from Dark et al. (2011). The historical plant models were used to "paint a picture" of what the wetlands would have looked like prior to extensive development (Figures 61). These images provided an opprtunity to compare the Ballona Creek watershed’s past and current extent and appearance, encouraging a deeper understanding of humanity’s impact on its landscape. It is difficult to envision the highly modified Ballona Creek waterhed supporting diverse and complex wetlands habitats, but these images served as tools for cultivating a new appreciation for the region’s consevation and restoration potential.

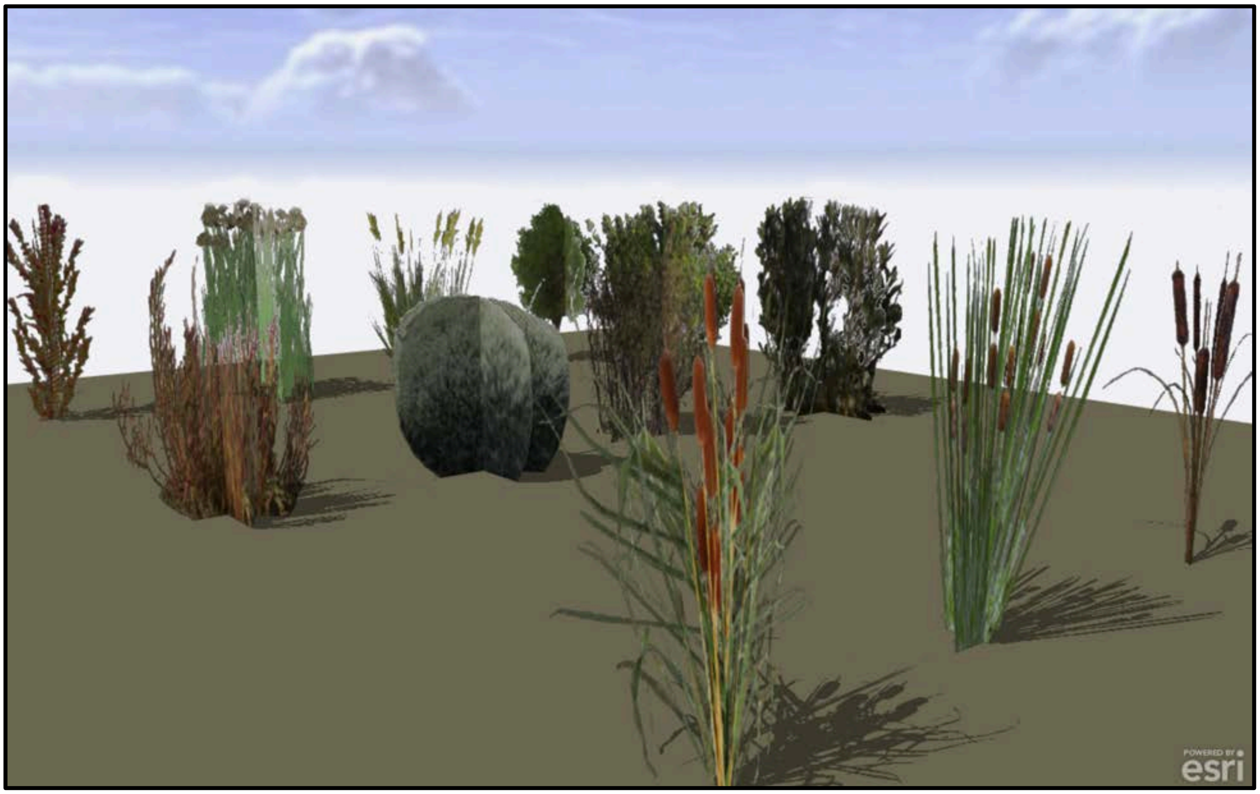


Figure 58. A model of the different species of Ballona Wetlands’ plants creating using .cga code in CityEngine.

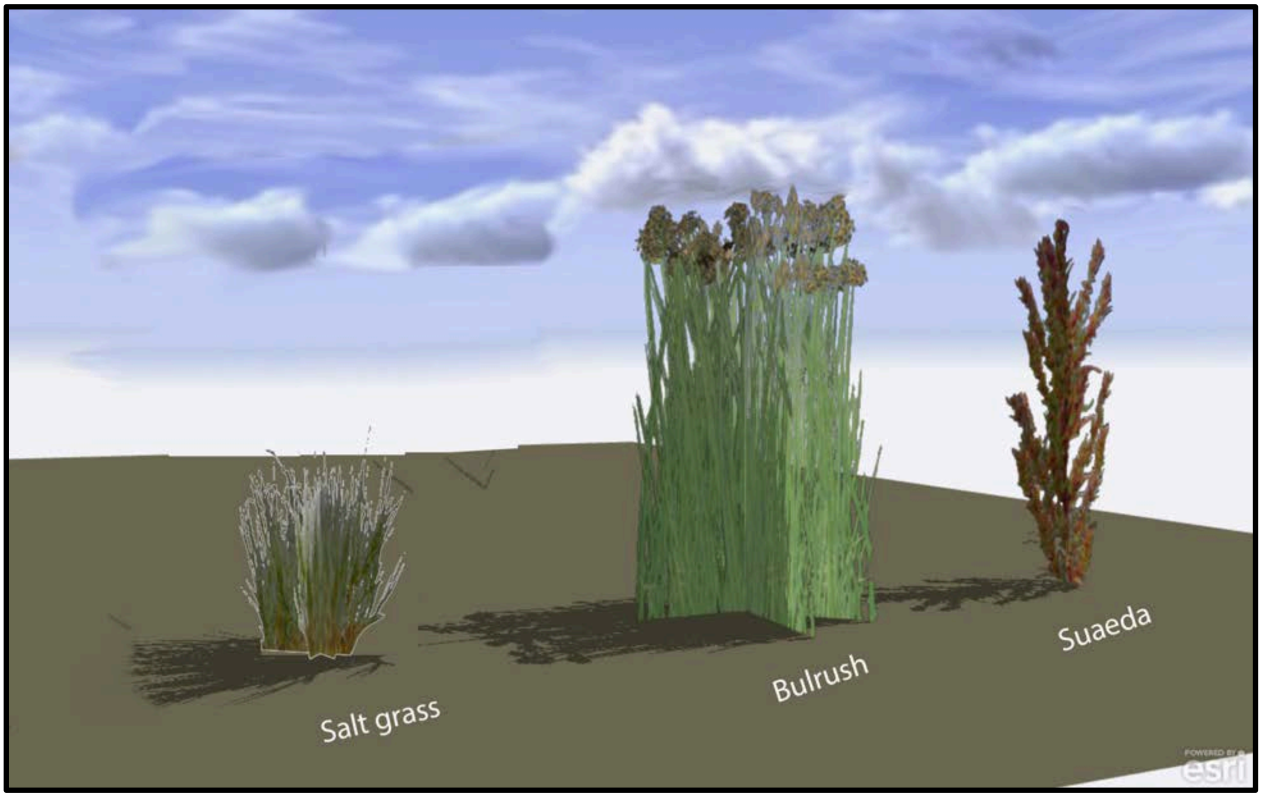


Figure 59. Scientific names of plant species listed left to right*: Distichlis spicata, Typha domingensis,* and *Amaranthaceae maritima*. The common names are listed below each plant.

