Hydrology Study of Cumulative Impacts for the Civic Center Area, Malibu, California

FINAL REPORT

Project ID 082026-W
August 27, 2010

This project was performed by Stone Environmental, Inc., McDonald Morrissey Associates, and Earth Consultants International for the City of Malibu, California.

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EXECUTIVE SUMMARY

In the summer of 2008, a groundwater modeling study to assess the overall impact of on-site wastewater treatment systems (OWTS) on the elevation of the water table in the Civic Center area was initiated by the City of Malibu. This study was conducted to address concerns expressed by the Los Angeles Regional Water Quality Control Board (LARWQCB) staff regarding groundwater mounding in the area. The project's cumulative approach was intended to enable the City of Malibu to consider off-site impacts of wastewater percolation from OWTS on the water table elevation beneath other existing and proposed projects. A consulting team consisting of Stone Environmental, Inc., McDonald Morrissey Associates Inc., and Earth Consultants International, Inc., with support from Land and Air Surveyors and Entrix, Inc. (the Project Team) was selected to complete the study.

A wide range of existing data regarding the Civic Center area's hydrology and hydrogeology were collected and assessed to inform the City of Malibu and its consultants in development of the conceptual and numerical groundwater flow models. The data collection area encompassed areas underlain by the alluvial groundwater flow systems in the Civic Center and Winter Canyon areas, as well as the surrounding upland areas that are underlain primarily by bedrock. The area included in the numerical groundwater flow model is limited to the locations of saturated alluvium. All horizontal position and elevation information for spatial data was provided in or converted to the horizontal datum North American Datum of 1983 (NAD 1983 or NAD83) and vertical datum North American Vertical Datum of 1988 (NAVD 1988 or NAVD88) for use in analysis, model construction, and model calibration.

Climatic data, including monthly precipitation and evapotranspiration information, were obtained from Pepperdine University's Malibu campus and from other sources as appropriate for the 2003-2009 simulation period. The simulation period includes an exceptionally wet season (the winter of 2004-2005), addressing concerns about the dynamic cumulative effects of both traditional OWTS with year-round discharge and Title 22 reuse systems with seasonal discharge during severe wet-weather stress conditions.

Hydrography, including stream channels within the study area and Lagoon boundaries, were updated to correspond to the new digital elevation model obtained for use in this study as the upper boundary to the numerical model. A search was conducted for surface water level measurements in Malibu Creek and Lagoon, but aside from the stream gage elevation information from the United States Geological Survey stream gage on Malibu Creek near Cross Creek Road, Malibu Creek and Lagoon water levels collected during the Risk Assessment study, and new measurements collected during this study, no existing surface water level measurements that could be used for modeling purposes were discovered. Information about whether the barrier beach separating Malibu Lagoon from the Pacific Ocean was open or closed during the simulation period was collected from log books obtained from the Los Angeles County lifeguard station at Surfrider Beach, and used to determine stress periods and controls on Lagoon stage in the model.

The extents and bottom elevations of excavations into which storm drainage infrastructure was installed were digitized, where known or available from design or as-built drawings, and were compared to water table elevations as recorded in monitoring wells located nearest the route of each mapped drain. There is some evidence that storm drainage infrastructure in the Civic Center alluvial area has a localized and minor effect on ground water elevations. However, the impact does not rise to a level of significance that necessitates the inclusion of storm drain infrastructure in the groundwater flow model. In addition, the design of the Legacy Park detention basin includes an impervious liner; since there will be no significant infiltration from the basin that might result in artificial recharge to the groundwater flow system, the basin was not considered as input to the model.

Final approval drawings from 230 systems (in addition to the records for 143 systems that were included from the Risk Assessment data collection effort) were georeferenced and the locations of OWTS components were digitized. Approximately 407 parcels with OWTS are located in the study area, 347 of which serve single family residential dwellings, and 49 serve commercial, institutional, and multifamily occupancies. There are three offsite wastewater treatment systems located on parcels separate from the wastewater generation sources, which serve a total of 11 parcels. Two of these systems are shared systems with discharge locations in Winter Canyon, while the third is the Los Angeles County Malibu Administrative Complex on Civic Center Way. Permit data and/or approval drawings were available for 297 (or approximately three quarters) of the OWTS in the study area—a significant improvement over the inventory completed in 2001-2002, when permit data or approval drawings were available for about one quarter of the systems in the study area. Information about OWTS throughout the City of Malibu is also available through the City’s web-based Integrated Wastewater Information Management System (IWIMS).

Specific and accurate estimates of water use and discharges to OWTS were a key component of simulating existing conditions in the Civic Center Area and of predicting the potential impacts of potential municipal wastewater treatment and reuse systems with soil-based discharge. Water use data provided by the County of Los Angeles Department of Public Works Water District #29 were aggregated by subareas within the study area to provide a more accurate estimate of actual wastewater flows, and to assess whether significant irrigation was occurring that needed to be accounted for in the model. Based upon the low-irrigation season water use data for Malibu Colony, a 400 gpd per household value for residential water recharge from OWTS was applied in the model for residential OWTS throughout the study area. In residential areas outside of Malibu Colony, per-household water usage in excess of 400 gpd was assumed to be used for irrigation and was therefore applied as irrigation rather than as infiltration from OWTS. For modeling purposes, it was assumed that reported water use on commercial properties (excluding nurseries, golf parks, and areas with extensive turf), and on multi-family properties, was utilized within buildings and dispersed through OWTS. If a nursery or property with significant turf contained a residence, it was treated as a residential property. Otherwise, all water use on the property was assumed to be used for irrigation.

Existing information regarding area geology and hydrogeology was synthesized from geologic, geotechnical, and hydrogeologic reports on file with the City of Malibu, as well as from compliance reports provided by the Los Angeles Regional Water Quality Control Board and unpublished hydrogeologic reports. In total, data were entered from 930 boring locations (including 383 from the Risk Assessment study) and 1148 test pits and/or trenches (including 628 from the Risk Assessment study). Although the number of available stratigraphic logs in the Civic Center area more than doubled since 2002, the vast majority of recent borings in alluvial areas did not advance to bedrock. While these stratigraphic logs provided valuable information about details of the alluvial area’s surficial geology, little additional information was uncovered about the elevation of bedrock underlying the Civic Center and Winter Canyon alluvial areas. Hydrogeologic information was entered for 232 monitoring wells, 98 of which were digitized or installed during the Risk Assessment study. Compliance reports submitted to the LARWQCB included well construction details and water level measurements that filled some gaps in the network of wells developed during the Risk Assessment study, particularly in Winter Canyon and in the vicinity of the current and former Chevron gas stations.

Examination of existing information sources led to the refinement of the narrative, conceptual understanding of the groundwater flow system underlying the Malibu Civic Center area and Winter Canyon, and to the identification of gaps in the existing datasets. Critical data gaps included a shortage of deep soil borings and other information regarding depth to bedrock in the active model area, and a lack of consistent topographic survey data for existing monitoring wells and water levels collected from multiple data sources and regulatory agencies.

New data collected during this study included intermittent and synoptic water level measurements, a new survey of monitoring well locations and elevations, and a seismic geophysical survey.

Water table measurements were collected at up to 66 monitoring wells and in Malibu Lagoon on 12 occasions, generally a month or more apart. The intermittent water level measurements and Lagoon stage measurements were utilized primarily in model construction and calibration. Synoptic water level data were collected on December 8, 2009 under open Lagoon (breached barrier beach) conditions. A water table contour map was developed to show overall water table contours under open Lagoon conditions. Water table elevations during this synoptic water level measurement event were slightly higher than those measured during the last synoptic event completed under breached barrier beach conditions in March 2004.

In order to utilize historic existing water level measurements as targets for model calibration, over 50 monitoring wells were re-surveyed in March 2010, and well construction details and calculated water table elevations were updated as appropriate.

A Multi-Channel Analysis of Surface Waves (MASW) seismic geophysical survey was conducted in the Civic Center alluvium and in the Winter Canyon alluvium in March 2010. The goal of this task was to increase the degree to which the lower model boundary reflected actual subsurface conditions. The MASW method uses ambient seismic waves, such as those generated by traffic on the Pacific Coast Highway, and has generally been useful in mapping bedrock surfaces to depths of 200 feet, and in locating zones of low density soils such as sand units. The MASW geophysical survey provided valuable information about the boundary between alluvial deposits and the underlying bedrock. The depth to bedrock as determined by the MASW survey near two transect lines running parallel to the Pacific Coast Highway in the Civic Center alluvium and at two points in northern Winter Canyon ranged from about 20 to 200 feet below land surface. The elevation of the bedrock surface in areas covered by the survey ranged from about 100 feet NAVD 1988 to about -200 feet NAVD 1988. The deepest portion of the bedrock valley beneath the Civic Center alluvium appeared to be just west of the intersection of the Pacific Coast Highway and Webb Way, although the elevation of the valley floor was expected to deepen further toward the ocean. Two of the transect lines located in Winter Canyon and the northernmost transect line completed in the Civic Center alluvium did not produce results that were acceptable for modeling purposes, and were not included in the model.

A numerical model was constructed to simulate groundwater flow in the alluvial deposits along Malibu Creek and Malibu Lagoon near the Malibu Civic Center area, and in Winter Canyon to the west of the Civic Center alluvium. The Project Team created a transient groundwater flow simulation with a monthly time step for the years 2003-2009. The transient model simulation, once calibrated to current conditions, was applied to the evaluation of three municipal wastewater collection and dispersal scenarios in order to provide preliminary assessment of the effect of municipal waste water dispersal options on the water table and to guide more detailed hydrogeologic investigations for proposed municipal dispersal sites. The three scenarios evaluated included:

- Scenario #1: 62,800 gallons per day of waste water collected from commercial properties in the Civic Center area and dispersed seasonally (October-March) at the Winter Canyon location now used by the Malibu Bay Company, in addition to the approximately 30,000 gpd already being treated and dispersed at the existing facility. Other existing discharges occurring elsewhere in the Winter Canyon alluvium and surrounding upland areas were unchanged in this scenario, and so these discharges were continued throughout the simulation period.
- Scenario #2: 50,000 gpd of waste water was collected from residential properties located along Cross Creek Road and in the Serra Retreat area (generally those within the area that contributes groundwater flow to Malibu Creek and Lagoon), and dispersed on the northern part of the Lower Yamaguchi parcel (west of Stuart Ranch Road).
- Scenario #3: Scenarios #1 and #2 were run simultaneously in order to evaluate the cumulative effects of both strategies.

Modeling results suggest that a seasonal loading rate of an additional 63,000 gallons per day, as described in Scenario #1, may be possible at the Winter Canyon location. The limiting factor in Winter Canyon is likely to be water level increases in the southern part of the Canyon where the water table is closest to land surface, especially during high water periods such as the one experienced in 2004-2005. Model results further suggest that a loading rate of 50,000 gallons per day on the Lower Yamaguchi parcel, as described in Scenario #2, could cause groundwater levels to reach or nearly reach land surface, especially during a very wet period like 2004-2005. However, there are no site-specific characterization data, such as deep borings or wells, on the Lower Yamaguchi site that would more precisely inform the model predictions. The cumulative impact of the two scenarios combined, as in Scenario #3, is minimal. Since the two discharges were applied in alluvial areas that are separated from each other by a bedrock ridge, this result is expected and reasonable.

The calibrated transient simulation developed during this project is a powerful analytical model that can now be applied to evaluate other scenarios for reclaimed water dispersal, in conjunction with the design of a municipal wastewater reclamation/dispersal alternative within the Civic Center and Winter Canyon areas. The model is, and will remain, an effective tool for the City's use in the development of its Wastewater Management Plan for the Civic Center Area.

The following recommendations are offered for the City's consideration:

Additional field testing should be conducted on any specific proposed municipal reclaimed water dispersal site, such as in Winter Canyon, to verify the area's capacity to accept additional reclaimed water. Field verification should include definition of the bedrock surface, measurement of groundwater levels in bedrock and the alluvium, delineation of subsurface stratigraphy, and a full scale hydraulic loading test with detailed monitoring of surrounding water levels. These data, along with design details for any proposed dispersal system, will allow a more definitive evaluation of the ultimate waste water dispersal capacity in Winter Canyon and in other areas.

Additional field work is necessary to characterize subsurface conditions at the Yamaguchi parcel if any municipal reclaimed water dispersal is to occur, particularly with regard to the horizontal and vertical extent of the underlying Civic Center gravel, connection with the ocean, and characterization of groundwater elevations beneath the site. The northern portion of this parcel may have some capacity to disperse reclaimed water, but the property's capacity appears to be less than 50,000 gallons per day.

Groundwater levels in the network of monitoring wells established during this project, or a representative subset of these wells, should be measured monthly on a routine basis. Lagoon stage should also be monitored monthly or more frequently. These data are invaluable to ongoing and future analyses of municipal waste water dispersal strategies, and significant gaps in these datasets should be avoided if at all possible. Similarly, collection of weather data from Pepperdine University and water use data from Water District #29 should be continued and incorporated into future modeling applications.

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1. INTRODUCTION

The City of Malibu (Malibu) has long placed a priority on appropriate use of on-site wastewater systems for treatment and reuse of valuable water resources. From 2001 through 2004, Malibu conducted a study entitled, “Risk Assessment of Decentralized Wastewater Treatment Systems in High Priority Areas in the City of Malibu, California” with funding from the Santa Monica Bay Restoration Commission (SMBRC) (Stone Environmental, 2004). The study (referred to here as the Risk Assessment) used a three-dimensional, steady-state numerical modeling tool to evaluate the impacts of on-site wastewater treatment systems (OWTS) on groundwater quality and to delineate directions of groundwater flow from major wastewater dispersal areas. The outcomes of the Risk Assessment were used to refine Malibu’s citywide wastewater management program. In 2005, the modeling work completed for the Risk Assessment was expanded to estimate nitrate loading to Malibu Lagoon from a range of municipal wastewater reclamation and dispersal alternatives (Questa Engineering, 2005). In addition, Malibu has been developing a facilities plan for a municipal wastewater collection and reclamation system since 2006.

In the summer of 2008, a cumulative groundwater mounding study was requested by the Los Angeles Regional Water Quality Control Board (LARWQCB) to assess the overall impact of proposed wastewater percolation systems on the elevation of the water table in the Civic Center area (Figure 1). The cumulative approach of this study would enable the City of Malibu to consider off-site impacts of wastewater percolation on the water table elevation beneath other existing and proposed projects. This study was designed and implemented to focus on the impacts of existing and potential future wastewater recharge quantity from many geographically distributed on-site wastewater treatment systems (OWTS) on groundwater elevations. A consulting team consisting of Stone Environmental, Inc. of Montpelier, Vermont (Stone), McDonald Morrissey Associates Inc. of Concord, New Hampshire, Earth Consultants, Inc. of Santa Ana, California (ECI), and Land & Air Surveying, Inc. of Malibu, California—referred to in this report as the Project Team—was selected to complete the study, referred to here as the Malibu Hydrology Study.

The Malibu Hydrology Study was designed and implemented to include essentially the same geographic area encompassed by the 2004 Risk Assessment Study (Figure 1). The study area encompasses the alluvial groundwater flow systems in the Civic Center and Winter Canyon areas, as well as the upland areas of the watershed that are underlain primarily by bedrock. The area included in the numerical groundwater flow model is limited to locations where saturated alluvium is present (Figure 2).

During the data collection and model construction phases of the study, a combination of steady-state and transient modeling was added to the original scope of work in order to evaluate the transient cumulative effects of OWTS dispersal under the stress of seasonal high water level conditions. This approach was incorporated to address LARWQCB staff concerns regarding several then-proposed Title 22 wastewater reclamation/reuse systems within the Civic Center area. These systems tend to have minimal and intermittent discharges, compared to the more consistent discharges expected from traditional on-site wastewater treatment systems. The Project Team proposed, and the City agreed, to utilize a steady-state simulation to evaluate continuous wastewater dispersal, and transient simulations to evaluate short term wastewater dispersal. The results of the simulations would then be combined and superimposed on a map of high groundwater level conditions, and the resulting water table map could be used to estimate depths to groundwater below the ground surface during a high groundwater stress condition.

As data collection and analysis efforts progressed, the Project Team determined that sufficient datasets existed to create a transient groundwater flow simulation with a monthly time step for the years 2003-2009. The simulation period includes an exceptionally wet season (the winter of 2004-2005), addressing concerns about the dynamic cumulative effects of both traditional OWTS with year-round discharge and Title 22 reuse systems with seasonal discharge during severe wet-weather conditions. This transient simulation more accurately represents actual groundwater flow conditions and therefore replaces the superimposed transient/steady-state approach that was originally proposed.

In November 2009, the LARWQCB adopted Resolution No. R4-2009-007, “Amendment to the Water Quality Control Plan for the Coastal Watersheds of Ventura and Los Angeles Counties to Prohibit On-site Wastewater Disposal Systems in the Malibu Civic Center Area”. Partially in response to this Prohibition, the Project Team’s focus shifted from modeling the impacts of potential future development projects such as the Malibu Lumber OWTS to modeling the impacts of potential municipal-scale soil-based dispersal systems.

This final report summarizes the work completed over the course of the Malibu Hydrology Study:

- Section 2 summarizes the methods employed to collect and analyze datasets for model construction, as well as the methods utilized for construction, calibration, and application of the numerical groundwater flow model.
- Section 3 summarizes the results of data collection and assessment processes, as well as the results of application of the numerical model to three potential municipal wastewater dispersal scenarios.
- Section 4 contains the conclusions and recommendations of the study.

The appendices to this report include detailed supporting information:

- Description of the numerical groundwater flow model, including development of the conceptual model, model construction, application, and conclusions of the modeling effort, is included in Appendix A.

- The methodology for and results of the Multi-Channel Analysis of Surface Waves (MASW) geophysical survey, completed during this study in an effort to better understand depths to bedrock beneath the Civic Center alluvium, are included in Appendix B.

2. METHODS AND PROCEDURES

The data collection and analysis processes, methods, and procedures utilized during this study are described in the following section. Briefly, Section 2.1 lists and describes the existing information sources that were examined to create a narrative, conceptual understanding of the groundwater flow system underlying the Malibu Civic Center area and Winter Canyon. A short description of the conceptual model and data gaps uncovered during the assessment of existing datasets is included as Section 2.2. The methods employed in the collection of new data and in groundwater flow model construction and application are described in Sections 2.3 and 2.4, respectively.

2.1. Data Collection from Existing Datasets and Records

A wide range of existing data regarding the Civic Center area's hydrology and hydrogeology were collected and assessed, as described below. The assessment and analysis of these datasets, and their applicability to model development, are discussed in Section 3. The extent of the area over which information was collected in order to inform the groundwater flow model is shown in Figures 1 and 2. Unless otherwise specified, all position and elevation information was provided in or converted to the horizontal datum North American Datum of 1983 (NAD 1983 or NAD83) and vertical datum North American Vertical Datum of 1988 (NAVD 1988 or NAVD88) for use in analysis, model construction, and model calibration. Where applicable, GIS datasets, database files, and tabular datasets were constructed or revised as described below.

2.1.1. Climate

Precipitation and evapotranspiration datasets collected during 2002-2003 were updated to include information through the end of 2009. The nearest local source of this information is Pepperdine University's monitoring program, which includes precipitation, soil moisture, groundwater levels, and runoff and has been in operation since 1997 (Figure 2). The University's annual Hydrogeologic Monitoring Program Reports, and relevant datasets therein, were obtained with the University's permission (Daniel B. Stephens & Associates, Inc 2006, 2007a, 2007b, 2007c, 2008, 2009, and 2010).

Climate information from nearby climate data collection sites, including Santa Monica Pier (station 047953), and the LA County Department of Public Works' Big Rock Mesa precipitation gage (near-real-time station, alert ID 320) were also obtained and reviewed.

2.1.2. Topography

An aerial topographic survey for the Civic Center area was completed in 2005-2006, from which a digital elevation model (0.91-foot vertical accuracy at 95% confidence level) was produced (LAR-IAC, 2006). The digital elevation model is a proprietary dataset provided courtesy of the Los Angeles Region Imagery

Acquisition Consortium (LAR-IAC) and Infotech Enterprises America Inc.. This dataset was obtained under license from Infotech Enterprises America for use in mapping and model construction.

2.1.3. Surface Water (Hydrography)

The digitized stream channel for Malibu Creek created during the Risk Assessment study (Stone Environmental, 2004) was updated to correspond to the new digital elevation model (Section 2.1.2) and to account for recent stream channel migration. The digitized stream channels for Winter Canyon and the unnamed stream north of Serra Retreat were similarly updated (Figures 1 and 2).

The digitized shoreline boundaries of Malibu Lagoon during breached and flooded conditions were updated from those digitized during the Risk Assessment study (Stone Environmental, 2004), in order to account for the condition of the Lagoon following restoration efforts and to correspond to the new digital elevation model (Section 2.1.2). Updates were based on the ranges and averages of measured Malibu Lagoon elevations and 2-foot topographic contours generated from the digital elevation model, and the boundaries were confirmed by comparison with historical orthophotographs taken between 2003 and 2009. The Lagoon boundary for the breached condition was digitized at the 4-foot elevation contour (NAVD 1988 vertical datum) or based on 2007 orthophotography, whichever boundary appeared to be lower or smaller. The flooded condition Lagoon boundary was digitized generally at the 8-foot elevation contour.

Stream gage height and discharge information from the United States Geological Survey stream gage on Malibu Creek near Cross Creek Road (station ID 11105510) was collected for the station's period of record, beginning in December 2007 (US Geological Survey, 2010). The stream gage datum is reported by the USGS as NGVD 1929, so gage elevation and water surface elevations were converted to vertical datum NAVD 1988 for analysis and modeling use.

Automated observations of surface water elevations were intermittently collected by Las Virgenes Municipal Water District (LVMWD) staff in 2003-2004 in Malibu Lagoon at the Pacific Coast Highway bridge (Stone Environmental, 2004). The water depths in the raw data files provided by LVMWD were converted to water table elevation for the Risk Assessment modeling effort. Similar raw data files containing water level data were provided to the project by LVMWD for 2004-2009. However, the raw data files could not be converted accurately to Lagoon surface elevation and were not evaluated further or used in model construction.

Information regarding the dates during which Malibu Lagoon was breached or flooded was collected from the daily log books maintained at the lifeguard station on Surfrider Beach (County of Los Angeles, 2003-2009).

2.1.4. Stormwater Management Systems

Information about both current and proposed stormwater collection and detention infrastructure in the Civic Center area, as well as information about discharge flows from the existing stormwater treatment system near Malibu Creek, was collected and evaluated.

Design and/or record engineering drawings for stormwater collection features located along Civic Center Way, Cross Creek Road, and Pacific Coast Highway were obtained from the City of Malibu (County of Los Angeles 1964a and 1964b, County of Los Angeles Flood Control District 1981). The design drawings were georeferenced, and the extents of excavation into which the drains were installed were digitized (Figure . The bottom elevations of the excavations, where these elevations could be obtained from the plans, were converted from NGVD 1929 vertical datum to NAVD 1988 and retained in GIS.

The storm drains along Cross Creek Way and the Pacific Coast Highway appear to have been constructed differently than as represented in the design drawings. At the least, the plan drawings could not be georeferenced to completely line up with known surface features (driveways, debris basins, etc.). The digitized polygons for the 'drains' (bottom of excavations housing the storm drain pipes) compromise between a computer-aided design (CAD) file provided by the City showing extent of drains (City of Malibu 2008), and the design drawings with extents and bottom elevations of the excavations. The digitized drains for these drains should be considered planning-level information, and may not accurately reflect what was constructed.

The georeferenced design drawing for the storm drain that runs beneath and parallel to Civic Center Way corresponded reasonably well with known surface features and with the CAD file provided by the City, as far west as the intersection of Civic Center Way and Stuart Ranch Road. The CAD file indicates a 36"-45" drain running the length of Stuart Ranch Road which drains south to the Civic Center Way drain. However, no design drawings were available for this drain, so the bottom elevation or extents of any excavations associated with this drain could not be determined.

Two other drains are shown in the CAD file provided by the City which may be of interest. One begins at the intersection of Malibu Road and Webb Way, and drains south through Malibu Colony to the Pacific Ocean. The other is located south of the Pacific Coast Highway, between the Cross Creek Road intersection and the Lagoon. However, no design drawings are available for either of these drains, so limits of construction excavation and/or excavation bottom elevations could not be estimated.

Although the design of the stormwater detention basin at Legacy Park continued to evolve during the data collection phase of this project, design drawings and site plans were obtained from RMC Water and Environment and the City of Malibu (RMC 2009) and the bathymetry of the detention basin was evaluated.

The City of Malibu maintains a stormwater treatment facility located on the Civic Center Way storm drain, near the intersection of Civic Center Way and Cross Creek Road. Flows through the facility are metered, and recorded approximately weekly. The facility was brought on line in April 2007. The weekly metered flow data was obtained in electronic format from the City of Malibu (City of Malibu 2009) and the values were converted to units of gallons per day for assessment.

2.1.5. On-site Wastewater Treatment System (OWTS) Data

Existing data regarding OWTS were updated to confirm design flows and dispersal field locations. System approval drawings were obtained electronically from the City of Malibu for OWTS constructed after June 2002, which was the end of the data collection effort for the Risk Assessment study (Stone Environmental 2004). In addition, a significant number of quarterly compliance reports for WDR-permitted systems were made available to the project team by the Los Angeles Regional Water Quality Control Board in September-October 2008. These documents were scanned at the Regional Board offices, and were organized by site and system.

Assessor's data for the study area was obtained from the City of Malibu. Parcel and structure data were imported into an MS Access database to serve as the foundation for collecting and locating existing OWTS data. Approval or as-built drawings from the City and Regional Board files were georeferenced and the locations of OWTS components, including dispersal fields, were digitized in GIS where such data were not already included in the City's datasets or in the City's Integrated Wastewater Information Management System (IWIMS). Relevant system information, including design flows and dispersal system bottom depths or elevations where available, was added to the existing database.

Final approval drawings from 230 systems (in addition to the records for 143 systems that were included from the Risk Assessment data collection effort) were georeferenced and the locations of OWTS components were digitized in GIS as shown on Figure 8. Boring locations and test pit locations shown on site plans were also digitized in GIS where encountered (see Section 2.1.7.1). Table 1 includes a description of each property's use and OWTS system type within the study area.

Data regarding the horizontal extent and location of many OWTS were available. However, as was noted during the Risk Assessment, data regarding the vertical dimension of on-site systems was often not readily available since that information is generally not submitted with OWTS permit applications (Stone Environmental, 2004).

2.1.6. Water Use

Aggregated water use data were requested from and were provided by the County of Los Angeles Department of Public Works Water District #29 (County of Los Angeles, 2009). These data were provided on the condition that they not be utilized in any way that disclosed water usage values for individual properties, and that the data not be distributed to any other party. These data were utilized to accurately quantify the input of water into the groundwater flow system via OWTS. Indoor and outdoor water use on each grouping of parcels was differentiated by comparing seasonal differences in use, particularly between wet and dry seasons.

2.1.7. Hydrogeology

Existing information from geologic, geotechnical, and hydrogeologic reports on file with the City of Malibu, as well as from compliance reports provided by the Los Angeles Regional Water Quality Control Board and unpublished hydrogeologic reports, was reviewed and incorporated into existing datasets as described below.

2.1.7.1. Soil Borings and Test Pit Logs

Available data regarding soil boring locations and stratigraphic logs, monitoring well locations and construction, and test pit locations were collected and entered into a Microsoft Access database. Available locations and stratigraphic logs from soil borings and test pits were retrieved from geotechnical and geological reports for locations in the study area as submitted to the City of Malibu and retained in the City's LibertyNet web-based document management system. Particular attention was given to reports and applications submitted since June 2002.

Locations of all wells, borings, and test pits were also digitized in GIS. If surveyed ground surface elevations were recorded with the boring logs, these elevations were retained in the database and the vertical datum the elevations were measured under were recorded. Otherwise, ground surface elevations were assigned to the digitized boring locations based on the digital elevation model. Stratigraphic logs were linked to the soil boring and test pit locations where feasible.

A significant number of quarterly compliance reports for WDR-permitted systems and Underground Storage Tank (UST) locations were made available to the project team by the Los Angeles Regional Water Quality Control Board in September-October 2008. Many of these documents, particularly the UST compliance documents, contained records of soil borings and test pits which were added to the existing database as described above.

In addition, published and unpublished hydrogeologic investigation reports were obtained for properties where significant work was completed since June 2002, including work at the Malibu Sycamore Village, Malibu Lumber, Legacy Park, Cross Creek Plaza/Malibu Village, and La Paz properties. Boring logs were scanned or digitized, boring locations were digitized, and key information was added for each new boring to the existing database as described above.

In total, data were entered from:

- 930 boring locations (including 383 from the Risk Assessment study)
- 1148 test pits (including 628 from the Risk Assessment study)

2.1.7.2. Monitoring Wells and Water Level Measurements

Available data regarding monitoring well locations and construction for wells installed since June 2002 were collected and entered into a database. Information entered into the database included ground surface and top-of-casing elevations, well diameter, total well depth, depth to top and bottom of well screen, bedrock depth, well use, installation date, and data source. Data sources evaluated during this step included geologic, geotechnical, and hydrogeologic reports submitted to the City of Malibu, WDR and UST compliance reports submitted to the Los Angeles Regional Water Quality Control Board, and unpublished hydrogeologic reports, as described in Section 2.1.7.1 above.

The locations of new monitoring wells were digitized and added to the existing GIS dataset, and electronic well construction logs were linked to the well locations where the logs were available.

Any ground water level readings and/or water table elevations as included in new hydrogeologic investigation reports were entered into the database.

All relevant elevation data (top-of-casing, top of street box or ground surface, etc.) was recorded in the database, as was the vertical datum for each data record. All records that were recorded as the NGVD 1929 vertical datum were converted to NAVD 1988. The rationale for including historic groundwater level monitoring data in the subset of information used for modeling was as follows:

1. The latitude and longitude for the monitoring well location, the top of casing or measuring point elevation, screened interval of the well (top and bottom of screen below top of casing), and horizontal and vertical datums must be documented on the well construction log or in a report that we reviewed. Water level measurements must be reported to the nearest 0.01 foot below the surveyed top of casing/measuring point, although water level measurements converted to elevation in feet above mean sea level based on a known and reported datum (NAVD 1988 or NGVD 1929) were also acceptable.
2. In several cases, part or all of the documentation described above did not exist in documents reviewed. A significant number of wells and water table measurements were recorded relative to a site-specific datum or an unspecified sea level datum. Where significant numbers of water table measurements existed at a location surveyed to a relative or unspecified datum, the corresponding well was flagged for potential surveying later in the project (Section 2.3.2).

In total, data were entered for 212 monitoring wells, 98 of which were digitized or installed during the Risk Assessment (Stone Environmental, 2004).

2.2. Conceptual Model Development

A review of existing reports and studies, and the data sources described above, were used to develop a conceptual understanding of sources and sinks of groundwater in the hydrogeologic system. The conceptual model was developed to provide information for the three-dimensional numerical modeling tool used to evaluate the impacts of on-site wastewater treatment systems on groundwater levels and the response of the water table to artificial recharge from OWTS under current and potential future conditions.

At this stage of model development, the sources of water to the system included recharge from upland runoff, recharge from 408 on-site and offsite OWTS, infiltration of precipitation, and infiltration from Malibu Creek. The sinks for groundwater included discharge to the Pacific Ocean and Malibu Lagoon. More specific information about development of the conceptual model is included in Appendix A.

2.2.1. Identification of critical data gaps

The following critical data gaps were identified during the development of the conceptual model:

- The lack of deep borings and other information regarding depth to bedrock in the study area. Depth to bedrock information was needed to define the bottom of the alluvial aquifer system. A few additional deep borings were advanced in the alluvial system since the publication of the Risk Assessment study, but these were generally terminated at the Civic Center Gravels rather than advancing to competent bedrock.
- The lack of consistent topographic survey data for existing monitoring wells and water levels collected from multiple data sources. Information regarding well construction and water levels collected from hydrogeologic reports, WDR and UST compliance reports, and other existing sources (Section 2.1.7.2) greatly expanded the available database of wells and water levels for use in analysis. However, these datasets were often internally and externally inconsistent, and the horizontal and vertical datums under which locations and elevations were collected were not consistently reported. This inconsistency made many of the newly collected data challenging if not impossible to use for model calibration.

2.3. Collection of New Data

New data collected during this study included ongoing monthly and synoptic water level measurements, a new survey of monitoring well locations and elevations, and a seismic geophysical survey.

2.3.1. Water Level Measurements

The main purposes of collecting water level measurements in the context of this project were to expand the record of regular water table measurements for use in transient modeling, and to obtain an updated current snapshot of groundwater elevations underlying the Civic Center area. In order for these ‘snapshots’ to be accurate, a selection of wells spaced at reasonable intervals across the alluvial area were necessary. The selection rationale was, in order of priority:

1. Wells that were installed, surveyed, or monitored during the Risk Assessment, where surveyed locations and top-of-casing elevations were available and permission to continue monitoring was obtained (and where the wells still existed).
2. Wells that were installed since the Risk Assessment on public or private property where surveyed locations and top-of-casing elevations were available, and where permission to collect water table measurements was granted.
3. For the synoptic water table measurement event described below, wells installed or identified since the Risk Assessment that fill gaps in the existing network after priority #2--where permission was obtained to collect water table measurements, and where top-of-casing elevations may not be surveyed to NGVD 1929 or NAVD 1988, but where permission to do so could be obtained at a later date.
4. For the synoptic water table measurement event, wells installed and monitored as part of WDR or UST compliance programs, where permission was obtained from permittees and where top-of-casing elevations may not be surveyed to NGVD 1929 or NAVD 1988, but where permission to do so could be obtained at a later date

Manual groundwater level measurements were taken approximately monthly. Measurements were performed according to Stone SOP 6.2.6, which is available upon request. The water level indicator was decontaminated between monitoring wells, and an electric water level indicator was used to measure the water level at the surveyed monitoring point for each well. Water level observations were recorded on the field forms to the nearest 0.01 foot. Manual observation of surface water elevation was made in Malibu Lagoon at the Pacific Coast Highway bridge at the beginning and end of each groundwater level measurement event. Observations of surface water elevation for Malibu Lagoon were collected from the monitoring point on the bridge using weighted tape. After each event, the water level measurements were entered into the project geodatabase for further analysis and reporting. Water level measurements were converted to elevations by subtracting each water level measurement from the elevation of the appropriate monitoring point.

Synoptic water level measurements used to construct a water table map for the hydrogeologic model were collected in an additional event on December 8, 2009 from a network of monitoring wells that were surveyed to the nearest 0.01 ft. The data were collected within a relatively short time frame (approximately 2 hours) in order to avoid effects of transient water level changes. During this measurement event, observations of surface water stage were also made on Malibu Creek at the PCH highway bridge. All water level measurements taken during this event were collected according to Stone SOP 6.2.6.

2.3.2. Monitoring Well Survey

Land and Air Surveying of Malibu, California surveyed monitoring well locations and top-of-casing elevations in March 2010. The following categories of monitoring wells were included in the survey:

1. Wells where water level measurements were collected during the December 2009 synoptic measurement event (Section 2.3.1), but for which surveyed locations and/or top-of-casing elevations with confirmed horizontal and vertical datums were not available.
2. Wells where a significant historic water level dataset was recorded in units of feet below top-of-casing, but for which only a site-specific or unspecified datum for TOC elevation was available. Such datasets were recorded for several sites including the Los Angeles County Water Pollution Control Plant serving Maison de Ville, the Malibu Bay Company WDR-permitted system in Winter Canyon, Malibu Village's (formerly Cross Creek Plaza's) WDR compliance wells, and the current and former Chevron gas station locations.
3. Wells that were previously surveyed, but whose top-of-casing elevations may have changed due to construction activity or damage to the protective well cover.
4. Wells that were previously surveyed, but where monitoring wells have been referred to under different naming conventions over time—and thus, where multiple locations in the historic database had the potential to correspond to the same monitoring well (particularly in the Malibu Village area).

A total of 51 monitoring wells were surveyed or re-surveyed; the surveyed locations and elevations were entered into the project database.

Following the completion of the monitoring well survey, the well construction data and water level measurements entered from hydrogeologic studies and regulatory compliance reports were comprehensively reviewed. Water levels corresponding to the newly surveyed wells were converted to water table elevation in feet NAVD 1988 as described in Section 2.3.1. In the Malibu Village area, well construction details and hydrographs were compared side-by-side for wells that were reported with different identifiers in hydrogeologic or WDR compliance reports, and monitoring well records and water level datasets were combined where it was apparent that the two identifiers corresponded to the same well (e.g., similar well depths or screened intervals were observed for wells from different reports that were in close proximity, and water levels from different reports on the same day or within a few days were near-identical).

2.3.3. Geophysical Survey

The thickness of unconsolidated sediments varies significantly throughout the Civic Center area. While the surficial geology near the ground surface has been studied and mapped in detail, much less is known about deposits 50-100 feet or more below the ground surface—and very few soil borings have been advanced to the bedrock underlying the Civic Center area. Geophysical investigations of the subsurface in the Civic Center area by Dr. John Izbicki of the US Geological Survey in 2009, using electrical resistivity, provided additional detail about zones of clay vs. sand and gravel, and about the upper limit of the Civic Center Gravels. The resistivity survey, however, did not generally reach the interface between alluvial deposits and the underlying bedrock.

Detailed information about depths to bedrock throughout the Civic Center groundwater flow system would enable the construction of significantly more accurate model scenarios for predicting water table response to artificial recharge from community and individual on-site wastewater treatment systems under both current and potential future conditions.

Geophysical surveys can provide information on the depth to bedrock for lower costs and with more complete coverage than is possible by test drilling. These surveys generally work on the principle that the seismic velocity of subsurface material is related to the density of the material. Methods using surface waves of various wave-lengths have been developed to map variations in the competency of the subsurface to depths of over 200 feet. The most versatile of these methods, the Multi-Channel Analysis of Surface Waves (MASW) has been found to be very successful in mapping the bedrock surface, as well as in finding zones of low density soils such as sand units.

A Multi-Channel Analysis of Surface Waves (MASW) seismic survey was conducted by Entrix, Inc. of Fort Meyers, Florida in March 2010. The MASW survey was conducted to determine depths to bedrock across the study area. The goal of this task was to increase the degree to which the lower boundary of the conceptual and hydrogeologic models reflect actual subsurface conditions, and therefore to decrease model uncertainty in this dimension.

Data were collected along three profile lines, oriented approximately east-west across the Civic Center area west of Malibu Creek. Two profiles and two single-line points were collected in the Winter Canyon alluvium. The lines were run on the public right of way of the roads or on open land, where appropriate permissions were obtained. The survey was designed to achieve a depth of penetration of about 200 feet. Details of the MASW survey methods are included in Appendix B.

2.4. Groundwater Model Development

A groundwater model provides a mathematical simulation of groundwater flow and solute transport. Three-dimensional groundwater modeling remains a well-established approach to analyzing the impact of on-site wastewater treatment systems on groundwater quantity and/or quality (USGS, 1999; USGS, 2001; Walter and Whealan, 2004; Morgan et al., 2007). The groundwater model was developed for this project as a specific tool for assessing the response of the water table to artificial recharge from OWTS, both under current management conditions and with the implementation of a potential municipal scale treatment, reuse, and dispersal system. This data defined the construction, calibration, and verification of the model." The model is based on available data collected and processed within the scope of this project, and those data defined and informed the construction, calibration, and verification of the model. The details of model development are described in Appendix A, while this section briefly describes the modeling methods in general terms.

2.4.1. Numerical Model Purpose and Construction

The purposes for groundwater flow modeling of the Malibu Civic Center area are to provide preliminary analyses of the effect of municipal waste water dispersal strategies on groundwater levels and to guide site characterization data collection efforts for centralized dispersal sites. The groundwater model used for this investigation is based upon the model constructed as part of the Risk Assessment project (Stone Environmental, 2004). Major modifications made for this study include refined horizontal and vertical discretization, incorporation of additional water use, water level and geotechnical data collected since 2004, and transient model calibration to water level variations observed during the period from 2003 to 2009.

The extent of the model was designed to simulate groundwater flow in the alluvial deposits that underlie the Malibu Civic Center area along Malibu Creek and Lagoon. The model domain also includes the alluvial deposits in Winter Canyon and sections of shoreline east and west of the main body of the alluvium.

The numerical groundwater model code used for this investigation is MODFLOW2000, which was developed by the U.S. Geological Survey (Harbaugh et al., 2000). MODFLOW2000 requires that the model area be subdivided into blocks. For this model, the alluvial areas in the Civic Center and Winter Canyon were divided into a grid of rectangles 30 feet long and 30 feet wide (the previous model used a grid spacing of 50 feet). The model grid was divided vertically into five layers, the thicknesses of which varied from a few feet or less near the edges to 50 feet or more where the alluvial deposits were the thickest (the previous model was divided into four layers). Specifications describing aquifer hydraulic properties, recharge, discharge, and other factors that can affect the groundwater flow system were determined for each block in the model grid. Specifications were also made to describe flow conditions along each boundary of the model. For transient simulations such as this one, the initial water table elevation must be specified for each block at the start of the simulation. The groundwater model then calculates water table elevation for each block in the model grid at each time interval specified in the model input files—in this case, monthly from January 2003 through December 2009.

2.4.2. Model Calibration

The model calibration process included a combination of trial and error simulations and automated parameter estimation. During calibration, recharge from precipitation/upland runoff and model hydraulic conductivity values were adjusted to improve the model calculated match between computed and observed water levels. The hydraulic conductivity values were also modified based upon a combination of pilot points and zones.

Recharge values were adjusted by modifying the relationship between monthly precipitation and monthly recharge. In addition, the rate of upland recharge entering the areas north of Serra Retreat and along the eastern shoreline was reduced to improve model calculated groundwater elevations. Recharge rates were increased near the wetland west of the Civic Center Way/Stuart Ranch Road intersection to improve model calculated water levels in that area.