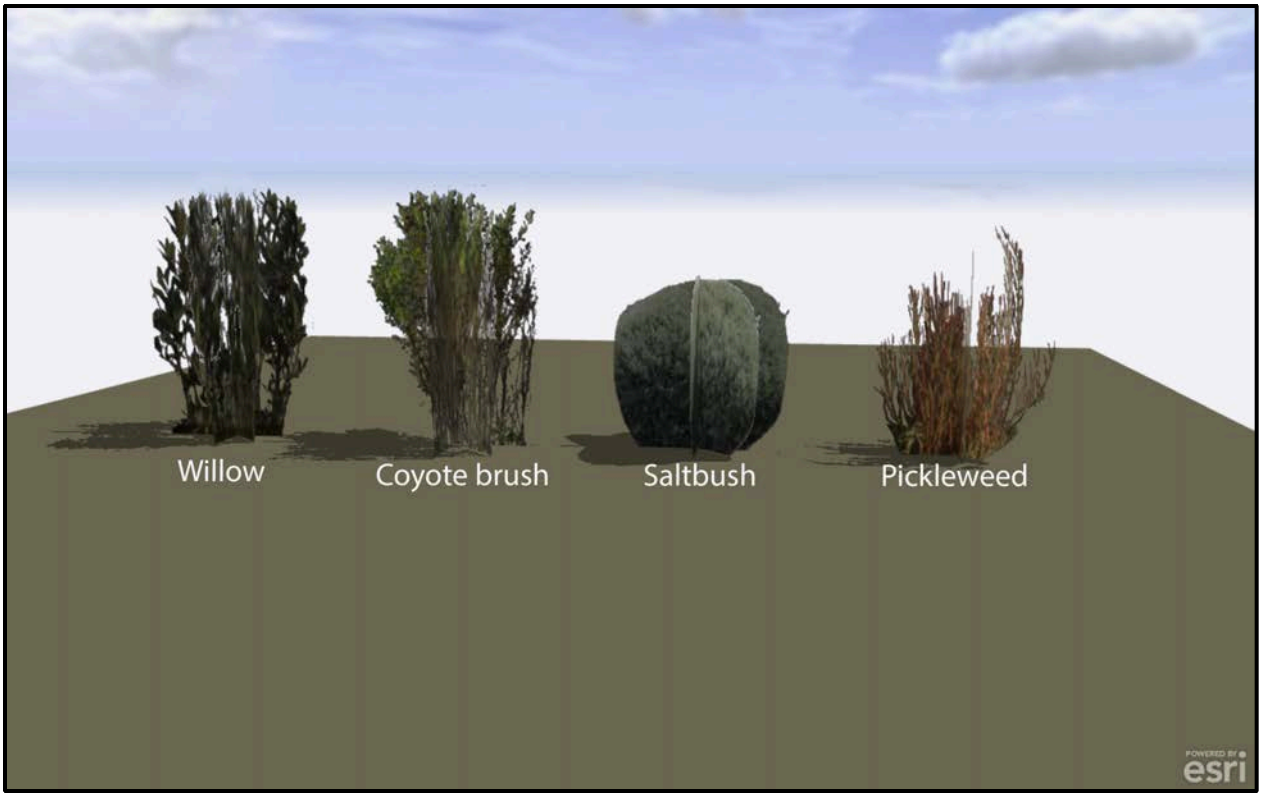


Figure 60. Scientific names of plant species listed left to right: *Salix lasiolepis, Baccharis pilularis, Atriplex lentiformis,* and *Salicornia virginica*. The common names are listed below each plant.

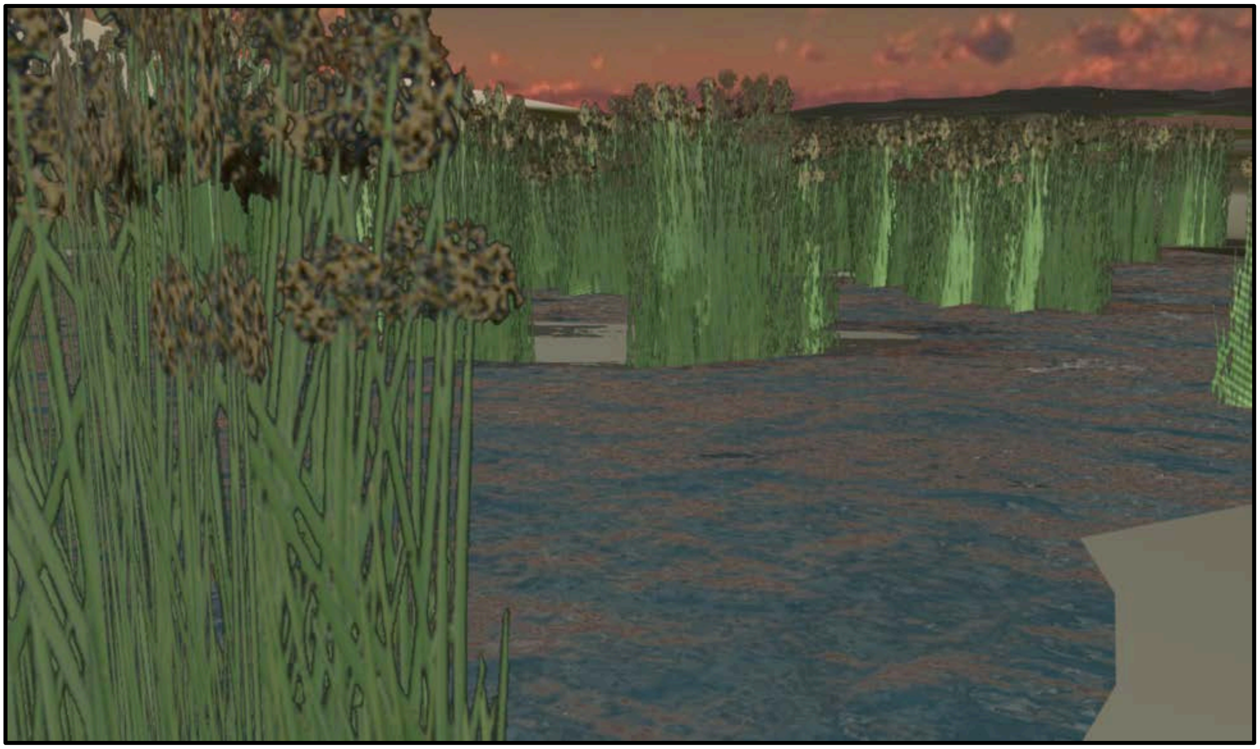


Figure 61. This is an example of mass modeling 3D plants (*Typha domingensis)* on the historical 3D terrain.

4.2.2.2 CityEngine Landscape Model

The 3D historical terrain was texturized with imagery and plant models to reconstruct the Ballona Wetlands (Figures 62, 63, 64). Views of heavily degraded habitats, such as the dunes and vernal pools, were captured in Figures 65 and 66, to suggest what these historical features looked like in the past. Several comparisons of the model to historical resources, such as maps (see Figure 67) and images, (Figures 68 and 69) were made to assess its realism and accuracy to the historical habitat. The model was compared to aerial imagery of Ballona Wetlands’ in 2103 to visualize the difference in its extent as shown in Figure 70.

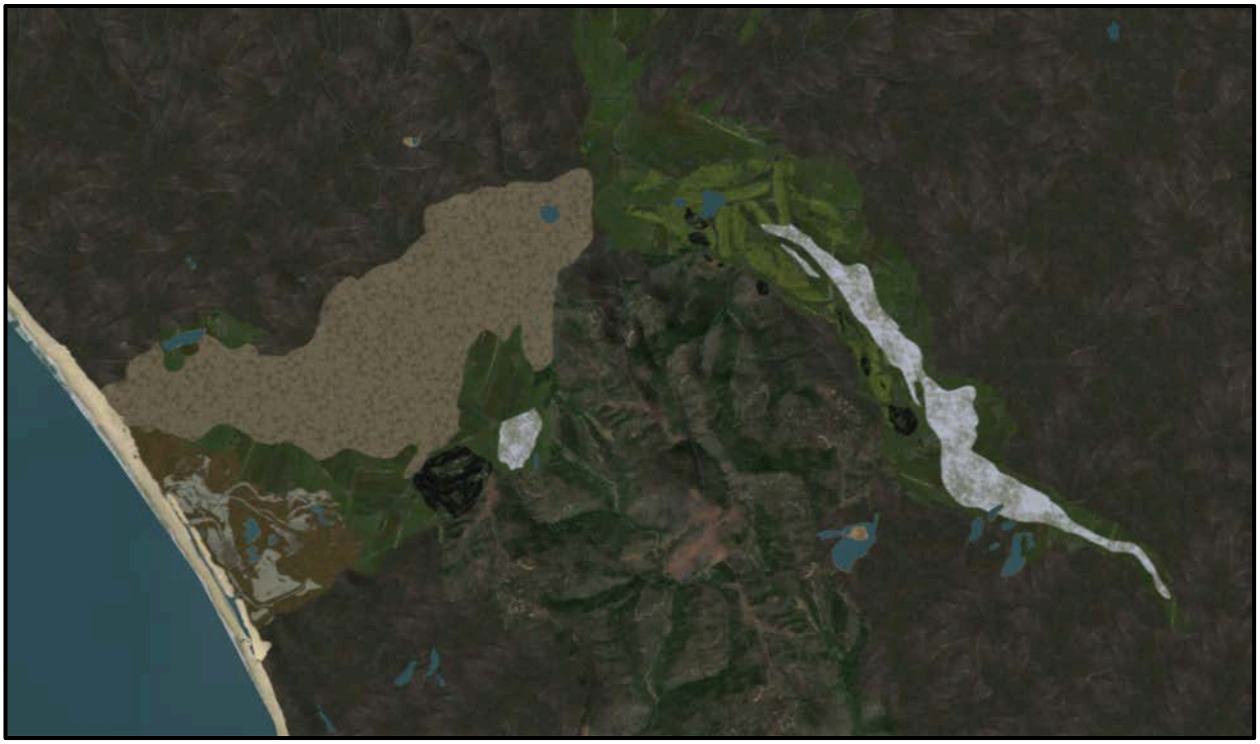


Figure 62. This is an example of an aerial view of the landscape model. Imagery from Google Earth was selected, from similar habitats and elevation, and edited to texture the historical 3D terrain.

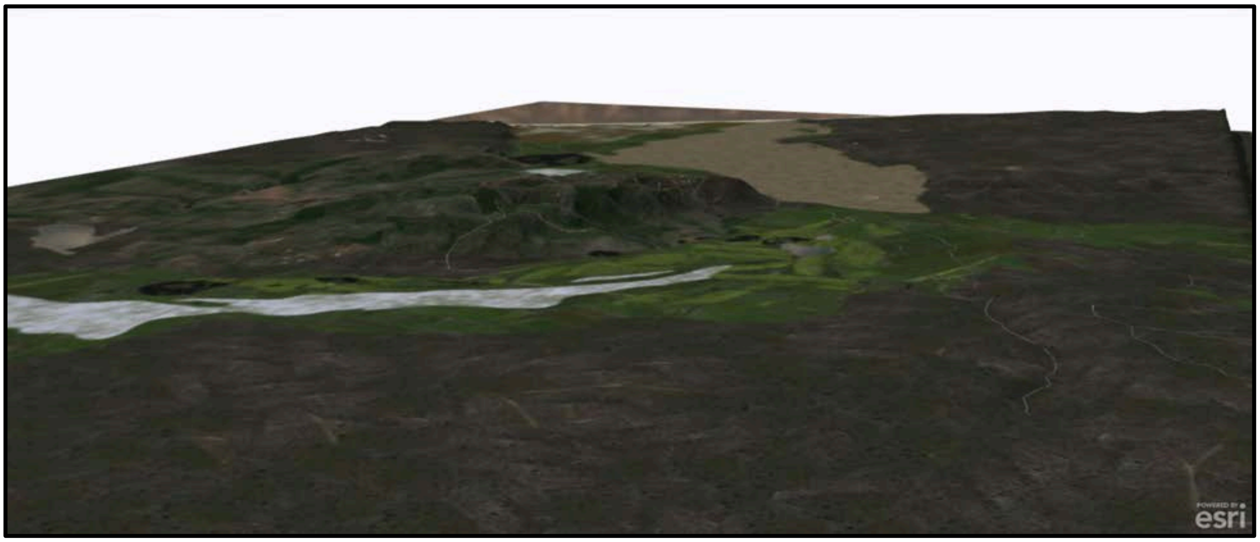


Figure 63. A view of the model that was angled west towards the Ballona Wetlands and the Pacific Ocean.