Water level targets used in model calibration included 2,022 observations at 100 locations. The calibration statistics comparing these targets to model-calculated water levels are considered to be acceptable given the wide range of water levels in the model area. Differences between model calculated and observed water table elevations that were calculated for December 8, 2009, the day that the synoptic water level measurement was made for this study (Section 2.3.1) were generally one foot or less. In general, model calculated water levels tend to be slightly higher than observed elevations.

Hydrographs showing a comparison of model calculated and observed groundwater elevations were reviewed for representative locations throughout the model area. Observation of these hydrographs was used to further improve the match between observed and model calculated water levels.

2.4.3. Model Application

The purposes of the model, as stated earlier, are to assess the effect of potential municipal wastewater dispersal systems on groundwater levels and to guide data collection efforts for site characterization at specific municipal dispersal sites. The potential municipal dispersal scenarios involve collection of distributed waste water from specific areas, treatment, and seasonal, soil-based dispersal of the treated waste water at specific locations.

Based upon discussions with the City of Malibu staff, three municipal waste water dispersal scenarios were analyzed with the calibrated transient model. In each scenario described below, existing distributed dispersal practices were stopped and the appropriate volume of waste water dispersal was applied at specified municipal dispersal locations. The calibrated transient model simulation for the 2003-2009 period formed the basis for evaluating the municipal dispersal scenarios. For each scenario, groundwater level changes were evaluated beneath the dispersal bed and at a down gradient location. Water level changes over the entire model area were also calculated for each scenario at the critical high water period (March 2005).

In the first scenario, 62,800 gallons per day of waste water was collected from commercial properties in the Civic Center area and dispersed at the existing waste water treatment location in Winter Canyon now used by the Malibu Bay Company. This waste water flow was added to the approximately 30,000 gpd already being treated and dispersed at the existing facility. This scenario assumed that all other existing wastewater flows from other sources discharging to the Winter Canyon alluvium and surrounding upland areas would remain unchanged. The additional 62,800 gallons per day of seasonal wastewater dispersal was simulated only during the period from October through March, when irrigation and other water reuse needs are expected to be lower than the available volume of reclaimed water.

In the second scenario, 50,000 gpd of waste water was collected from residential properties located along Cross Creek Road and in the Serra Retreat area (generally those within the area that contributes groundwater flow to Malibu Creek and Lagoon), and dispersed on the northern part of the Lower Yamaguchi parcel (west of Stuart Ranch Road).

In a third modeling scenario, waste water was collected from both potential service areas as described above and dispersed at the corresponding locations simultaneously in order to evaluate the cumulative effects of both strategies.

3. RESULTS AND ANALYSIS

Section 3 summarizes the results and analysis of existing datasets, generation of new data to further inform model construction (including water level measurements, a monitoring well survey, and geophysical survey work), and the results of construction and application of the transient groundwater flow simulation for the years 2003-2009. In many cases, additional details are included in Appendices A and B.

3.1. Existing Data

Results and analysis of existing datasets that were utilized in model construction and calibration are described below. Additional detail is available in Appendix A. For the discussion that follows, all geographic information is reported in horizontal datum NAD 1983 and vertical datum NAVD 1988.

3.1.1. Climate

Precipitation records collected on the Pepperdine University campus between 2003 and 2009 indicate that both an exceptionally wet year and an exceptionally dry year were observed during the data collection period (Figure 3). During the winter of 2004-2005, a total of 32.12 inches of precipitation were recorded at the bottom of Pepperdine's Malibu campus, while 31.75 inches of precipitation were recorded at the top of campus. In contrast, during the winter of 2006-2007, only 0.97 inches of precipitation were recorded at the bottom of campus, and 4.21 inches were recorded at the top of campus.

Similar precipitation trends were observed at other nearby climate monitoring stations, such as the Santa Monica Pier co-op station (Figure 3). At the Santa Monica Pier station, the 2004-2005 winter was the seventh wettest winter on record (with a period of record beginning in 1937, extending to the present), and the month of February 2005, with 11.68 inches of precipitation recorded at Santa Monica Pier, was the third wettest February on record. The probability of 10 inches or more of precipitation occurring in any given month at the Santa Monica Pier station is about 5%. The 2004-2005 winter precipitation season may therefore be reasonably considered a critical period in terms of significant precipitation recharge to the water table, and subsequent seasonally high groundwater conditions in the Civic Center and Winter Canyon alluvial groundwater flow systems.

3.1.2. Topography

The digital elevation model obtained from LAR-IAC was used directly as the upper boundary of the groundwater flow model (Appendix A). The relatively high resolution of the digital elevation model supported the creation of ground surface topographic contours at two-foot intervals. An example of the level of detail possible using this digital elevation model is shown in Figures 4 and 5.

3.1.3. Surface Water

Updated hydrography, including stream channels within the study area and Lagoon boundaries, is shown on Figure 1 and on subsequent maps.

Aside from the stream gage elevation information from the United States Geological Survey stream gage on Malibu Creek near Cross Creek Road, and Malibu Creek and Lagoon water levels collected during the Risk Assessment study, no existing surface water level measurements that could be used for modeling purposes were discovered. Raw pressure transducer data files provided by LVMWD could not be converted accurately to Lagoon surface elevation (Section 2.1.3), and other ongoing monitoring programs in Malibu Lagoon have focused on water quality parameters rather than water table measurements (e.g., Heal the Bay 2009).

Lifeguards keep daily records of whether the barrier beach separating Malibu Lagoon from the Pacific Ocean is open or closed (Los Angeles County, 2003-2009). Table 2 summarizes the major periods during which the Lagoon was open or closed during 2003-2009, and the lifeguards' daily observations are displayed on Figure 3. On average, each year the Lagoon's barrier beach was breached, and the Lagoon was open to the Pacific Ocean, for about 230 days; the barrier beach was closed and the Lagoon was isolated from the Pacific Ocean for about 135 days. During the wet year of 2005, however, the barrier beach was only closed for 33 days (Figure 3 and Table 2). In contrast, during the relatively dry year of 2007, the barrier beach was closed for 213 days.

3.1.4. Stormwater Management Systems

The extents and bottom elevations of excavations into which the drains were installed were digitized, where known or available from design or as-built drawings, were compared to water table elevations as recorded in monitoring wells located nearest the route of each mapped drain. Figure 6 shows elevations of the base of storm drain installation excavations (in feet NAVD 1988), where known, as compared to hydrographs from a selection of the nearest active monitoring wells. (The monitoring well locations and water level measurements that are included in this assessment are discussed in more detail in Sections 3.1.7 and 3.2.1.)

The monitoring wells located along the Civic Center Way storm drain are generally 90-150 feet from the nearest known elevation of the base of the storm drain excavation (Figure 6). Along the western half of the Civic Center Way drain, water table elevations in the nearest monitoring wells are generally 1.5 to 3.5 feet higher than the base elevation of the storm drain excavation. If the storm drain were acting as a subsurface conduit for shallow groundwater flow, and exerting significant control on the nearby water table elevations, it would be expected that water table elevations in these nearby wells would be closer to the storm drain base elevation. Towards the eastern end of the Civic Center Way storm drain, nearby water table elevations are generally lower and closer to the storm drain base elevation; however, water table elevations are not markedly lower near the drain excavation area as compared to other nearby monitoring wells to the south.

It appears that preferential flow of groundwater along the Civic Center Way storm drain towards Malibu Creek and Lagoon is at best a minor sink for groundwater flow in this alluvial system. To test this hypothesis, metered flows through the City of Malibu's stormwater treatment facility on Civic Center Way were compared to precipitation records from Pepperdine University, to understand the potential significance of groundwater inflow into the storm drain system for modeling purposes. During months when little or no precipitation was recorded by Pepperdine's gages, average flows through the stormwater treatment facility were generally 5,000 gpd or less (Figure 7). While it is possible that a greater volume of groundwater may be following the gravel bedding beneath the drains, the dry-weather infiltration into the Civic Center Way drain translates to a flow of 0.008 cubic feet per second or less. Wet-weather flows are much higher, but these flows primarily reflect surface water runoff conducted through the drain rather than groundwater infiltration.

The effects of subsurface stormwater infrastructure on ground water elevations, if they appear at all, seem to be confined to areas immediately adjacent to the drain excavations. For example, along the Cross Creek Road storm drain, at least one well shows water table elevations close to that of the storm drain base elevation (Figure 6). In this case, the nearest monitoring well is located less than 25 feet from the storm drain.

As described above, there is some evidence that storm drainage infrastructure in the Civic Center alluvial area has a localized and minor effect on ground water elevations. However, the impact does not rise to a level of significance that necessitates the inclusion of storm drain infrastructure in the groundwater flow model.

The design of the Legacy Park detention basin includes an impervious liner (RMC 2009). Since there will be no significant infiltration from the basin that might result in artificial recharge to the groundwater flow system, the design drawings were not considered further as inputs to the model.

3.1.5. On-site Wastewater Treatment Systems (OWTS)

Final approval drawings from 230 systems (in addition to the records for 143 systems that were included from the Risk Assessment data collection effort) were georeferenced and the locations of OWTS components were digitized in GIS as shown on Figure 8. Approximately 407 parcels with OWTS are located in the study area (Table 1 and Figure 8). There are three offsite wastewater treatment systems located on parcels separate from the wastewater generation sources, which serve a total of 11 parcels.

Two of these systems are shared systems with discharge locations in Winter Canyon, while the third is the Los Angeles County Malibu Administrative Complex on Civic Center Way.

Approximately 347 OWTS serve single family residential dwellings and 49 OWTS serve commercial, institutional, and multifamily occupancies. Fifty-six residential parcels and three commercial/multifamily OWTS are located in upland areas underlain by bedrock to the north of the Civic Center alluvium (Table 1). One residential and nine commercial/multifamily OWTS are located in the bedrock and alluvial areas contributing to the Winter Canyon alluvium. Along the Pacific Ocean, there are 185 residential OWTS and 17 commercial/multi-family OWTS (Table 1). North of Malibu Colony in the Civic Center alluvial area, there are 18 commercial/multifamily OWTS. In the vicinity of Malibu Creek and Serra Retreat, there are 105 residential and two commercial/multifamily systems in both bedrock and alluvial areas (Table 1).

Permit data and/or approval drawings were available for 297 (or approximately three quarters) of the OWTS in the study area. This is a significant improvement over the inventory completed during the Risk Assessment study, which found that permit data or approval drawings were available for 93 OWTS, or about one quarter of such systems in the study area (Stone Environmental, 2004). Twenty eight of the 297 OWTS with permits or approval drawings utilized advanced treatment as part of an alternative system, more than triple the nine such systems recorded during the Risk Assessment study (Stone Environmental, 2004). The remaining OWTS generally utilized traditional septic tanks and either drainfields or seepage pits.

3.1.6. Water Use

Specific and accurate estimates of water use and discharges to OWTS were a key component of simulating existing conditions in the Civic Center Area and of predicting the potential impacts of future major development or potential municipal wastewater treatment solutions with soil-based discharge. Although information on the design of OWTS in the study area was available for a larger number of specific systems, water consumption on a property may bear little relation to an OWTS' designed treatment capacity, particularly on properties with significant landscape irrigation requirements.

Aggregated water use data were provided by the County of Los Angeles Department of Public Works Water District #29 (County of Los Angeles, 2009-2010). These data were aggregated by subareas within the study area to provide a more accurate estimate of actual wastewater flows, and to assess whether significant irrigation was occurring that needed to be accounted for in the model.

During the Risk Assessment study, water use data were adjusted to account for irrigation and other outdoor use by using average water use data from Malibu Colony as an indicator of indoor water use (Stone Environmental, 2004). Malibu Colony remains a reasonable representation of indoor water use, as the parcels are densely developed. The previous estimate of residential water recharge from OWTS based on indoor water use was 500 gallons per day (gpd) per household (Stone Environmental, 2004). The average water use for the residences in this group over the entire 2003-2009 period was 490 gpd. During the low-irrigation season (February and March), the average water use in the Malibu Colony Shoreline area was 397 gpd per household. Based upon the low-irrigation season data for Malibu Colony, a 400 gpd per household value for residential water recharge from OWTS was applied for residential OWTS throughout the study area. In residential areas outside of Malibu Colony, per-household water usage in excess of 400 gpd was assumed to be used for irrigation and was therefore applied as irrigation rather than as infiltration from OWTS (see Appendix A, Sections 2.2.2 and 2.2.5 for details).

For modeling purposes, it was assumed that reported water use on commercial properties (excluding nurseries, golf parks, and areas with extensive turf), and on multi-family properties such as the DeVille Way condominiums, was utilized within buildings and dispersed through OWTS. If a nursery or property with significant turf contained a residence, it was treated as a residential property. Otherwise, all water use on the property was assumed to be used for irrigation (see Appendix A, Sections 2.2.2 and 2.2.5).

3.1.7. Hydrogeology

Existing information was synthesized from geologic, geotechnical, and hydrogeologic reports on file with the City of Malibu, as well as from compliance reports provided by the Los Angeles Regional Water Quality Control Board and unpublished hydrogeologic reports. The results of the data extraction efforts are summarized below. The conceptual model section of Appendix A provides integration of and additional references for the existing hydrogeologic data for the study area.

3.1.7.1. Soil Borings and Test Pit Logs

The locations of soil borings, test pits, and test trenches either retained from the Risk Assessment study database (Stone Environmental, 2004) or digitized during the collection of existing data are shown on Figure 9. In total, data were entered from:

- 930 boring locations (including 383 from the Risk Assessment study)
- 1148 test pits and/or trenches (including 628 from the Risk Assessment study)

Where stratigraphic logs were available for soil boring locations, the stratigraphic log was evaluated to determine the depth (if any) at which the boring encountered bedrock. These locations are shown on Figure 9. Although the number of available stratigraphic logs in the Civic Center area more than doubled since 2002, the vast majority of recent borings in alluvial areas did not advance to bedrock. While these stratigraphic logs provided valuable information about details of the alluvial area’s surficial geology, little additional information was uncovered about the elevation of bedrock underlying the alluvial area. In a few cases, such as in the vicinity of the Pacific Coast Highway bridge over Malibu Lagoon, soil boring information was discovered that was not previously available to the project team.

3.1.7.2. Monitoring Wells and Water Level Measurements

The locations of monitoring wells retained from the Risk Assessment study database (Stone Environmental, 2004) or digitized during the collection of existing data are shown on Figure 10. In total, data were entered for 232 monitoring wells, 98 of which were digitized or installed during the Risk Assessment study.

The strengths and weaknesses of including existing well construction details and water level measurements from a wide variety of data sources, including unpublished reports, WDR compliance reports, and UST compliance reports, are clearly illustrated in Figure 10. For example, including well construction details and water level measurements from UST and WDR compliance reports filled some gaps in the network of wells developed during the Risk Assessment study, particularly in Winter Canyon and in the vicinity of the current and former Chevron gas stations. However, monitoring wells installed for compliance purposes were often surveyed only to a site-specific vertical datum or were referenced to “sea level”, rather than to a clearly referenced geodetic datum (NGVD 1929 or NAVD 1988). In order to utilize these historic water level measurements as targets for model calibration, over 40 monitoring wells were re-surveyed and the well construction details and calculated water table elevations updated as appropriate (see Section 3.2.2).

Review of existing monitoring wells and water level measurements also highlighted the possibility that, depending upon the consultant collecting and reporting water level measurements, the same monitoring well was reported using several different names and several slightly different locations. This was particularly apparent in the Malibu Village (formerly Cross Creek Plaza) area, adjacent to Malibu Lagoon.

3.2. New Data

New field observation data collected during this study included intermittent water level readings, synoptic water level readings, a survey of monitoring well locations and measuring points, and surface geophysics.

3.2.1. Water Level Data

Water level measurements were used to understand groundwater flow directions and gradients by preparing water table contour map from synoptic water level measurement events. Water level measurements collected on a monthly basis, as well as historical water level datasets collected on quarterly or longer time scales, were also used to understand the groundwater flow system’s physical response to precipitation events, variations in Lagoon stage, tidal conditions, and seasonal or longer-term changes in the amount of water recharging the flow system and flowing past individual monitoring well locations. The locations of monitoring wells where new water level measurements were collected within the scope of this study are shown on Figure 11.

3.2.1.1. Water Table Contour Map

The goal of the synoptic water level measurement event, as in the Risk Assessment study, was to minimize the impact of tidal and Lagoon stage fluctuations on ground water levels. Synoptic water level data were collected on December 8, 2009 under open Lagoon (breached barrier beach) conditions (Table 4). A water table contour map (Figure 12) shows the overall water table contours under open Lagoon conditions. Water table elevations during this synoptic water level measurement event were slightly higher than those measured during the last synoptic event completed under breached barrier beach conditions in March 2004 (Appendix A and Stone Environmental, 2004).

The synoptic data included measuring water levels in three pairs of monitoring wells to understand the vertical component of groundwater flow. The lower well in each pair is screened in the Civic Center Gravels; and the upper wells are screened in the water table aquifer (Earth Consultants International, Inc. 2000a). The water table elevations in the shallower of the pair of wells remained consistently higher than the water level elevations in the deeper of the pair, which was similar to previous results indicating an apparent downward vertical gradient in this area.

3.2.1.2. Monthly Water Table Measurements

Water table measurements were collected at up to 66 monitoring wells on 12 occasions, generally a month or more apart. Since it took several hours to complete the water level measurements, the monthly water table data do not necessarily account for tidal or other short-term variations in water levels. A summary of the water table measurements taken during the study is included as Table 5. A summary of Lagoon stage measurements collected before and after each monthly round of ground water level measurements is reported in Table 3.

The monthly water level measurements and Lagoon stage measurements were utilized primarily in model construction and calibration. Refer to Appendix A for additional discussion of ground water level trends in the Civic Center area.

3.2.2. Monitoring Well Survey

A survey of the locations and elevations of 51 monitoring wells was completed in March 2010 to supplement the survey conducted during the Risk Assessment (Stone Environmental, 2004) and to establish accurate locations and measuring point elevations for a number of wells for which significant historical depth to groundwater or water table elevation datasets were available. A summary of the well names, coordinates, measuring point elevations, and street box or ground surface elevations where the survey was conducted is included as Table 6.

Further discussion of the locations where historic water level data and water level data generated during this study were used in the model may be found in Appendix A, Section 2.5.

3.2.3. Geophysical Survey

The MASW geophysical survey provided valuable information about the boundary between alluvial deposits and the underlying bedrock. A total of seven transect lines were completed in the main alluvial area and in Winter Canyon; the locations of these lines are shown on Figure 13. Reportable results from the MASW survey are shown in Figure 14. Appendix B contains a detailed discussion of the results and conclusions of the MASW survey.

During processing of the MASW survey results, it became apparent that transect lines 4 and 5, located in Winter Canyon, were oriented at too much of an angle relative to the Pacific Coast Highway (the main source of seismic signals in the study area). This orientation resulted in results showing unreasonably high velocity layers at the surface and lower velocity layers at depth, a situation that could only occur if unconsolidated deposits were overlain by bedrock. Lines 4 and 5 were laid out along roadways (Figure 13), in the only orientation possible given the limited open space available. Line 1, which was executed across undeveloped land near the northern edge of the main alluvium (Figure 13), also suffered from an anomalously high velocity zone in the shallow portion of the profile. This line produced estimated depth to bedrock values that were deeper than the available drilling data. Given the geometry problems related to Lines 1, 4, and 5 and the limited land available to reorient these lines into more favorable orientations, only the results from Lines 2, 3, 6 and 7 were reported and utilized in the model.

Lines 2 and 3 lie roughly parallel to the Pacific Coast Highway, above the assumed center of the bedrock valley (Figure 13). Numerous borings have been drilled in this area, but none were deep enough to encounter bedrock. This area was of the greatest interest to the project team and was the area where depth to bedrock information was most needed.

The depth to bedrock as determined by the MASW survey in the vicinity of Lines 2, 3, 6, and 7 ranged from about 20 to 200 feet below land surface. The elevation of the bedrock surface ranged from about 100 feet NAVD 1988 to about -200 feet NAVD 1988. Figure 14 shows bedrock elevations from Lines 2, 3, 6, and 7 and from a line of borings that encountered bedrock along the northern edge of the bedrock valley as recorded in the project soil boring database (Section 2.1.7.1). The deepest portion of the bedrock valley appears to be just west of the intersection of the Pacific Coast Highway and Webb Way, although the elevation of the valley floor was expected to deepen toward the ocean.

Further details regarding the integration of the MASW survey results into the construction of the bedrock surface of the groundwater flow model are located in Appendix A, Section 2.1.1.

3.3. Groundwater Flow Model Application

A numerical model was constructed to simulate groundwater flow in the alluvial deposits along Malibu Creek and Malibu Lagoon near the Malibu Civic Center area, and in Winter Canyon to the west of the Civic Center alluvium. The objectives of the modeling were to provide preliminary assessment of the effect of municipal waste water dispersal options on the water table and to guide more detailed hydrogeologic investigations for municipal dispersal sites.

As described in Section 2.4.3, three municipal waste water dispersal scenarios were analyzed with the calibrated transient model simulation for the 2003-2009 period (the parcels involved in each scenario are illustrated in Figure 15):

- Scenario #1: 62,800 gallons per day of waste water was collected from commercial properties in the Civic Center area and dispersed seasonally (October-March) at the Winter Canyon location now used by the Malibu Bay Company, in addition to the approximately 30,000 gpd already being treated and dispersed at the existing facility and in addition to existing discharges occurring elsewhere in the Winter Canyon alluvium and surrounding upland areas..
- Scenario #2: 50,000 gpd of waste water was collected from residential properties located along Cross Creek Road and in the Serra Retreat area (generally those within the area that contributes groundwater flow to Malibu Creek and Lagoon), and dispersed on the northern part of the Lower Yamaguchi parcel (west of Stuart Ranch Road).
- Scenario #3: Scenarios #1 and #2 were run simultaneously in order to evaluate the cumulative effects of both strategies.

3.3.1. Scenario #1: Commercial Properties, Winter Canyon Dispersal

The application of reclaimed waste water in the Winter Canyon alluvium under Scenario #1 results in a model-predicted water level increase of 1-10 feet over time directly beneath the infiltration area, as compared to the current condition base run. The water level change varies as a function of time because the simulated dispersal occurs cyclically between October and March. The minimum depth of the water table below land surface directly beneath the dispersal area (about 38 feet) occurs in the third year of dispersal, which is equivalent to the 2004-05 winter precipitation season. Down-gradient from the

Scenario #1 dispersal area at the base of Winter Canyon, the model predicted groundwater level also varies cyclically, with increases as compared to the current condition base run ranging from less than a foot to approximately 2 feet. The minimum water table depth below land surface (approximately 2 feet) occurs in the third year of dispersal, which is equivalent to the 2004-05 winter precipitation season.

A map illustrating model predicted water level changes over the entire model area for Scenario #1at the highest water level condition during the simulation period, which occurred in March 2005, is shown in Figure 16. Red areas on this map indicate that water levels increase compared to the current condition base run, while blue areas indicate predicted water level decreases. Water table declines of about one foot or less were predicted in the area where distributed discharge is eliminated, and water table increases of about 1-10 feet were predicted in Winter Canyon in response to the increased dispersal rate.

3.3.2. Scenario #2: Serra Area Residential Properties, Western Alluvium Dispersal

The application of reclaimed waste water in the western portion of the Civic Center alluvium, directly beneath the potential infiltration beds on the Yamaguchi parcel under Scenario #2, results in a model-predicted ground water level increase of 2-20 feet over time as compared to the current condition base run. As with Scenario #1, the water level change varies as a function of time because the simulated dispersal occurs cyclically, during October through March. The minimum depth of the water table below land surface directly beneath the proposed dispersal area (about two feet) occurs in the third year of dispersal, which is equivalent to the 2004-05 winter precipitation season. Down-gradient from the Scenario #2 proposed dispersal area, near the intersection of Stuart Ranch Road and Civic Center Way, the model predicted groundwater level also varies seasonally, with model predicted water levels increasing by 1-3 feet as compared to the current condition base run. Again, the minimum water table depth below land surface (less than one foot) occurred in the third year of the simulation, which is equivalent to the 2004-05 winter precipitation season.

A map of model predicted water level changes over the entire model area for Scenario #2 at the highest water level condition during the simulation period, which occurred in March 2005, is shown in Figure 17. Water level decreases of approximately one foot or less are predicted to occur in the area where distributed discharge was eliminated, while water level increases of 1-20 feet were predicted to occur directly below and surrounding the dispersal beds on the Yamaguchi parcel in response to the increased dispersal rate. This application scenario clearly illustrates the risks of centralizing the dispersal of reclaimed water, especially during years of relatively high winter precipitation conditions.

3.3.3. Scenario #3: Simultaneous Application of Scenarios #1 and #2

In Scenario #3, both Scenarios #1 and #2 were run simultaneously to determine the cumulative impacts of both scenarios. A map showing model predicted water level changes over the entire model area for

Scenario #3 during the high water level condition is shown in Figure 18. Comparing Figure 18 to the water level change maps presented in Figures 16 and 17 shows that combining the two scenarios has only a minimal cumulative effect that is restricted to the western portion of the Civic Center alluvium. Since ground water in the Winter Canyon alluvium is hydraulically isolated from groundwater in the Civic Center alluvium by a ridge of bedrock, this result is expected and reasonable.

4. CONCLUSIONS AND RECOMMENDATIONS

Information regarding the hydrology and hydrogeology of the Malibu Civic Center area and Winter Canyon was collected from a significant number of existing data sources, and this information was utilized in the development of a conceptual understanding of the groundwater flow system that underlies the study area. This “conceptual model” was used to identify data gaps, and in several instances new data were collected to fill those gaps. The datasets created from the existing data, conceptual model, and new data were used to construct a numerical, transient groundwater flow simulation for the years 2003-2009. The simulation period included a particularly wet season during the winter of 2004-2005, which may reasonably be considered a “critical” water table condition with regard to seasonally high ground water levels. The transient model simulation, once calibrated to current conditions, was applied to the evaluation of three municipal wastewater collection and dispersal scenarios in order to provide preliminary assessment of the effect of municipal waste water dispersal options on the water table and to guide more detailed hydrogeologic investigations for proposed municipal dispersal sites.

Modeling results suggest that a seasonal loading rate of an additional 63,000 gallons per day may be possible at the Winter Canyon location, depending on the depths of existing and/or proposed seepage pits. Depth to the water table in the upper part of the Canyon beneath the Malibu Bay Company dispersal beds is sufficient. The limiting factor in the ultimate Winter Canyon dispersal rate is likely to be water level increases in the southern, lower part of the Canyon where the water table is closest to land surface such as near SMBRP-11 and in the swale just north of the Pacific Coast Highway. This will be especially true during high water periods such as the one experienced in 2004-2005.

Model results further suggest that a loading rate of 50,000 gallon per day on the Yamaguchi parcel could cause groundwater levels to reach or nearly reach land surface, especially during a very wet period like 2004-2005. The critical areas are generally down gradient of the proposed dispersal beds at locations where ground water is closest to land surface, such as the Smith artificial wetland and on the lower part of the Malibu Sycamore Village parcel. There are no deep borings or wells on this site that allow a detailed characterization of site conditions.

The applications of this calibrated model extend beyond the current study. The model can now be used for preliminary evaluations of other scenarios of reclaimed water dispersal in conjunction with the design of a municipal wastewater reclamation/dispersal alternative within the Civic Center and Winter Canyon areas. The model can also be improved through collection and inclusion of site-specific characterization data, such as additional soil borings, bedrock depths, hydraulic conductivity tests, or loading tests, in order to refine capacity estimates on key properties in Winter Canyon and in the western portion of the Civic Center alluvium. The model is, and will remain, an effective tool for the City’s use in the development of its Wastewater Management Plan for the Civic Center Area.

4.1. Recommendations

Although the modeling results suggest that additional loading is possible in Winter Canyon they do not guarantee that more loading would be acceptable. Additional field testing should be conducted in Winter Canyon to verify the area's capacity to accept additional reclaimed water. This work should include better definition of the bedrock surface, additional measurement of groundwater levels in bedrock and the alluvium, better delineation of subsurface stratigraphy, and--most importantly—a full scale hydraulic loading test with detailed monitoring of water levels. These activities, along with details concerning the proposed design of dispersal systems, would provide data that will allow a more definitive evaluation of the ultimate waste water dispersal capacity in Winter Canyon.

Although no site-specific characterization data exist for the Yamaguchi parcel, a considerable amount of detailed hydrogeologic data are available for the Malibu Sycamore Village parcel immediately to the east. Assuming conditions on the Yamaguchi parcel are similar to conditions on the adjacent Malibu Sycamore Village parcel, the northern part of the Yamaguchi parcel may be able to disperse some reclaimed water, but the property's capacity is probably less than 50,000 gallons per day. Additional field work is necessary to characterize subsurface conditions at this location. Of special importance is definition of the horizontal and vertical extent of the underlying Civic Center gravel, connection with the ocean, and characterization of groundwater elevations beneath the site.

As a result of this project and previous investigations, a surveyed network of monitoring wells has been established in the valley. Groundwater levels in the network of monitoring wells evaluated during this project, or a representative subset of these wells, should be measured monthly on a routine basis. Because of the significant effect that the stage of Malibu Lagoon has on nearby groundwater levels, the lagoon stage should also be monitored monthly or more frequently. These data are invaluable to ongoing and future analyses of municipal waste water dispersal strategies, and significant gaps in these datasets should be avoided if at all possible.

Ground water and surface water monitoring data collected in the upper part of Winter Canyon by Pepperdine University are valuable, especially if the Winter Canyon site is used for additional dispersal. Periodic collection and review of this information will also prove valuable to ongoing and future analysis of municipal waste water dispersal options in the Civic Center area. Similarly, water use data from LA County Water District #29 for the study area should be collected and assessed regularly to keep the transient groundwater model simulations current.

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APPENDICES

APPENDIX A: GROUNDWATER MODEL REPORT

APPENDIX B: MASW SURVEY REPORT (ENTRIX, INC.)

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Figure 1: Study Area

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Sources: Political Boundaries, TIGER FILES, U.S. Bureau of the Census; Roads, StreetMap Pro; Streams and Lagoon, digitized by Stone from Ditigal Elevation Model, Infotech Enterprises America, 2007; Study Area, Stone.

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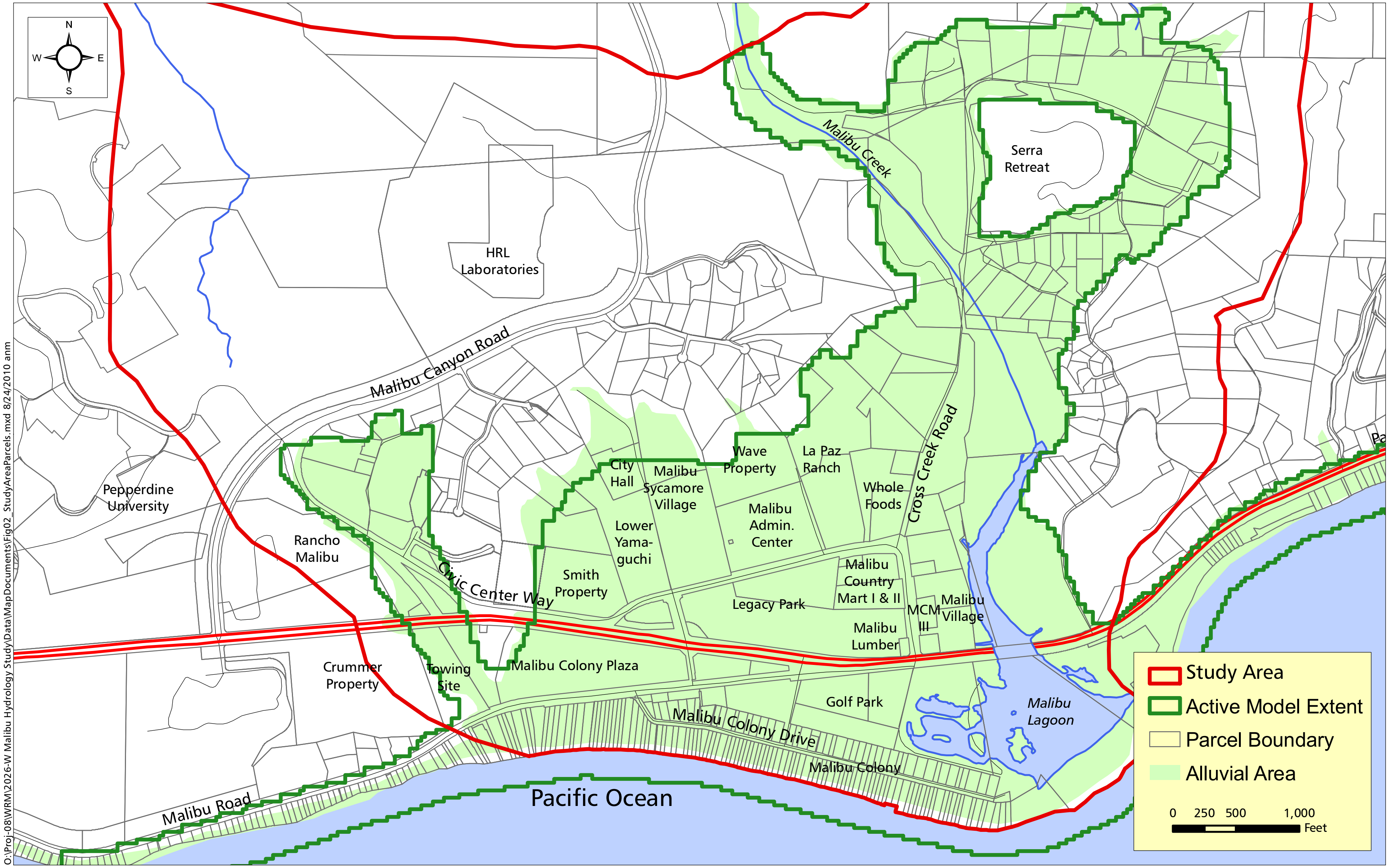

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Figure 2: Study Area Parcels and Landmarks

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Sources: Roads, StreetMap Pro; Streams and Lagoon, digitized by Stone from Ditigal Elevation Model, Infotech Enterprises America, 2007; Parcel Boundaries, Los Angeles County Assessor; Active Model Extent, McDonald Morrissey Assoc., Alluvial Area and Study Area, Stone.

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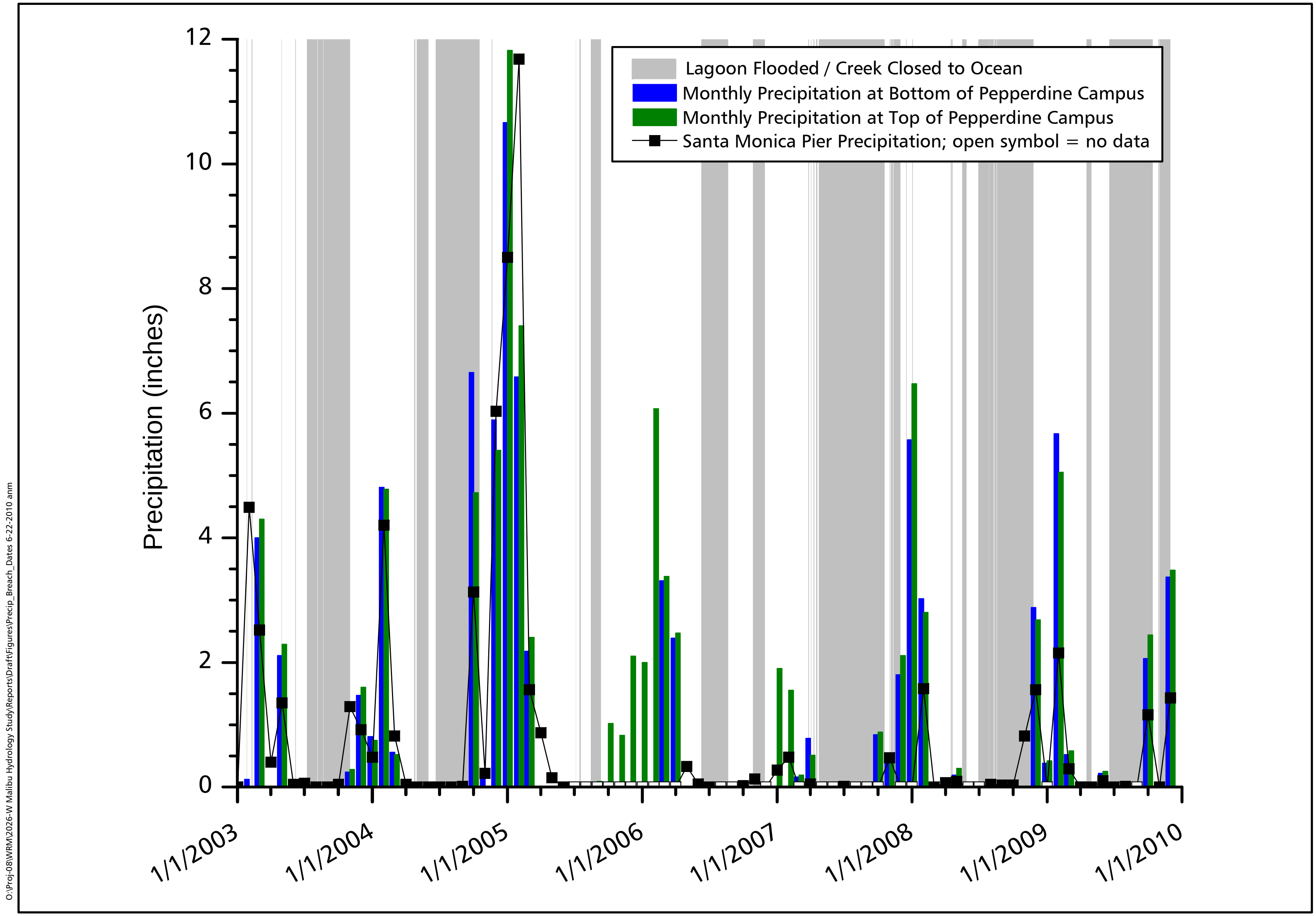

Figure 3: Monthly Precipitation and Daily Malibu Lagoon Conditions

Hydrology Study of Cumulative Impacts for the Civic Center Area

City of Malibu, California

Source: Pepperdine University, 2003-2009; NOAA Western Regional Climate Center,, 2003-2009; LA County lifeguard records, 2003-2009.

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Figure 4: Ground Surface (2-Foot Topographic Contours), Legacy Park Vicinity

Hydrology Study of Cumulative Impacts for the Civic Center Area

City of Malibu, California

Sources: Topographic contours generated from LAR-IAC 2006-2007 digital elevation model, 2009; Hydrography, digitized by Stone using LAR-IAC 2006-2007 digital elevation model, 2009; Imagery, ESRI, 2007.

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Figure 5: Ground Surface (2-Foot Topographic Contours), Winter Canyon Vicinity

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Note: Only 10-foot elevation contours are drawn above 120 feet NAVD 88.
Sources: Topographic contours generated from LAR-IAC 2006-2007 digital elevation model, 2009; Hydrography, digitized by Stone using LAR-IAC 2006-2007 digital elevation model, 2009; Imagery, ESRI, 2007.

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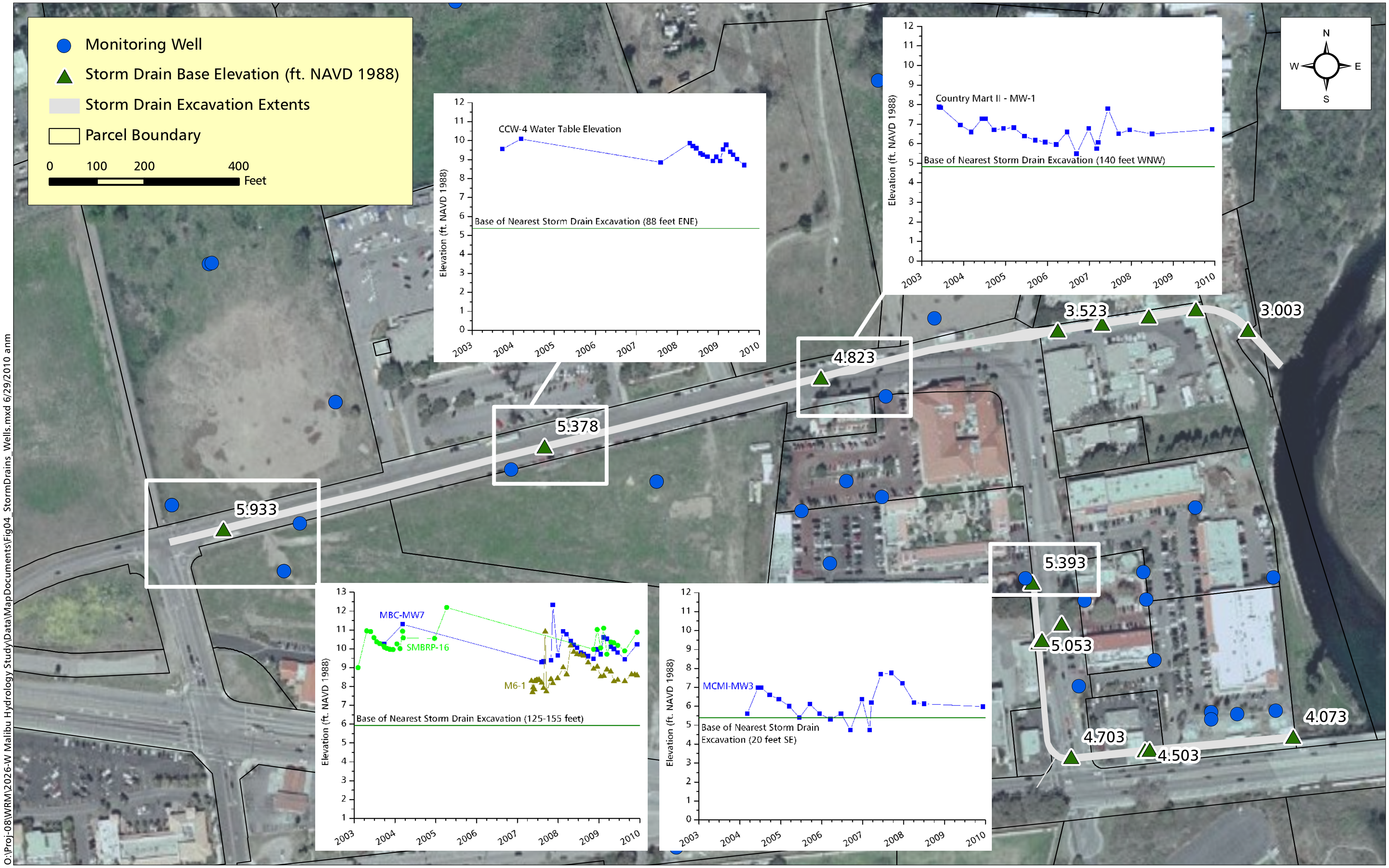

Figure 6: Known Storm Drain Excavation Elevations and Proximal Hydrographs

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Sources: Groundwater Well Locations, Stone, 2004, digitized by Stone, 2009, and/or surveyed by Land & Air Surveying, 2010;
Water levels, Stone database, 2010 (as gathered and/or digitized from multiple sources as detailed in report); Parcel boundaries, Los Angeles County; Imagery, ESRI.