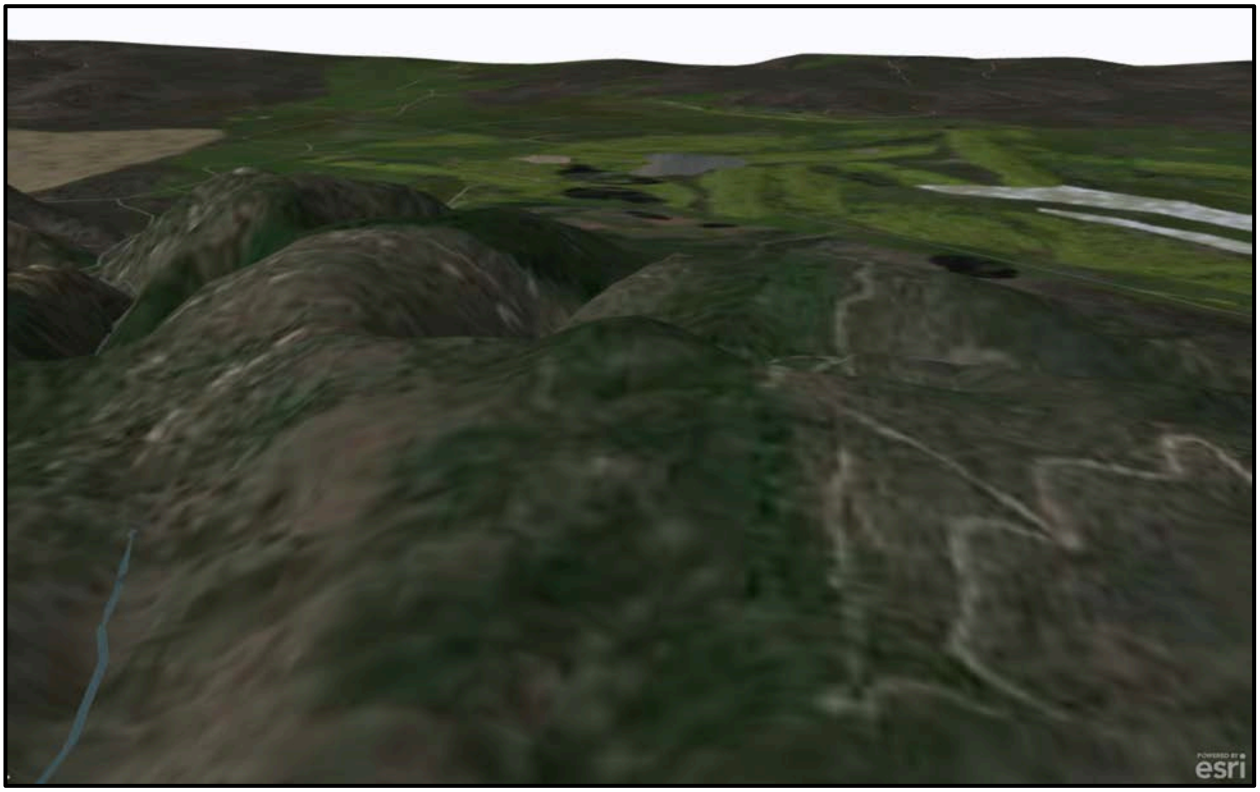


Figure 64. A view, which faced north-east, from the top of Baldwin Hills. Historically, this region was alkali meadows and valley freshwater marshes.

Figure 65. An image looking inland from the Pacific Ocean that suggested what the historical dunes looked like at Ballona Wetlands based on the 3D terrain.