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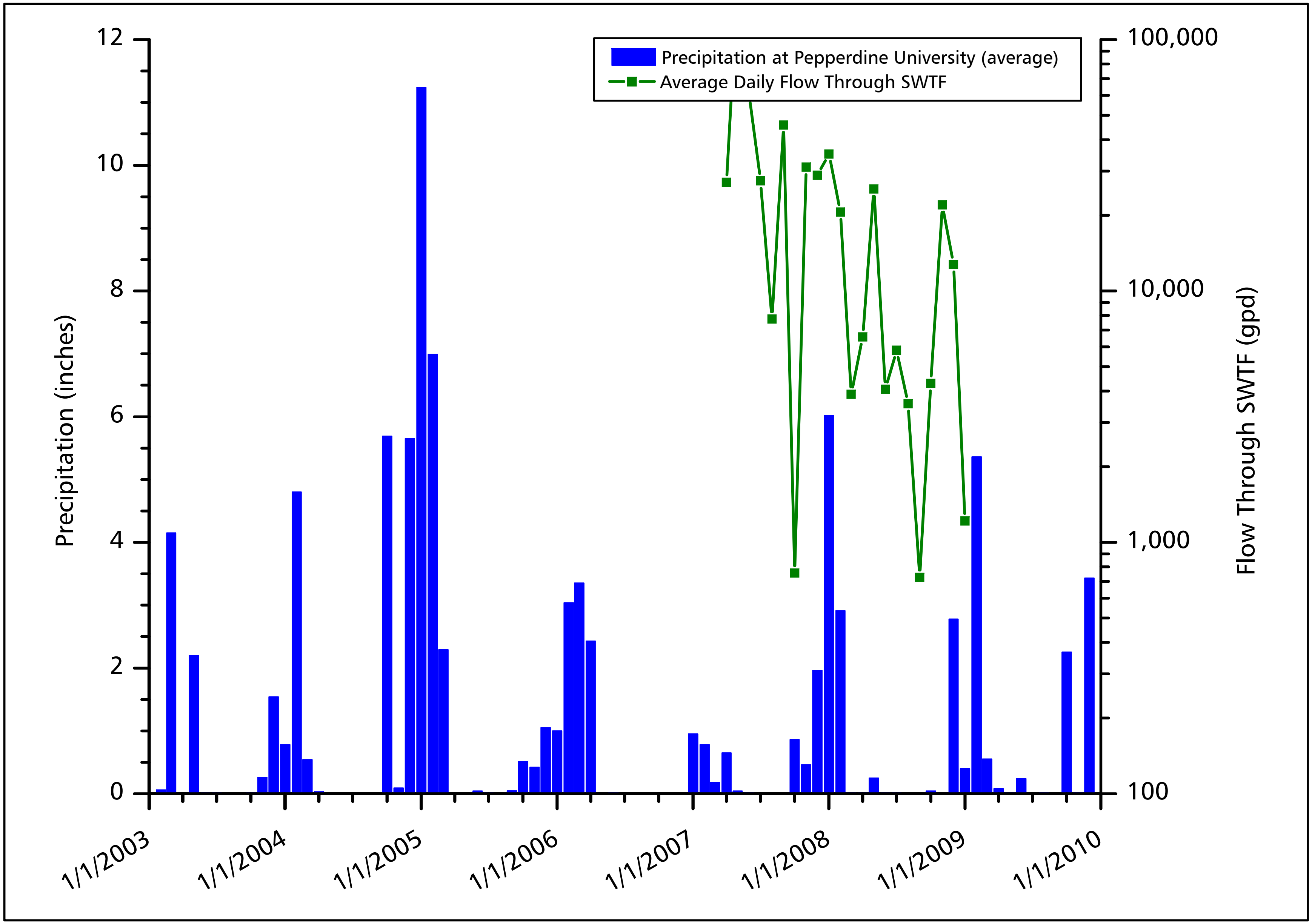

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Figure 7: Monthly Precipitation and Average Flows Through Malibu Stormwater Treatment Facility (SWTF)

Hydrology Study of Cumulative Impacts for the Civic Center Area

City of Malibu, California

Source: Pepperdine University, 2003-2009; City of Malibu, 2007-2009.

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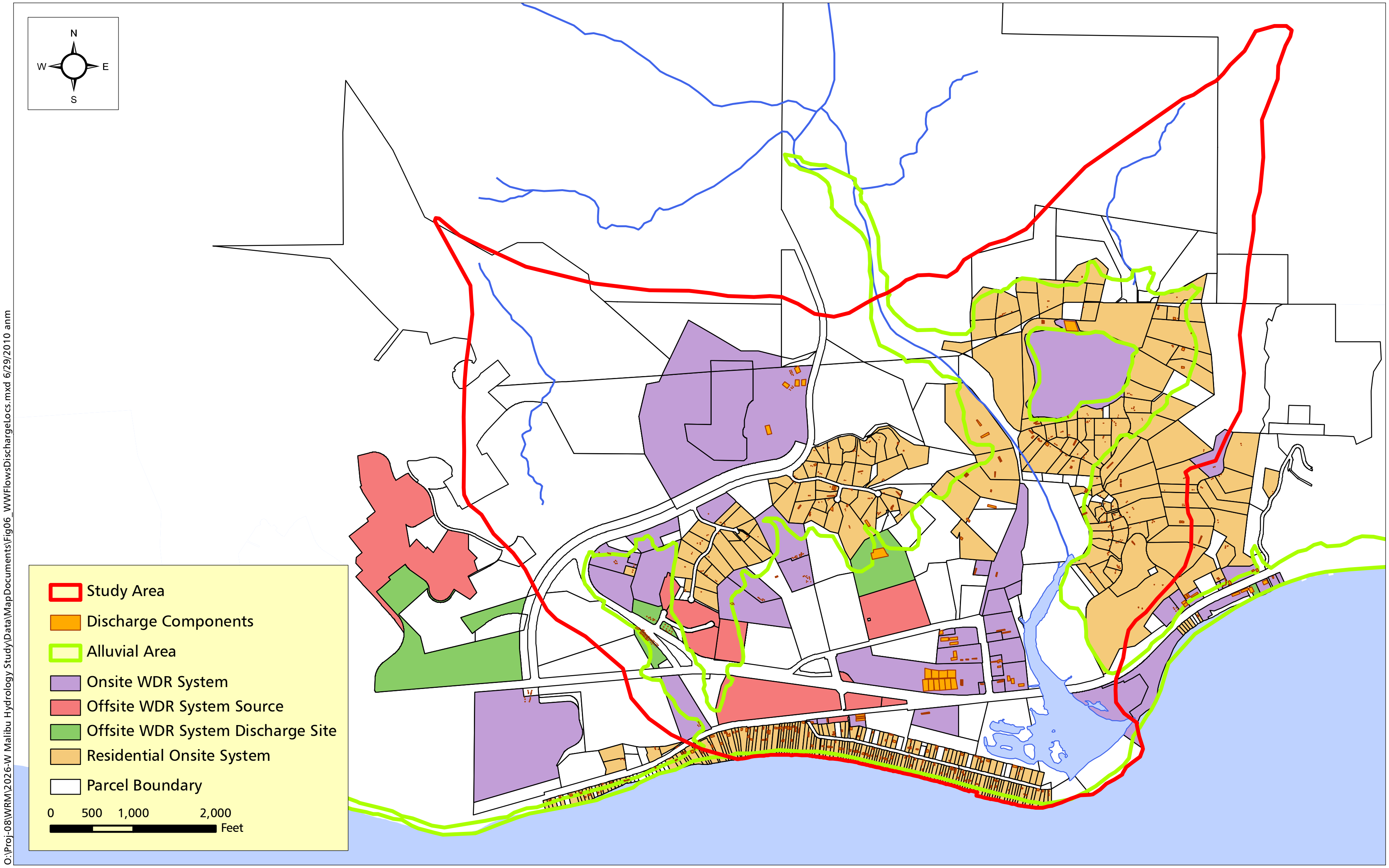

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Figure 8: Wastewater Flow Sources and Discharge Locations

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Sources: Groundwater Well Locations and Leachfields, digitized by Stone, 2009;
Study Area, Stone; Parcel boundaries, City of Malibu; Imagery, ESRI.

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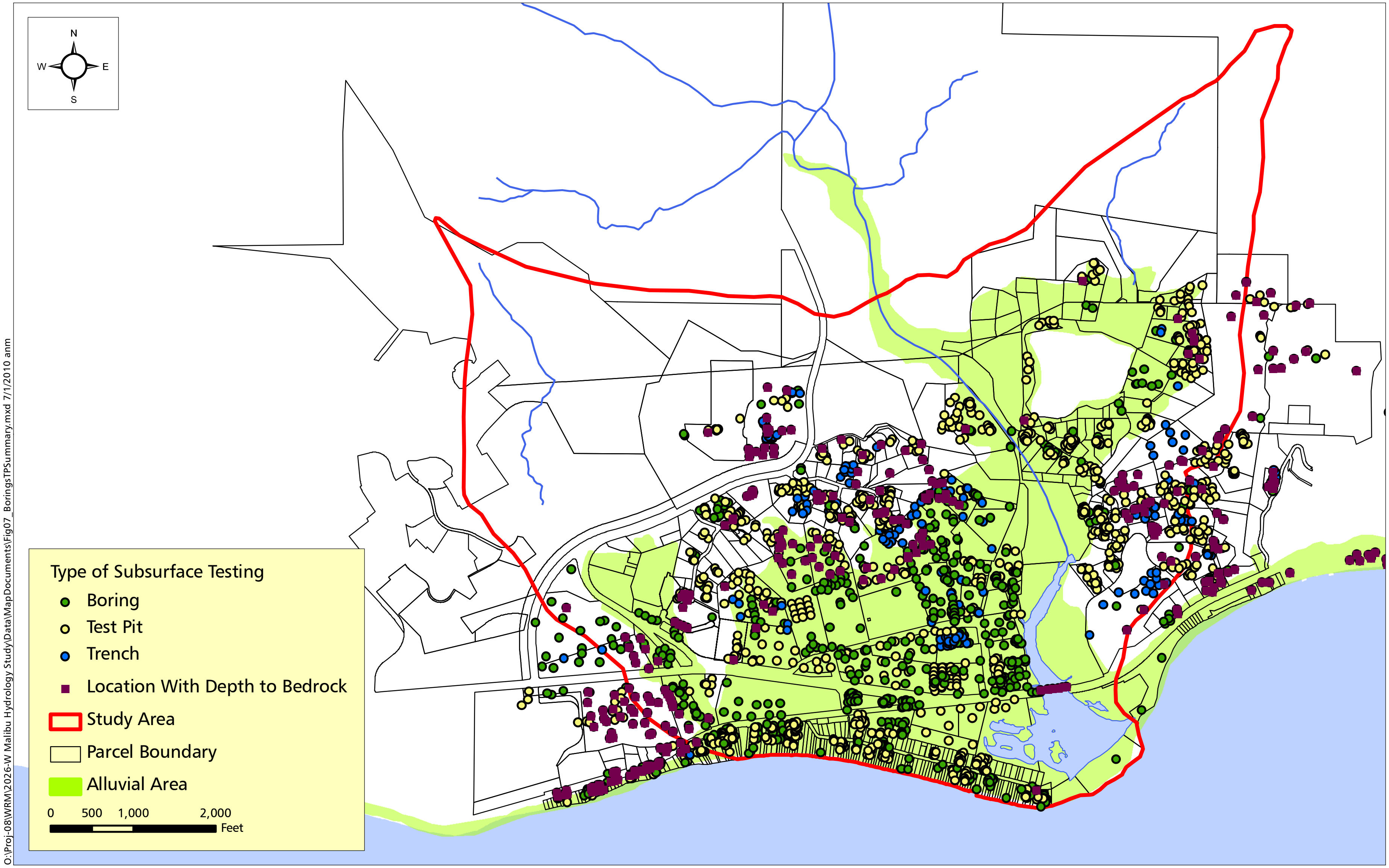

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Figure 9: Existing Soil Boring and Test Pit Locations

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Sources: Soil Boring, Test Pit, and Trench Locations, digitized by Stone, 2002-2009; Hydrography, digitized by Stone using LAR-IAC 2006-2007 topography, 2009; Study Area and Alluvial Recharge Area, Stone, 2004

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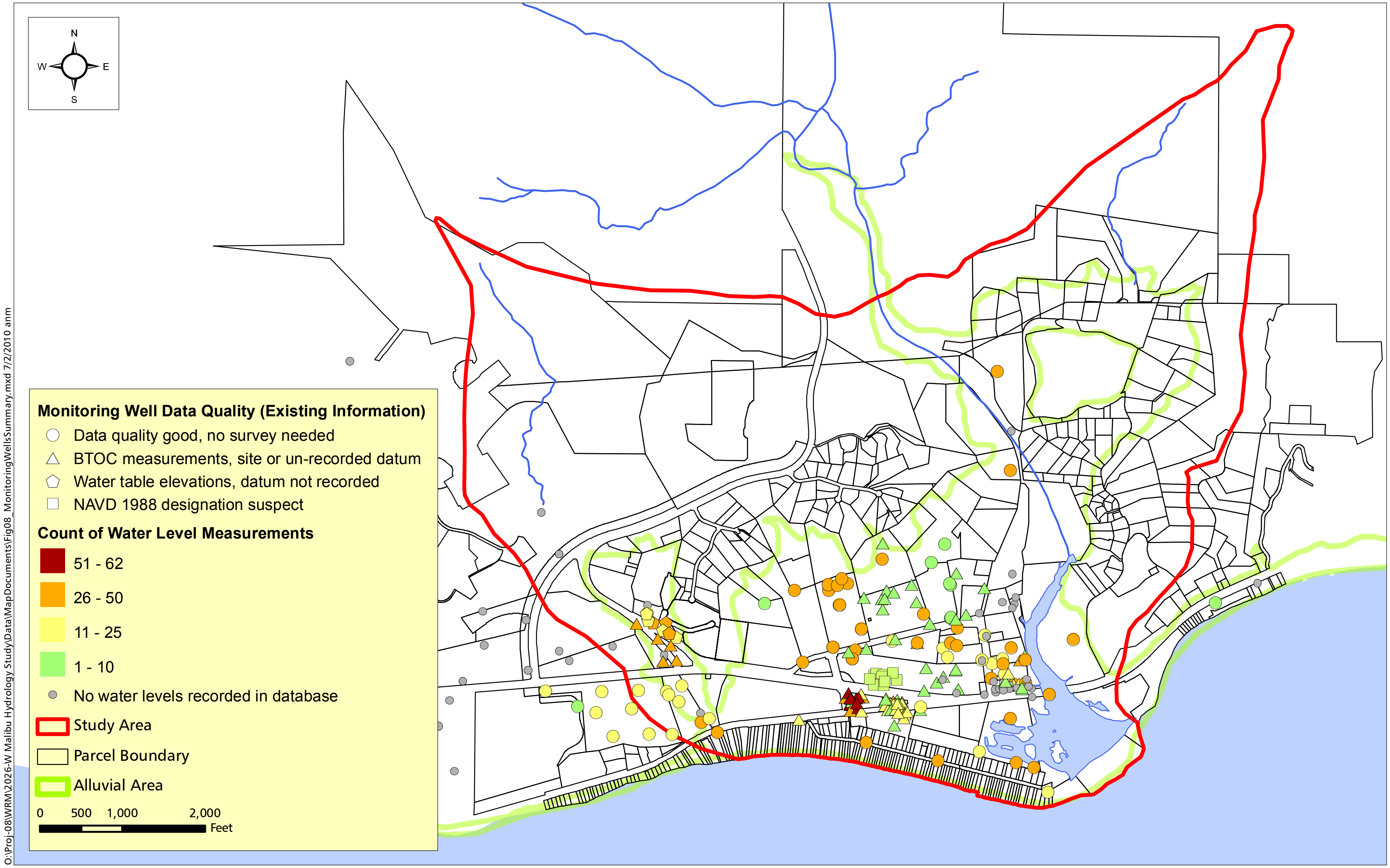

Figure 10: Summary of Monitoring Well Locations and Water Level Data

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Sources: Groundwater Well Locations, digitized by Stone, 2009 and/or surveyed by Land & Air Surveying, 2010; Water Levels, entered by Stone, 2002-2009; Study Area, Stone; Hydrography, digitized by Stone from LAR-IAC digital elevation model, 2009; Parcel boundaries, Los Angeles County.

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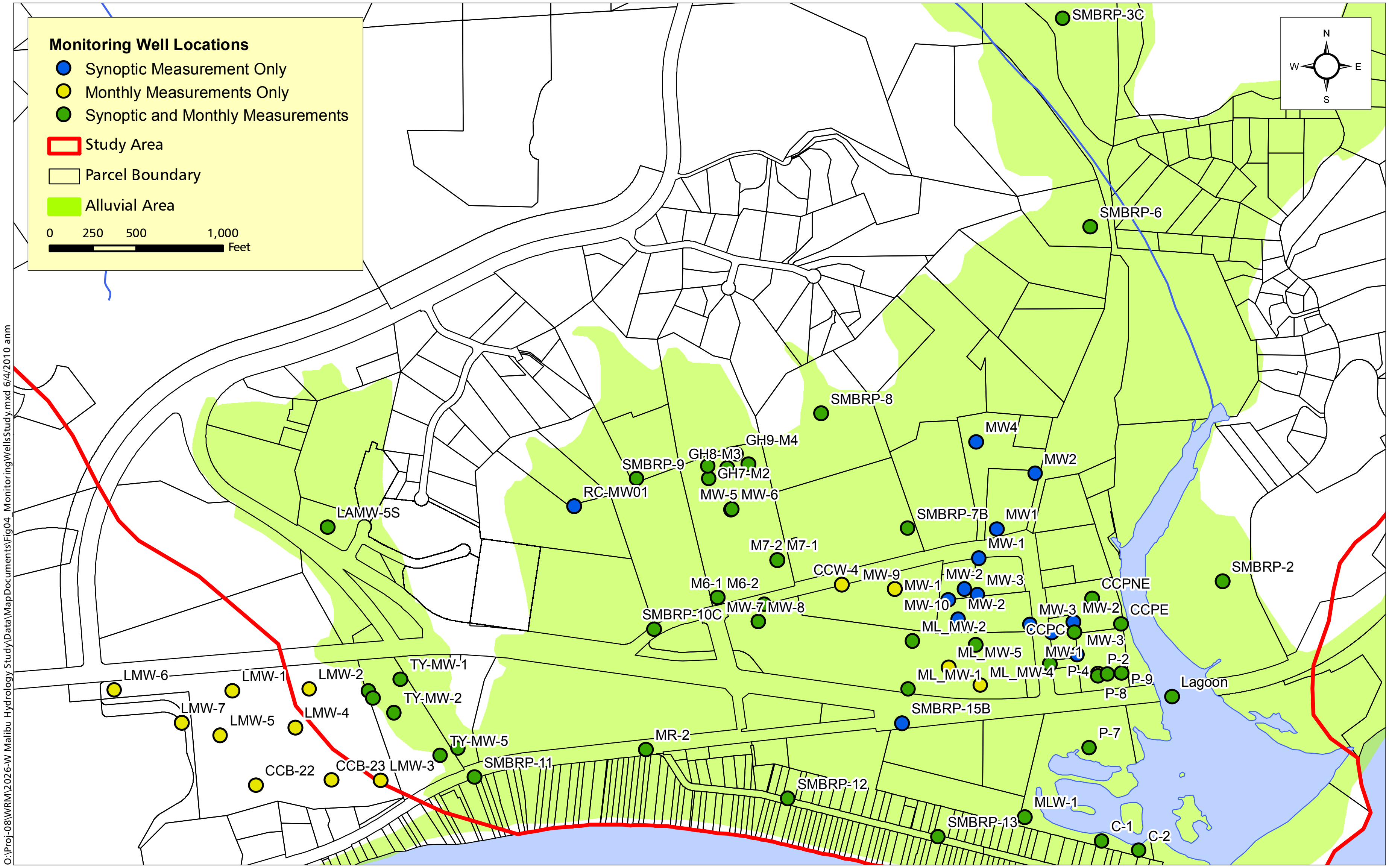

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Figure 11: Monitoring Well Locations - Detail

Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Sources: Groundwater Well Locations, digitized by Stone, 2009 and/or surveyed by Land & Air Surveying, 2010; Study Area, Stone; Parcel boundaries, Los Angeles County.

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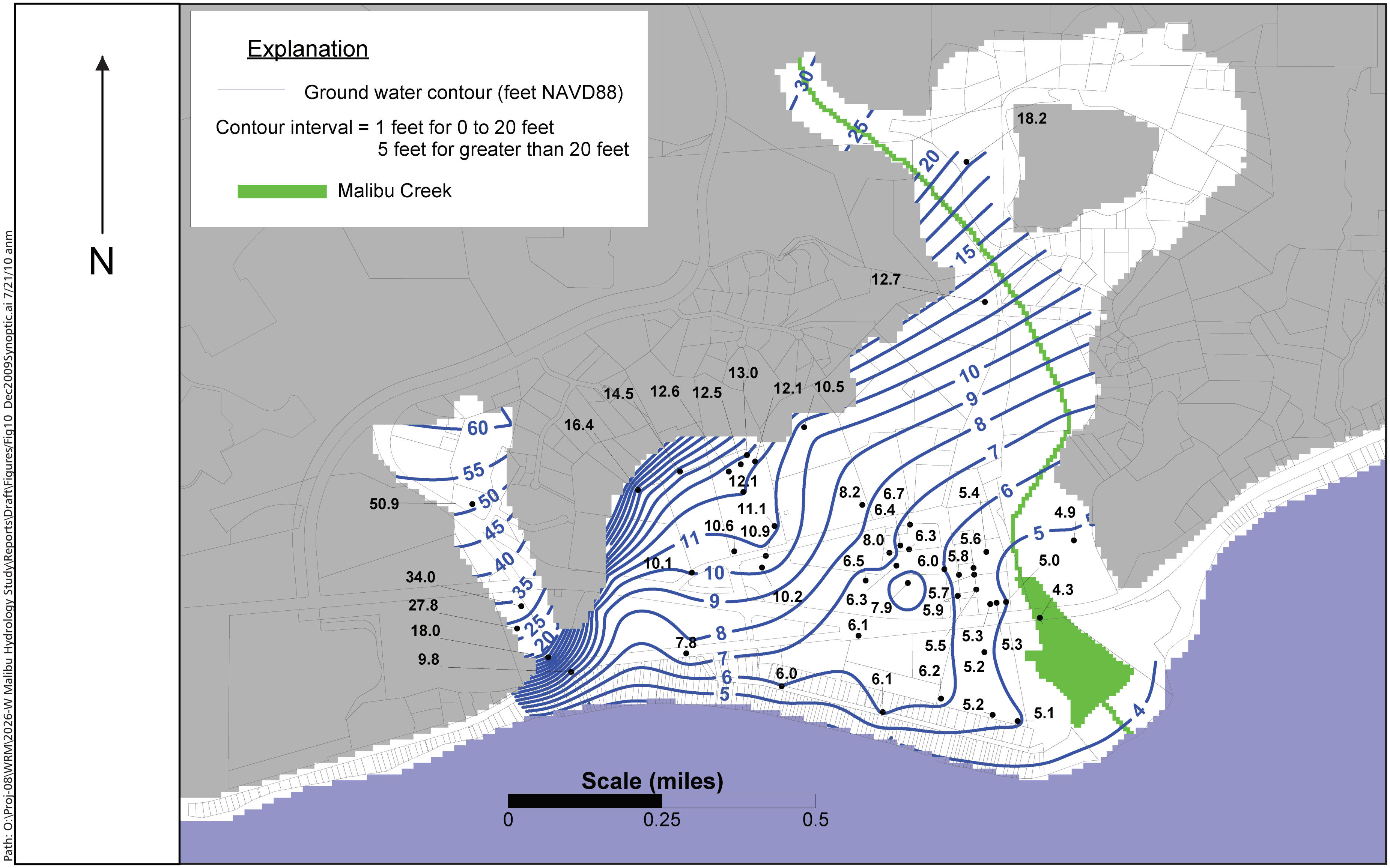

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Figure 12: Water Levels Measured on December 8, 2009, Breached Lagoon
Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Source: Field observations by Stone, McDonald Morrissey Associates, Fugro West Inc., December 2009; modified from Appendix A Figure 2.12.

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Figure 13: Multi-Channel Analysis of Surface Waves (MASW) Survey Transects and Locations
Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Source: Field observations by Entrix, Inc., March 2010; modified from Appendix B Figure 1.

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Figure 14: Multi-Channel Analysis of Surface Waves (MASW) Survey Results

Hydrology Study of Cumulative Impacts for the Civic Center Area

City of Malibu, California

Note: Bedrock elevations shown on this map are in feet NAVD88.

Source: Field observations by Entrix, Inc., March 2010; modified from Appendix B Figure 6.

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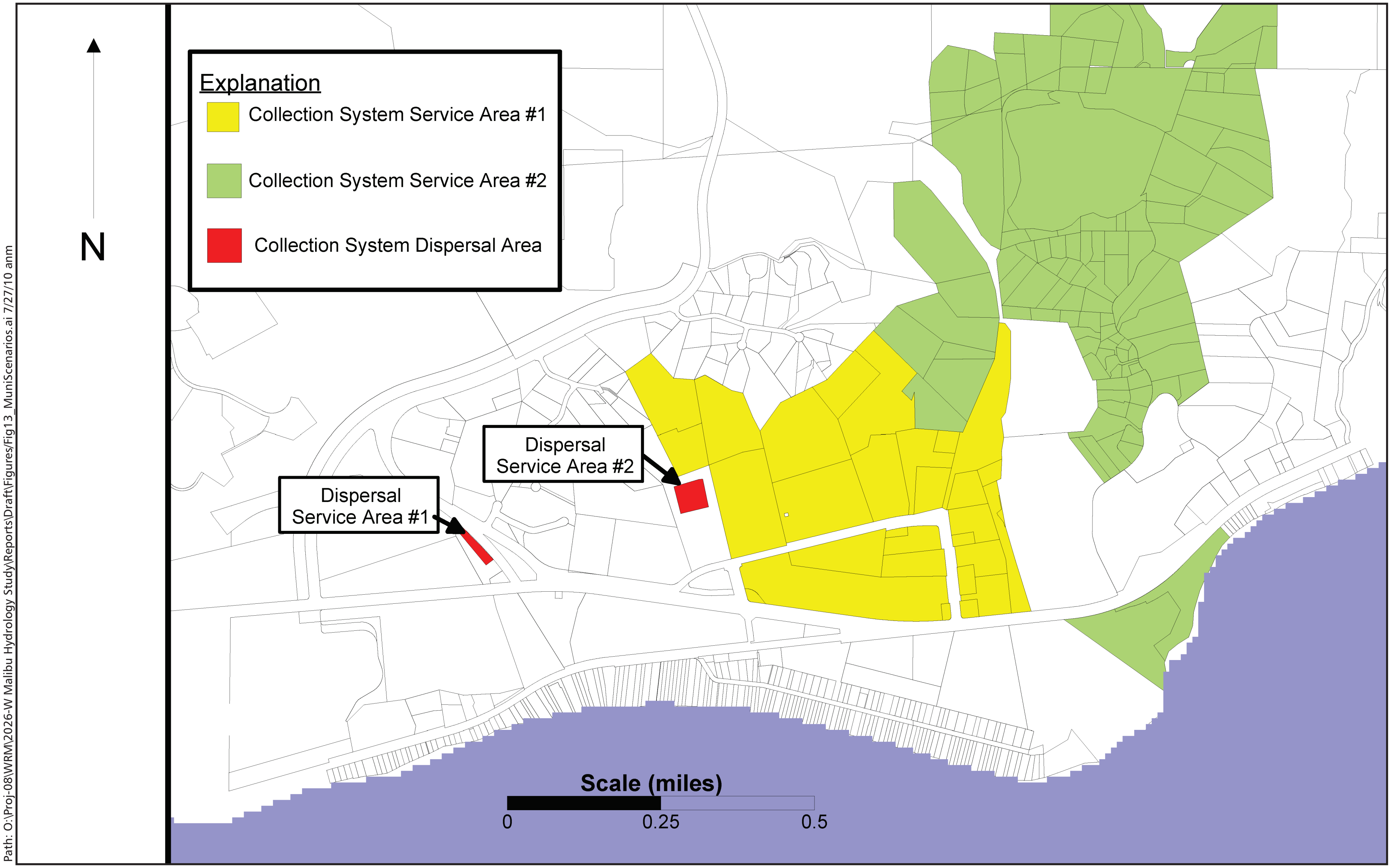

Figure 15: Collection System Service Areas and Dispersal Locations for Municipal Model Application
Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Source: Municipal scenario collection and service areas by RMC, 2010; modified from Appendix A Figure 3.16.

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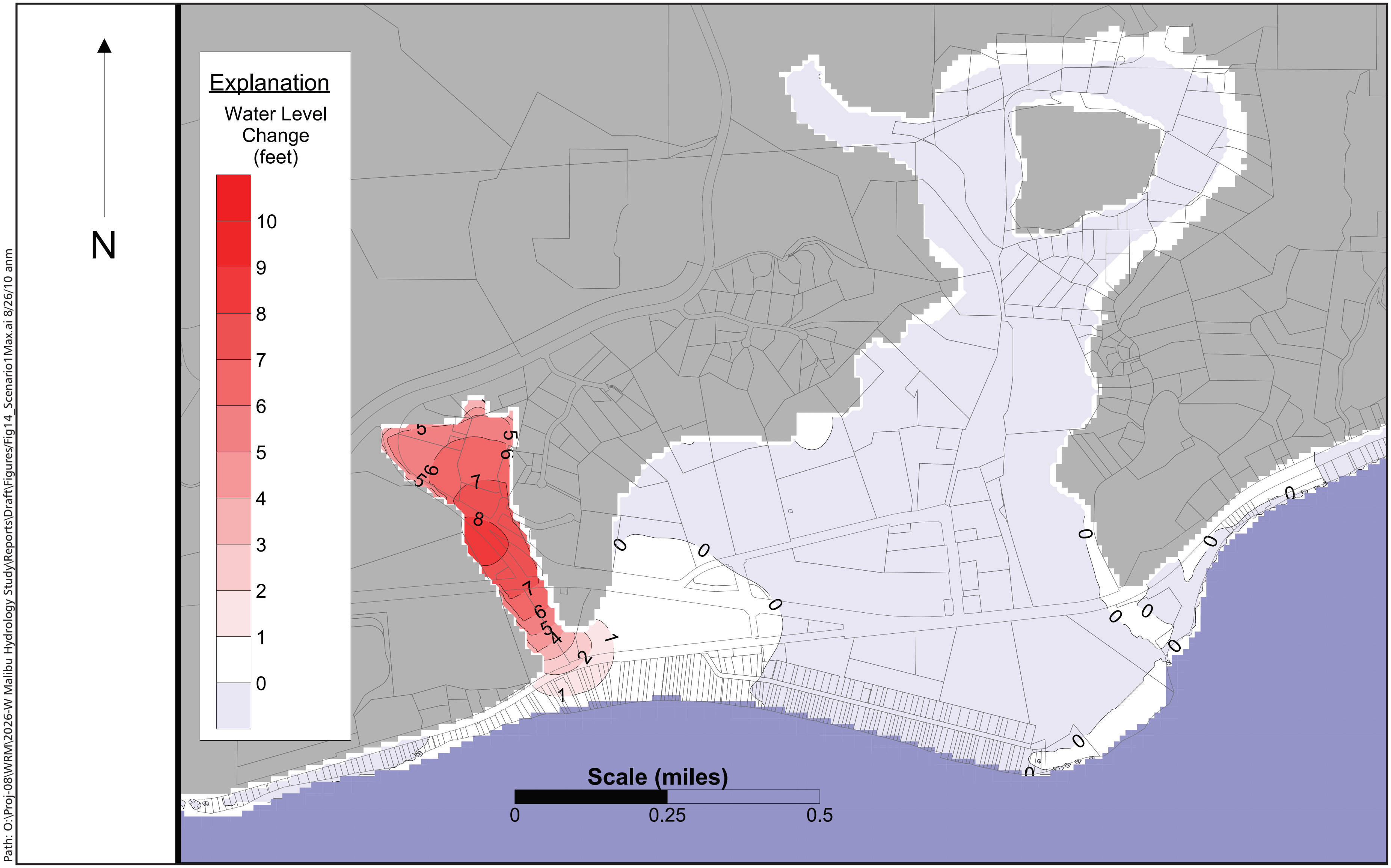

Figure 16: Water Table Changes Caused at High Water Condition, Scenario #1
Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Source: Municipal scenario collection and service areas by RMC, 2010; modified from Appendix A Figure 3.19.

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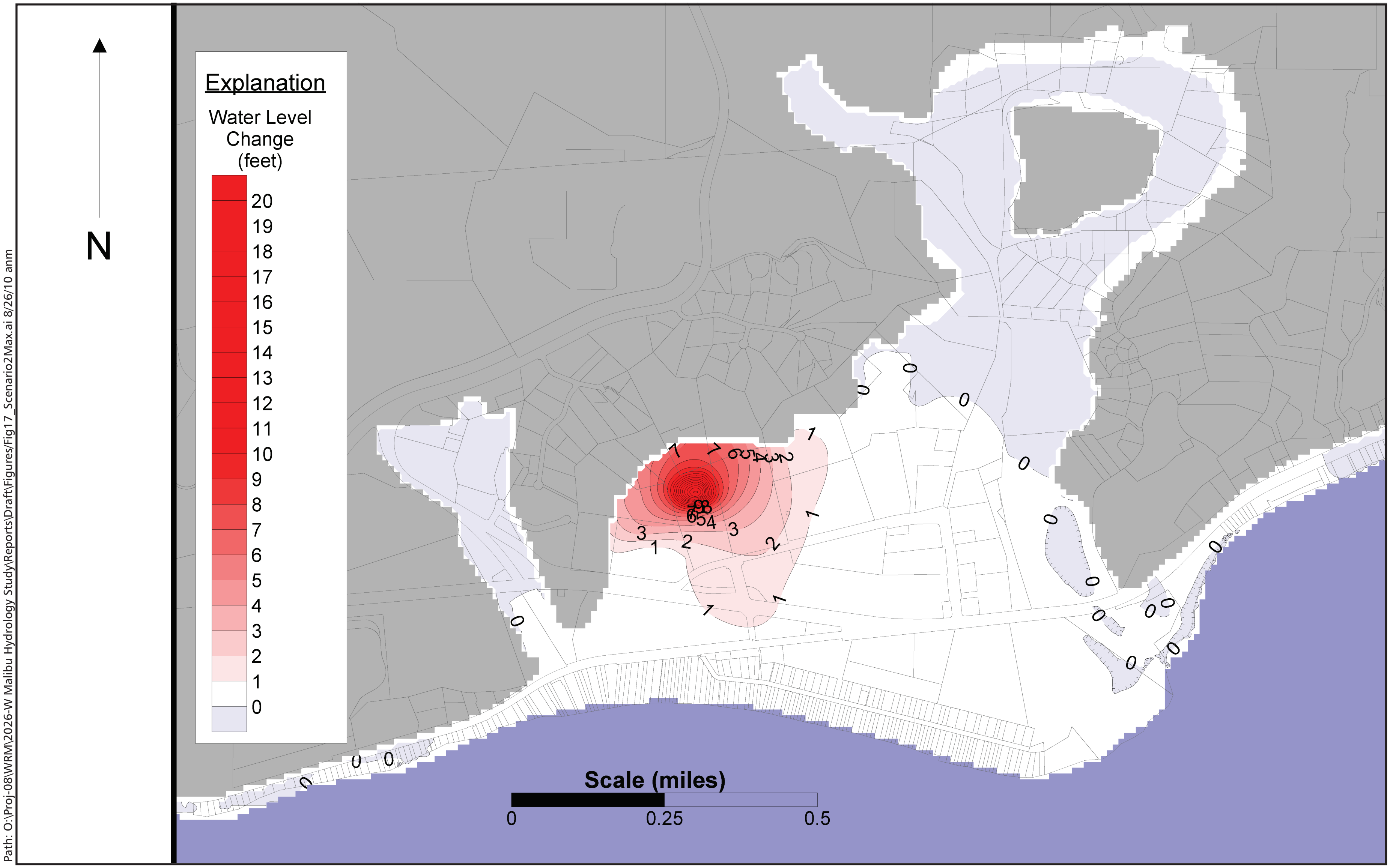

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Figure 17: Water Table Changes Caused at High Water Condition, Scenario #2
Hydrology Study of Cumulative Impacts for the Civic Center Area
City of Malibu, California

Source: Municipal scenario collection and service areas by RMC, 2010; modified from Appendix A Figure 3.22.

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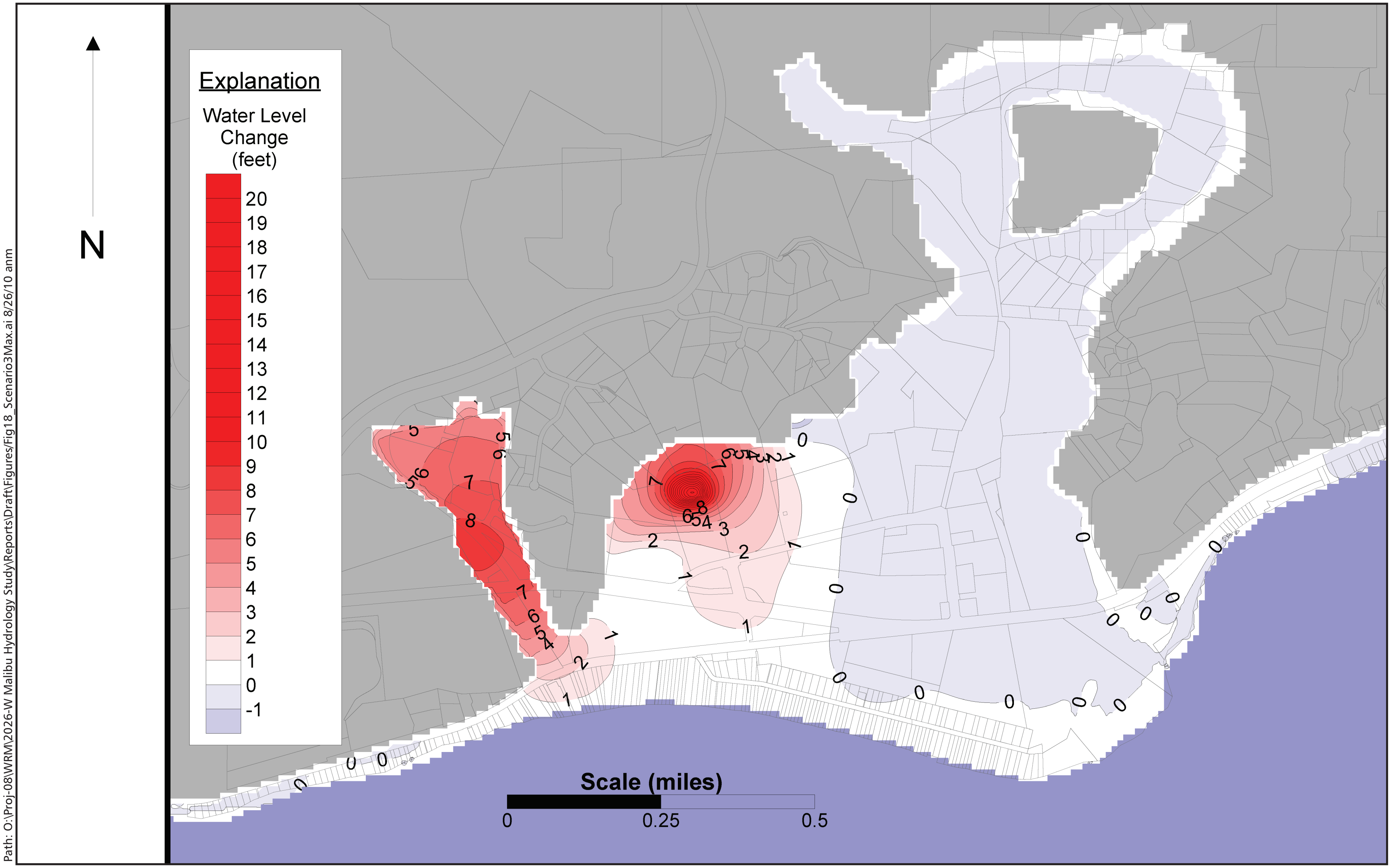

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Figure 18: Water Table Changes Caused at High Water Condition, Scenario #3

Hydrology Study of Cumulative Impacts for the Civic Center Area

City of Malibu, California

Source: Municipal scenario collection and service areas by RMC, 2010; modified from Appendix A Figure 3.23.

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Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1: List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
Coast View/Knolls				
4458026007	COAST VIEW DR	Residential		onsite
4458027002	COAST VIEW DR	Residential		onsite
4458027003	COAST VIEW DR	Residential		onsite
4458026006	COAST VIEW DR	Residential		onsite
4458027004	COAST VIEW DR	Residential		onsite
4458026015	COAST VIEW DR	Residential		onsite
4458026014	COAST VIEW DR	Residential		onsite
4458027005	COAST VIEW DR	Multi-Family	Double	onsite
4458026004	COAST VIEW DR	Residential		onsite
4458027029	COAST VIEW DR	Residential		onsite
4458026003	COAST VIEW DR	Residential		onsite
4458026010	MALIBU KNOLLS RD	Residential		onsite
4458026011	MALIBU KNOLLS RD	Residential		onsite
4458026012	MALIBU KNOLLS RD	Residential		onsite
4458026013	MALIBU KNOLLS RD	Residential		onsite
4458026009	MALIBU KNOLLS RD	Residential		onsite
4458025001	MALIBU KNOLLS RD	Residential		onsite
4458026008	MALIBU KNOLLS RD	Residential		onsite
4458025022	MALIBU KNOLLS RD	Residential		onsite
4458027025	WINTER CANYON RD	Institutional	Religious	onsite
Colony View/Harbor Vista/Malibu Crest				
4458025020	COLONY VIEW CIR	Residential		onsite
4458025025	COLONY VIEW CIR	Residential		onsite
4458025016	COLONY VIEW CIR	Residential		onsite
4458025015	COLONY VIEW CIR	Residential		onsite
4458025012	COLONY VIEW CIR	Residential		onsite
4458025010	COLONY VIEW CIR	Residential		onsite
4458025011	COLONY VIEW CIR	Residential		onsite
4458024004	HARBOR VISTA DR	Residential		onsite
4458024043	HARBOR VISTA DR	Residential		onsite
4458024025	HARBOR VISTA DR	Residential		onsite
4458024031	HARBOR VISTA DR	Residential		onsite
4458024001	HARBOR VISTA DR	Residential		onsite
4458024029	HARBOR VISTA DR	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

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TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4458025014	HARBOR VISTA DR	Residential		onsite
4458024034	HARBOR VISTA DR	Residential		onsite
4458025013	HARBOR VISTA DR	Residential		onsite
4458024009	HARBOR VISTA DR	Residential		onsite
4458025019	HARBOR VISTA DR	Residential		onsite
4458024010	HARBOR VISTA DR	Residential		onsite
4458024011	HARBOR VISTA DR	Residential		onsite
4458024012	HARBOR VISTA DR	Residential		onsite
4458025024	HARBOR VISTA DR	Residential		onsite
4458024013	HARBOR VISTA DR	Residential		onsite
4458025006	HARBOR VISTA DR	Residential		onsite
4458025018	HARBOR VISTA DR	Residential		onsite
4458025017	MALIBU CANYON RD	Residential		onsite
4458024038	MALIBU CREST DR	Residential		onsite
4458024042	MALIBU CREST DR	Residential		onsite
4458024041	MALIBU CREST DR	Residential		onsite
4458024039	MALIBU CREST DR	Residential		onsite
4458024040	MALIBU CREST DR	Residential		onsite
4458024022	MALIBU CREST DR	Residential		onsite
4458024023	MALIBU CREST DR	Residential		onsite
4458024021	MALIBU CREST DR	Residential		onsite
4458024015	MALIBU CREST DR	Residential		onsite
4458024014	MALIBU CREST DR	Residential		onsite
Commercial/Institutional/Multi-Family				
4458027903		Institutional	Government Property	onsite
4458020010	CIVIC CENTER WAY	Commercial	Commercial	onsite
4458020004	CIVIC CENTER WAY	Commercial	Professional Building	onsite
4458022904	CIVIC CENTER WAY	Institutional	Government Property	offsite source
4458021063	CIVIC CENTER WAY	Residential		offsite source
4452011029	CROSS CREEK RD	Commercial	Commercial	onsite
4458022802	CROSS CREEK RD	Institutional	Utility	onsite
4452011037	CROSS CREEK RD	Commercial	Nursery or Greenhouse	onsite
4452012024	CROSS CREEK RD	Commercial	Store and residential combination	onsite
4452011035	CROSS CREEK RD	Commercial	Office Building	onsite
4452011803	CROSS CREEK RD	Institutional	Utility	onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4458020014	CROSS CREEK RD	Commercial	Shopping center (neighborhood)	onsite
4452011039	CROSS CREEK RD	Commercial	Stores	onsite
4452011042	CROSS CREEK RD	Commercial	Shopping center (neighborhood)	onsite
4458021014	DE VILLE WAY	Residential		offsite source
4458027058	DE VILLE WAY	Residential		offsite source
4458029006	MALIBU CANYON RD	Industrial	Heavy manufacturing	onsite
4458029012	MALIBU CANYON RD	Industrial	Heavy manufacturing	onsite
4458029013	MALIBU CANYON RD	Industrial	Heavy manufacturing	onsite
4458029015	MALIBU CANYON RD	Industrial	Heavy manufacturing	onsite
4458025023	MALIBU CANYON RD	Institutional	Church	onsite
4458001003	MALIBU RD	Commercial	Commerical	onsite
4458002019	MALIBU RD	Commercial	Bank	offsite source
4458002900	MALIBU RD	Institutional	Govn't owned property / Police & Fire stations	onsite
4458002018	MALIBU RD	Commercial	Office Building	onsite
4458019010	MALIBU RD	Commercial	Shopping center / Lift	offsite source
4458018004	MALIBU RD	Commercial	Store and residential combination	onsite
4452005902	PACIFIC COAST HWY	Institutional	Govn't owned property / Vacant	onsite
4452006902	PACIFIC COAST HWY	Institutional	Govn't owned property / Open	onsite
4452006903	PACIFIC COAST HWY	Institutional	Govn't owned property / Open	onsite
4458020901	PACIFIC COAST HWY	Commercial	Commercial	offsite source
4452004027	PACIFIC COAST HWY	Multi-Family	Five or more apartments or units	onsite
4452005020	PACIFIC COAST HWY	Multi-Family	Five or more apartments or units	onsite
4452005031	PACIFIC COAST HWY	Commercial	Motel - under 50 units / 3 stories	onsite
4452019011	PACIFIC COAST HWY	Commercial	Office Building	onsite
4452019010	PACIFIC COAST HWY	Institutional	Religious	onsite
4452019009	PACIFIC COAST HWY	Institutional	Religious	onsite
4452019004	PACIFIC COAST HWY	Commercial	Restaurant	onsite
4452019003	PACIFIC COAST HWY	Commercial	Restaurant	onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4452019002	PACIFIC COAST HWY	Commercial	Motel - under 50 units	onsite
4452011043	PACIFIC COAST HWY	Commercial	Shopping center (neighborhood)	onsite
4452011033	PACIFIC COAST HWY	Commercial	Service Station	onsite
4458020002	PACIFIC COAST HWY	Commercial	Office Building	onsite
4458019008	PACIFIC COAST HWY	Commercial	Service Station	offsite source
4458020016	PACIFIC COAST HWY	Commercial	Commercial	onsite and offsite source
4458019006	PACIFIC COAST HWY	Commercial	Service Station	offsite source
4458018900	PACIFIC COAST HWY	Institutional	Govn't owned property / Open	onsite
4458038010	PACIFIC COAST HWY	Institutional	College	onsite
4452014064	SERRA RD	Institutional	Home for aged & others	onsite
4458021172	STUART RANCH RD	Institutional	Religious	onsite
4458021002	STUART RANCH RD	Institutional	Club	onsite
4452016003	SWEETWATER MESA RD	Commercial	Warehousing, distribution, storage	onsite
4458027036	VISTA PACIFICA	Residential		offsite source
4458027034	WINTER CANYON RD	Commercial	Store and residential combination	onsite
4458027023	WINTER CANYON RD	Institutional	Religious	onsite
4458027024	WINTER CANYON RD	Institutional	Church	onsite
4458027900	WINTER CANYON RD	Institutional	Govn't owned property / Open	onsite
Malibu Colony Golf Park				
4458004040	MALIBU COLONY RD	Residential		onsite
4458001006	MALIBU RD	Commercial	Commercial	onsite
Malibu Colony/Shoreline				
4452008017	MALIBU COLONY DR	Residential		onsite
4452008014	MALIBU COLONY DR	Residential		onsite
4452008030	MALIBU COLONY DR	Residential		onsite
4452008026	MALIBU COLONY DR	Residential		onsite
4452010032	MALIBU COLONY DR	Residential		onsite
4452009016	MALIBU COLONY DR	Residential		onsite
4452010028	MALIBU COLONY DR	Residential		onsite
4452010009	MALIBU COLONY DR	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4452009018	MALIBU COLONY DR	Residential		onsite
4452009019	MALIBU COLONY DR	Residential		onsite
4452010029	MALIBU COLONY DR	Residential		onsite
4452009022	MALIBU COLONY DR	Residential		onsite
4452009021	MALIBU COLONY DR	Residential		onsite
4452009020	MALIBU COLONY DR	Residential		onsite
4452009015	MALIBU COLONY DR	Residential		onsite
4452010003	MALIBU COLONY DR	Residential		onsite
4458004031	MALIBU COLONY DR	Residential		onsite
4458004032	MALIBU COLONY DR	Residential		onsite
4452010019	MALIBU COLONY DR	Residential		onsite
4458004033	MALIBU COLONY DR	Residential		onsite
4458004034	MALIBU COLONY DR	Residential		onsite
4458003023	MALIBU COLONY DR	Residential		onsite
4458004035	MALIBU COLONY DR	Residential		onsite
4458003022	MALIBU COLONY DR	Residential		onsite
4458003021	MALIBU COLONY DR	Residential		onsite
4458004037	MALIBU COLONY DR	Residential		onsite
4458004038	MALIBU COLONY DR	Residential		onsite
4458004039	MALIBU COLONY DR	Residential		onsite
4458003018	MALIBU COLONY DR	Residential		onsite
4458004041	MALIBU COLONY DR	Residential		onsite
4458004042	MALIBU COLONY DR	Residential		onsite
4458004043	MALIBU COLONY DR	Residential		onsite
4458003015	MALIBU COLONY DR	Residential		onsite
4458004047	MALIBU COLONY DR	Residential		onsite
4458004048	MALIBU COLONY DR	Residential		onsite
4458004049	MALIBU COLONY DR	Residential		onsite
4458004050	MALIBU COLONY DR	Residential		onsite
4458004051	MALIBU COLONY DR	Residential		onsite
4458004054	MALIBU COLONY DR	Residential		onsite
4458004055	MALIBU COLONY DR	Residential		onsite
4458005040	MALIBU COLONY DR	Residential		onsite
4458005038	MALIBU COLONY DR	Residential		onsite
4458005037	MALIBU COLONY DR	Residential		onsite
4458005036	MALIBU COLONY DR	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4458005035	MALIBU COLONY DR	Residential		onsite
4458005033	MALIBU COLONY DR	Residential		onsite
4458005031	MALIBU COLONY DR	Residential		onsite
4458003029	MALIBU COLONY DR	Residential		onsite
4458005030	MALIBU COLONY DR	Residential		onsite
4458005028	MALIBU COLONY DR	Residential		onsite
4458002014	MALIBU COLONY DR	Residential		onsite
4458005027	MALIBU COLONY DR	Residential		onsite
4458002011	MALIBU COLONY DR	Residential		onsite
4458005026	MALIBU COLONY DR	Residential		onsite
4458005025	MALIBU COLONY DR	Residential		onsite
4458002010	MALIBU COLONY DR	Residential		onsite
4458005024	MALIBU COLONY DR	Residential		onsite
4458005023	MALIBU COLONY DR	Residential		onsite
4458005021	MALIBU COLONY DR	Residential		onsite
4458006041	MALIBU COLONY DR	Residential		onsite
4458006040	MALIBU COLONY DR	Residential		onsite
4458002003	MALIBU COLONY DR	Residential		onsite
4458006038	MALIBU COLONY DR	Residential		onsite
4458002017	MALIBU COLONY DR	Residential		onsite
4458006037	MALIBU COLONY DR	Residential		onsite
4458006034	MALIBU COLONY DR	Residential		onsite
4458004044	MALIBU COLONY RD	Residential		onsite
4452008016	MALIBU COLONY RD	Residential		onsite
4452010017	MALIBU COLONY RD	Residential		onsite
4452008028	MALIBU COLONY RD	Residential		onsite
4452010024	MALIBU COLONY RD	Residential		onsite
4452008027	MALIBU COLONY RD	Residential		onsite
4452010023	MALIBU COLONY RD	Residential		onsite
4452008025	MALIBU COLONY RD	Residential		onsite
4452008024	MALIBU COLONY RD	Residential		onsite
4452008023	MALIBU COLONY RD	Residential		onsite
4452010031	MALIBU COLONY RD	Residential		onsite
4452008022	MALIBU COLONY RD	Residential		onsite
4452008021	MALIBU COLONY RD	Residential		onsite
4452008020	MALIBU COLONY RD	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4452010012	MALIBU COLONY RD	Residential		onsite
4452008019	MALIBU COLONY RD	Residential		onsite
4452008018	MALIBU COLONY RD	Residential		onsite
4452009027	MALIBU COLONY RD	Residential		onsite
4452009026	MALIBU COLONY RD	Residential		onsite
4452009017	MALIBU COLONY RD	Residential		onsite
4452009025	MALIBU COLONY RD	Residential		onsite
4452010008	MALIBU COLONY RD	Residential		onsite
4452009024	MALIBU COLONY RD	Residential		onsite
4452009023	MALIBU COLONY RD	Residential		onsite
4452010027	MALIBU COLONY RD	Residential		onsite
4452010005	MALIBU COLONY RD	Residential		onsite
4452010002	MALIBU COLONY RD	Residential		onsite
4458004036	MALIBU COLONY RD	Residential		onsite
4458003019	MALIBU COLONY RD	Residential		onsite
4458003017	MALIBU COLONY RD	Residential		onsite
4458004045	MALIBU COLONY RD	Residential		onsite
4458004046	MALIBU COLONY RD	Residential		onsite
4458003014	MALIBU COLONY RD	Residential		onsite
4452009014	MALIBU COLONY RD	Residential		onsite
4458003013	MALIBU COLONY RD	Residential		onsite
4458004052	MALIBU COLONY RD	Residential		onsite
4458004053	MALIBU COLONY RD	Residential		onsite
4458003027	MALIBU COLONY RD	Residential		onsite
4458003026	MALIBU COLONY RD	Residential		onsite
4458005039	MALIBU COLONY RD	Residential		onsite
4458003009	MALIBU COLONY RD	Residential		onsite
4458003008	MALIBU COLONY RD	Residential		onsite
4458005034	MALIBU COLONY RD	Residential		onsite
4458003030	MALIBU COLONY RD	Residential		onsite
4458005032	MALIBU COLONY RD	Residential		onsite
4458005029	MALIBU COLONY RD	Residential		onsite
4458003028	MALIBU COLONY RD	Residential		onsite
4458005022	MALIBU COLONY RD	Residential		onsite
4458002006	MALIBU COLONY RD	Residential		onsite
4458002004	MALIBU COLONY RD	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4458006036	MALIBU COLONY RD	Residential		onsite
4458006035	MALIBU COLONY RD	Residential		onsite
4458006033	MALIBU RD	Residential		onsite
4458006032	MALIBU RD	Residential		onsite
4458006031	MALIBU RD	Residential		onsite
4458006030	MALIBU RD	Residential		onsite
4458006029	MALIBU RD	Residential		onsite
4458006028	MALIBU RD	Residential		onsite
4458006027	MALIBU RD	Residential		onsite
4458006026	MALIBU RD	Residential		onsite
4458006025	MALIBU RD	Residential		onsite
4458006023	MALIBU RD	Residential		onsite
4458006022	MALIBU RD	Residential		onsite
4458007028	MALIBU RD	Residential		onsite
4458007027	MALIBU RD	Residential		onsite
4458007026	MALIBU RD	Residential		onsite
4458007025	MALIBU RD	Residential		onsite
4458007024	MALIBU RD	Residential		onsite
4458007023	MALIBU RD	Residential		onsite
4458007022	MALIBU RD	Residential		onsite
4458007021	MALIBU RD	Residential		onsite
4458007016	MALIBU RD	Residential		onsite
4458007015	MALIBU RD	Residential		onsite
4458007020	MALIBU RD	Residential		onsite
4458007019	MALIBU RD	Residential		onsite
4458007018	MALIBU RD	Residential		onsite
4458007017	MALIBU RD	Residential		onsite
4458008017	MALIBU RD	Residential		onsite
4458008016	MALIBU RD	Residential		onsite
4458008015	MALIBU RD	Residential		onsite
4458008014	MALIBU RD	Residential		onsite
4458008013	MALIBU RD	Residential		onsite
4458008018	MALIBU RD	Residential		onsite
4458008003	MALIBU RD	Residential		onsite
4458008002	MALIBU RD	Residential		onsite
4458008001	MALIBU RD	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4458009013	MALIBU RD	Residential		onsite
4458009012	MALIBU RD	Residential		onsite
4458018005	MALIBU RD	Residential		onsite
4458009009	MALIBU RD	Residential		onsite
4458018020	MALIBU RD	Residential		onsite
4458009001	MALIBU RD	Residential		onsite
4458010015	MALIBU RD	Residential		onsite
4458010016	MALIBU RD	Residential		onsite
4458010017	MALIBU RD	Residential		onsite
4458018011	MALIBU RD	Residential		onsite
4458018012	MALIBU RD	Residential		onsite
4458010019	MALIBU RD	Residential		onsite
4458010018	MALIBU RD	Residential		onsite
4458010012	MALIBU RD	Residential		onsite
4458010011	MALIBU RD	Residential		onsite
4458010010	MALIBU RD	Residential		onsite
4458010008	MALIBU RD	Residential		onsite
4458010007	MALIBU RD	Residential		onsite
4458010006	MALIBU RD	Residential		onsite
4458010005	MALIBU RD	Residential		onsite
4458010004	MALIBU RD	Residential		onsite
4458010003	MALIBU RD	Residential		onsite
4458010001	MALIBU RD	Residential		onsite
4458011002	MALIBU RD	Residential		onsite
4458011003	MALIBU RD	Residential		onsite
4458011004	MALIBU RD	Residential		onsite
4452019008	PACIFIC COAST HWY	Institutional	Religious	onsite
4452005025	PACIFIC COAST HWY	Residential		onsite
4452005004	PACIFIC COAST HWY	Residential		onsite
4452005022	PACIFIC COAST HWY	Residential		onsite
4452005018	PACIFIC COAST HWY	Residential		onsite
4452005002	PACIFIC COAST HWY	Residential		onsite
4452005001	PACIFIC COAST HWY	Residential		onsite
Nursery				
4458021003	COAST VIEW DR	Commercial	Nursery or Greenhouse	onsite
4458021173	STUART RANCH RD	Commercial	Commercial	onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

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Date/init: 7/26/2010 anm

TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4458021005	STUART RANCH RD	Commercial	Nursery or Greenhouse	onsite
Serra Vicinity				
4452015035	CROSS CREEK LN	Residential		onsite
4452015034	CROSS CREEK LN	Residential		onsite
4452015023	CROSS CREEK LN	Residential		onsite
4452015033	CROSS CREEK LN	Residential		onsite
4452015025	CROSS CREEK LN	Residential		onsite
4452015026	CROSS CREEK LN	Residential		onsite
4452015031	CROSS CREEK LN	Residential		onsite
4452015027	CROSS CREEK LN	Residential		onsite
4452015030	CROSS CREEK LN	Residential		onsite
4452015042	CROSS CREEK LN	Residential		onsite
4452015029	CROSS CREEK LN	Residential		onsite
4452027010	CROSS CREEK RD	Residential		onsite
4452027009	CROSS CREEK RD	Residential		onsite
4452014006	CROSS CREEK RD	Residential		onsite
4452015024	CROSS CREEK RD	Residential		onsite
4458023003	CROSS CREEK RD	Residential		onsite
4458023009	CROSS CREEK RD	Residential		onsite
4458022021	CROSS CREEK RD	Residential		onsite
4458022026	CROSS CREEK RD	Residential		onsite
4458022003	CROSS CREEK RD	Residential		onsite
4452015003	MARIPOSA DE ORO ST	Residential		onsite
4452015014	MARIPOSA DE ORO ST	Residential		onsite
4452015007	MARIPOSA DE ORO ST	Residential		onsite
4452015010	MARIPOSA DE ORO ST	Residential		onsite
4452015040	MARIPOSA DE ORO ST	Residential		onsite
4452015006	MARIPOSA DE ORO ST	Residential		onsite
4452015036	MARIPOSA DE ORO ST	Residential		onsite
4452015021	MARIPOSA DE ORO ST	Residential		onsite
4452015020	MARIPOSA DE ORO ST	Residential		onsite
4452015022	MARIPOSA DE ORO ST	Residential		onsite
4452015019	MARIPOSA DE ORO ST	Residential		onsite
4452015018	MARIPOSA DE ORO ST	Residential		onsite
4452027015	PALM CANYON LANE	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4452014065	PALM CANYON LANE	Multi-Family	Four Units (any combination)	onsite
4452027018	PALM CANYON LANE	Residential		onsite
4452027016	PALM CANYON LANE	Residential		onsite
4452027013	PALM CANYON LANE	Residential		onsite
4452027011	PALM CANYON LANE	Residential		onsite
4452027012	PALM CANYON LANE	Residential		onsite
4452014004	PALM CANYON LANE	Residential		onsite
4452012028	PALM CANYON LANE	Residential		onsite
4452027021	RETREAT CT	Residential		onsite
4452027022	RETREAT CT	Residential		onsite
4452027019	RETREAT CT	Residential		onsite
4452027023	RETREAT CT	Residential		onsite
4452012023	SERRA RD	Residential		onsite
4452026008	SERRA RD	Residential		onsite
4452026009	SERRA RD	Residential		onsite
4452026007	SERRA RD	Residential		onsite
4452026010	SERRA RD	Residential		onsite
4452026011	SERRA RD	Residential		onsite
4452026019	SERRA RD	Residential		onsite
4452026018	SERRA RD	Residential		onsite
4452026012	SERRA RD	Residential		onsite
4452026013	SERRA RD	Residential		onsite
4452026016	SERRA RD	Residential		onsite
4452026014	SERRA RD	Residential		onsite
4452026015	SERRA RD	Residential		onsite
4452018011	SERRA RD	Residential		onsite
4452013001	SERRA RD	Residential		onsite
4452018012	SERRA RD	Residential		onsite
4452013002	SERRA RD	Residential		onsite
4452018013	SERRA RD	Residential		onsite
4452013003	SERRA RD	Residential		onsite
4452018015	SERRA RD	Residential		onsite
4452013009	SERRA RD	Residential		onsite
4452018006	SERRA RD	Residential		onsite
4452018008	SERRA RD	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4452018016	SERRA RD	Residential		onsite
4452018009	SERRA RD	Residential		onsite
4452018017	SERRA RD	Residential		onsite
4452018018	SERRA RD	Residential		onsite
4452018019	SERRA RD	Residential		onsite
4452018020	SERRA RD	Residential		onsite
4452012014	SERRA RD	Residential		onsite
4452012012	SERRA RD	Residential		onsite
4452012015	SERRA RD	Residential		onsite
4452013005	SERRA RD	Residential		onsite
4452017001	SERRA RD	Multi-Family	Double	onsite
4452012007	SERRA RD	Residential		onsite
4452012016	SERRA RD	Residential		onsite
4452012013	SERRA RD	Residential		onsite
4452012022	SERRA RD	Residential		onsite
4452012009	SERRA RD	Residential		onsite
4452012011	SERRA RD	Residential		onsite
4452012020	SERRA RD	Residential		onsite
4452026004	SERRA RD	Residential		onsite
4452020088	SWEETWATER CANYON DR	Residential		onsite
4452016008	SWEETWATER MESA RD	Residential		onsite
4452016018	SWEETWATER MESA RD	Residential		onsite
4452016017	SWEETWATER MESA RD	Residential		onsite
4452025006	SWEETWATER MESA RD	Residential		onsite
4452016004	SWEETWATER MESA RD	Residential		onsite
4452016019	SWEETWATER MESA RD	Residential		onsite
4452016016	SWEETWATER MESA RD	Residential		onsite
4452016020	SWEETWATER MESA RD	Residential		onsite
4452016007	SWEETWATER MESA RD	Residential		onsite
4452016015	SWEETWATER MESA RD	Residential		onsite
4452017004	SWEETWATER MESA RD	Residential		onsite
4452017007	SWEETWATER MESA RD	Residential		onsite
4452017005	SWEETWATER MESA RD	Residential		onsite
4452017008	SWEETWATER MESA RD	Residential		onsite
4452017009	SWEETWATER MESA RD	Residential		onsite
4452013008	SWEETWATER MESA RD	Residential		onsite

Source: LA County Assessor and City of Malibu, 2005; system types, Stone 2009-2010.

TABLE 1 (continued): List of Properties in Study Area

AIN	Property Location	Property Use	Additional Description	System Type
4452013007	SWEETWATER MESA RD	Residential		onsite

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 2: Summary of Malibu Lagoon Barrier Beach Conditions by Year

Year	Barrier Beach Breached, Creek Open	Barrier Beach Intact, Creek Closed
2003	January 1-July 9; November 4-December 31	July 10-November 3
2004	January 1-May 1; June 3-June 21; October 19-December 31	May 2-June 2; June 22-October 18
2005	January 1-August 15; September 13-December 31	August 16-September 12
2006	January 1-June 10; August 23-October 28; November 30-December 31	June 11-August 22; October 29-November 29
2007	January 1-April 28; October 20-November 2; December 2-December 31	April 29-October 19; November 3-December 1
2008	January 1-May 17; May 29-June 29; November 26-December 31	May 18-May 28; June 30-November 25
2009	January 1-April 18; May 2-June 18; October 15-November 1; December 2-December 31	April 19-May 1; June 19-October 14; November 2-December 1

Source: LA County lifeguard daily records, 2003-2009.

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Date: 3/10/2010 anm

Hydrology Study of the Civic Center Area

City of Malibu, California

TABLE 3: Malibu Lagoon Surface Water Level Measurements

Date	Time	Depth to Water (ft. below MP)	Water Table Elevation (ft. NAVD88)
12/16/2008	7:36:00 AM	22.55	5.09
12/16/2008	4:39:00 PM	25.27	2.26
1/16/2009	6:55:00 AM	24.82	2.82
1/16/2009	12:40:00 PM	24.85	2.79
2/12/2009	6:20:00 AM	25.31	2.33
2/12/2009	10:59:00 AM	23.52	4.12
3/13/2009	7:23:00 AM	25.5	2.14
3/13/2009	12:10:00 PM	24.1	3.54
4/17/2009	6:50:00 AM	23.9	3.74
4/17/2009	11:50:00 AM	23.89	3.75
5/15/2009	7:07:00 AM	24.8	2.84
5/15/2009	12:19:00 PM	25.05	2.5
6/18/2009	7:10:00 AM	22.65	4.99
6/18/2009	3:20:00 PM	22.6	5.04
8/20/2009	7:20:00 AM	21.35	6.29
8/20/2009	2:10:00 PM	21.41	6.23
10/20/2009	6:40:00 AM	25	2.64
11/17/2009	7:30:00 AM	22.15	5.49
11/17/2009	12:45:00 PM	22.01	5.63
12/8/2009	7:38:00 AM	23.29	4.35
12/8/2009	9:22:00 AM	23.46	4.18
1/28/2010	8:30:00 AM	21.85	5.79
1/28/2010	1:30:00 PM	25.15	2.49

Source: Field Observations, Earth Consultants International, 2008-2010.

STONE ENVIRONMENTAL, INC.

Notes: MP = monitoring point. NAVD88 = North American Vertical Datum 1988; Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment.

1. Location for the Lagoon measurement point is LVMWD-1 (nail on southerly side of PCH Bridge, by Las Virgenes Municipal Water District standpipe and probe).
2. Survey elevation for the Lagoon monitoring point is 27.64 ft. NAVD88.

Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptLagoonSummary]

Date/init: 6/9/2010 anm

Hydrology Study of the Civic Center Area

City of Malibu, California

TABLE 4: Synoptic Water Level Measurements, Breached Lagoon Condition, December 8, 2009

Well ID	MP Elevation (ft. NAVD88)	Depth to Water (ft. below MP)	Water Table Elevation (ft. NAVD88)
C-1	11.47	6.28	5.19
C-2	11.19	6.09	5.10
CCPC	12.48	6.75	5.73
CCPE	13.01	7.91	5.10
CCPNE	13.66	8.23	5.43
CCPSW	13.52	7.66	5.86
ECI-RC-MW01	41.90	25.51	16.39
GH10-M5	35.51	23.39	12.12
GH6-M1	39.76	27.14	12.62
GH7-M2	43.98	dry	dry
GH8-M3	39.18	26.64	12.54
GH9-M4	40.97	27.95	13.02
Lagoon	27.64	23.29	4.35
Lagoon	27.64	23.46	4.18
LAMW-2	98.08	42.89	55.19
LAMW-5S	104.10	53.21	50.89
LAMW-6	91.50	43.47	48.03
LAMW-7	86.81	39.85	46.96
LY-GWMW1	19.45	14.72	4.73
LY-GWMW2	20.11	13.63	6.48
LY-GWMW3	20.99	13.08	7.91
M6-1	15.05	6.46	8.59
M6-2	15.03	4.39	10.64
M7-1	17.61	7.44	10.17
M7-2	17.57	6.42	11.15
MBCMW-5	28.98	16.97	12.06
MBCMW-6	29.09	21.35	7.67
MBCMW-7	16.64	6.29	10.24
MBCMW-8	16.53	9.33	7.31
MBCWC-MW2	32.20	18.87	11.63
MLW-1	11.26	5.01	6.25
MR-2	15.06	7.24	7.82
MW-1	12.46	4.49	7.97
MW-1	14.39	7.66	6.73

Source: Field Observations, Stone Environmental, McDonald Morrissey Associates, Earth Consultants International, and Fugro, 2009.

STONE ENVIRONMENTAL, INC.

Notes: MP = monitoring point. NAVD88 = North American Vertical Datum 1988; Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment.

Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptSynopticSummary]

Date/init: 6/7/2010 anm

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 4 (continued): Synoptic Water Level Measurements, Breached Lagoon Condition, December 8, 2009

Well ID	MP Elevation (ft. NAVD88)	Depth to Water (ft. below MP)	Water Table Elevation (ft. NAVD88)
MW-1	13.41	7.63	5.78
MW-2	11.71	5.40	6.31
MW-2	15.58	9.18	6.40
MW-2	13.04	7.41	5.63
MW-3	13.41	7.43	5.98
MW-3	15.66	9.31	6.35
MW-3	12.45	6.91	5.54
P-4	12.01	6.76	5.25
P-7	10.67	5.47	5.20
P-8	12.74	7.41	5.33
P-9	12.16	7.14	5.02
SMBRP-10C	16.25	6.18	10.07
SMBRP-11	18.35	8.52	9.83
SMBRP-12	12.62	6.63	5.99
SMBRP-13	13.58	7.45	6.13
SMBRP-15B	16.77	10.68	6.09
SMBRP-16	14.56	3.68	10.88
SMBRP-2	13.13	8.23	4.90
SMBRP-3C	36.53	18.33	18.20
SMBRP-6	26.88	14.16	12.72
SMBRP-7B	18.99	10.81	8.18
SMBRP-8	48.84	38.38	10.46
SMBRP-9	50.32	35.79	14.53
TY-MW-1	61.99	28.01	33.98
TY-MW-2	60.87	33.02	27.85
TY-MW-3	99.20	68.43	30.77
TY-MW-4	94.71	53.37	41.34
TY-MW-5	31.76	13.77	17.99
WF-MW1	16.04	7.71	8.33
WF-MW2	15.75	7.55	8.20
WF-MW4	18.86	8.82	10.04

Source: Field Observations, Stone Environmental, McDonald Morrissey Associates, Earth Consultants International, and Fugro, 2009.

Notes: MP = monitoring point. NAVD88 = North American Vertical Datum 1988; Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment.

Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptSynopticSummary]

Date/init: 6/7/2010 anm

Hydrology Study of the Civic Center Area

City of Malibu, California

TABLE 5: Monthly Water Level Measurements Summary

	Water Table Elevation (ft. NAVD88)											
Well ID	11/14/2008	12/16/2008	1/16/2009	2/12/2009	3/13/2009	4/17/2009	5/15/2009	6/18/2009	8/20/2009	10/20/2009	11/17/2009	1/28/2010
C-1	6.63	5.15	4.44	4.93	3.37	4.71	4.68	5.47	6.47	6.02	6.06	5.95
C-2		5.19	4.31	4.81	4.51	4.63	4.68	5.44	6.44	5.99	6.08	6.11
CCB-22		37.54	37.35	37.21	37.12	37.09	37.01	36.77	36.45	36.18	36.08	35.74
CCB-23		28.87	28.73	28.68	28.6	28.42	28.73	28.3	28.06	27.91	27.8	27.6
CCPC		5.16	4.88	5.11	4.86	5.39	5.02	6.08	6.95		6.58	
CCPE	2.66	4.27	4.98	4	3.87	4.86	4.34	5.89	7.02	4.41	6.42	6.39
CCPNE		4.79	4.57	4.68		5.14	4.74	5.97		4.81		6.26
CCPSW	6.93	5.42	5	5.39	5.07	5.49	5.13	6.07	6.91	5.42	6.57	5.8
CCW-4	8.925	9.135	8.925	9.535	9.775	9.415	9.255	9.025	8.705			
ECI-RC-MW01										16.21	16.08	16.99
GH10-M5	13.08	12.84	12.8	12.83	13.33	13.71	13.57	13.13	12.61	11.11	12.02	12.52
GH6-M1	13.66	13.38	13.31	13.37	13.81	14.16	14.2	13.83	13.32	12.85	12.68	12.98
GH7-M2	13.95	13.69	13.66	13.72	14.12	14.67	14.7	14.19	13.78			
GH8-M3	13.53	13.25	13.21	13.29	13.85	14.23	14	13.66	13.16	12.6	12.51	12.9
GH9-M4	13.51	13.22	13.51	13.64	14.78	14.92	14.48	13.81	13.19	12.67	12.87	13.34
LAMW-5S	52.14	51.95	51.88	52.18	52.38	51.6	52.67	52.31	51.88	51.5	51.27	51.66
LMW-1		116.77	116.54	116.46	116.65	116.7	116.72	116.42	115.88	115.48	115.24	114.7
LMW-2		104.28	103.23	102.77	102.69	102.72	101.94	102.39	101.64	100.66	100.43	99.21
LMW-3		11.73	11.69	11.86	12.09	11.86	11.81	11.78	11.73	11.66	11.58	11.9
LMW-4		119.16	119.06	119.13	119.37	119.36	119.59	117.03	118.44	117.94	117.69	117.61
LMW-5		119.14	119.04	119.14	119.34	119.17	119.27	118.88	118.41	117.91	117.65	117.58
LMW-6						139.41	140.03	140.02	139.97	139.44	139.15	138.36
LMW-7								116.52	115.92	115.41	115.31	114.84
LY-GWMW1							5.57	6.24				
LY-GWMW2							5.69	6.33				
LY-GWMW3							5.52	6.27				

Source: Field Observations, Earth Consultants International, 2008-2010.

STONE ENVIRONMENTAL, INC.

Notes: MP = monitoring point. NAVD88 = North American Vertical Datum 1988; Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment. Blank fields indicate that no water level measurement was collected.

Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptMonthlySummary]

Date/init: 6/7/2010 anm

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 5 (continued): Monthly Water Level Measurements Summary

Well ID	Water Table Elevation (ft. NAVD88)											
	11/14/2008	12/16/2008	1/16/2009	2/12/2009	3/13/2009	4/17/2009	5/15/2009	6/18/2009	8/20/2009	10/20/2009	11/17/2009	1/28/2010
LY-GWMW4							5.53	6.23				
LY-GWMW5												
M6-1	8.93	9.06	8.52	8.57	8.9	8.79	8.28	8.35	8.28	8.64	8.63	9.45
M6-2	10.13	11.35	10.2	11.66	10.65	10.46	10.44	10.28	9.98	10.33	9.92	11.78
M7-1	10.57	11.01	10.32	11.48	10.82	10.57	10.5	10.41	10.01	10.11	9.88	11.81
M7-2	11	11.65	10.79	12.28	11.6	11.14	11.15	10.91	10.58	10.62	10.18	12.65
MBCMW-10	8.46	8.25	7.23	7.82	7.38	7.54	7.12	7.61	7.39	7.84		8.58
MBCMW-5	13.03	12.84	12.73	12.92	13.24	13.37	13.41	13.13	12.63	12.13	12.08	12.69
MBCMW-6	8.4	8.04	6.93	7.63	7.23	7.06	6.79	7.42	7.47	7.77	7.87	7.78
MBCMW-7	9.48	9.97	9.71	10.61	10.53	10.11	9.99	9.8	9.45			10.32
MBCMW-8	7.455	7.395	6.635	7.115	6.635	6.825	6.595	6.925	6.495			7.845
MBCMW-9	8.29	8.35	8.24	9.01	9.17	8.78	8.65	8.37	8.2	8.56		9.51
MBCWC-MW2	12.37	12.26	11.56	12.59	12.32	11.65	11.75	10.82	13.7	13.75	13.41	13.45
MLW-1	6.375	5.715	5.005	5.695	5.345	5.305	5.305	5.805	6.305	6.105		
MR-2		7.92					8.02	7.89	7.89	8.12	7.88	8.26
P-2		4.73		4.6	4.43	4.98	4.6	5.79		4.68		
P-4	6.83	4.66	4.39	4.55	4.38	4.92	4.55	5.75	6.81	4.71	6.29	5.36
P-7	6.92	5.19	4.54	4.88	4.67	4.95	4.67	5.76	6.71	5.42	6.27	5.53
P-8		4.63	4.44	4.55	4.39	5	4.65	5.88	6.99	4.75	6.42	5.62
P-9	6.93	4.18	4.15	4.07	3.97	4.8	4.35	5.76	6.94	4.31	6.28	5.76
SMBRP-10C	9.57	10.79	10.63	12.71	12.63	11.4	10.89	10.5	9.8	9.65	9.85	13.04
SMBRP-11	10.04	10.22	9.85	10.63	10.31	10.01	10.1	10.1	10.02	10.2	9.75	10.56
SMBRP-12	5.645	5.735	4.885	5.795	5.415	5.125	5.245	5.505	5.745	6.295	5.615	5.115
SMBRP-13	6.05	5.36	4.52	5.56	5.23	4.79	4.6	5.22	5.7	6.07		5.44
SMBRP-15B										5.935	6.325	5.965
SMBRP-16	9.97	11.02	10.05	11.09	9.71	10.36	10.31	10.18	9.89			11.12

Source: Field Observations, Earth Consultants International, 2008-2010.

STONE ENVIRONMENTAL, INC.

Notes: MP = monitoring point. NAVD88 = North American Vertical Datum 1988; Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment. Blank fields indicate that no water level measurement was collected.
Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptMonthlySummary]
Date/init: 6/7/2010 anm

TABLE 5 (continued): Monthly Water Level Measurements Summary

	Water Table Elevation (ft. NAVD88)											
Well ID	11/14/2008	12/16/2008	1/16/2009	2/12/2009	3/13/2009	4/17/2009	5/15/2009	6/18/2009	8/20/2009	10/20/2009	11/17/2009	1/28/2010
SMBRP-2		4.711	3.971	4.281	4.041	4.471	4.121	5.221	6.731	4.521	6.221	4.711
SMBRP-3C	16.92	18.49	17.56	18.43	17.88	17.71	17.23	16.9	14.47	17.12	16.51	19.52
SMBRP-6		12.715	11.825	12.575	12.065	11.975	11.535	11.235	8.875	11.615	10.195	13.035
SMBRP-7B	8.405	8.285	8.155	8.565	5.915	8.355	8.245	8.145	8.135	7.765	7.615	9.185
SMBRP-8	10.62	10.37	10.94	11.03	13.43	12.37	11.8	11.43	11.4	10.13	10.33	11.83
SMBRP-9	15.42	15.19	15.11	15.18	15.62	16.01	16.18	15.98	15.64	14.92	14.7	14.8
TY-MW-1	34.16	34.41	34.1	34.99	35.02	34.5	34.4	34.25	33.78		33.87	35.07
TY-MW-2	28.08	28.27	28.03	28.91	28.94	28.34	28.29	28.09	27.7		27.8	28.96
TY-MW-3	31.13	31.27	31.09	31.95	32.03	31.41	31.35	31.18	30.71		30.84	46.06
TY-MW-4	41.72	41.69	41.63	41.75	40.9	41.69	41.81	41.73	41.52		41.53	27.44
TY-MW-5	17.86	18.13	17.86	18.57	18.51	18.08	18.05	17.91	17.62	18.06	17.76	18.7
WF-MW1												8.21
WF-MW2												8.53
WF-MW4												10.68

Source: Field Observations, Earth Consultants International, 2008-2010.

STONE ENVIRONMENTAL, INC.