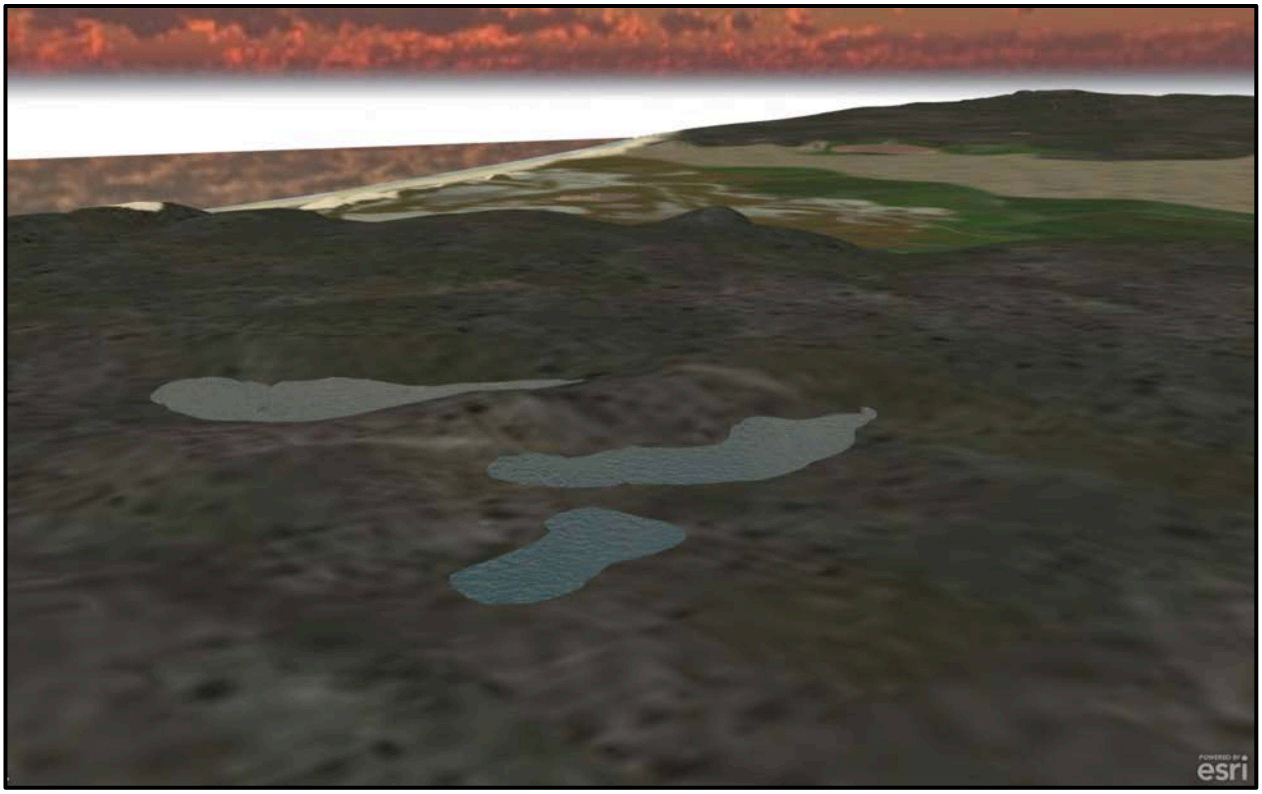


Figure 66. An example of the vernal pools on the Westchester bluffs, after a winter rain, overlooking the Ballona Wetlands. Their locations are from Dark et al. (2011).

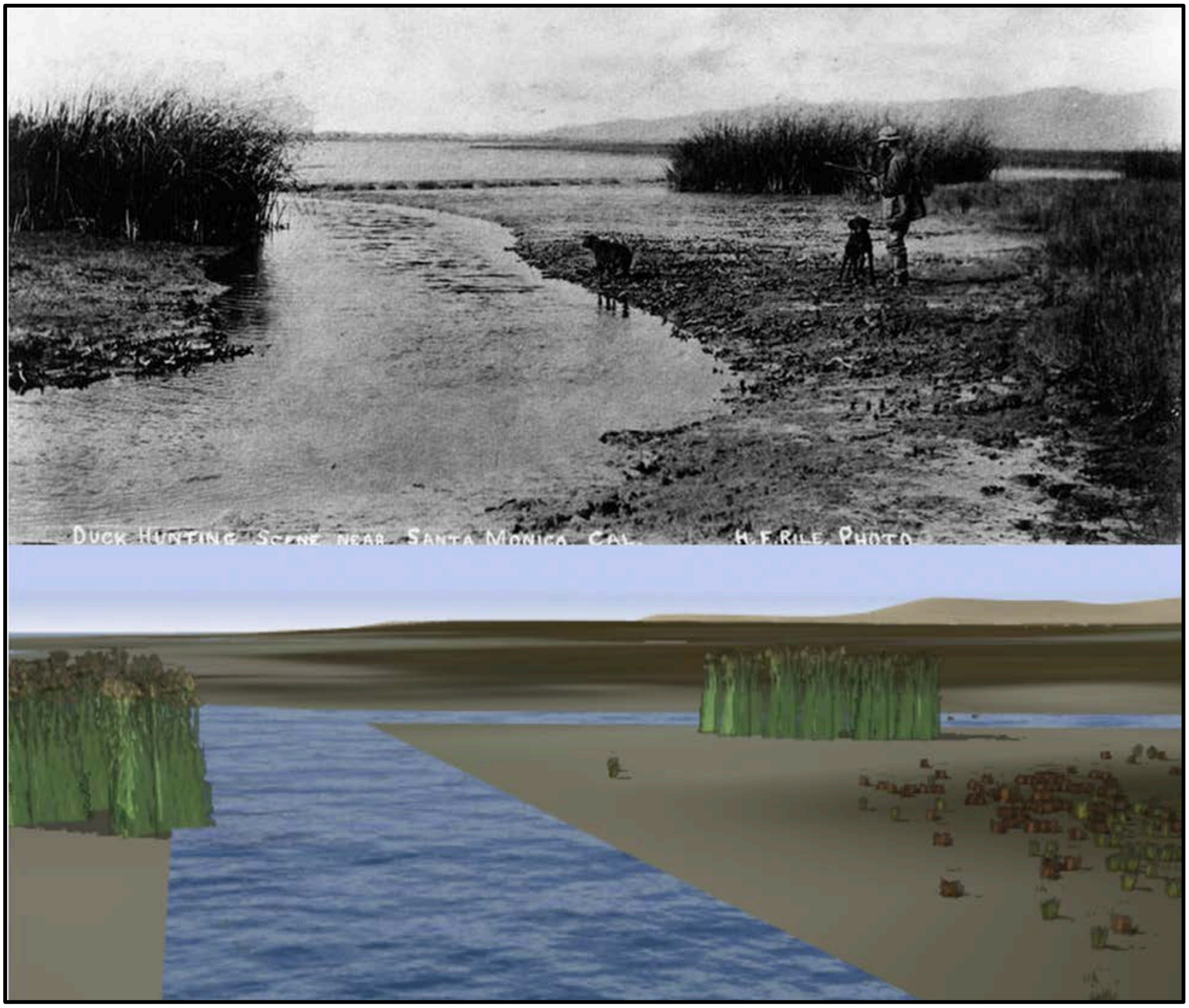


Figure 67. This was an example comparing a historical photograph from the Los Angeles Public Library of Ballona Wetlands and the CityEngine model. The stream's locations were derived from the topographic maps and the plants (Bulrush, Pickleweed, and Saltgrass) were based on the author's understanding of the area.

Figure 68. Another example of "Lake Ballona," comparing the CityEngine model to a historical photograph from the Los Angeles Public Library. The historical dunes' elevation information was derived from the topographic maps.

Figure 69. Comparison of the USGS 1896 Redondo topographic map and the CityEngine 3D model with historical habitats from Dark et al. (2011).