Notes: MP = monitoring point. NAVD88 = North American Vertical Datum 1988; Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment. Blank fields indicate that no water level measurement was collected.

Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptMonthlySummary]

Date/init: 6/7/2010 anm

Hydrology Study of the Civic Center Area
City of Malibu, California
TABLE 6: Summary of Monitoring Well Survey Results

AIN	Well ID	Latitude (ft. NAD83)	Longitude (ft. NAD83)	Measuring Point Elevation (ft. NAVD88)	Ground Elevation (ft. NAVD88)
4452007903	Lagoon	1835631.61	6354793.13	27.64	N/A
4452011039	MW-2	1836061.57	6354224.54	13.04	N/A
4452011042	CCPC	1836003.47	6354230.67	12.48	13.24
4452011042	CCPE	1836050.08	6354499.31	13.01	13.38
4452011042	CCPNE	1836197.97	6354334.32	13.66	14.28
4452011042	MW_2	1836099.59	6354492.67	13.60	14.07
4452011042	MW-3	1836044.60	6354434.51	13.63	14
4452011043	CCPSW	1835820.50	6354088.35	13.52	14.07
4452011043	CCSC-2	1835711.01	6354457.14	11.82	N/A
4452011043	CCSC-3	1835695.08	6354468.13	10.00	N/A
4452011043	MW-4	1835886.65	6354294.20	13.04	13.34
4452011043	P-2	1835764.82	6354367.51	11.72	12.12
4452011043	P-4	1835750.01	6354367.51	12.01	12.4
4452011043	P-5	1835750.01	6354358.05	12.10	12.63
4452011043	P-8	1835761.38	6354422.34	12.74	13.23
4452011043	P-9	1835768.32	6354503.87	12.16	12.61
4458006032	MR-2	1835327.06	6351758.88	15.06	15.22
4458019006	EW-7	1835594.25	6352481.92	17.55	17.78
4458019006	EW-8	1835469.31	6352476.49	16.56	17.03
4458019006	MW-11	1835589.58	6352324.08	16.73	17.14
4458019006	MW-12	1835595.77	6352536.17	17.58	17.81
4458019006	MW-9	1835432.06	6352382.90	14.31	14.81
4458019006	W-1	1835582.44	6352383.91	17.62	17.97
4458019006	W-2	1835523.00	6352459.14	16.94	17.2
4458019006	W-3	1835514.09	6352375.36	15.97	16.71
4458019006	W-4A	1835541.04	6352401.63	17.75	18.06
4458019006	W-5	1835583.83	6352454.58	17.93	18.5
4458019008	B-23	1835581.87	6352812.90	18.44	19.1
4458019008	B-27	1835497.47	6352802.14	15.98	16.6
4458019008	B-38	1835543.46	6353007.42	18.27	18.53
4458019008	B-39	1835548.31	6352903.60	18.13	18.53
4458020016	ML_MW-1	1835675.14	6353272.74	19.45	19.98

Source: Field Observations, Land Air Surveyors and Earth Consultants International, 2010.

STONE ENVIRONMENTAL, INC.

Notes: NAD83 = North American Datum 1983 (feet); NAVD88 = North American Vertical Datum 1988 (feet); Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment. N/A = For some points, ground surface elevation was not recorded.
Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptWellSurveySummary]
Date/init: 6/9/2010 anm

Hydrology Study of the Civic Center Area

City of Malibu, California

TABLE 6 (continued): Summary of Monitoring Well Survey Results

AIN	Well ID	Latitude (ft. NAD83)	Longitude (ft. NAD83)	Measuring Point Elevation (ft. NAVD88)	Ground Elevation (ft. NAVD88)
4458020016	ML_MW-2	1835952.47	6353298.05	20.11	20.58
4458020016	ML_MW-3	1835931.38	6353660.59	20.99	21.41
4458020016	ML_MW-4	1835696.68	6353688.34	17.78	N/A
4458020016	SMBRP-16	1836163.94	6352442.00	14.56	15.17
4458021013	LAMW-2	1836501.33	6350151.12	98.08	98.49
4458021013	LAMW-3	1836368.55	6350187.39	90.17	90.41
4458021013	LAMW-6	1836404.39	6350112.93	91.50	92.08
4458021013	LAMW-7	1836324.78	6350268.66	86.81	87.49
4458022001	MW1	1836597.97	6353782.26	16.04	16.35
4458022001	MW2	1836919.89	6354004.26	15.75	16.3
4458022001	MW4	1837100.76	6353663.65	18.86	18.7
4458022019	SMBRP-8	1837266.93	6352770.21	48.84	48.75
4458027904	LAMW-1	1836497.30	6349991.49	101.25	101.63
4458027904	LAMW-4	1836529.06	6349933.91	102.73	103.49
4458027904	LAMW-5	1836612.70	6349916.70	104.54	105.07
4458027904	LAMW-5S	1836609.54	6349922.28	104.10	104.81
4458028020	Well 01	1836485.90	6349793.95	107.74	108.14
4458028020	Well 02	1836303.90	6350050.17	93.69	93.92
4458028020	Well 03	1836223.75	6350209.02	83.35	83.7
4458028020	Well 04	1836046.58	6350276.83	83.30	83.6
4458028020	Well 05	1836033.65	6350115.02	87.27	87.54

Source: Field Observations, Land Air Surveyors and Earth Consultants International, 2010.

STONE ENVIRONMENTAL, INC.

Notes: NAD83 = North American Datum 1983 (feet); NAVD88 = North American Vertical Datum 1988 (feet); Los Angeles County benchmarks from the Malibu Quad 2003 Adjustment. N/A = For some points, ground surface elevation was not recorded.
Path: O:\Proj-08\WRM\2026-W Malibu Hydrology Study\Data\GISData\082026Geodatabase_MSupdates_2003.mdb [rptWellSurveySummary]
Date/init: 6/9/2010 anm

Groundwater Flow Modeling Report
City of Malibu
Malibu, California

Prepared for

City of Malibu, California

by

McDonald Morrissey ASSOCIATES, Inc.

Concord, New Hampshire

August 27, 2010

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1.0 INTRODUCTION

The groundwater model prepared for this project expands upon and enhances previous modeling analyses completed for the City of Malibu in 2004. The 2004 work was documented in the report "Risk Assessment of Decentralized Wastewater Treatment Systems in High Priority Areas in the City of Malibu, California" (2004). The purpose of the original 2004 modeling project was to evaluate groundwater quality impacts of on-site waste-water dispersal on groundwater and receiving waters in the Civic Center area. In 2005, that study was expanded to estimate nitrate loading to Malibu Lagoon from a range of municipal wastewater reclamation and dispersal alternatives (Questa Engineering, 2005).

The City of Malibu has been developing a facilities plan for a municipal wastewater collection and reclamation system since 2006. When the present modeling project was started in 2008, the purpose for modeling was to evaluate the cumulative hydraulic impacts of subsurface waste water dispersal on groundwater levels located in the central part of the Civic Center area. That purpose, and consequent model design, were driven partly by the fact that several new dispersal systems were being proposed for the Civic Center Area near Malibu Creek and Lagoon including the Malibu Sycamore Village, LaPaz, Whole Foods and Malibu Lumber sites (Figures 1.1 and 1.2).

In November of 2009, approximately one-year after the start of this study, the Los Angeles Regional Water Quality Control Board (LARWQCB) adopted a prohibition on any new subsurface waste water dispersal in the Malibu Civic Center area and required existing systems to halt subsurface dispersal within ten years. Meanwhile, the City has continued its planning for a municipal waste water collection and reclamation system. Because of the prohibition, modeling the cumulative impact of several proposed individual dispersal systems has become much less relevant. The purpose for modeling has now shifted to evaluation of the hydraulic effects of municipal waste water collection and dispersal strategies.

Dispersal location(s) that are currently being contemplated by the City include Winter Canyon and the west side of the main body of alluvium away from Malibu Lagoon and Creek. Waste water dispersed in Winter Canyon and the west side of the alluvium these areas would ultimately flow to the ocean and not to the lagoon, and groundwater flow travel times from these locations to the Pacific Ocean are at least several years long (Stone Environmental, Inc., 2004). Another possible dispersal strategy that has been discussed is deep injection into the Civic Center gravels.

The original project's data collection and model design were not specifically focused on Winter Canyon and the western part of the alluvium but rather on the main body of the alluvial deposits beneath the Civic Center area. Despite this, the model can be used to guide more detailed site investigations in specific areas that have been identified as possible municipal dispersal sites. The model can also be used to make preliminary analyses to evaluate feasibility of municipal waste water dispersal strategies and the effects of such dispersal on the groundwater flow system.

The study area, which is shown on Figure 1.1, extends from Winter Canyon on the west to Sweetwater Canyon on the east and includes upland areas that drain toward the alluvial deposits. The extent of mapped alluvial deposits in the Civic Center area and Winter Canyon are shown in Figure 1.3. The active model area covers the alluvial and beach deposits shown in Figure 1.3.

1.1 Previous Modeling Investigations

Previous groundwater modeling studies include the following.

Earth Consultants International, Inc (2000) prepared a two-dimensional steady-state groundwater flow model for the Malibu Bay Company. The purpose of the model was to evaluate the effects of additional waste water dispersal at the Malibu Bay Company site in Winter Canyon. The model covered an area of about 40 acres and simulated flow in alluvial deposits within the Canyon between Malibu Canyon Road and the Ocean.

Stone Environmental, Inc. and McDonald Morrissey Associates, Inc.(2004) prepared three-dimensional steady-state groundwater flow models for the City of Malibu. The purpose of that modeling was to evaluate groundwater quality impacts of on-site waste-water dispersal on groundwater and receiving waters in the Civic Center area. The model covered an area of about 560 acres including mapped alluvial areas in the Civic Center and Winter Canyon. In 2005, Questa Engineering, Inc. and McDonald Morrissey Associates, Inc. evaluated the impacts of nitrogen loading on Malibu Lagoon using the 2004 groundwater flow model.

Fugro West, Inc. (2005) prepared a three-dimensional steady-state groundwater model for Sterling Capital. The purpose of the modeling was to evaluate the hydraulic effects of waste water dispersal at the proposed Malibu-LaPaz Ranch development. The Fugro model domain covers about 100 acres, centered on the LaPaz site, and falls entirely within the area covered by the 2004 Stone/McDonald Morrissey model.

2.0 CONCEPTUAL MODEL

The conceptual model of the groundwater flow system includes a description of the hydrogeologic setting, a generalized water budget and definition of the flow system. The conceptual model is by nature a simplification of actual field conditions and is necessary because a complete reconstruction of the field system is not possible (Anderson and Woessner, 1992). The conceptual model is used to guide construction of the numerical model.

2.1 Hydrogeologic Setting

There are two primary hydrostratigraphic units within the study area: bedrock and alluvium. Bedrock is at or near land surface in the upland areas and beneath the unconsolidated sediments (alluvium) that are present in the Civic Center area along Malibu Creek and Lagoon. These units are briefly described below.

2.1.1 Bedrock

The Malibu Coast Fault is mapped across the study area in an east-west direction and is aligned approximately along Civic Center Way (Leighton, 1994). North of the Malibu Fault the near-surface bedrock is described as Tertiary marine and non-marine sandstone and siltstone and Miocene volcanics. The sandstones and siltstones are assigned to the Lower Topanga and Sespe Formations. South of the Malibu Fault the near surface rock consist of Tertiary marine shales, mudstones and diatomaceous rocks assigned to the Monterey Formation (Earth Consultants International, 2009). The near surface rocks are assumed to have some permeablility due to fracturing and weathering.

The interpreted elevation of the top of bedrock is shown in Figure 2.1. The bedrock surface shown in Figure 2.1 is based upon data available as of May 2010. Much of the data used to construct bedrock surface was available for the previous modeling effort (Stone Environmental, Inc., 2004). Additional data collected since then include resistivity geophysical surveys completed by the U.S. Geological Survey (Izbicki, written communication, 2009). MASW (Multichannel Analysis of Surface Waves) surveys done for this investigation (Appendix B), and from drill data collected for site specific studies done in the Civic Center area since 2004.

Examination of the bedrock surface shown in Figure 2.1 shows that the lowest bedrock elevations occur in the western and central part of the alluvial deposit, to the west of the current location of Malibu Creek and Lagoon. There are many drill holes that can be used to define depth to rock where it is relatively shallow such as near the contact between alluvium and the valley wall. However there are few deep borings that reach bedrock in the main body of the alluvium and in Winter Canyon.

2.1.2 Alluvium

Alluvial sediments deposited in the Civic Center area by Malibu Creek, and other small drainages, are estimated to range in thickness from a feather edge near the valley walls to more than 200 feet (ft) in the central and western part of the main body of alluvium. The alluvial materials can be subdivided into two general categories, 1) a shallow sequence of fine-grained estuarine deposits and 2) underlying coarse grained “Civic Center Gravels” (GeoSoils, 1989; Leighton, 1994; ECI, 2000a; ECI, 2000b; Ambrose and Orme, 2000; Fugro West, Inc., 2005; Geosyntec Consultants, 2007). These units are capped by modern floodplain deposits and, in some locations, with artificial fill. The above described stratigraphy is illustrated in Figure 2.2 includes a north-south trending geologic cross-sections A-A' originally presented by Leighton (1994).

The shallow deposits tend to be very fine grained, containing clay and silt layers, especially in the central part of the alluvium. This is illustrated by the cross-section in Figure 2.3 which was prepared by Geosyntec (2009) as part of the Legacy Park characterization study. These very fine grained deposits are interpreted to extend from just north of Civic Center Way south to Malibu Colony Road and from the western edge of the main body of the alluvium near the Racquet Club, to the west side of Cross Creek Plaza.

The shallow deposits tend to be coarser grained near the valley walls along the northern edge of the alluvium, and to the east along the present day course of Malibu Creek and Lagoon. Figure 2.4 includes the cross-section B-B' prepared by ECI (2009) as part of the Malibu Sycamore Village characterization study and shows the north to south transition from coarser to finer grained deposits along that property.

The Civic Center Gravels underlie the shallow estuarine deposits over much of the Civic Center area. These deposits are described by Leighton (1994) as consisting of predominantly sands, with gravel and cobbles. The top of the Civic Center Gravels is relatively flat, dipping slightly to the south and west. The elevation of the top of the gravels is at approximately -30 ft NAVD88 (North American Vertical Datum 1988). The Civic Center Gravels are interpreted to extend from just north of Civic Center Way south to Malibu Road on the west side of the alluvium and from just north of Civic Center Way to the Pacific Coast Highway near the eastern edge of Legacy Park (Leighton, 1994, Cross section A-A') as shown in Figure 2.2. The full thickness and horizontal extent of the Civic Center Gravels is not known because of a lack of deep borings in the main body of the alluvium and along the coast.

2.1.3 Hydraulic Properties of the Alluvium

Hydraulic properties of the saturated alluvium have been estimated by a variety of techniques at several different locations in the study area. Slug tests conducted on three wells completed in alluvium in Winter Canyon yielded hydraulic conductivities that ranged from 13-53 feet per day (ft/d) (Earth Consultants International, 2000a). A groundwater model of the Winter Canyon alluvium used hydraulic conductivities ranging from 22 to 66 ft/d (Earth Consultants International, 2000a).

Laboratory testing of clay samples collected from borings near the City of Malibu offices along Civic Center Way reported hydraulic conductivity estimates of 0.00014 and 0.00076 ft/d (Earth Consultants International, June, 2000b). Slug tests conducted on five shallow wells, located near a wastewater dispersal system in Cross Creek Plaza gave hydraulic conductivity estimates that range from 0.6 to 4 ft/d (URS Greiner Woodward Clyde, 1999). The same study estimated hydraulic conductivities of 200-400 ft/d in the Cross Creek Plaza area based upon results of bromide tracer and coliphage seeding tests.

Slug tests conducted on observation wells completed for a study by Stone Environmental, Inc. (2004) range from less than 1 ft/d to 123 ft/d with an average value of 13 ft/d. These wells are generally less than 50 feet deep and are screened across the water table. The highest hydraulic conductivity (123 ft/d) was at well SMBRP-3c which is located in the coarse deposits along upper Malibu Creek. The groundwater flow model that was developed as part of the Stone Environmental, Inc. report (2004) used hydraulic conductivity values in the vicinity of the Malibu Sycamore Village property (previously called IOKI) immediately east of Stuart Ranch Road and north of Civic Center Way site that ranged from about 5 ft/d for interbedded fine to medium grained materials to 100-400 ft/d for the coarse grained Civic Center gravels and alluvium along Malibu Creek..

Water supply in the Malibu Civic Center was originally provided by the Marblehead Land Company, and then by the Malibu Water Company, from wells drilled into alluvial deposits and shallow bedrock along Malibu Creek. The first of these wells was drilled in 1902 and the final well was installed in about 1959. Specific capacity data from the wells was used to estimate transmissivity with a method described by Driscoll (1986). Estimated transmissivities for the old production wells range from approximately 10,000 ft^2/d to 23,000 ft^2/d, which translates to hydraulic conductivities of 200-500 ft/d (Stone Environmental, Inc., 2004).

Hydraulic testing of six observation wells reported by Fugro West Inc. (2005) during a hydrogeologic investigation of the proposed La Paz Ranch development reported hydraulic conductivities ranging from 0.5 to 13 ft/d. Materials described as silt had reported hydraulic conductivities of 0.4 to 1.2 ft/d. Silty sands had reported conductivities of 8-9 ft/d, and conductivity of sand was reported to range 0.5 to 13 ft/d. A model constructed as part of the Fugro (Fugro West Inc., 2005) investigation used hydraulic conductivities ranging from 0.5 to 100 ft/d.

Table 2.1: Reported Hydraulic Conductivities for Subsurface Soils in the Malibu Civic Center Area

Hydraulic Conductivity (K)	Aquifer or Soil Type	Source	Notes
0.00014 – 0.00076 ft/day	Clay aquitard above Civic Center Gravels	ECI, 2000b	Laboratory permeameter readings from Civic Center area
0.6 – 4 ft/day	Shallow alluvium	URS, 1999	Slug testing near Cross Creek Plaza
200 – 400 ft/day	Alluvium	URS, 1999	Bromide tracer and coliphage seeding tests near Cross Creek Plaza
<1.0 – 123 ft/day; average of 13 ft/day	Most wells in alluvium; the 123 ft/day K was located in coarse-grained deposits along upper Malibu Creek	Stone Environmental, Inc., 2004	Slug testing of wells in the downtown area
5 – 16 ft/day	Shallow aquifer; fine-medium grained alluvium	Stone Environmental, Inc., 2004	Groundwater flow model of downtown area
100 ft/day	Civic Center Gravels	Stone Environmental, Inc., 2004	Groundwater flow model of downtown area
200 – 500 ft/day	Civic Center Gravels	Stone Environmental, Inc., 2004	Estimate based on historic production well
0.5 – 13 ft/day	Shallow aquifer; sand	Fugro West, 2005	Slug test, La Paz Ranch
0.4 – 1.2 ft/day	Shallow aquifer; silt	Fugro West, 2005	Slug test, La Paz Ranch
9 ft/day	Shallow aquifer; sand/silt	Fugro West, 2005	Slug test, La Paz Ranch
8 – 9 ft/day	Deep aquifer; silty sands	Fugro West, 2005	Slug test, La Paz Ranch
0.5 – 100 ft/day	Alluvium	Fugro West, 2005	Field data and modeled K values
8 – 9 ft/day	Upper alluvium on MSV site, vicinity proposed drainfields	ECI, 2009	Estimated from results of site-specific percolation tests

The hydraulic conductivity values in Table 2.1 were used as a guide in specifying hydraulic properties in the model. Values of hydraulic conductivity in the model vary from a fraction of a foot per day to several feet per day for relatively fine grained materials to several hundred feet per day for coarse grained deposits.

2.2 Sources of Groundwater

Groundwater recharge to alluvial deposits in the study area occurs by several different processes as follows:

1) Surface-water and groundwater runoff from upland areas recharges alluvial deposits as it flows from the upland to the edges of the alluvial deposits on the valley floor. Surface water infiltration is especially evident in the western part of the alluvium at the artificial wetland near the intersection of Civic Center Way and Stuart Ranch Road, on what is referred to in this report as the Smith Parcel.

2) Direct recharge of groundwater from subsurface waste water dispersal occurs within the main body of alluvium at each dispersal bed. Dispersal systems in upland areas adjacent to the alluvium can also provide indirect recharge to alluvial deposits in the form of groundwater runoff.

3) Infiltration of precipitation directly into the alluvium can occur where land is not covered with impervious surfaces.

4) Recharge from infiltration of Malibu Creek into alluvial deposits occurs when surface water flow infiltrates into permeable alluvium in the upper reaches of the creek.

5) Excess irrigation required to flush root zones on the main body of alluvium, for maintenance of turf and other vegetation, results in groundwater recharge. Irrigation in upland areas also can cause groundwater recharge to the alluvium via ground and surface water runoff.

The degree to which each of these various mechanisms of recharge can be quantified is variable. Recharge caused by infiltration of sub surface waste water dispersal may be easiest to quantify because recharge rates are directly related to water use and water use data are available for the study area. Recharge from infiltration of Malibu Creek along the upper reaches of alluvial deposits may be estimated from stream gaging data. Recharge from infiltration of precipitation and upland runoff cannot be directly measured and therefore must be estimated.

Information from water budget analyses that provide some guidance for these estimates come from data collection and reporting done for the Pepperdine campus which is adjacent to this study area (Daniel B. Stephens & Associates, Inc., 2007a, 2007b, 2008a, 2008b, 2009, 2010). Pepperdine calculates an annual water balance for the campus based upon an extensive data collection network that includes measurement of precipitation, soil moisture, irrigation water use, surface runoff, and estimates of evapotranspiration. A summary of annual, campus-wide water balances from Pepperdine for the period from 2003 through 2009 is included in Table 2.2

Table 2.2 -- Summary of annual water budget calculations for irrigated areas of the Pepperdine Campus, in inches per water year.

Water Year	Irrigation (I)	Precipitation (P)	Surface Runoff (RO)	Infiltration (Inf) [I + P - RO]	ET (AET)	Storage Change (ΔS)	Deep Percolation (DP) [Inf-AET- ΔS]
2002-03	27.26	13.22	8.42	32.07	29.12	0.87	2.08
2003-04	36.81	9.68	2.93	43.44	43.52	-1.13	1.18
2004-05	25.52	39.00	44.21	20.32	41.79	-0.03	2.45
2005-06	30.27	24.84	42.69	12.42	42.61	-0.24	0.32
2006-07	33.33	8.22	40.27	1.27	40.00	0.13	0.14
2007-08	31.00	15.18	42.35	3.84	40.07	0.78	1.50
2008-09	27.33	11.03	3.99	34.37	32.33	0.08	1.96

The information in Table 2.2 corresponds only to irrigated areas on the Pepperdine campus; hardscape and non-irrigated naturally vegetated areas are not included. Examination of Table 2.2 illustrates that precipitation is highly variable from year to year, evapotranspiration rates are consistently greater than available precipitation and therefore considerable amounts of irrigation are required. The amount of deep percolation, which gives a general indication of groundwater recharge, varies considerably from year to year ranging from a fraction of an inch to several inches. Deep percolation can occur despite the high annual evapotranspiration rates, because most of the precipitation falls in winter months when evapotranspiration rates are lowest.

2.2.1 Recharge from Upland Runoff

Upland areas adjacent to the alluvium provide recharge to the groundwater flow system. This recharge includes two components; groundwater in the upland that travels downgradient to recharge the alluvium, and surface-water runoff from the upland that infiltrates as it passes the uplands onto the more permeable alluvium. Estimates of the amount of recharge from uplands are made by delineating the drainage areas of contributing uplands along with an estimate of available ground and surface water runoff. A map showing the upland areas that contribute recharge to groundwater in the alluvium is shown in Figure 2.5. The size of each contributing area is summarized in Table 2.3.

Only a small fraction of the total precipitation in upland areas can become recharge to the alluvium because of runoff and evapotranspiration (Table 2.2). A small amount of precipitation will infiltrate in upland areas, flow through shallow overburden and bedrock and recharge the alluvium. In addition, some of the surface runoff from upland areas may infiltrate the alluvium near the contact with alluvium and bedrock. Based upon estimated deep percolation calculated for the Pepperdine Campus it was assumed that the average annual rate of recharge from upland runoff during the period 2003-2009 range from less than an inch per year to several inches per year.

Table 2.3. -- Extent of upland sub-drainage areas.

Sub-Basin	Area (ft^2)
Winter Canyon	9,619,226
West Alluvium	3,645,542
Northwest Alluvium	4,482,120
North Alluvium	1,919,216
Malibu Tributary	9,955,536
Serra	1,028,450
East Alluvium	5,446,559
East Shore	771,059
Sweetwater Canyon	17,696,143
West Shore 1	1,466,626
West Shore 2	3,874,105
TOTAL UPLAND	59,904,582

2.2.2 Soil Absorption System Recharge

Waste water dispersal is estimated from water use data provided by County of Los Angeles Water Supply District #29 (County of LA, written communication, 2009). The data used for this study include bimonthly water use by user, over the period from 2003-2009. A more complete description of the water use database is included in the main report (Stone Environmental, Inc., 2010). A summary of water use for the period from 2003 through 2009 is included in Table 2.4. The water use information is summarized by group based upon specific geographic areas as shown in Figure 2.6.

The Malibu Colony Shoreline group includes all of the Malibu Colony residences and residences along adjacent shorelines east and west of the Colony. This group is characterized by relatively small lot sizes and therefore by relatively small areas that require irrigation. The average water use for the residences in this group, over the period from 2003-2009, was 490 gpd (gallons per day). During the low-irrigation season, which is assumed to occur in February and March, the average water use was approximately 397 gpd. Based upon these data it was assumed that the average waste water dispersal from each of the residences in this group was 400 gpd.

The Serra Vicinity group is characterized by large lot sizes with relatively large irrigated areas. The average 2003-2009 water use in this group is 2,524 gpd and, in the low irrigation season, average water use is 1,705 gpd. For the purpose of this study it was assumed that each of the residences in this group has on site waste water dispersal of 400 gpd if the total water use was equal to or greater than 400 gpd. If the water use at a parcel in this group was less than 400 gpd all of the water was assumed to be waste water dispersal. Any water use greater than 400 gpd is assumed to be used for irrigation.

Upland areas adjacent to the alluvium have lot sizes that are generally larger than the Colony and smaller than those in the Serra area. Average 2003-2009 water use for these areas is approximately 1,152 gpd. For the purpose of this study it was assumed that each of the residences in this group has on site waste water dispersal of 400 gpd if the total water use was equal to or greater than 400 gpd. If the water use at a parcel in this group was less than 400 gpd all of the water was assumed to be waste water. Any water use greater than 400 gpd is assumed to be used for irrigation.

Commercial water users are predominantly located in the Civic Center area in Cross Creek Plaza and Malibu Colony Plaza. There are also a few commercial users along the eastern shoreline and in Winter Canyon. Two of the largest commercial waste water dispersals occur in Winter Canyon at the County of Los Angeles treatment plant which serves the condominium development along DeVille Way, and the Malibu Company treatment plant, which serves Malibu Colony Plaza. Waste water dispersal at all of the commercial properties is assumed to be equal to the reported water use.

Several locations in the area have extensive irrigation of turf and other plantings. These locations include nurseries, a small golf park with extensive turf areas, and a horse farm/estate. At each of these locations the majority of the reported water use is assumed to be for irrigation. If specific parcels in this group include a residence the waste water dispersal at the residence is assumed to be 400 gpd. If the parcel doesn't include a residence all of the water is assumed to be use for irrigation.

Table 2.4 – Summary of water use in the study area for the period 2003-2009, in gallons per day.

	All Months			Feb/Mar		
Group	Average	Min	Max	Average	Min	Max
Malibu Colony Shoreline	490	43	3,462	397	22	2,256
Upland Areas	1,152	171	2,966	1,062	63	11,800
Serra Vicinity	2,524	99	15,358	1,705	25	9,118
Commercial	5,997	182	52,596	5,154	116	51,449
Nurseries/Golf Courses	3,408	258	5,019	1,996	123	3,411

2.2.3 Infiltration of Precipitation

Daily precipitation data are collected at two gauges located on the Pepperdine Campus which is along the western edge of the study area (Daniel B. Stephens & Associates, Inc., 2007a, 2007b, 2008a, 2008b, 2009, 2010). Monthly precipitation data for the period 2003-2009 from Pepperdine is shown in Figure 2.7. The data shown in Figure 2.7 are predominantly from the lower campus gage, supplemented by the upper campus gage during seven months when the lower campus gage was not recording and by data from a County of Los Angeles gage for four months when both campus gages were inoperable. Examination of Figure 2.7 illustrates the fact that most of the precipitation in the study area occurs during the winter months. During the period from 2003 to 2009 annual precipitation varied from 7.97 inches in 2003 to 23.38 inches in 2005.

Long term precipitation data (1937-2009) from Santa Monica Pier, California ID 047953, indicate that average annual precipitation is 11.88 inches and the maximum annual precipitation over the same period is 25.4 inches. During 2005, precipitation at Santa Monica was 25.19 inches, one of the wettest years on record for that site. Based upon this information it is assumed that the 2003-2009 period considered in this study includes a year (2005) which can be characterized as being representative of very wet conditions.

Some of the precipitation that falls directly on the alluvium becomes groundwater recharge. This recharge is assumed to be small because most rain comes as intense winter storms with considerable runoff and much of the runoff is diverted to surface water via storm sewers. There are several areas atop the alluvium that are paved, through which there is no infiltration. In unpaved areas some of the precipitation will run off and some will be lost to evapotranspiration. For the proposes of this study it was assumed that average annual recharge from direct infiltration of precipitation would generally be less than 5% of annual precipitation.

2.2.4 Malibu Creek Infiltration

Infiltration of stream flow is a common source of recharge to alluvial aquifers. Recharge occurs as streams flow from steep upland areas, which are predominantly bedrock, onto more permeable, relatively flat alluvial deposits. The rate of recharge is controlled by the difference in head between the stream and the underlying groundwater and the permeability of the streambed and underlying alluvial deposits.

Infiltration of stream flow has been observed as Malibu Creek exits the canyon and crosses onto the alluvial deposits along the coastal plain. Some of this water is lost to evapotranspiration and to infiltration along the stream channel above the main body of alluvium but, based upon available data, a significant amount recharges the alluvial deposits in the Civic Center area. These recharge rates are estimated to be on the order of 0.5 to 2 cfs (ft^3/s) during low flows and may be higher during flood conditions (Stone Environmental, Inc., 2004).

Malibu Creek stream flow data are collected at the County of Los Angeles Flood Control District continuous recording gage F130R, (formerly USGS gaging station 111055500), located 0.3 mi downstream of Cold Creek and approximately 3.5 miles upstream from Arizona Crossing. The gaging station was installed in 1931 and operated cooperatively by the USGS and the County of Los Angeles until 1978. From 1979 until the present the gage has been operated by County of Los Angeles. Flows recorded at the gage include releases from the Las Virgenes Municipal Water District Tapia Water Treatment Facility which was constructed in 1965.

The U.S. Geological Survey has operated a stream gage near the bridge over Malibu Creek on Cross Creek Road since December 2007. Daily flows at the U.S. Geological Survey gage, and the County gage 3.5 miles upstream, are shown in Figure 2.8 for the period December 2007 to October 2009. During winter periods, when most of the precipitation and associated runoff occurs, stream flow is generally greater at the downstream gage. During the summer/fall period when there is very little precipitation there is a consistent loss of flow between the two gages of about 1-10 cfs (cubic feet per second). During these periods flow at the upstream gage is mostly from release of treated waste water at the Tapia Plant. By the time this flow reaches the downstream gage at Cross Creek Road much of the water has infiltrated into the alluvium along Malibu Creek.

In addition to the stream gage data from 2007-2009 described above, infiltration of stream flow has been observed as Malibu Creek exits the canyon and crosses onto the alluvial deposits along the coastal plain on several earlier occasions. On August 23, 1999 flow at the County gaging station was measured at 1.4 cfs and a similar flow was observed the following day about 4,000 feet above the mouth of the Canyon. Another 2,300 feet downstream, flow had decreased to about 1 cfs and 3,300 further downstream, just below Cross Creek Road, the stream was dry (Entrix, Inc., 1999). On September 10, 1998 a similar pattern was noticed. Flow near the mouth of the canyon was 8.2 cfs and

600 feet downstream of Cross Creek Road it was 6.4 cfs, a decrease of 1.8 cfs (Entrix, Inc., 1999).

On September 24, 2003 Malibu Creek had an average daily flow of 3.0 cfs at the County gage (written comm., County of LA DPW, April 2, 2004). Stream flow in the Creek was measured at 0.6 cfs 3,200 feet above Cross Creek Road/Arizona Crossing and the stream channel was dry just above the Cross Creek Road bridge (written comm., McDonald Morrissey Associates, Inc., 2003)

Entrix (1999) also states that LVMWD staff observed that “the stream is almost always dry below Cross Creek Road in the late summer months.” Examination of streamflow records show that average daily flows during the late summer months are typically 2-4 cfs. Some of this water is lost to evapotranspiration and to infiltration along the stream channel above the main body of alluvium but, based upon available gaging data, a significant amount recharges the alluvial deposits in the Civic Center area. These recharge rates are estimated to be on the order of 0.5 to 2 cfs during low flows and may be higher during flood conditions. Stream flow that infiltrates to groundwater during dry periods may move as hyporheic flow through the coarse alluvium along the Malibu Creek channel and ultimately discharge to the upper reaches of the lagoon.

2.2.5 Excess Irrigation

Recharge to groundwater from infiltration of excess irrigation is likely to occur at locations where turf and landscaping are maintained. Some of the water used for irrigation seeps through the soil zone and becomes round-water recharge. In Malibu, the private golf park, commercial nurseries, horse farms and extensively landscaped properties all use significant quantities of water for irrigation. A map showing locations within the Civic Center alluvium and Winter Canyon alluvium where recharge from excess irrigation is assumed to occur is shown in Figure 2.9.

In the northern part of the study area, along Malibu Creek and near Serra Retreat, the amount of recharge from excess irrigation was estimated by subtracting estimated waste water disposal (400 gallons per day per residence) from the total reported water use for the area and applying one-half of the remainder as recharge from excess irrigation. The same approach was used in each of the upland areas that are adjacent to the alluvium and at the nursery located on the west side of the study area. At the properties that make up the golf park, those parcels with no dispersal system are assumed to get 50% of the water use as recharge from excess irrigation and parcels with dispersal systems are assumed to receive 50% of all water use above 400 gpd as recharge from excess irrigation.

The amount of irrigation that actually becomes groundwater recharge is dependent upon site specific conditions including soil permeability, irrigation practices, land slope, evapotranspiration and other factors. The assumption made in this study that 50% of water use above 400 gpd becomes groundwater recharge is probably on the high side and would occur as a result of inefficient irrigation practice combined with permeable soils. For the purpose of this study this assumption was assumed to be reasonable.

2.3 Sinks for Groundwater

Groundwater sinks are areas where groundwater discharges out of the alluvial groundwater flow system. Potential groundwater sinks include natural discharge to surface waters and the ocean, evapotranspiration from riparian vegetation, and pumping wells used for irrigation or other water uses in the study area.

2.3.1 Discharge to Ocean and Malibu Lagoon

Water table maps constructed in order to determine general directions of groundwater flow in the alluvium, and to differentiate between groundwater flow to the ocean and lagoon, were prepared by Stone Environmental, Inc. (2004). Data used to construct those water table maps were collected on September 25, 2003 and on March 9, 2004. During the September 2003 measurement the barrier beach was intact and the lagoon was flooded. During the March 2004 measurement the barrier beach was breached and flow in Malibu Creek was discharging to the ocean. In addition, as part of this study, a synoptic water level measurement was conducted on December 8, 2009 during a condition when the lagoon was partially breached. During each of the three synoptic measurements mentioned above groundwater levels and lagoon stage were measured during a relatively short period of time to minimize the effects that tidal variations had on groundwater elevations.

Contour maps of observed water levels for the September 2003, March 2004 and December 2009 measurements are shown in Figures 2.10, 2.11 and 2.12 respectively. During both the flooded and breached lagoon conditions groundwater from the western side of the alluvial flow system, and from Winter Canyon alluvium, discharges to the ocean. Groundwater flow from the eastern side of the alluvial flow system discharges to Malibu Lagoon and Creek. The groundwater flow divide can shift slightly depending upon lagoon conditions but in general, available groundwater level maps show that groundwater in the alluvial deposits in Winter Canyon and the west side of the alluvial deposits discharges to the Ocean. Groundwater in the central and eastern parts of the alluvium discharges to the Lagoon, except along the eastern shoreline near Malibu Pier where groundwater discharges to the ocean.

2.3.2 Evapotranspiration

Evapotranspiration from groundwater can occur where the root zone of vegetation is at or below the water table. The most likely place for this to occur in the study area is along Malibu Creek and lagoon where there is riparian vegetation and shallow depths to water. The Las Virgenes Water District estimated the water demand of riparian vegetation along Malibu Creek downstream of the Tapia Water Reclamation Facility (Letter from Las Virgenes Water District to National Marine Fisheries Service, September 2, 1998) using a method that takes into account vegetation species type and density along with microclimatic characteristics. Results of this study estimate that riparian vegetation consumes approximately 1.2 cfs of water in the reach below the treatment plant and Cross Creek Road, a distance of about 4 miles, which is approximately 0.3 cfs per mile.

2.3.3 Pumping

The County of Los Angeles Department of Health Services – Environmental Health Division regulates water supply wells in Malibu. All water wells require permits issued by the County of Los Angeles Environmental Health Division. At present there is no documentation of any pumping wells in the study area however, observations made during field studies indicate that there may be a few private domestic wells in the study area that are being used for irrigation. The amount of pumping that occurs from such wells is considered to be negligible.

2.4 Summary of Sources and Sinks for Groundwater

A summary of the average-annual model-calculated groundwater budget for the Malibu and Winter Canyon alluvial deposits during 2003-2009 is shown in Figure 2.13. The same information is also summarized Table 2.5. The major sources of recharge to the alluvium in the model area are waste water dispersal, stream infiltration and irrigation return. The total waste water dispersal, which includes upland and alluvial portions in Figure 2.13 and Table 2.5, comprises about 40% of the estimated average annual recharge to groundwater in the model area. Stream infiltration makes up about 35% of average annual recharge, and irrigation return from in upland and alluvial areas makes up 13%. Recharge from upland runoff and direct infiltration of precipitation make up the remaining 12% . On average, approximately 51% of groundwater in the model area discharges to the lagoon, 39% goes to the ocean and the remaining 10% is lost to groundwater evapotransiration.

Table 2.5 -- Summary of model estimated average annual groundwater budget for the Civic Center alluvium and Winter Canyon.

Groundwater Inflows				Groundwater Outflows			
Recharge	rate in cfs	rate in gpd	Percent of Total	Discharge	rate in cfs	rate in gpd	Percent of Total
Net Stream Infiltration[1]	0.54	347,436	35%	Lagoon[2]	0.78	507,120	51%
Waste Water Alluvium	0.43	275,771	28%	Ocean	0.59	383,236	39%
Waste Water Upland	0.19	119,615	12%	Evapotranspiration	0.15	95,589	10%
Upland Runoff	0.13	86,300	9%				
Irrigation Return Upland	0.11	71,553	7%				
Irrigation Return Alluvium	0.09	58,697	6%				
Precipitation Alluvium	0.04	25,175	3%				
TOTAL RECHARGE	1.52	984,548	100%	TOTAL DISCHARGE	1.53	985,945	100%

[1]-Stream infiltration is net of inflow and outflow along upper reach of Malibu Creek (0.84 cfs in along upper end minus 0.31 cfs out along lower end)
[2]- Discharge to the Lagoon is entirely from the Civic Center alluvium.

2.5 Groundwater Levels

As part of this project water level data were collected from previous studies and organized into a single database. The data were obtained from a variety of sources including the RWQCB, the City of Malibu, studies done by private consultants and from the previous modeling effort completed for the City of Malibu (Stone Environmental, Inc., 2004). Surveying of monitoring wells was also done as part of this investigation to supplement previous surveying (Stone Environmental, Inc., 2004) and to establish accurate locations and measuring point elevations for several wells for which depth to groundwater was available. Horizontal locations of wells were surveyed to the California State Plane V NAD1983 datum in units of feet. Vertical elevations were surveyed to the NAVD1988 datum in units of feet. Locations where groundwater level data were used for this study are shown in Figure 2.14a and 2.14b. A more complete description of the water level database is included in the main body of this report (Stone Environmental, Inc., 2010).

Groundwater in the Civic Center area typically occurs at shallow depths, generally between 2 to and 50 feet bgs (below the ground surface) (Geosyntec, 2007; Stone Environmental, 2004; Subsurface Designs, 2002; Bing Yen and Associates, 2001; ECI, 2000b; GeoConcepts; 1999; Leighton, 1994a). Maps showing groundwater elevations for three different times are shown in Figures 2.10, 2.11 and 2.12. A map showing distance from land surface to groundwater in December 2009 is shown in Figure 2.15. Groundwater levels tend to be closest to land surface in the vicinity of Malibu Lagoon and Creek and the greatest depths to groundwater generally occur along the edges of the alluvium near the transition to upland areas, and in Winter Canyon.

There are a few locations where nested wells allow comparison of shallow and deep groundwater levels. These locations include the following wells pairs, MW-5&6; MW-7&8; MW-9&10; M6-1&2; and M7-1&2. Examination of water levels from these wells shows that here is a downward gradient from the shallow sequence of fine-grained estuarine deposits to the underlying coarse grained Civic Center Gravels. During the December 8, 2009 synoptic water level measurement the difference between shallow and deep water levels varied from 4.39 feet at the MW5&6 well pair to 0.98 feet at M7-1&2 well pair.