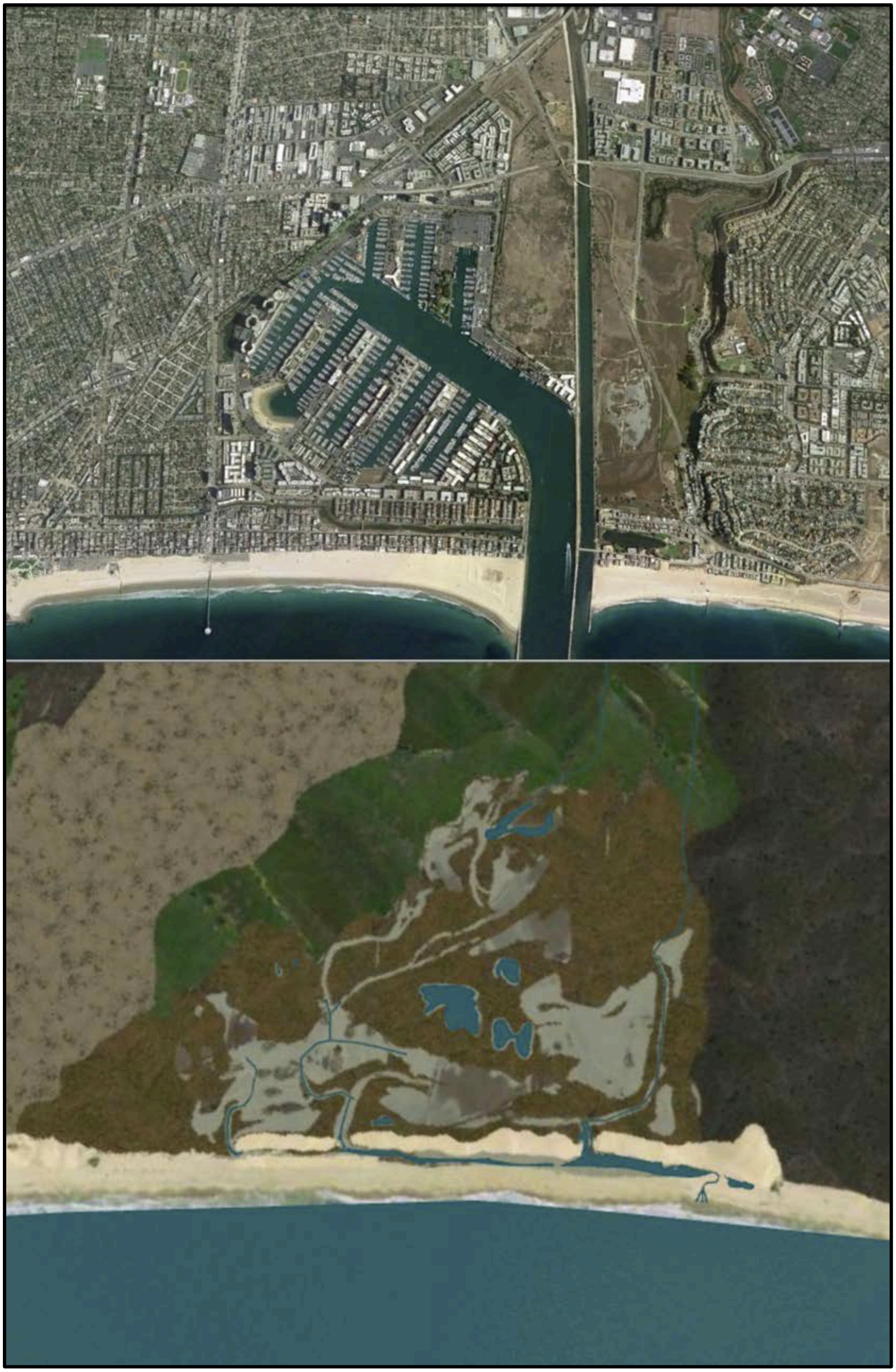


Figure 70. An aerial image of the 2013 extent of Ballona wetlands compared to the historical CityEngine 3D model.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

5.1 Conclusions

The results from this study illustrate a unique historical perspective of the late 19th century Ballona Creek watershed. These models suggest that the graphic editing and GIS techniques developed by this study are efficient in converting historical resources into valuable tools for environmental management. Preprocessing of the topographic maps with the open-source software GIMP contributed to previous studies that used pixel values to reduce undesirable map features. Easily replicated and requiring minimal expertise in raster image manipulation, the GIMP preprocessing techniques provide a methodology for extracting map information without proprietary software or complex algorithms. To improve GIMP's ability to isolate contour lines, the number of colors allotted in the transformation of the RGB image to an index image could be assessed. In this study, the maximum number of colors that can be assigned to an index image were used – 256 colors. However, fewer colors may require less testing of each pixel value and prevent the excess of colors from creating minute differences that may cause fragmentation of contour lines. Different color values could be selected and their outputs overlaid onto the topographic map, testing the efficiency and accuracy of GIMP in identifying contour lines at a particular value. A higher percentage of contour lines initially aligning with the topographic map would suggest a particular indexed value improves the likelihood of successfully extracting the contour lines in their entirety.

This study provides a robust methodology for generating a historical DEM based on heterogeneous historical resources. The results suggest that historical resources can be converted into the required GIS formats to produce a hydrologically-correct DEM. In this study, a 10-foot grid was used to generate the historical DEM's resolution to improve its ability to be compared to the Los Angeles County 2006 10-foot DEM. These comparisons are portrayed by the "Elevation Change Raster," which reflects the Ballona Creek watershed's transition from cattle-ranching to agriculture, and its history of extensive development. Comparisons between the historical and 2006 DEM highlight regions that have been relatively stable, for example the undisturbed salt marshes and pans at the Ballona Wetlands. The Ballona Creek watershed's history of human development is also visible in the "Elevation Change Raster." For example, the vernal pools that once existed according to Mattoni and Longcore (1997), and have since been destroyed by urban development, are identifiable by the increases in elevation at their known locations. Similarly, major freeways, which required extensive reshaping and leveling of the terrain, are distinguishable in the model by their linear patterns of increased and decreased elevation. Additionally, the "Elevation Change Raster" visualizes the tons of fill that were displaced from the construction of Playa del Rey and dumped into the remaining Ballona Wetlands. Analyzing the model's topography changes could also lead to identifying unknown historical features. The results of comparing the historical and 2006 DEM are best suited as environmental management tools for understanding human development processes and their affect on the terrain. Although this study calculated the change in elevation throughout the last century in the Ballona Creek watershed, the significance of the "Elevation Change Raster" is that it illuminates major trends in the topography. Inaccuracies introduced by the historical resources and their conversion into GIS datasets hinders the historical DEM from being used as a credible source for absolute elevation values. The historical DEM relies on elevation information comprised from the earliest forms of USGS topographic maps when they were created by field surveyors sketching the contours lines based on various tools for measuring vertical angles and point positions (Usery et al. 2009). Additionally, the topographic maps have different years of creation and contour intervals: 1894 Redondo (25 foot) and 1902 Santa Monica (50 foot). The differences between the two contour intervals are most apparent at the Baldwin Hills, where there is the greatest concentration of contour lines. The contour lines extracted from the topographic maps are the only source of elevation information for the historical DEM; their location is only based on the georeferenced maps. After being spatially adjusted, the vector contour lines were manually corrected to pair with contour lines found on the topographic maps. Differences in the thickness of the topographic map's contour lines affect the placement of the vector contour lines' vertices, location, and overall smoothness. These factors introduce location errors for the DEM, possibly by several meters.