Groundwater levels in the Civic Center area of Malibu fluctuate in response to several factors. These factors include variations in precipitation, runoff into the artificial wetland, lagoon stage, and tide stage. In general, groundwater level variations in Winter Canyon, and on the west side of the alluvium, are most closely related to variations in precipitation. Groundwater levels at wells in the vicinity of the lagoon, especially east of Cross Creek Road are closely related to variations in lagoon stage. Groundwater levels in wells completed in the Civic Center Gravel also exhibit water-level variations that are affected by lagoon stage. Groundwater levels in wells closest to the coast, especially those wells south of the Pacific Coast Highway are most directly influenced by tidal variations.

The relationship between precipitation and groundwater levels within the study area during the period from 2003-2009 is illustrated in Figures 2.16a through 2.16c. Wells SMBRP-9, and SMBRP-10C are located on the west side of the alluvium above the Civic Center Gravel, and Well03 is located in Winter Canyon. All of the wells in Figures 2.16a through 2.16c show a strong correlation between water levels and precipitation. In general, water levels rise immediately after storms and then recede during dry periods. Well SMBRP-10C, located near the artificial wetland near the intersection of Stuart Ranch Road and Civic Center Way, shows abrupt groundwater level fluctuations that are caused at least in part, by periodic flooding of the artificial wetland. Water levels in the Winter Canyon well, Well03, shows a distinctive peak during the winter period in 2004-5 when record rainfall occurred.

Conditions in Malibu Lagoon have a significant effect on groundwater levels in the Civic Center area, especially at wells closest to the lagoon. Lagoon conditions are dependent upon the condition of the barrier beach that forms along the interface between the lagoon and ocean. Figure 2.17 shows the lagoon stage and the water level in wells P-1, P-4 and MLW-1 during a period when the lagoon transitions from a flooded to breached condition.

Examination of Figure 2.17 clearly shows that when the barrier beach is intact, which generally occurs during dry weather periods, the lagoon is flooded and groundwater levels in nearby wells are high. When the barrier beach is absent, generally during wet periods when flow in Malibu Creek is highest, the lagoon drains and groundwater levels in nearby wells are lowest. Figure 2.17 also shows that fluctuations in the lagoon stage caused by tidal variations are considerably damped when the lagoon is flooded. When the lagoon is breached, and therefore open to the Ocean, the lagoon stage is directly influenced by the tide. The same appears to be true for shallow groundwater levels near the lagoon. Examination of the groundwater levels for wells in Figure 2.17 shows that the tide caused fluctuations in groundwater are damped when the lagoon is flooded, especially at well P-1, and less damped when the lagoon is breached.

3.0 NUMERICAL GROUNDWATER FLOW MODEL

The purposes for groundwater flow modeling of the Malibu Civic Center area are to provide preliminary analyses of the effect of municipal waste water dispersal strategies on groundwater levels and to guide site characterization data collection efforts for municipal dispersal sites. The groundwater model used for this investigation is based upon the model that was constructed as part of the Santa Monica Bay Restoration Project that was completed for the City of Malibu by Stone Environmental, Inc. (2004). Major modifications made for this study include refined horizontal and vertical grid spacing, incorporation of additional water use, water level and geotechnical data collected since 2004, and transient model calibration to groundwater level variations observed during the period from 2003 to 2009.

3.1 Construction

The numerical groundwater model code used for this investigation is MODFLOW2000, which was developed by the U.S. Geological Survey (Harbaugh and others, 2000). MODFLOW2000 requires that the groundwater flow domain be subdivided into blocks. Specifications describing aquifer hydraulic properties, recharge, discharge, and other factors that can affect the groundwater flow system are required for each block in the model grid. Specifications must also be made to describe flow conditions along each boundary of the model domain (boundary conditions), and for transient simulations, initial groundwater elevation must be specified for each block at the start of the simulation (initial conditions). The groundwater model calculates a groundwater elevation for each block in the model grid at each discrete time interval specified in the model input files.

3.1.1 Model Grid

The model developed for this study covers an area that is approximately 1 square mile as shown in Figure 3.1. The extent of the model allows simulation of groundwater flow in alluvial deposits that underlie Winter Canyon and the entire Malibu Civic Center area along Malibu Creek and Lagoon. The model grid has uniform horizontal spacing of 30 feet and is subdivided into 5 layers. The total number of active cells in the model domain is 135,366. Layer thickness varies from a few feet or less near the edges of the model to a maximum of about 50 feet or more where the alluvial deposits are thickest.

Model layers 1, 2 and 3 are designed to represent the shallow interbedded sands and silts that exist atop the Civic Center gravels. The top of model layer 4 was set at an elevation of -30 feet in the Civic Center area in order to correspond to the top surface of the Civic Center gravels. The bottom of the model was designed to be at the contact between alluvium represented in model layer 5 and the underlying bedrock (Figure 2.1).

3.1.2 Time Discretization

A summary of model time stepping and stress periods is included in Table 3.1. The model simulation includes a total of 104 stress periods. A stress period is defined a segment of time in which modeled hydraulic stresses and boundary conditions are held constant. The first stress period is a steady-state simulation of average hydraulic conditions in the aquifer during the period from 2003 to 2009. Stress periods 2 through 104 are transient simulations that are generally one month long. Some stress periods are shorter than one month in order to more accurately represent conditions (flooded or breached) in the lagoon. The total simulation time is 7 years or 2,526 days, starting on January 1, 2003 and ending on December 31, 2009. Most stress periods have one time step. However, stress periods that include a changing lagoon condition, i.e. when the lagoon changes from flooded to breached, or vice versa, have three time steps.

Table 3.1 -- Summary of model stress periods and time steps.

		Stress Period Start Time		Stress Period Stop Time				
Stress Period Number	*Type*	*Date*	*Model Time (days)*	*Date*	*Model Time (days)*	*Stress Period Duration (days)*	*Number of Time Steps per Stress Period*	*Breached Lagoon/Flooded Lagoon*
1	SS	January 1, 2003	0	January 1, 2003	0.00001	0.00001	1	*Breached*
2	TR	January 1, 2003	0.00001	January 31, 2003	31	31	1	*Breached*
3	TR	February 1, 2003	31	February 28, 2003	59	28	1	*Breached*
4	TR	March 1, 2003	59	March 31, 2003	90	31	1	*Breached*
5	TR	April 1, 2003	90	April 30, 2003	120	30	1	*Breached*
6	TR	May 1, 2003	120	May 31, 2003	151	31	1	*Breached*
7	TR	June 1, 2003	151	June 30, 2003	181	30	1	*Breached*
8	TR	July 1, 2003	181	July 8, 2003	189	8	1	*Breached*
9	TR	July 9, 2003	189	July 31, 2003	212	23	3	*Flooded*
10	TR	August 1, 2003	212	August 31, 2003	243	31	1	*Flooded*
11	TR	September 1, 2003	243	September 30, 2003	273	30	1	*Flooded*
12	TR	October 1, 2003	273	October 31, 2003	304	31	1	*Flooded*
13	TR	November 1, 2003	304	November 3, 2003	307	3	3	*Flooded*
14	TR	November 4, 2003	307	November 30, 2003	334	27	1	*Breached*
15	TR	December 1, 2003	334	December 31, 2003	365	31	1	*Breached*
16	TR	January 1, 2004	365	January 31, 2004	396	31	1	*Breached*
17	TR	February 1, 2004	396	February 29, 2004	425	29	1	*Breached*
18	TR	March 1, 2004	425	March 31, 2004	456	31	1	*Breached*
19	TR	April 1, 2004	456	April 30, 2004	486	30	1	*Breached*
20	TR	May 1, 2004	486	May 31, 2004	517	31	3	*Flooded*
21	TR	June 1, 2004	517	June 21, 2004	538	21	3	*Breached*
22	TR	June 22, 2004	538	June 30, 2004	547	9	1	*Flooded*
23	TR	July 1, 2004	547	July 31, 2004	578	31	1	*Flooded*
24	TR	August 1, 2004	578	August 31, 2004	609	31	1	*Flooded*
25	TR	September 1, 2004	609	September 30, 2004	639	30	1	*Flooded*
26	TR	October 1, 2004	639	October 18, 2004	657	18	1	*Flooded*
27	TR	October 19, 2004	657	October 31, 2004	670	13	3	*Breached*
28	TR	November 1, 2004	670	November 30, 2004	700	30	1	*Breached*
29	TR	December 1, 2004	700	December 31, 2004	731	31	1	*Breached*
30	TR	January 1, 2005	731	January 31, 2005	762	31	1	*Breached*
31	TR	February 1, 2005	762	February 28, 2005	790	28	1	*Breached*
32	TR	March 1, 2005	790	March 31, 2005	821	31	1	*Breached*
33	TR	April 1, 2005	821	April 30, 2005	851	30	1	*Breached*
34	TR	May 1, 2005	851	May 31, 2005	882	31	1	*Breached*
35	TR	June 1, 2005	882	June 30, 2005	912	30	1	*Breached*
36	TR	July 1, 2005	912	July 31, 2005	943	31	1	*Breached*
37	TR	August 1, 2005	943	August 15, 2005	958	15	1	*Breached*
38	TR	August 16, 2005	958	August 31, 2005	974	16	3	*Flooded*
39	TR	September 1, 2005	974	September 12, 2005	986	12	1	*Flooded*
40	TR	September 13, 2005	986	September 30, 2005	1,004	18	3	*Breached*
41	TR	October 1, 2005	1,004	October 31, 2005	1,035	31	1	*Breached*
42	TR	November 1, 2005	1,035	November 30, 2005	1,065	30	1	*Breached*
Stress	*Type*	Stress Period Start Time		Stress Period Stop Time		*Stress*	*Number of*	*Breached*

Period Number		*Date*	*Model Time (days)*	*Date*	*Model Time (days)*	*Period Duration (days)*	*Time Steps per Stress Period*	*Lagoon/Flooded Lagoon*
43	TR	December 1, 2005	1,065	December 31, 2005	1,096	31	1	*Breached*
44	TR	January 1, 2006	1,096	January 31, 2006	1,127	31	1	*Breached*
45	TR	February 1, 2006	1,127	February 28, 2006	1,155	28	1	*Breached*
46	TR	March 1, 2006	1,155	March 31, 2006	1,186	31	1	*Breached*
47	TR	April 1, 2006	1,186	April 30, 2006	1,216	30	1	*Breached*
48	TR	May 1, 2006	1,216	May 31, 2006	1,247	31	1	*Breached*
49	TR	June 1, 2006	1,247	June 10, 2006	1,257	10	1	*Breached*
50	TR	June 11, 2006	1,257	June 30, 2006	1,277	20	3	*Flooded*
51	TR	July 1, 2006	1,277	July 31, 2006	1,308	31	1	*Flooded*
52	TR	August 1, 2006	1,308	August 22, 2006	1,330	22	1	*Flooded*
53	TR	August 23, 2006	1,330	August 31, 2006	1,339	9	3	*Breached*
54	TR	September 1, 2006	1,339	September 30, 2006	1,369	30	1	*Breached*
55	TR	October 1, 2006	1,369	October 28, 2006	1,397	28	1	*Breached*
56	TR	October 29, 2006	1,397	October 31, 2006	1,400	3	3	*Flooded*
57	TR	November 1, 2006	1,400	November 30, 2006	1,430	30	1	*Flooded*
58	TR	December 1, 2006	1,430	December 31, 2006	1,461	31	3	*Breached*
59	TR	January 1, 2007	1,461	January 31, 2007	1,492	31	1	*Breached*
60	TR	February 1, 2007	1,492	February 28, 2007	1,520	28	1	*Breached*
61	TR	March 1, 2007	1,520	March 31, 2007	1,551	31	1	*Breached*
62	TR	April 1, 2007	1,551	April 28, 2007	1,579	28	1	*Breached*
63	TR	April 29, 2007	1,579	April 30, 2007	1,581	2	3	*Flooded*
64	TR	May 1, 2007	1,581	May 31, 2007	1,612	31	1	*Flooded*
65	TR	June 1, 2007	1,612	June 30, 2007	1,642	30	1	*Flooded*
66	TR	July 1, 2007	1,642	July 31, 2007	1,673	31	1	*Flooded*
67	TR	August 1, 2007	1,673	August 31, 2007	1,704	31	1	*Flooded*
68	TR	September 1, 2007	1,704	September 30, 2007	1,734	30	1	*Flooded*
69	TR	October 1, 2007	1,734	October 19, 2007	1,753	19	1	*Flooded*
70	TR	October 20, 2007	1,753	October 31, 2007	1,765	12	3	*Breached*
71	TR	November 1, 2007	1,765	November 2, 2007	1,767	2	1	*Breached*
72	TR	November 3, 2007	1,767	November 30, 2007	1,795	28	3	*Flooded*
73	TR	December 1, 2007	1,795	December 31, 2007	1,826	31	3	*Breached*
74	TR	January 1, 2008	1,826	January 31, 2008	1,857	31	1	*Breached*
75	TR	February 1, 2008	1,857	February 29, 2008	1,886	29	1	*Breached*
76	TR	March 1, 2008	1,886	March 31, 2008	1,917	31	1	*Breached*
77	TR	April 1, 2008	1,917	April 30, 2008	1,947	30	1	*Breached*
78	TR	May 1, 2008	1,947	May 17, 2008	1,964	17	1	*Breached*
79	TR	May 18, 2008	1,964	May 28, 2008	1,975	11	3	*Flooded*
80	TR	May 29, 2008	1,975	May 31, 2008	1,978	3	3	*Breached*
81	TR	June 1, 2008	1,978	June 29, 2008	2,007	29	1	*Breached*
82	TR	June 30, 2008	2,007	June 30, 2008	2,008	1	3	*Flooded*
83	TR	July 1, 2008	2,008	July 31, 2008	2,039	31	1	*Flooded*
84	TR	August 1, 2008	2,039	August 31, 2008	2,070	31	1	*Flooded*
85	TR	September 1, 2008	2,070	September 30, 2008	2,100	30	1	*Flooded*

Stress	*Type*	Stress Period Start Time	Stress Period Stop Time	*Stress*	*Number of*	*Breached*

Period Number		Date	Model Time (days)	Date	Model Time (days)	Period Duration (days)	Time Steps per Stress Period	Lagoon/Flooded Lagoon
86	TR	October 1, 2008	2,100	October 31, 2008	2,131	31	1	*Flooded*
87	TR	November 1, 2008	2,131	November 25, 2008	2,156	25	1	*Flooded*
88	TR	November 26, 2008	2,156	November 30, 2008	2,161	5	3	*Breached*
89	TR	December 1, 2008	2,161	December 31, 2008	2,192	31	1	*Breached*
90	TR	January 1, 2009	2,192	January 31, 2009	2,223	31	1	*Breached*
91	TR	February 1, 2009	2,223	February 28, 2009	2,251	28	1	*Breached*
92	TR	March 1, 2009	2,251	March 31, 2009	2,282	31	1	*Breached*
93	TR	April 1, 2009	2,282	April 18, 2009	2,300	18	1	*Breached*
94	TR	April 19, 2009	2,300	May 1, 2009	2,313	13	3	*Flooded*
95	TR	May 2, 2009	2,313	May 31, 2009	2,343	30	3	*Breached*
96	TR	June 1, 2009	2,313	June 18, 2009	2,361	18	1	*Breached*
97	TR	June 19, 2009	2,361	June 30, 2009	2,373	12	3	*Flooded*
98	TR	July 1, 2009	2,373	July 31, 2009	2,404	31	1	*Flooded*
99	TR	August 1, 2009	2,404	August 31, 2009	2,435	31	1	*Flooded*
100	TR	September 1, 2009	2,435	September 30, 2009	2,465	30	1	*Flooded*
101	TR	October 1, 2009	2,465	October 14, 2009	2,479	14	1	*Flooded*
102	TR	October 15, 2009	2,479	October 31, 2009	2,496	17	3	*Breached*
103	TR	November 1, 2009	2,496	November 30, 2009	2,526	30	3	*Flooded*
104	TR	December 1, 2009	2,526	December 31, 2009	2,557	31	3	*Breached*

3.1.3 Boundary Conditions

Model boundary conditions are shown in Figure 3.1 and were specified as follows. The bottom model boundary, which is at the contact between alluvium and underlying bedrock was assumed to be impermeable. The top boundary, represented by the water table, receives flow from infiltration of precipitation, excess irrigation, stream leakage and from wastewater dispersal that varies by stress period. Specified flux boundaries were used along the edges of the active model grid to simulate recharge from upland areas adjacent to the alluvium. Recharge from the uplands includes contributions from groundwater and surface-water runoff, wastewater dispersal and excess irrigation.

A specified head boundary condition was assigned to the contact between the alluvial deposits and the Pacific Ocean in model layer 1. Beneath this, in model layers 2-5, the boundary was simulated as no-flow which represents a sharp interface between fresh and salt water. The elevation of the specified head that represents the ocean was set based upon average monthly tide elevation at Santa Monica, California Station ID 9410840 as shown in Figure 3.2. Detailed modeling of the salt/fresh interface is not considered to be necessary for the purposes of this project. The reasons for this include the fact that there is no pumping in the alluvium that could cause salt water intrusion and the proposed waste water dispersal loading is sufficiently far from the ocean such that groundwater level and groundwater velocity changes near the ocean are minimal.

Malibu Creek and Lagoon were represented as head dependent boundaries in the model using the GHB package in MODFLOW. Leakage to or from the groundwater system is based upon the difference between Malibu Creek stage and adjacent groundwater elevations, and the hydraulic conductivity of the streambed materials. Stage was determined from measuring points, located on Malibu Creek near Arizona Crossing and at the PCH (Pacific Coast Highway) bridge over Malibu Lagoon, and supplemented with topographic data. Initial estimates of streambed conductance were made using streambed area and a hydraulic conductivity of 1 ft/day. Along the upper reaches of Malibu Creek the GHB package specifications were set to maintain an infiltration rate of approximately 1.0 cfs (cubic feet per second) when the lagoon is breached and 0.6 cfs when the lagoon is flooded.

The extent of the lagoon represented by the GHB package varies depending upon whether the lagoon is flooded or breached as shown in Figure 3.1. When the lagoon is flooded, which usually occurs during the dry summer months, there is a stretch of dry channel between Cross Creek Road and the upper end of the lagoon and the GHB cells are active only above and below the dry stretch. When the lagoon is breached, which usually occurs when Malibu Creek floods in response to winter rains, the channel is continuously wet and GHB cells are specified along the entire reach of channel in the model area. The elevation of the lagoon is set in the GHB package using available stage data and information on conditions in the lagoon (flooded or breached). The lagoon conditions data where provided in daily notes maintained during the period from 2003 to 2009 at the life guard station on Surfrider Beach.

The DRAIN package in MODFLOW was used to simulate the artificial wetland on the Smith parcel. The stage elevation was set in order to control build-up of groundwater levels and to limit levels to the pool elevation at that location.

3.1.4 Hydraulic Parameters

Initial estimates of hydraulic conductivity of alluvial deposits in the model area were guided by observations that were detailed in the 'Conceptual Model' section of this report and were refined during model calibration. Values of hydraulic conductivity used in the model for layers 1-5 are shown in Figures 3.3 through 3.7. The highest values of hydraulic conductivity are used to represent the coarse grained sands and gravel along the present course of Malibu Creek and in the Civic Center Gravels in model layer 4 (Figure 3.6). The lowest values represent fine-grained sediments included in the shallow estuarine deposits represented by model layers 1-3. The specific yield of subsurface deposits was assumed average 0.12 based upon a review of stratigraphic logs and values reported in the literature.

3.1.5 Recharge and Discharge

Recharge to alluvium from waste water dispersal was simulated with the WELL package in MODFLOW. Locations where subsurface waste water dispersal was simulated in the model are shown in Figure 3.8. On parcels where the exact location of the subsurface dispersal systems were known they were mapped to the appropriate model cells(s). On parcels where the location of the subsurface dispersal system was unknown the dispersal was mapped to the model cell nearest to the centroid of the property. For parcels in upland areas adjacent to the alluvium, subsurface dispersal was mapped to the edge of the alluvium as shown on Figure 3.8.

The rate of waste water dispersal simulated in the model is based upon bimonthly water use data for each parcel provided by County of Los Angeles. The water users, and assumptions about dispersal rates, were grouped into five general areas/categories as shown in Figure 2.6. The dispersal rates were specified in the model as follows:

1) Malibu Colony shoreline area -- 400 gpd (gallons per day), no irrigation.

2) Upland areas -- If total water use is less than or equal to 400 gpd then the waste water dispersal rate is the actual reported bimonthly water use. If the reported water use is more than 400 gallons per day then the dispersal rate is specified as 400 gpd and remaining water is assumed to be used for irrigation

3) Serra Vicinity -- same as for Upland Areas described above.

4) Commercial -- Waste water dispersal is equal to the total reported bimonthly water use, no irrigation.

5) Nurseries/Golf Park -- Waste water dispersal is 400 gpd if there is a residence on the property. The remaining water use is assumed to be for irrigation. If there is no residence the waste water dispersal rate is zero and all water is assumed to be used for irrigation.

Recharge from excess irrigation was simulated in the model using the RIVER package in MODFLOW at locations shown in Figure 3.9. The rate of recharge from excess irrigation is assumed to be equal to 50% of any bimonthly reported water use in excess of 400 gpd for those properties shown in Figure 3.9 that include a residence.

Recharge from residential properties in upland areas adjacent to the alluvium is also assumed to be equal to 50% of any bimonthly reported water use in excess of 400 gpd, and is applied to the edge of the active model areas as shown in Figure 3.9. Recharge from excess irrigation at the Nurseries/Golf Park properties is 50% of bimonthly water use if there is no residence on the property.

Recharge from infiltration of precipitation on the alluvial deposits and from runoff originating in upland areas was simulated in the model with the RECHARGE package in MODFLOW at locations shown in Figure 3.10. Recharge to the alluvium from runoff originating in upland areas, shown in Figure 2.5, is estimated based upon the size of the upland area (Table 2.3) and is applied to the edge of the active model area at the locations shown in Figure 3.10. Recharge from infiltration of precipitation on the alluvium occurs only on unpaved areas as shown in Figure 3.10.

The rate of recharge from infiltration of precipitation on the alluvium is based upon the graph shown in Figure 3.11. The graph was developed during model calibration and relates monthly precipitation to monthly recharge rates. The exponential form of the graph resulted from the need to increase recharge during wet periods such that model calculated water levels would more closely match observed water levels. Examination of Figure 3.11 shows that total monthly precipitation of seven inches would result in a total monthly recharge of 0.5 inches. The maximum monthly precipitation during the model simulation period was 10.66 inches in January 2005, which resulted in a monthly recharge of approximately 3 inches.

Recharge rates from upland runoff were assumed to be twice the rate of direct recharge to alluvium from precipitation to account for infiltration of surface runoff and groundwater runoff from upland areas. The recharge curve in Figure 3.11 is applied to the transient model simulation with a two-month lag.

Evapotranspiration from groundwater was simulated with the ET package in MODFLOW in the model area where phreatophytes exist along the riparian zone adjacent to Malibu Creek and Lagoon as shown in Figure 3.12. The maximum evapotranspiration rate varies by stress period using monthly ET rates calculated for the Pepperdine Campus (Daniel B. Stephens & Associates, Inc., 2007a, 2007b, 2008a, 2008b, 2009, 2010). The extinction depth was set at 15 feet below land surface.

3.2 Calibration

The model calibration process included a combination of trial and error simulations and automated parameter estimation using the PEST numerical code (Watermark Numerical Computing, 1994). During calibration, model hydraulic conductivity values and recharge from precipitation/upland runoff, were adjusted to improve the model calculated match between computed and observed water levels. The hydraulic conductivity values were modified based upon a combination of pilot points and zones.

Recharge values were adjusted by modifying the relationship between monthly precipitation and monthly recharge shown in Figure 3.11. In addition, the rate of upland recharge from Malibu Tributary and Sweetwater Canyon were reduced to improve model calculated groundwater elevations in the alluvium north of Serra Retreat, and along the eastern shoreline. Recharge rates were increased in the vicinity of the Smith Parcel wetland shown in Figure 3.10 to improve the model calculated water levels in that area. A summary of annual recharge rates used in the calibrated model is included in Table 3.2.

Table 3.2 -- Summary of modeled annual recharge rates, in inches per year.

YEAR	Total Precipitation	Precipitation Recharge	Upland Runoff Recharge
2003	8.0	0.2	0.4
2004	18.9	0.6	1.2
2005	23.4	2.0	4.0
2006	17.4	0.3	0.6
2007	8.8	0.1	0.3
2008	11.7	0.2	0.5
2009	12.3	0.3	0.5
Average	14.4	0.5	1.1

Water level targets used in model calibration included 2,022 observations at 100 locations. The locations where groundwater levels were used for calibration are included in Figure 2.14a and 2.14b. A scatter diagram showing a comparison of model calculated and observed water levels from the final calibrated model are included in Figure 3.13. The final statistics of calibration are as follows: residual mean -0.1 ft, absolute residual mean 1.3 ft and sum of squares 6,870 ft^2. Given the range of water levels within the model area (71 ft) these statistical measures of match are considered to be acceptable.

A map showing the model calculated groundwater level distribution on December 8, 2009, the day that the synoptic water level measurement was made for this study, is shown in Figure 3.14. Also shown on Figure 3.14. are the residuals (differences between model computed and observed groundwater elevations) on that date. Examination of Figure 3.14 shows that the residuals are generally one foot or less which means that model calculated water levels compare closely with measured groundwater elevations on the day the synoptic water level measurement was made. In general, model calculated water levels tend to be slightly higher than observed elevations.

Hydrographs showing a comparison of model calculated and observed groundwater elevations are shown for representative locations in Figures 3.15a through 3.15g. Figures 3.15a and 3.15b show calculated and observed water levels for Well02 and SMBRP-11 which are both located in Winter Canyon. During 2003-2009 the observed water levels at Well02, in the upper part of the Canyon, range from approximately 47 to 61 ft NAVD88, a 14 foot variation. At SMBRP-11, in the lower part of the Canyon, observed water levels vary from 9.5 to 12 ft NAVD88, a 2.5 foot variation. At both locations the highest water levels correspond with the record high precipitation that occurred in winter of 2004-05. Examination of Figures 3.15a and 3.15b show that the model reasonably replicates the observed water level fluctuations at both locations.

Figures 3.15c, 3.15d, 3.15e and 3.15f show calculated and observed water levels for selected wells in the western part of the alluvium. Wells SMBRP-9 (Figure 3.15c), SMBRP-10C (Figure 3.15d) and SMBRP-16 (Figure 3.15e) are shallow wells completed above the Civic Center Gravels. Well MW-6 (Figure 3.15f) is deeper and is completed in the Civic Center Gravels.

Well SMBRP-9 (Figure 3.15c) is located near the valley wall and, like many of the wells in the study area, has a gap in available water level data from late 2003 to the middle of 2007. The model does a good job of replicating water levels at this location, especially in late time (2008-09), and predicts that the high water level would have occurred in response to the very wet winter of 2004-05. The model calculated high water level at SMBRP-9 (Figure 3.15c) is accentuated by its proximity to the valley wall and is clearly affected by runoff from the adjacent upland area.

Well SMBRP-10c (Figure 3.15d) is located adjacent to the Smith Parcel artificial wetland and is therefore affected by occasional flooding that occurs at the wetland in response to major precipitation events. The maximum observed and predicted water levels at this location also occur in response to precipitation in the winter of 2004-2005. The modeled water levels at this location tend to match the high end of the observed water levels but not the lower levels. Observed low elevations are approximately 8-9 ft NAVD88 and modeled low values are approximately 10-11 ft NAVD88.

Well SMBRP-16 (Figure 3.15e) is located in the northwest corner of the Legacy Park parcel. The observed water levels at this location are not as variable as those at SMBRP-9 (Figure 3.15c) or SMBRP-10c (Figure 3.15d) because this location is farther from the valley wall with its associated runoff, and farther from the Smith Parcel artificial wetland and its associated flooding. The modeled water levels at this location closely match observed data.

Well MW-6 (Figure 3.15f) is located in the center of the Malibu Sycamore Village parcel and is completed in the Civic Center gravels which are represented in model layer 4. The groundwater levels in this well are lower than those measured in the nearby shallow unconfined wells. Furthermore, water levels in this well do not vary in response to precipitation and runoff events in the same way that shallow wells do. Water levels in MW-6 well have smaller fluctuations than the shallow unconfined wells and are slightly affected by lagoon stage and tidal fluctuations. The model does a reasonable job of replicating the deep water level and fluctuations related to variations in tide/lagoon stage. Model calculated levels at MW-6 are slightly higher than observed values.

Well P-9 (Figure 3.15g) is located in the eastern part of the alluvium close to the lagoon. The observed water levels at this location directly reflect variations in lagoon stage and do not correlate with precipitation events like wells in Winter Canyon and the western part of the alluvium. The model calculated water levels are very close to observed elevations for the periods when data are available.

Final values of horizontal hydraulic conductivity resulting from model calibration are shown in Figures 3.3 through 3.7. The highest hydraulic conductivities (200-400 ft/d) occur along the present day channel of Malibu Creek in model layers 1, 2 and 3 and in the Civic Center gravels in model layer 4. In the western part of the alluvium, in model layers 1-3 above the Civic Center gravels, hydraulic conductivity are generally less than 10 ft/d ranging from 0.2 to 50 ft/d. The resulting ratios of horizontal to vertical hydraulic conductivity vary from about 100:1 in the fine to medium grained materials and 10:1 in coarse grained alluvial materials. Specific yield was 0.12 over the entire model area.

A detailed summary of the model calculated water budget for the calibrated model is included in Table 3.3. Table 3.3 includes a detailed water balance terms by year for the simulation period, including a balance for the steady-state initial condition run and an average for the 2003-2009 period. The average values are also summarized in the block diagram included in Figure 2.13 and in Table 2.5.

Table 3.3. Model calculated annual water budgets for the period 2003-2009, in gallons per day.

	Steady-State	2003	2004	2005	2006	2007	2008	2009	Average
Precipitation Recharge									
Alluvium (Exclusive of Winter Canyon)	25,691	11,827	28,813	67,525	20,861	9,839	14,989	16,068	24,275
Natural Upland Runoff									
East Shore 1	2,677	616	1,606	5,340	883	362	709	760	1,468
East Alluvium	17,744	4,085	10,648	35,401	5,856	2,398	4,700	5,040	9,732
Tributary	17,022	3,915	10,212	33,961	5,617	2,298	4,510	4,834	9,335
North Alluvium	6,214	1,431	3,728	12,394	2,051	840	1,645	1,765	3,408
Serra Retreat	3,681	849	2,209	7,343	1,215	498	974	1,046	2,019
Northwest Alluvium	15,658	3,603	9,392	31,227	5,166	2,115	4,146	4,445	8,585
West Alluvium	12,617	2,903	7,569	25,166	4,163	1,704	3,342	3,582	6,918
West Shore 1	5,032	1,158	3,020	10,043	1,661	680	1,334	1,429	2,761
East Shore 2	30,239	6,955	18,143	60,318	9,978	4,082	8,013	8,588	16,582
West Shore 2	13,262	3,050	7,957	26,456	4,376	1,790	3,514	3,766	7,273
Alluvium Irrigation Return									
Serra Retreat	23,359	30,047	27,445	38,181	51,737	55,938	51,572	40,633	42,222
Malibu Colony Golf Course	5,531	4,270	6,647	11,264	13,202	14,509	8,728	5,308	9,133
Nurseries	1,996	2,043	1,677	1,734	2,585	2,795	2,542	2,331	2,244
Estate	3,319	2,624	2,198	3,301	3,445	4,400	4,151	3,051	3,310
Miscellaneous	737	1,084	1,041	1,389	1,985	2,391	1,874	1,501	1,609
Remaining Alluvium	0	0	0	0	0	0	0	0	0
Upland Irrigation Return									
East Shore 1	1,914	3,281	2,838	4,158	5,508	5,913	5,689	4,694	4,583
East Alluvium	20,766	23,299	21,293	26,648	38,726	42,735	38,157	30,140	31,571
Tributary	0	0	0	0	0	0	0	0	0
North Alluvium	848	746	628	929	1,188	1,329	1,181	931	990
Serra Retreat	528	963	956	1,256	1,837	1,972	1,822	1,431	1,462
Northwest Alluvium	6,376	9,565	7,672	10,071	14,904	15,876	14,282	12,629	12,143
West Alluvium	7,264	8,604	7,305	7,658	11,160	11,790	10,335	9,224	9,440
West Shore 1	0	0	0	0	0	0	0	0	0
East Shore 2	5,229	6,115	4,908	7,021	9,826	11,129	10,078	7,952	8,147
West Shore 2	0	0	0	0	0	0	0	0	0
Malibu Creek Leakage									
Upper Creek	640,898	554,772	533,287	620,425	563,520	493,433	525,845	523,392	544,953
Lagoon	304	30,664	33,723	8,141	27,120	43,414	39,150	38,801	31,573
Waste Water Main Alluvium									
West Shore Septic	12,251	13,904	14,095	14,248	14,618	14,568	14,514	14,366	14,330
Commercial Septic	86,881	88,331	78,097	98,939	107,594	116,114	96,627	89,819	96,503
Colony Septic	50,002	52,726	52,933	53,168	53,511	53,516	53,911	53,535	53,328

East Shore Septic	2,400	2,400	2,407	2,400	2,400	2,332	2,407	2,400	2,392
Around Serra Septic	20,848	20,985	20,761	20,917	21,209	21,365	21,200	20,953	21,056
Waste Water Upland									
Upland Northwest NN Septic	49,826	50,042	52,157	49,436	54,219	63,635	60,551	53,841	54,840
Upland Northwest W Septic	6,071	8,166	7,021	8,271	9,079	9,130	8,581	8,450	8,386
Upland Northwest E Septic	8,524	9,334	9,291	9,313	9,775	9,945	9,872	9,606	9,591
Upland Northeast	10,509	12,275	12,140	12,304	12,774	12,945	12,872	12,698	12,572
Upland East Shore 1	7,974	8,078	7,985	8,024	8,442	8,738	8,294	7,791	8,193
Upland East Shore 2	1,524	2,662	2,627	3,001	3,210	3,615	3,898	3,607	3,231
Upland West Shore	10,518	11,610	12,531	18,976	27,358	26,480	18,493	13,927	18,482
Winter Canyon									
Winter Canyon Upland Recharge	33,212	7,644	19,932	66,274	10,961	4,486	8,800	9,434	18,219
Winter Canyon Alluvium Recharge	1,640	394	984	3,264	541	230	426	466	901
Winter Canyon Irrigation Return	0	97	93	130	254	313	218	150	179
Winter Canyon Upland Irrigation Return	2,301	4,914	4,278	2,226	2,499	2,857	2,841	2,906	3,217
Winter Canyon Upland Septic	4,254	4,615	3,916	3,904	4,519	4,618	4,444	4,222	4,320
Winter Canyon Alluvium Septic	5,863	8,986	8,665	10,569	13,157	12,965	12,193	10,609	11,021
MBC Waste Water	34,491	30,272	28,891	29,048	33,366	35,665	32,145	28,552	31,134
County of LA Waste Water	28,978	43,517	43,599	41,666	49,326	53,284	47,428	43,222	46,006
Change in Storage	0	-11,342	32,599	-10,327	-2,736	8,460	-12,597	-14,195	-1,448
Flow to Ocean	340,211	337,562	352,008	475,185	383,820	396,959	380,152	356,967	383,236
Evapotranspiration	74,137	83,572	100,226	101,414	112,703	117,171	76,521	77,513	95,589
Malibu Creek	299,753	184,930	152,157	353,627	212,564	133,062	182,026	164,253	197,517
Lagoon	542,241	505,755	500,548	591,920	540,901	535,093	556,956	539,679	538,693
Smith Parcel Wetland	0	0	0	0	0	0	0	0	0
Total In	1,246,975	1,099,421	1,137,316	1,513,426	1,247,383	1,191,029	1,182,998	1,123,898	1,213,639
Total Out	1,256,342	1,100,477	1,137,539	1,511,818	1,247,251	1,190,744	1,183,057	1,124,219	1,213,587
In - Out	-9,367	-1,056	-223	1,608	132	285	-59	-321	52
Percent Discrepancy	0	0	0	0	0	0	0	0	0

3.3 Application

As previously stated in this report, the purposes for groundwater flow modeling are to provide preliminary analyses of the effect of municipal waste water dispersal strategies on groundwater levels and to guide site characterization data collection efforts for municipal dispersal sites. Municipal dispersal strategies involve collection of distributed waste water from specific areas, treatment, and underground dispersal of the treated waste water at specific locations. Based upon discussions with the City of Malibu three municipal waste dispersal scenarios are analyzed with the calibrated transient model.

In the first scenario, waste water is collected from commercial properties in the Civic Center area, called Service Area #1, as shown in Figure 3.16, and dispersed at the existing waste water treatment location in Winter Canyon now used by the Malibu Bay Company. The present dispersal rate at the Winter Canyon location used by Malibu Bay Company is approximately 30,000 gpd as shown in Table 3.3. The total additional amount of treated waste water to be dispersed at that location is 62,800 gallons per day, which is approximately equivalent to the existing distributed dispersal rate for Service Area #1. The dispersal is assumed to occur during the period from October through March which is the period when the waste water cannot be utilized for alternative purposes such as irrigation.

In the second scenario, waste water is collected from Service Area #2, and dispersed on the northern part of the Lower Yamaguchi parcel. Service Area #2 and the dispersal location on the Yamaguchi parcel are shown in Figure 3.16. The total amount of dispersal on the Yamaguchi parcel is assumed to be 50,000 gpd which is slightly greater than the current distributed dispersal rate for Service Area #2.

In a third modeling scenario waste water is collected from Service Area #1 and Service Area #2, with dispersal at the corresponding locations, simultaneously in order to evaluate the cumulative effects of both dispersal areas.

The calibrated transient model simulation for the 2003-2009 period formed the basis for evaluating the municipal dispersal scenarios. For each municipal dispersal scenario the appropriate stresses were implemented in the transient model in order to determine groundwater level changes that would result. The stresses implemented in the model for each scenario include cessation of the distributed dispersal from the service area and addition of the appropriate amount of waste water dispersal at the municipal dispersal location.

For each scenario groundwater level changes are evaluated directly under the dispersal bed and at a down gradient locations. In addition, the groundwater level change over the entire model area is shown for each scenario at the critical high water period. The groundwater level changes are calculated by comparing model calculated heads from the base model run with corresponding heads calculated for each scenario.

The water level change that is predicted to occur for scenario #1 directly under the infiltration beds in Winter Canyon is illustrated in Figure 3.17. The hydrograph in Figure 3.17 shows model calculated heads for the base run in red and the calculated heads for scenario #1 in blue. The difference between the blue and red lines on Figure 3.17 is the model predicted water level increase caused by the dispersal scenario. The land surface at the infiltration bed is also shown in Figure 3.16 as the green line.

Examination of Figure 3.17 shows that the model predicted water level increase under the infiltration beds varies over time. The minimum increase is about 1-2 feet and the maximum increase is approximately 10 feet. The water level change varies as a function of time because the simulated dispersal occurs cyclically, during October through March of each year. The minimum depth below land surface, 37 feet at the location shown in Figure 3.17, occurs in the third year of dispersal, which is equivalent to the 2004-05 record high winter precipitation season.

Figure 3.18 shows the model predicted groundwater level changes that will occur as a result of scenario #1 at well SMBRP-11 which is located at the base of Winter Canyon. The difference between the base run, represented by the blue line, and the scenario #1 run, represented by the red line, varies cyclically ranging from less than a foot to approximately 2 feet. The minimum distance from land surface (approximately 2 feet) occurs in the third year of dispersal, which is equivalent to the 2004-05 record high winter precipitation season.

A map showing model predicted water level changes over the entire model area for scenario #1 is shown in Figure 3.19. The water level change map shown in Figure 3.19 corresponds to model stress period 32 (March 2005 as shown in Table 3.1) during the high water level condition. Red areas on Figure 3.19 show areas where the model predicts water level increases and blue areas are where there are predicted water level declines. Water level decreases of about one foot or less are predicted to occur in the area where distributed discharge is eliminated and water level increases of about 1-10 feet are predicted to occur in Winter Canyon in response to the increased dispersal rate.

The water level change that is predicted to occur for scenario #2 directly under the infiltration beds on the Yamaguchi parcel is illustrated in Figure 3.20. The hydrograph in Figure 3.20 shows model calculated heads for the base run in red and the calculated heads for scenario #2 in blue. The difference between the blue and red lines on Figure 3.20 is the model predicted water level increase caused by the dispersal scenario. The land surface at the infiltration bed is also shown in Figure 3.20 as the green line.

Examination of Figure 3.20 shows that the model predicted water level increase under the infiltration beds varies over time. The minimum increase is about 2-3 feet and the maximum increase is approximately 20 feet. The water level change varies as a function of time because the simulated dispersal occurs cyclically, during October through March. The minimum model predicted depth below land surface, less than one foot, occurs in the third year of dispersal, which is equivalent to the 2004-05 record high winter precipitation season.

Figure 3.21 shows the model predicted groundwater level changes that will occur as a result of scenario #1 at well M6-2 which is located down gradient of the dispersal beds, on the southeast corner of the Malibu Sycamore Village parcel. The difference between the base run, represented by the blue line, and the scenario #2 run, represented by the red line, varies cyclically ranging from one foot to approximately 3 feet. The minimum distance from land surface (less than one foot) occurs in the third year of dispersal, which is equivalent to the 2004-05 record high winter precipitation season.

A map showing model predicted water level changes over the entire model area for scenario #2 is shown in Figure 3.22. The water level change map shown in Figure 3.22 corresponds to model stress period 32 (March 2005 as shown in Table 3.1) during the high water level condition. Red areas on Figure 3.22 show areas where the model predicts water level increases and blue areas are where there are predicted water level declines. Water level decreases of about one foot or less are predicted to occur in the area where distributed discharge is eliminated and water level increases of about 1-20 feet are predicted to occur directly below the dispersal beds on the Yamaguchi parcel in response to the increased dispersal rate.

A map showing model predicted water level changes over the entire model area for scenario #3 is shown in Figure 3.23. In this simulation both scenarios #1 and #2 are run simultaneously to determine the cumulative impacts of both scenarios. The water level change map shown in Figure 3.23 also corresponds to model stress period 32 (March 2005 as shown in Table 3.1) during the high water level condition. Examination of Figure 3.22 and comparison with the water level change maps presented in Figures 3.19 for scenario #1, and 3.22 for scenario #2 shows that there is a minimal cumulative effect of adding both scenarios together. This result is not unexpected because groundwater in Winter Canyon is hydraulically isolated from groundwater the main body of alluvium by a low bedrock ridge.

3.4 Sensitivity Analyses

A series of model simulations were run to evaluate the sensitivity of model predicted water level increases in scenarios #1 and #2 to variations in individual model parameters. Model parameters that were evaluated include specific yield, horizontal hydraulic conductivity and vertical leakance. These are the parameters that have the greatest effect on water level rise predictions made with the model in response to waste water dispersal at the water table. A summary of the sensitivity runs is included in Table 3.4.

The specific yield value used in the base model run was 0.12. In the sensitivity runs specific yield was decreased throughout all model layers to 0.06 and increased to 0.18. Model horizontal hydraulic conductivity in layers 1 through 5 was increased and decreased by a factor of 30%. Model vertical leakance values between each model layer were increased by a factor of 10 and decreased by one-half in the sensitivity runs.

Each of the individual variations in model parameters that were tested during the sensitivity analyses caused a worsening of the model calibration statistics described in the calibration section of this report. A summary of the effect of each parameter variation on model calibration statistics is included in Table 3.4. Examination of Table 3.4 shows that increases to horizontal conductivity and vertical leakance and a decrease in horizontal hydraulic conductivity have the greatest effect on model calibration such that the calibration is no longer valid. Changes to specific yield and a decrease in vertical leakance had much less effect on the statistics of model calibration.

In order to evaluate effects of parameter variations on model predictions the model predicted groundwater level changes for scenarios #1 and #2 were tracked at locations directly under the dispersal beds and down gradient of the dispersal beds. The results are expressed as the maximum water level rise beneath the beds and down gradient of the beds in Table 3.3. These values can be compared to the maximum water level rise predicted for the base run in Table 3.3.

Examination of Table 3.3 shows that increases in specific yield, horizontal hydraulic conductivity and vertical leakance cause less groundwater mounding for a given discharge in each scenario. When model specific yield is increased to 0.18 the increased storage results in less groundwater mounding for a given discharge. When the horizontal conductivity and vertical leakance are increased there is less resistance to flow which results in less mounding for a given discharge. Decreases to each of these parameters cause the opposite to occur that is, a greater amount of mounding occurs for decreases in each parameter tested.

Table 3.4 Summary of sensitivity runs.

	Calibration Statistics			Maximum Water Level Rise Below Beds		Maximum Water Level Rise Downgradient of Beds	
Description	Residual Mean (ft)	Absolute Residual Mean (ft)	Sum of Residuals Squared (ft^2)	Service Area 1 Scenario (ft)	Service Area 2 Scenario (ft)	Service Area 1 Scenario (ft)	Service Area 2 Scenario (ft)
Base Run	-0.1	1.3	6,870	9.2	20.6	2.1	3.0
Increase Sy to 0.18 (from 0.12)	-0.1	1.3	7,556	9.0	20.0	2.0	2.9
Decrease Sy to 0.06 (from 0.12)	-0.1	1.3	7,121	18.6	23.2	5.7	3.7
Increase Horizontal Hydraulic Conductivity by 30%	0.9	1.8	16,059	3.6	17.2	0.7	2.1
Decrease Horizontal Hydraulic Conductivity by 30%	-1.9	2.2	21,835	19.3	26.3	4.7	4.3
Increase Vertical Leakance (10X)	2.0	2.5	20,898	8.5	9.2	-0.2	0.9
Decrease Vertical Leakance (0.5X)	-0.8	1.6	8,708	9.5	23.2	3.0	4.6

4.0 SUMMARY AND CONCLUSIONS

Modeling results suggest that a seasonal loading rate of an additional 63,000 gallons per day may be possible at the Winter Canyon location, depending upon the depths of the proposed seepage pits. Depth to the water table in the upper part of the Canyon beneath the Malibu Bay Company dispersal beds is sufficient. The limiting factor in the ultimate Winter Canyon dispersal rate will likely be caused by water level increases in the lower part of the Canyon in areas where the water table is closest to land surface such as near SMBRP-11 and in the swale above Malibu Road. This will be especially true during high water periods such as the one experienced in 2004-2005.

Although the modeling results suggest that additional loading is possible in Winter Canyon they do not guarantee that more loading would be acceptable. Additional field testing should be done in Winter Canyon to verify capacity for loading. This work should include the following: better definition of bedrock surface, additional measurement of groundwater levels in bedrock and the alluvium, better delineation of subsurface stratigraphy and most importantly a full scale hydraulic loading test with detailed monitoring of water levels. These activities, along with the proposed design of dispersal systems, would provide data that will allow a more definitive evaluation of the ultimate waste water dispersal capacity in Winter Canyon.

Model results suggest that a loading rate of 50,000 gallon per day on the Yamaguchi parcel could cause groundwater levels to reach land surface, especially during a very wet period like 2004-2005. The critical areas are generally down gradient of the proposed dispersal beds at locations where groundwater is closest to land surface such as the Smith artificial wetland and on the lower part of the Malibu Sycamore Village parcel. Unfortunately there are no deep borings or wells on this site that allow a detailed characterization of site conditions.

A considerable amount of hydrogeologic data exist just to the east of the Yamaguchi parcel on the Malibu Sycamore Village parcel. Assuming conditions on the Yamaguchi parcel are similar to conditions on the adjacent Malibu Sycamore Village parcel, the northern part of the Yamaguchi may be able to handle some waste water dispersal loading but it will probably be less than 50,000 gallons per day. Additional field work is definitely needed to characterize subsurface conditions at this location. Of special importance is definition of the horizontal and vertical extent of the underlying Civic Center gravel and the connection with the ocean and groundwater elevations beneath the site.

As a result of this project, and previous investigations, a network of monitoring wells has been established in the valley. Groundwater levels in these wells, or a representative subset of wells, should be measured monthly on a routine basis. Because of the significant effect that lagoon stage has on groundwater levels the lagoon stage should also be monitored monthly or more frequently. These data will prove invaluable to future analyses of municipal waste water dispersal strategies.

Groundwater and surface water monitoring data collected in the upper part of Winter Canyon by Pepperdine University are valuable especially if the Winter Canyon site is used for additional dispersal.

The model can be used for preliminary evaluations of other scenarios of reclaimed water dispersal in conjunction with the design of a municipal wastewater reclamation/dispersal alternative within the Civic Center and Winter Canyon areas.

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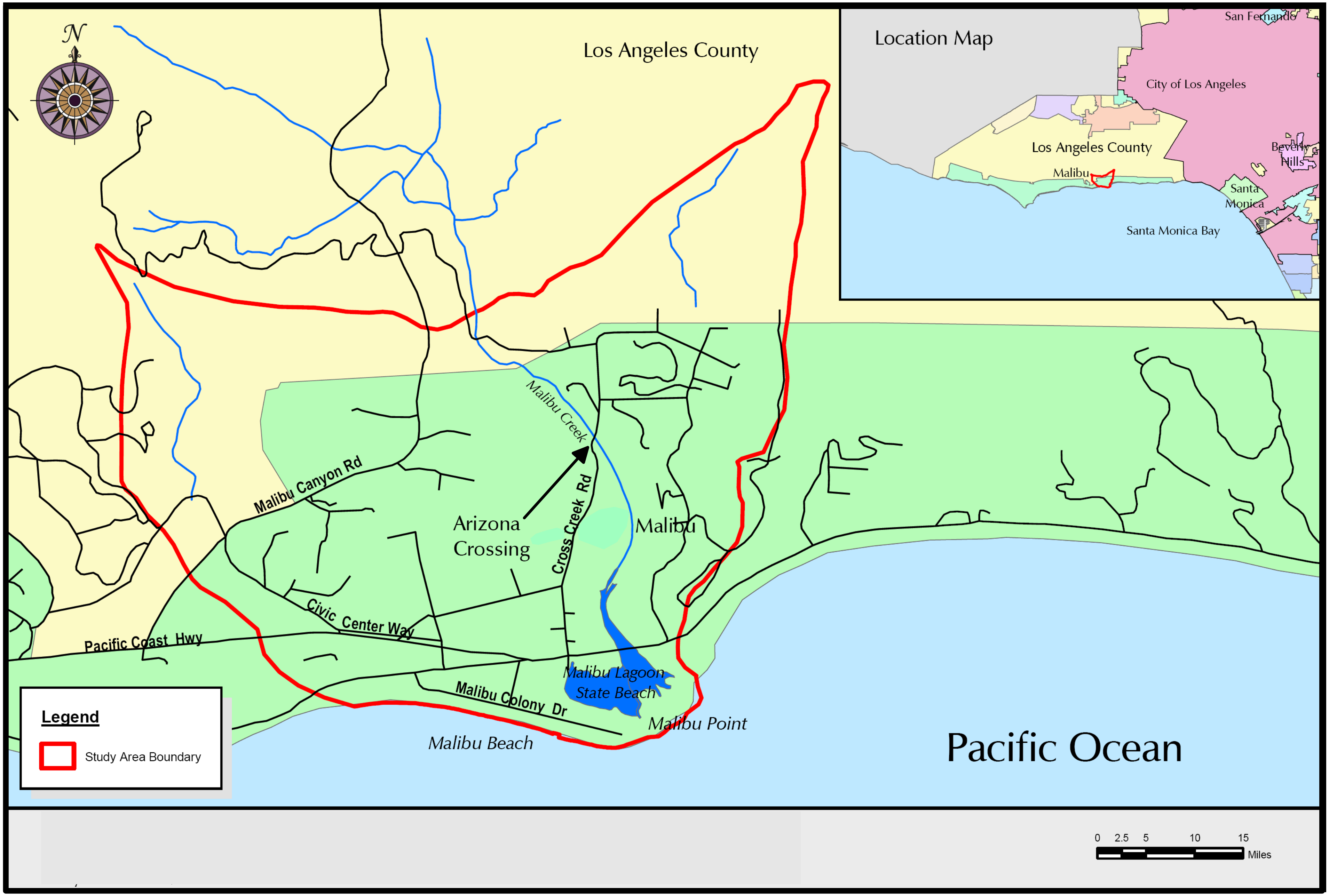


Figure 1.1. Map showing location of study area (modified from Stone Environmental, Inc., 2004).

McDonald Morrissey ASSOCIATES, Inc.

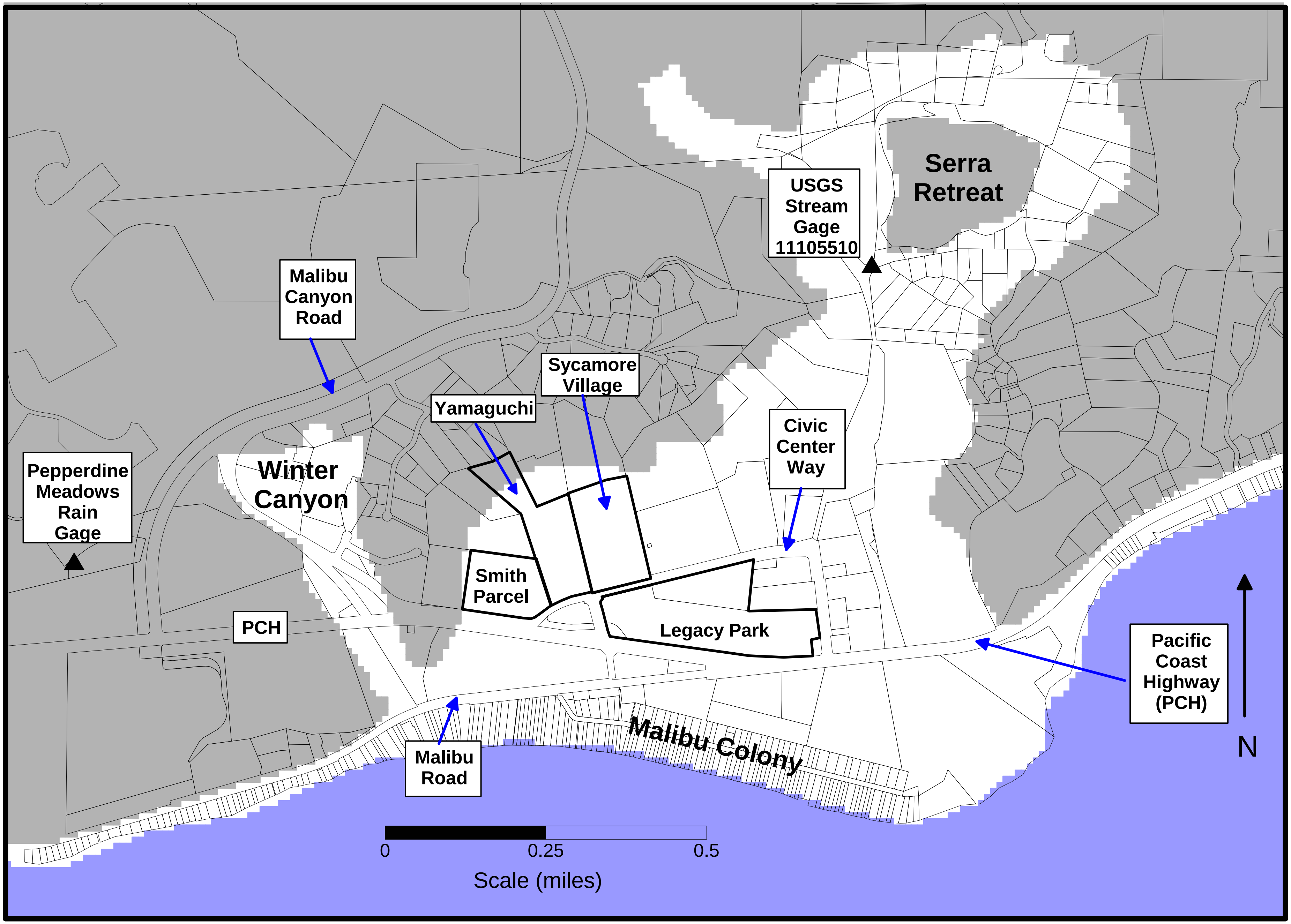


Figure 1.2. Map showing selected locations within the study area.

McDonald Morrissey ASSOCIATES, Inc.

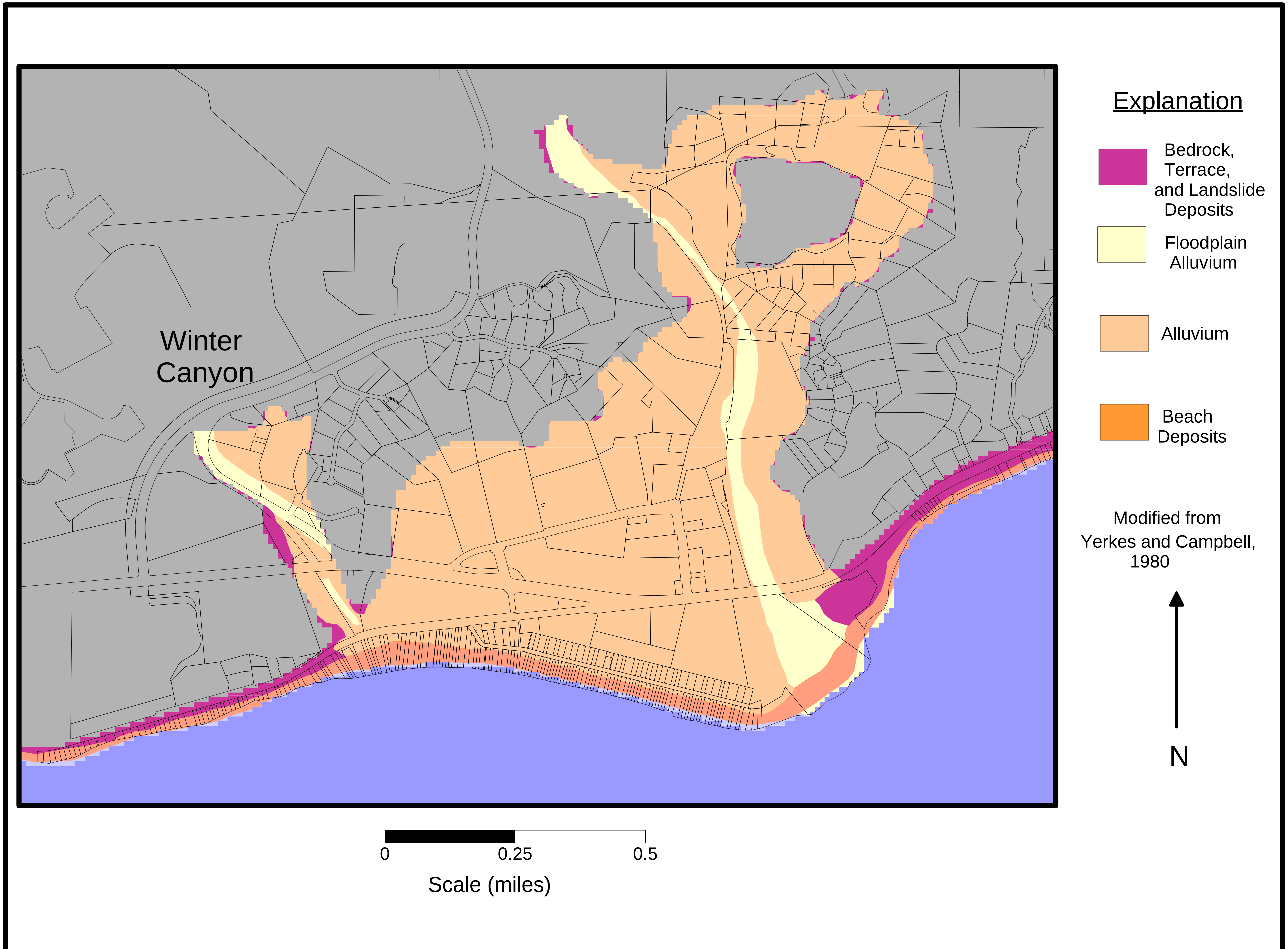


Figure 1.3. Map showing the extent of alluvium along Malibu Creek near the Malibu Civic Center area and Winter Canyon.

McDonald Morrissey ASSOCIATES, Inc.

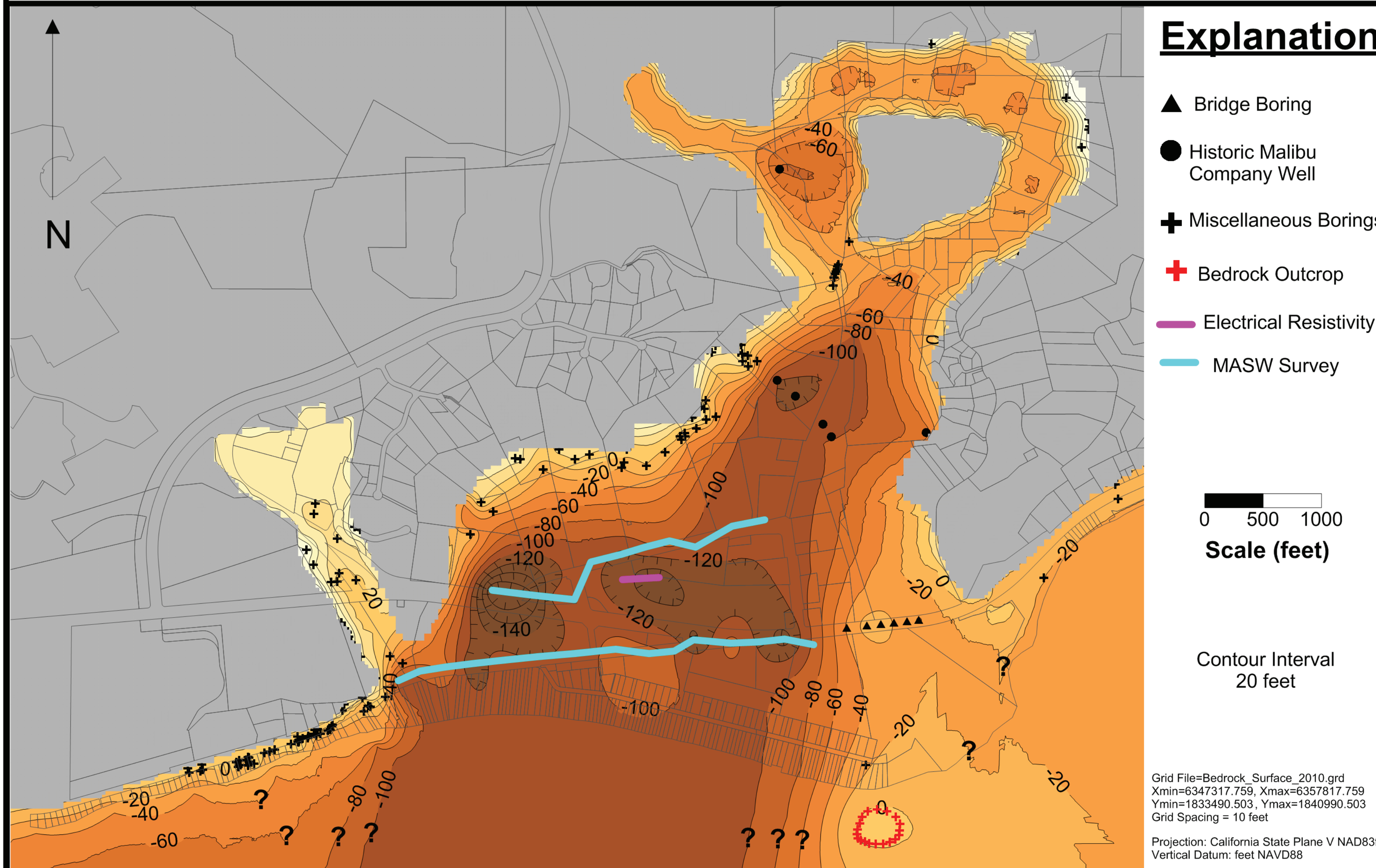


Figure 2.1. Map showing bedrock surface elevation beneath alluvial deposits, in feet NAVD88.

McDonald Morrissey ASSOCIATES, Inc.

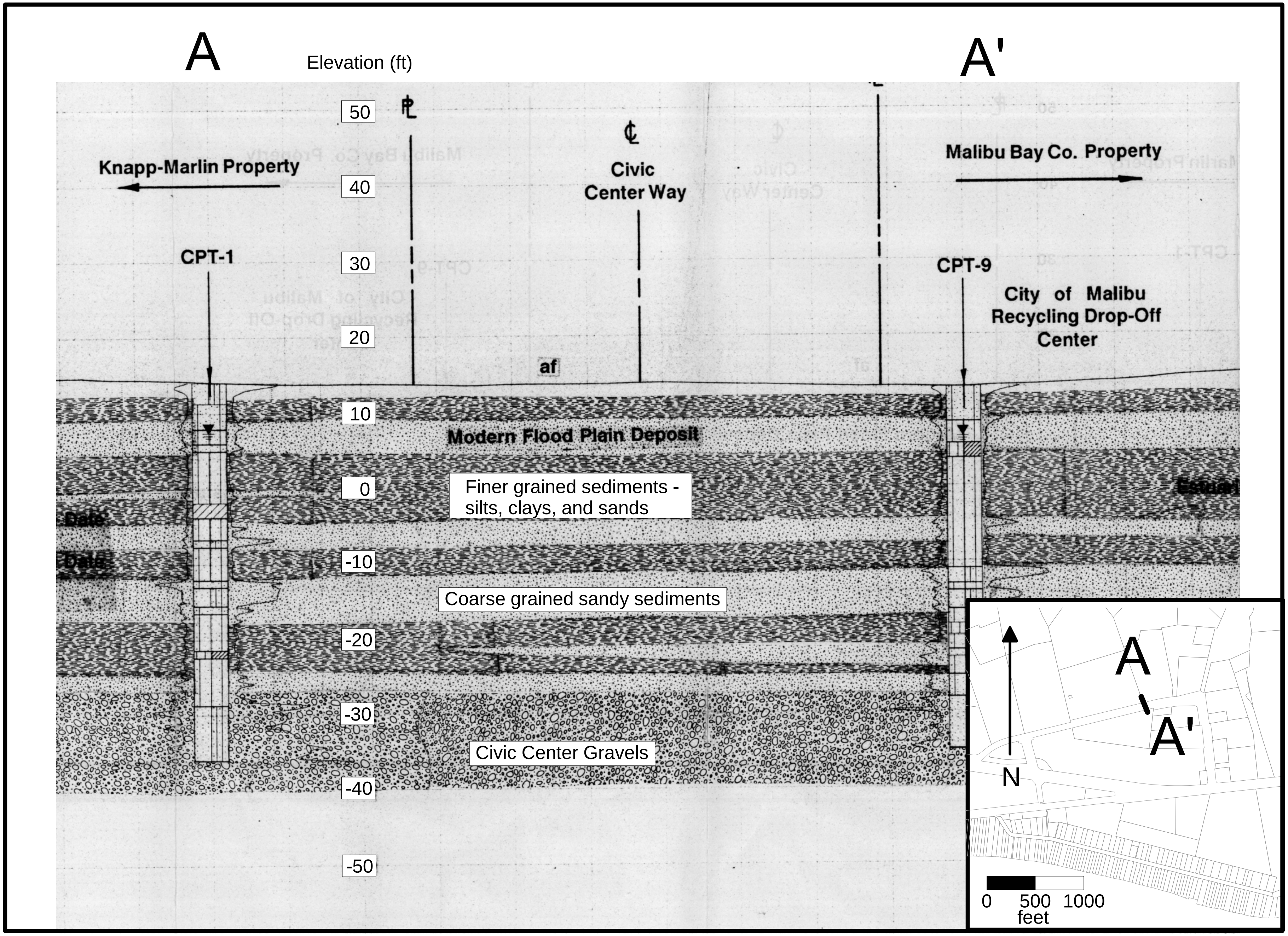


Figure 2.2. Geologic cross-section modified from Leighton, 1994.

McDonald Morrissey ASSOCIATES, Inc.

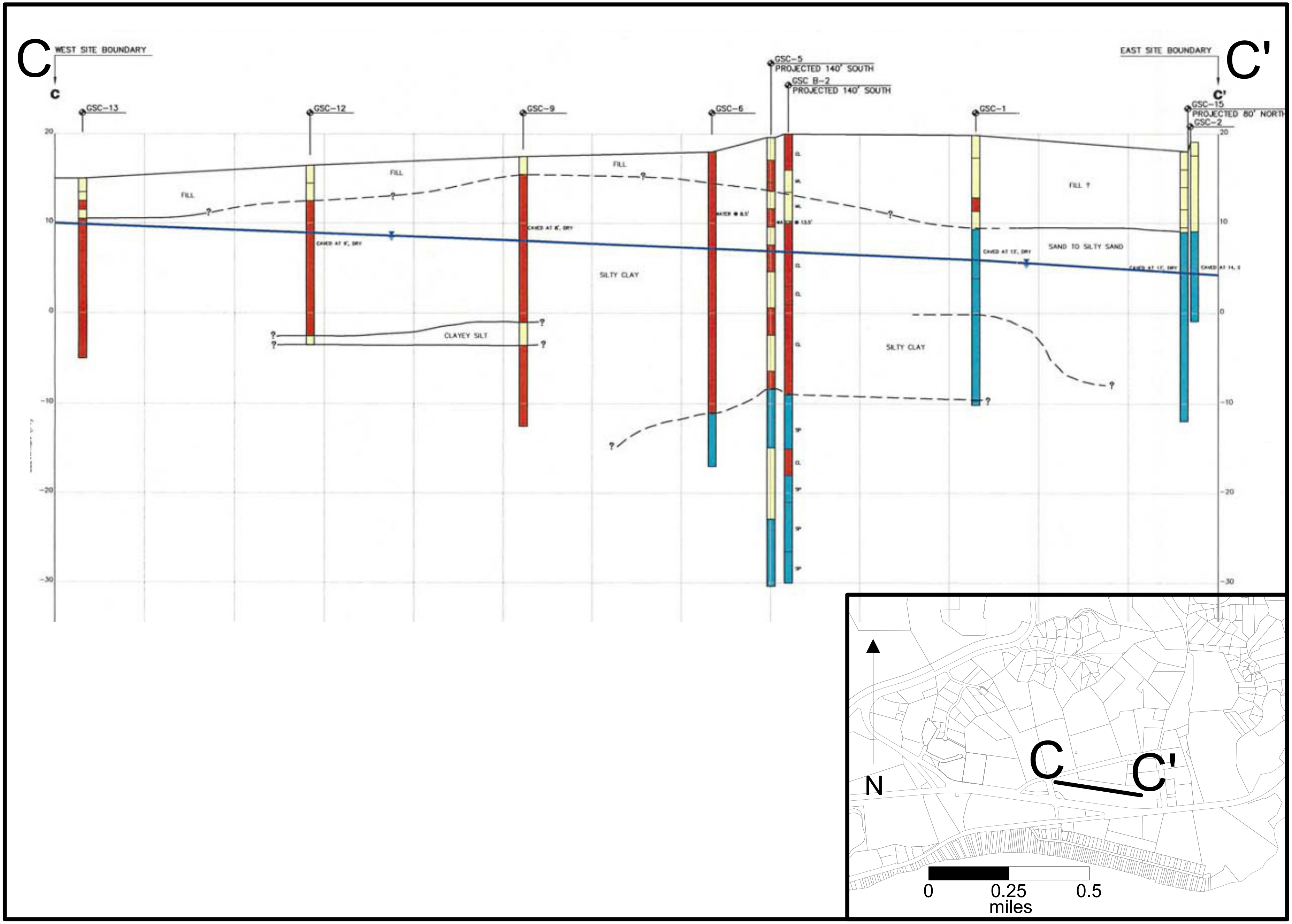


Figure 2.3. Geologic cross-section modified from Geosyntec, 2007.

McDonald Morrissey ASSOCIATES, Inc.

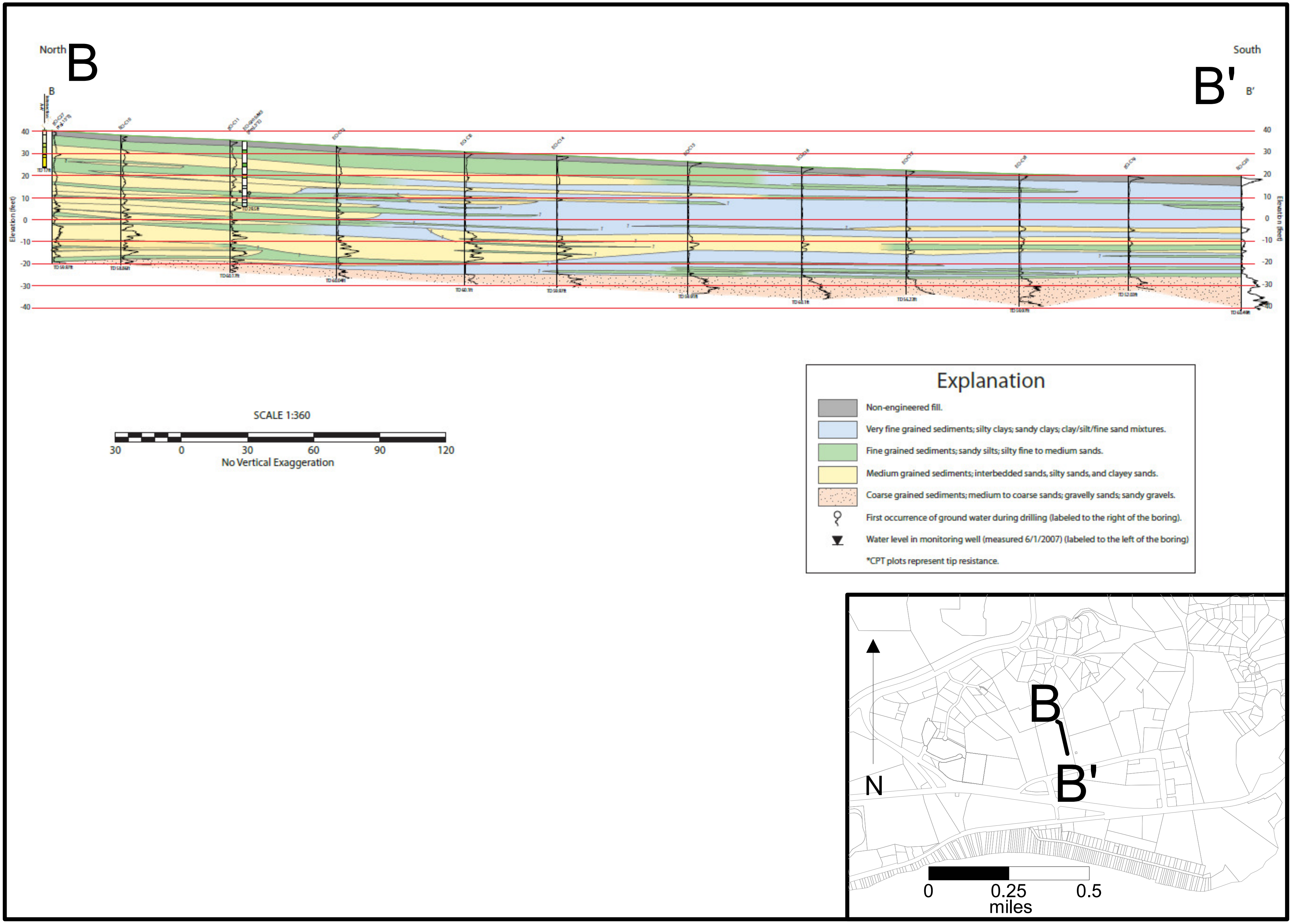


Figure 2.4. Geologic cross-section modified from ECI, 2009.

McDonald Morrissey ASSOCIATES, Inc.

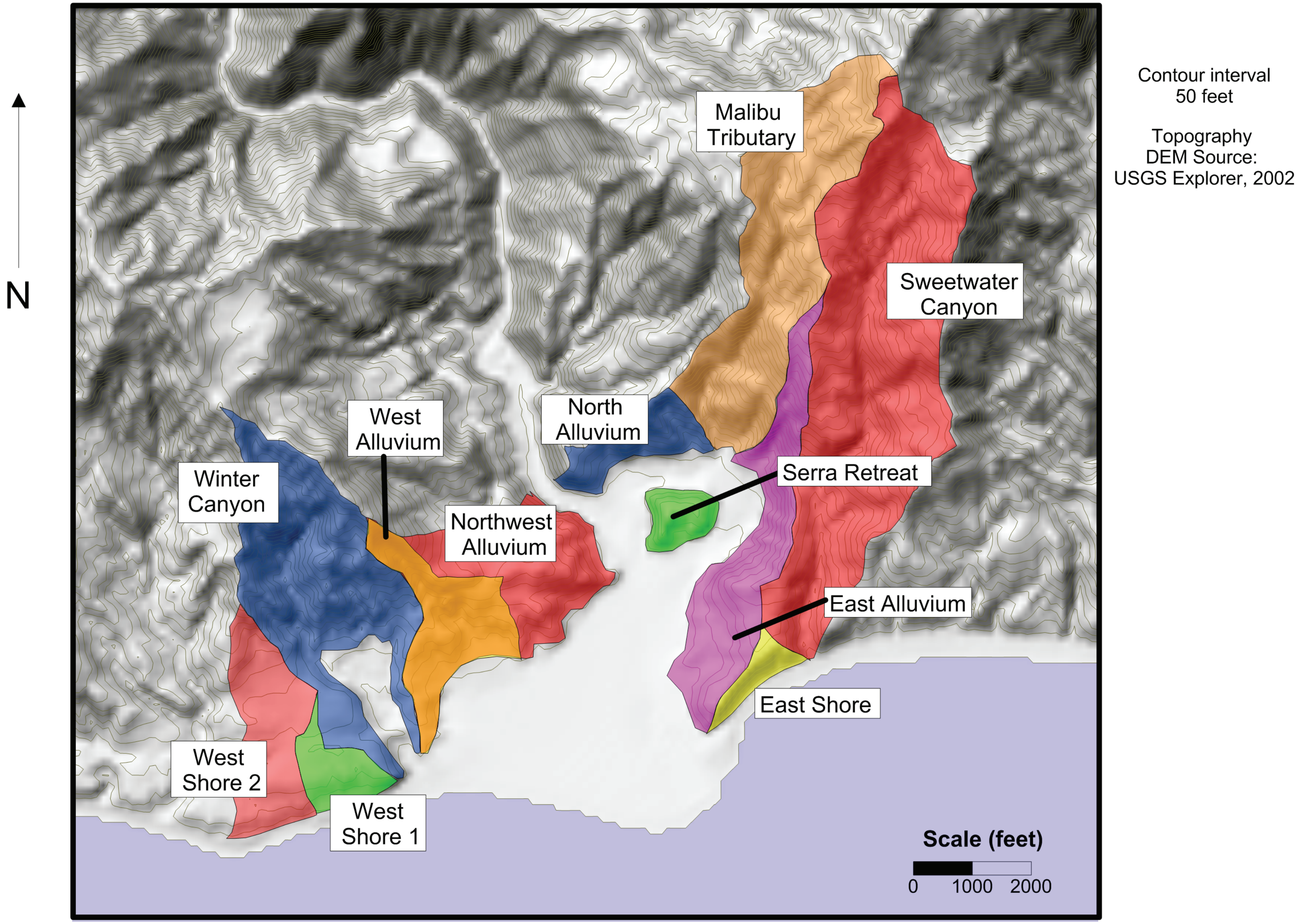


Figure 2.5. Map showing upland areas contributing recharge to Malibu alluvium.

McDonald Morrissey ASSOCIATES, Inc.

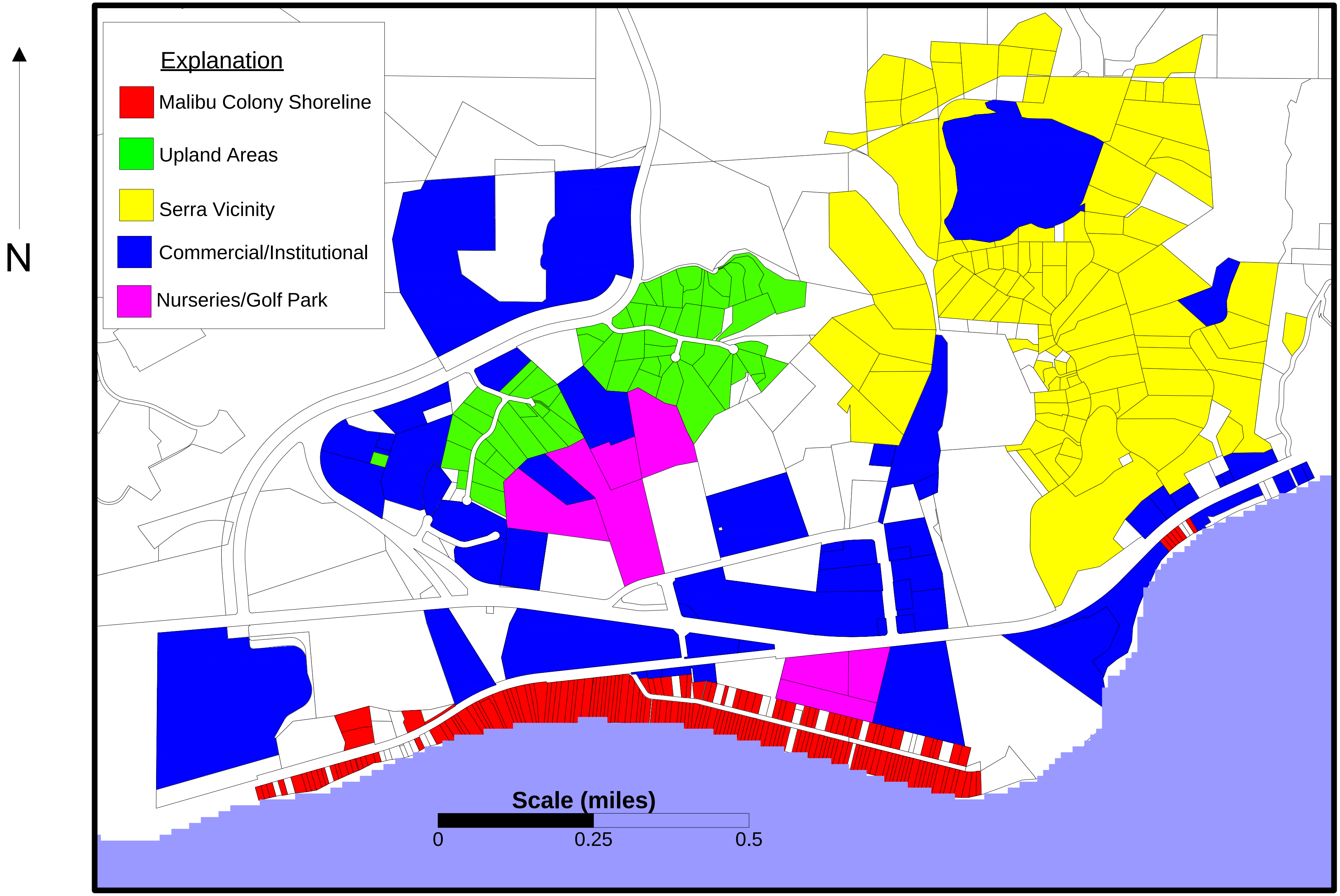


Figure 2.6. Map showing locations of areas used for water use summary.