This study contributed several techniques for improving 3D visualizations of historical landscapes. First, with landscapes lacking historical imagery to texture the surface of the 3D terrain, a workflow was designed to create texture files for CityEngine. This workflow provides proper instructions for generating a texture file, a void that needed to be filled to improve CityEngine's ability to model natural environments. Second, to overcome the ineffectiveness of the CityEngine vegetation library in modeling wetlands species, this study provides a detailed methodology for designing custom vegetation. Although only twelve plants were modeled for the Ballona Creek watershed, the methodology has the potential to produce all the vegetation for an environment model. Third, landscape visualizations require thousands of plants models to mimic ground cover species or to populate a large region. Future studies could build upon the mass modeling techniques of this study to further demonstrate the capabilities of CityEngine to replicate the dynamism and diversity of real world habitats.

Overall, the results from this study suggest 3D visualizations are a valuable tool for detecting elevation changes in the topography, identifying unknown historical features, and encouraging a deeper understanding of the importance of historical analysis. 3D visualizations provide a glimpse of how a historical landscape once looked and encourage viewers to understand the history and beauty of a landscape; this is especially important for severely degraded or damaged. When remnants of historical landscapes are visualized it educates environmental planners about their value and potential to be restored. For example, reconstructing the Ballona Wetlands' dunes challenges the perception of the landscape, guiding restoration efforts to include the historical features rather than abiding by traditional techniques. Environmental planners may be tempted to develop "intermittent streams and lacustrine fringe wetlands", an overly prescribed wetlands restoration plan, but historical analysis provides evidence for what features the landscape naturally supports (Stein 2010). Integrating historical 3D visualization information can prevent restoration projects from failing by introducing unnatural features. Historical 3D visualizations can model landscape functionality. For example, 3D visualizations that are built from hydrologically-correct DEMs can model hydrology functionality. How a historical landscape handled draining or flooding in the past can be modeled and analyzed, providing valuable information for restoration plans. 3D visualizations provide restoration projects with a historical benchmark, a tangible vision to direct restoration efforts. The imagination is spurred by the 3D visualizations – they create a vision of how urban development can coexist with natural environment.

5.2 Future Work

To improve the 3D model's hydrology analysis capabilities, the DEM's elevation pixels for streams and creeks should be individually evaluated. Specifically, confirming elevation pixels decrease in the direction of each hydrographic feature's drainage ensures proper stream and creek flow. A model based on an improved DEM provides a better understanding of how a landscape's historical watershed once appeared and functioned. Furthermore, hydrology restoration and conservation projects can use the model’s historical perspective to implement techniques that reflect an understanding of the complex relationship between the natural landscape’s past and current urban development processes. Similarly, the accuracy of the contour lines could be assessed for accuracy at the topographic map’s resolution. Variations in contour lines’ widths cause minute differences in the placement of the vertices when digitizing the lines by hand. These differences could potentially cause differences ranging from a few inches to several feet in the historical DEM. When assessing historical and contemporary DEMs, these subtle differences affect the overall confidence in the topography changes calculated from the comparison.

Further development of this study’s 3D environmental modeling techniques would continue to challenge CityEngine’s ability to visualize historical environments. This study’s twelve native vegetation models were merely an example of CityEngine’s potential to explicitly control the modeling of custom plants. A complete plant palette based on the vegetation documented in Dark et al. (2011) would be needed to truly model the historical habitats associated with the early 20th century Ballona Creek watershed. This study’s techniques for custom plant palettes would also enable environmental planners to accurately portray restoration and conservation vegetation goals by creating visualization that incorporate their proposed plant palette.

Modeling natural environments presents many challenges due to the wide spectrum of plant sizes and distributions. Plants can range in height from a few inches to several yards, and can be distributed uniformly, randomly, or clumped. The issue of scale forces the development of 3D model to evaluate and accept various tradeoffs. For example, in this study imagery was used to replicate uniformed habitats since CityEngine would crash when large regions were populated with hundreds of thousands of plant models. Improving the mass modeling of uniform vegetation species would enhance the realism of the model by providing a 3D textured surface for habitats compared to 2D imagery.

REFERENCES

Appleton, K., Lovett, A., Sunnenberg, G., and Dockerty, T. 2002. Rural Landscape Visualization from GIS Databases: A Comparison of Approaches, Options and Problems. *Computers, Environment and Urban Systems* 26: 141–62.

Chen, Y., and Wang, R., and Qian, J. 2006. Extracting contour lines from common-conditioned topographic maps. *IEEE Transactions on Geoscience and Remote Sensing* 44: 1048–1057

Chiang, Y.; S., L.; and Knoblock, C. A. 2014. A Survey of Digital Map Processing Techniques. *ACM Computing Surveys* 47(1):1--44.

Chiang, Y., Leyk, S., and Knoblock, C.A. 2013. Efficient and Robust Graphics Recognition from Historical Maps. *Proceedings of the 8th IAPR International Workshop on Graphics RECognition (GREC'13)* 7423: 23–35.

Dark S., Stein E.D., Bram D., Osuna J., Monteferante J., Longcore T., Grossinger R., Beller E. 2011). Historical ecology of the Ballona Creek watershed. Southern California Coastal Water Research Project. Technical Report #671.

Flaxman, M. 2010. GeoDesign: Fundamental Principles. Paper presented at the GeoDesign Summit, Redlands, CA. http://video.esri.com/watch/106/geodesign-fundamental-principles.

Goodchild, M. F., and D. M. Mark. 1987. The fractal nature of geographic phenomena. *Annals of Association of American Geographers* 77 (2): 265–278.

Grossinger, R., Striplen, C., Askevold, R., Brewster, E., Beller, E. 2007. Historical landscape ecology of an urbanized California valley: wetlands and woodlands in the Santa Clara Valley. *Landscape Ecol* 22:103-120 doi: 10.1007/s10980-007-9122-6.

Hall, Jr, Carlyle W. 2012. Protecting the Ballona Wetlands in West Los Angeles: A Look Back at Three Decades of Urban Habitat Advocacy, 6 Golden Gate U. Envtl. L.J., 25.

Hutchinson, M.F. 1989. A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. *Journal of Hydrology* 106: 211–272.

Khontanzad, A. and Zink, E. 2003. Contour line and geographic feature extraction from USGS color topographical paper maps. IEEE Transactions on Pattern Analysis and Machine Intelligence 25: 18–31.

Leyk, S. and Boesch, R. 2010. Colors of the Past: Color Image Segmentation in Historical Topographic Maps Based on Homogeneity. *GeoInformatica* 14(1): 1-21.

Maïm, J., Haegler, S., Yersin, B., Mueller, P., Thalmann, D., Van Gool, L. 2007. Populating Ancient Pompeii with Crowds of Virtual Romans. *Eurographics* 7.

Marsh, W.M. 2010. Landscape Planning: Environmental Applications. Hoboken, NJ. Jon Wiley and Sons 23-50.

Mattoni, R. and T.R. Longcore. 1997. The Los Angeles Coastal Prairie, a vanished community. *Crossosoma* 23(2):71–102.

Perkl, R. M. 2012. GeoDesign and Wildlife Corridors. *ArcNews* Summer Volume 34, No. 2.pdf

Reed, C. 2000. Importance of data integration and rendering to map visualisation. *GIM International* August, 50–53.

Sanderson, E. 2005. Urban Legend: Discovering Manhattan's Wetlands. *National Wetlands Newsletter* 27: 1, 15–17.

Sanderson, E. and Brown, M. 2007. Mannahatta: An ecological first look at the Manhattan landscape prior to Henry Hudson. *Northeastern Naturalist* 14: 545–570.

Sanderson, E. and LaBruna, D. 2005. Mapping the historical ecology and reconstructing the historical flora of the lower Bronx River: a guide for ecosystem restoration and outreach. New York City, NY: General Technical Report, Wildlife Conservation Society.

Scally, R. 2006. GIS for Environmental Management. Redlands, CA: Esri Press.

Shimizu, E. and Fuse, T. 2003. Rubber-sheeting of historical maps in GIS and its application to landscape visualization of old-time cities: focusing on Tokyo of the past. Proceedings of the 8th International Conference on Computers in Urban Planning and Urban Management.

Stein, E.D., Dark, S., Longcore, T., Grossinger, R., Hall, N., and Beland, M. 2010. Historical Ecology as a Tool for Assessing Landscape Change and Informing Wetland Restoration Priorities. *Wetlands* 30:589-601 doi: 10.1007/s13157-010-0050-x.

Stein, E.D., Dark, S., Longcore, T., Hall, N., Beland, M., Grossinger, R., Casanova, J., and Sutula, M. 2007. Historical ecology and landscape change of the San Gabriel River and floodplain. SCCWRP Technical Report #499. Southern California Coastal Water Research Project, Costa Mesa, California.

Usery, E., Varanka, D., and Finn, M. 2009. USGS History, Part 1: 1884–1980. *ArcNews* Fall 2009 Vol 31, No 3.pdf.

APPENDIX A: CITYENGINE CODE

Example of Vegetation Code:

```
version "2014.0"

attr height = rand(.005, .005)
attr wingWidth = rand(.05, .02)

Lot -->
	MakePart(0)
	MakePart(45)
	MakePart(90)

MakePart(rot) -->
	r(0,rot,0)
	s('1,0,0)
	center(xz)
	extrude(100)
	applyTexture("CoyoteBrush/coyoteBrush.tif")

dummy-->
s('1,height,'1)
#applyTexture("pickleweed.tif")
i("pickleweed.obj")

applyTexture(texfile) -->
	setupProjection(0, scope.xy, 1, 1)
	projectUV(0)
	normalizeUV(0, "uv", "separatePerFace")
	texture(texfile)
```

Vegetation Selector Code:

```
version "2011.1"


##############################################
# Attributes
#

# Driven by Object Attributes

@Group("ATTRS",1) @Order(1)
@Range("Trees","Shrub","Bush","Azalia","Iris","Fern","Rhododendron")
attr type = "Trees"

@Group("ATTRS",1) @Order(2) @Range(0,30)
attr height = 20

@Group("ATTRS",1) @Order(3) @Range(360)
attr ROTATION = rand(360)

# User Attributes

@Group("OPTIONS",2) @Order(1) @Range("low","high") @Description("High LOD only
available for Trees yet")
attr MODEL_LOD = "low"

@Group("OPTIONS",2) @Order(2)
attr MODEL_ASSET =
	case type == "Trees":
		case MODEL_LOD=="high": fileRandom("salt_bushv2_0.obj")
		else                  : fileRandom("salt_bushv2_0.obj")
	else:
		fileRandom("assets/vegetation/plants-billboards/"+type+"*.obj")

@Group("OPTIONS",2) @Order(3) @Range("Meters","Feet")
attr SIZE_UNIT = "Meters"

@Group("OPTIONS",2) @Order(4)
attr SIZE_RANDOMIZE = true

@Group("OPTIONS",2) @Order(5)
attr ROTATION_RANDOMIZE = true

##############################################
# Constants
#

const unitScale = case SIZE_UNIT=="Feet": 0.3048 else: 1
```

```
const randomScale = case SIZE_RANDOMIZE: rand(0.7,1.3) else: 1
const randomRotation = case ROTATION_RANDOMIZE: rand(0,360) else: 0


############################################
# Rules
#

@StartRule
Point -->
	alignScopeToAxes(y)
	s(0,height*unitScale*randomScale,0) center(xz)
	r(0,-ROTATION+randomRotation,0)
	i(MODEL_ASSET)
```

Mass Modeling Code:

```
version "2014.0"

attr numberPoints = 10000
attr groundHeight = 40
##attr place_on_terrain = yes

Init-->
        scatter(surface, numberPoints, uniform) { Leaf }
Leaf-->
        #translate(rel, world, 0, groundHeight, 0)
        i("tree_point_0.obj")
        s(0.5,0.5,0.5)
        t(0,groundHeight,0)
        ##s(0.2,0.3,0.1)
        color("#ff0000")
```