McDonald Morrissey ASSOCIATES, Inc.

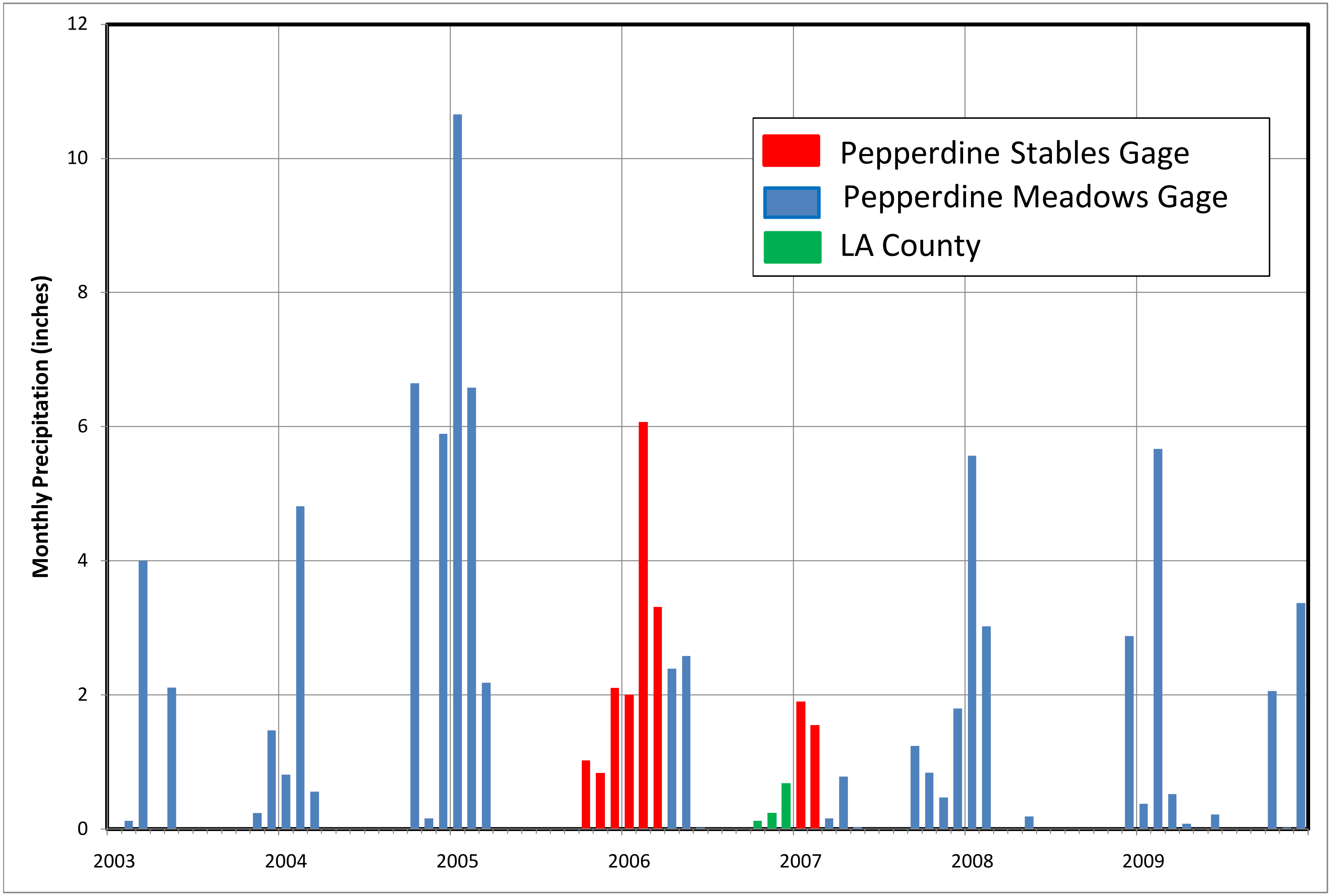


Figure 2.7. Graph showing monthly precipitation for the period 2003 to 2009.

McDonald Morrissey ASSOCIATES, Inc.

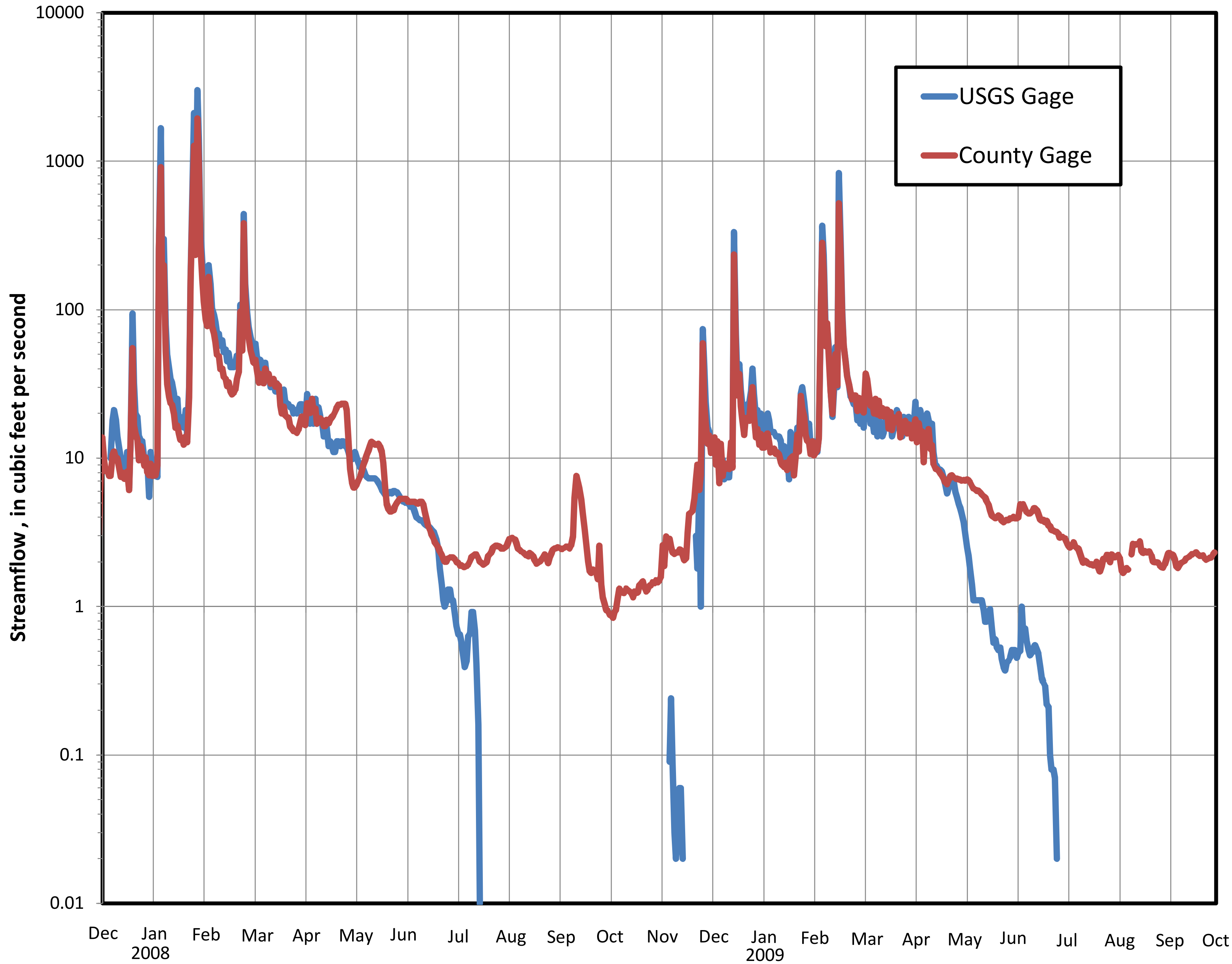


Figure 2.8. Graph showing daily stream flow in Malibu Creek at the U.S. Geological Survey and County gages.

McDonald Morrissey ASSOCIATES, Inc.

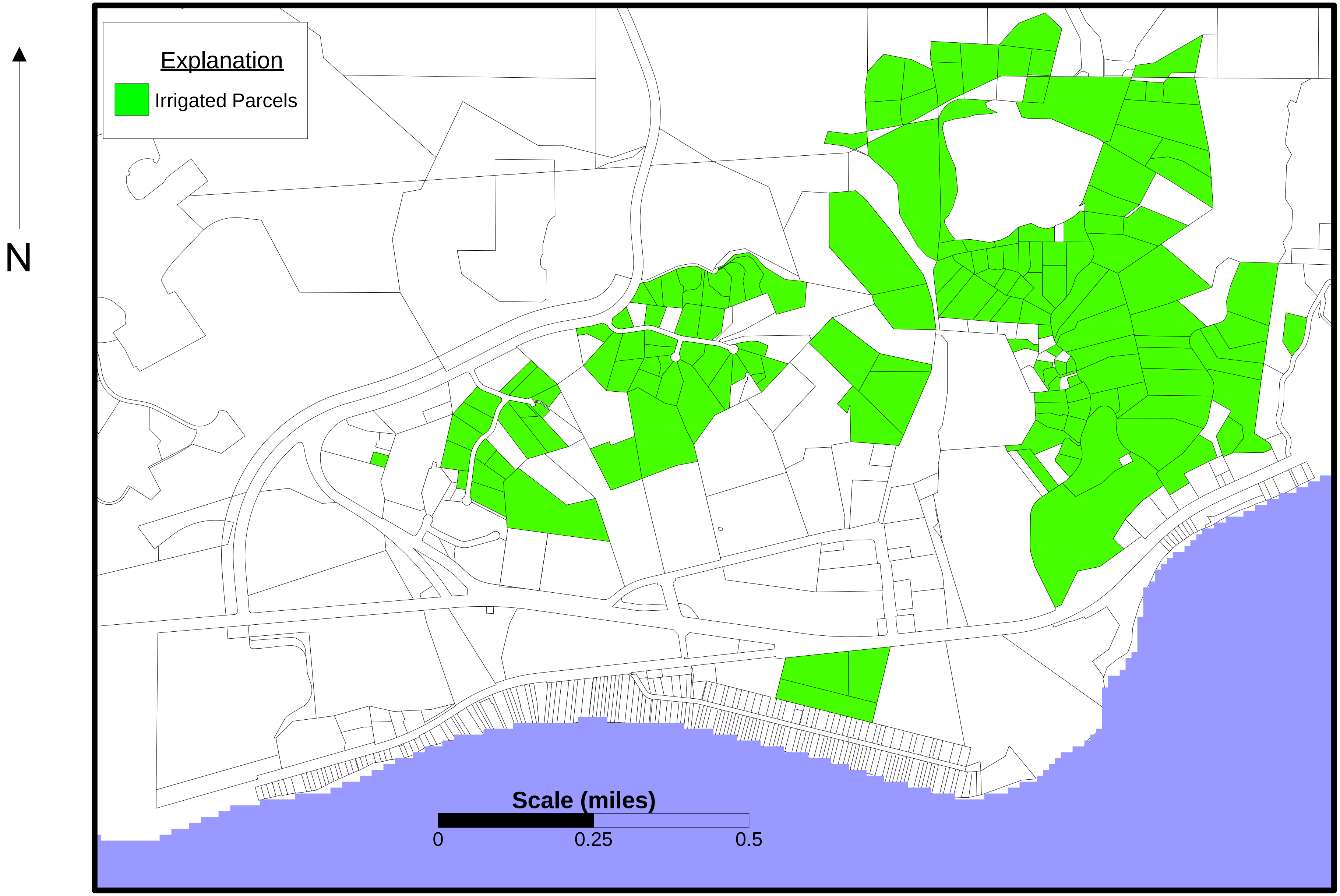


Figure 2.9. Map showing locations of where groundwater recharge from irrigation return occurs.

McDonald Morrissey ASSOCIATES, Inc.

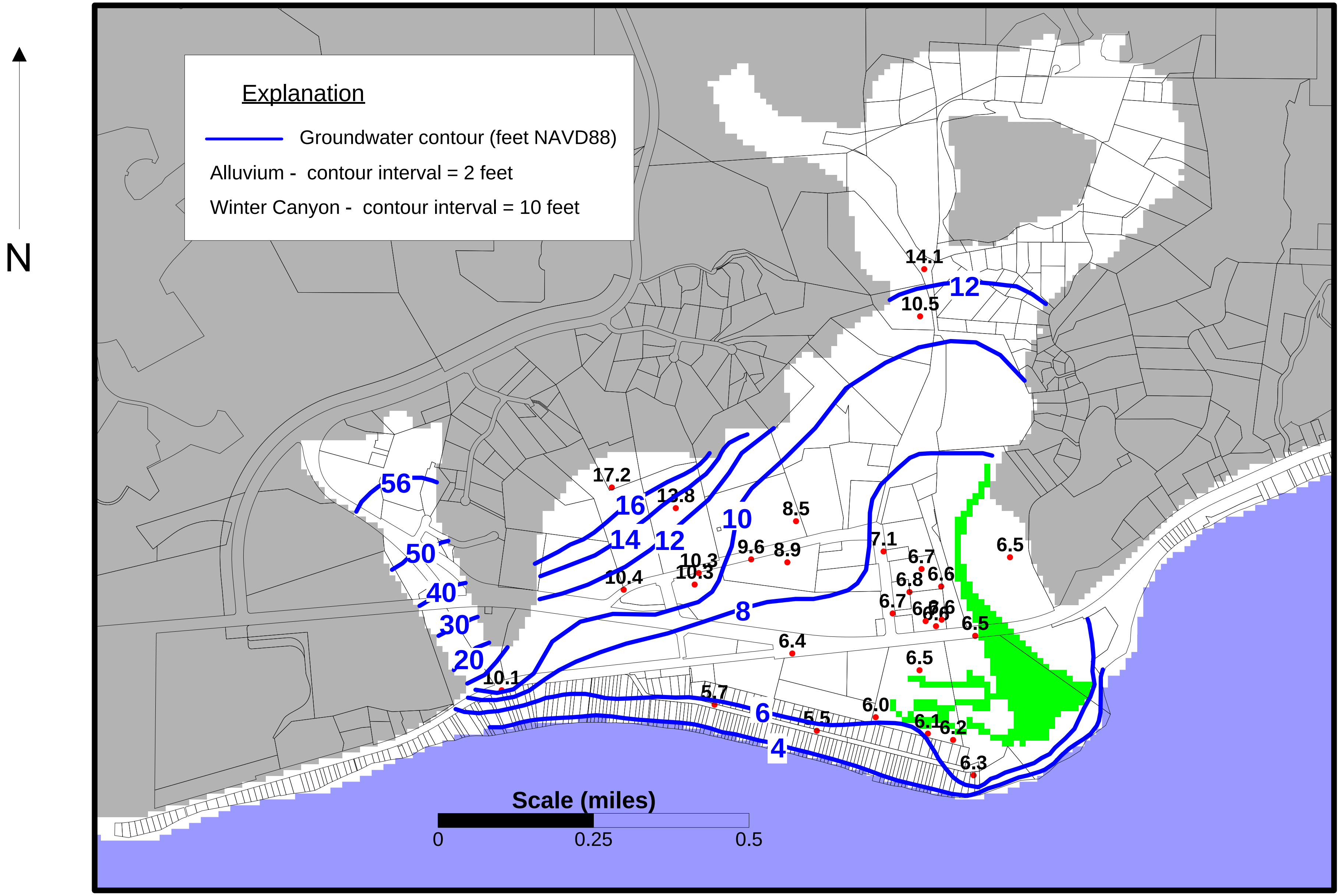


Figure 2.10. Map showing water levels measured on September 25, 2003 during flooded lagoon condition (modified from Stone Environmental, Inc., 2004).

McDonald Morrissey ASSOCIATES, Inc.

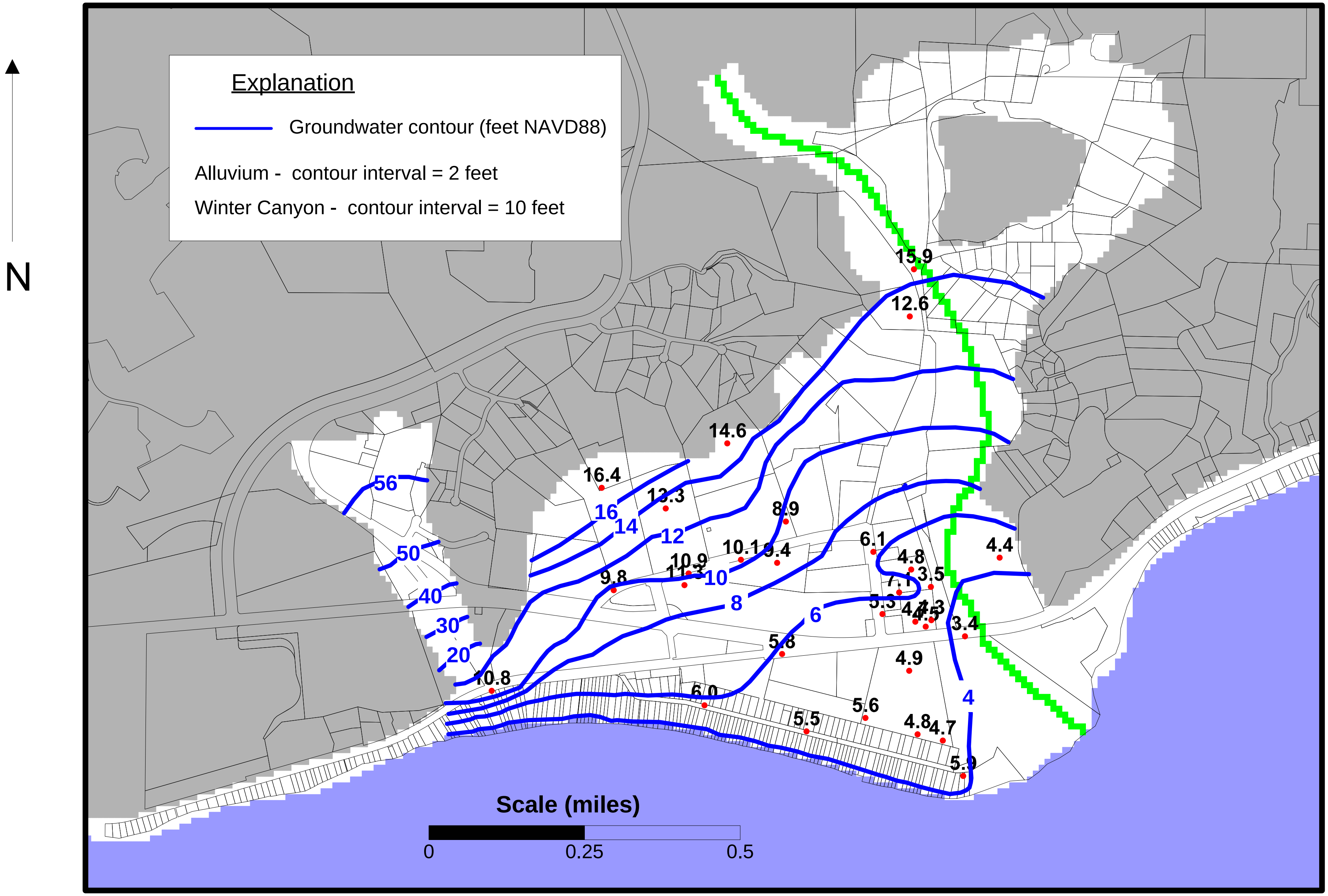


Figure 2.11. Map showing water levels measured on March 9, 2004 during breached lagoon condition (modified from Stone Environmental, Inc. 2004).

McDonald Morrissey ASSOCIATES, Inc.

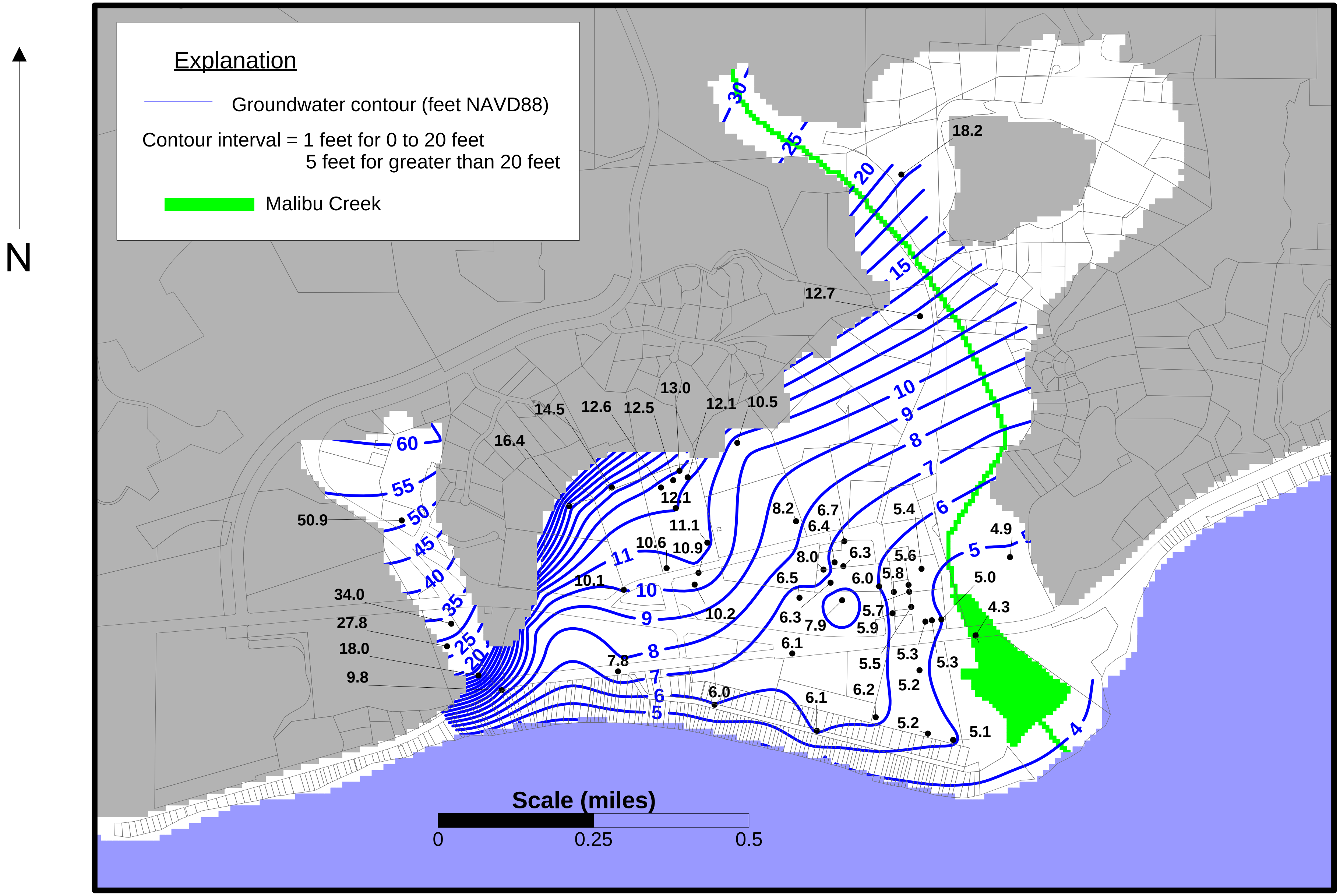
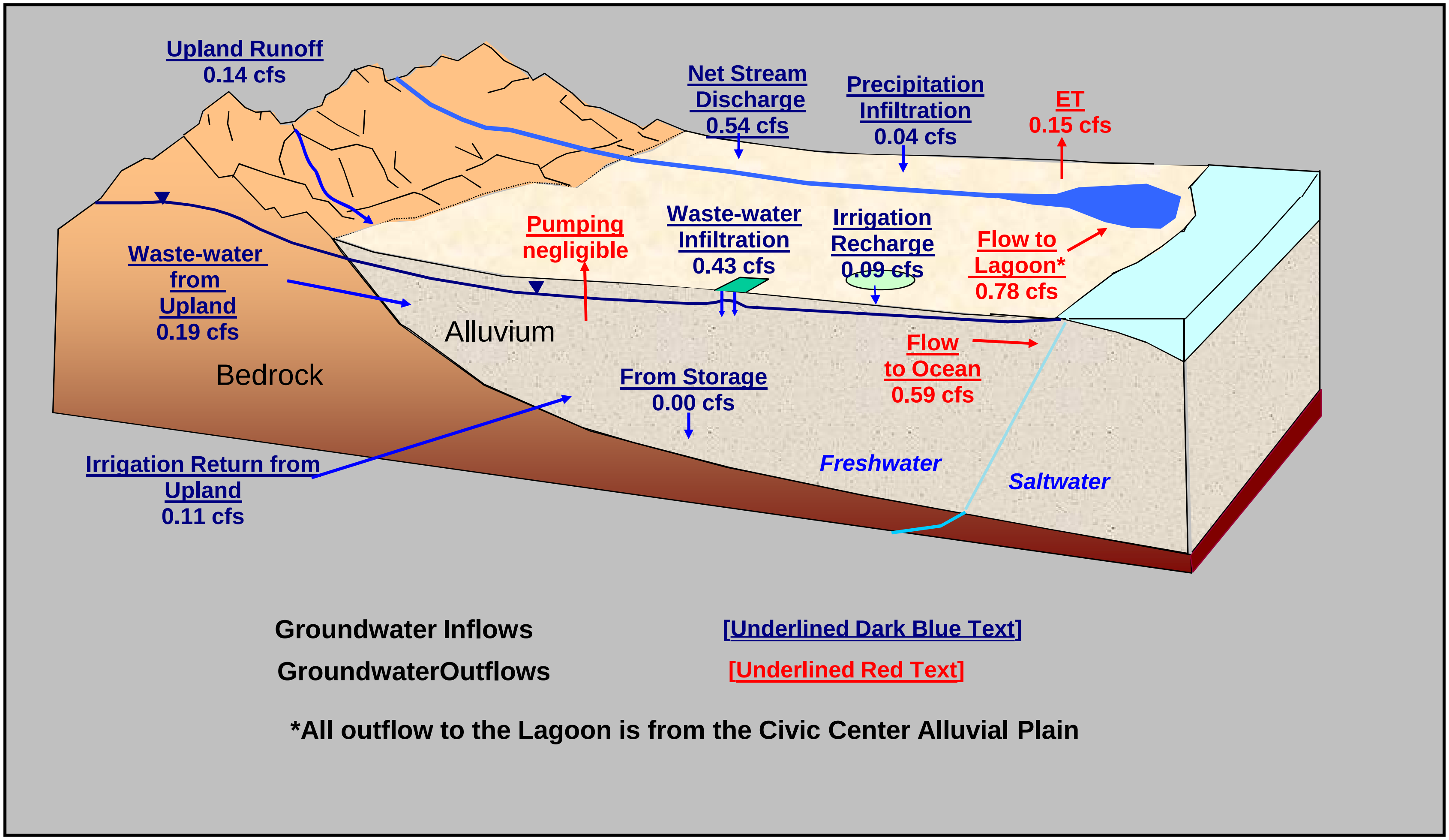


Figure 2.12. Map showing water levels measured on December 8, 2009 during breached lagoon condition.

McDonald Morrissey ASSOCIATES, Inc.



Source: Malibu16_PEST

Figure 2.13. Generalized block diagram summarizing model estimated average annual groundwater budget for the Malibu alluvium and Winter Canyon.

McDonald Morrissey ASSOCIATES, Inc.

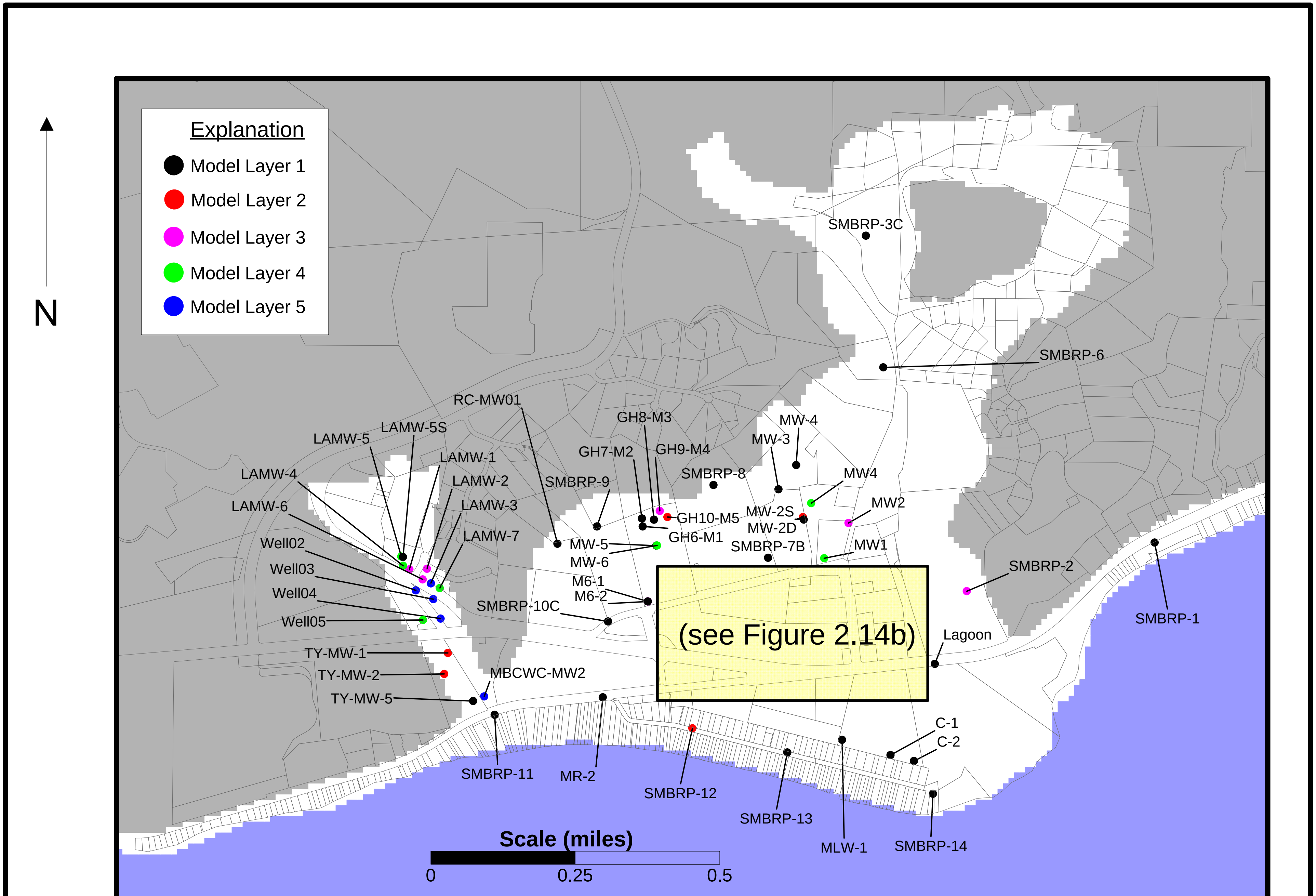


Figure 2.14a. Map showing location of where groundwater data were used for this study.

McDonald Morrissey ASSOCIATES, Inc.

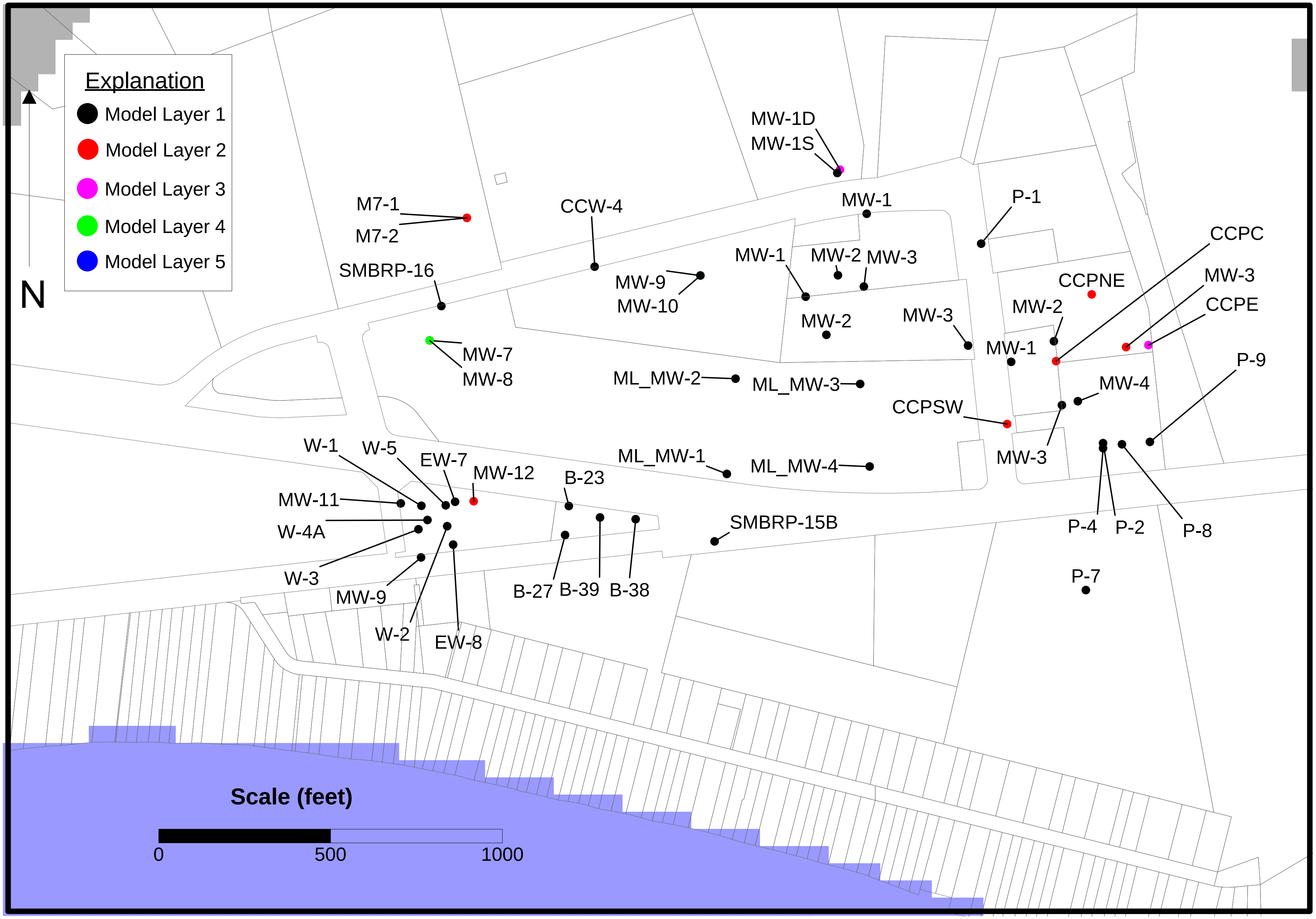


Figure 2.14b. Map showing location where groundwater level data were used for this study.

McDonald Morrissey ASSOCIATES, Inc.

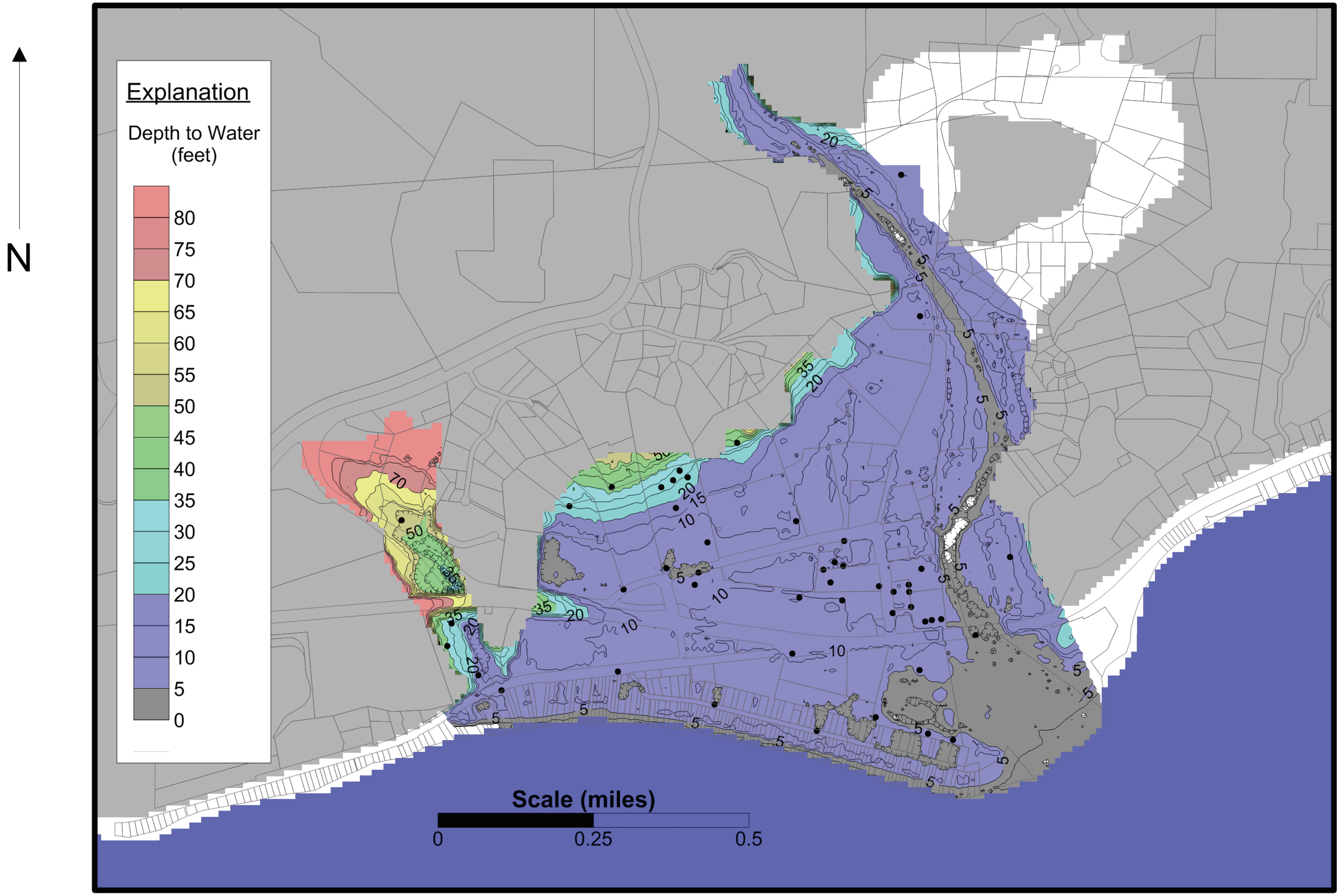
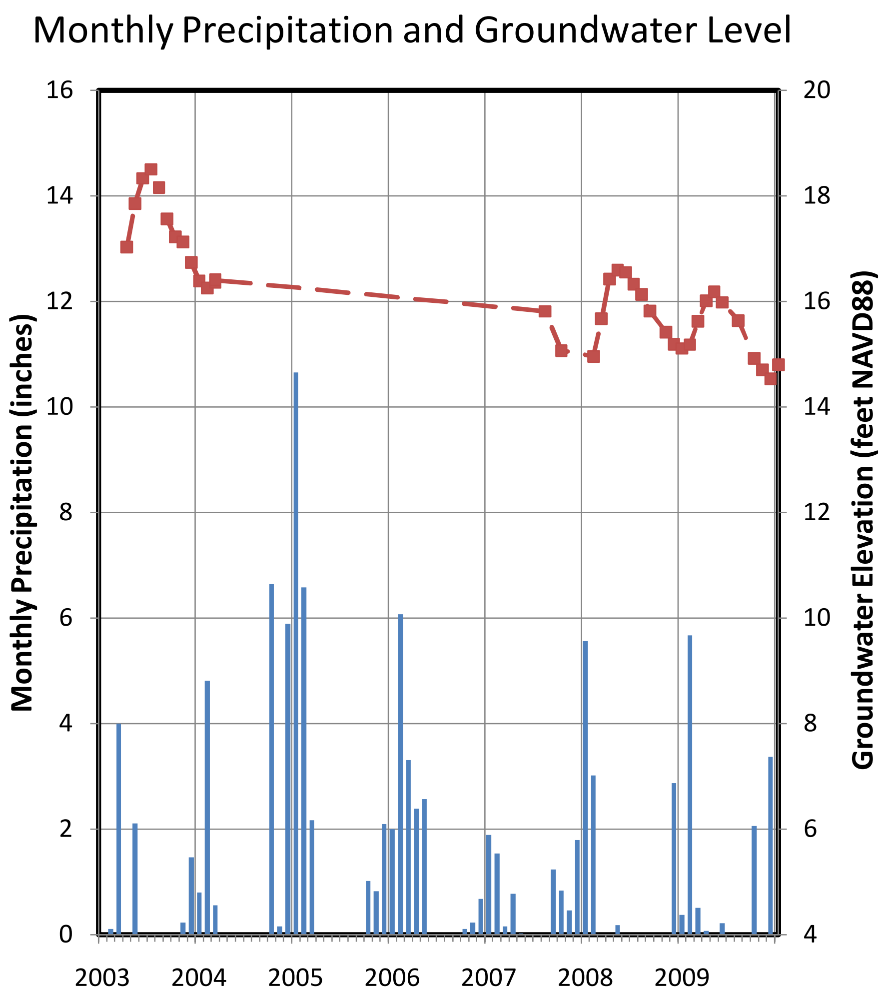


Figure 2.15. Map showing distance from land surface to groundwater on December 8, 2009.

McDonald Morrissey ASSOCIATES, Inc.



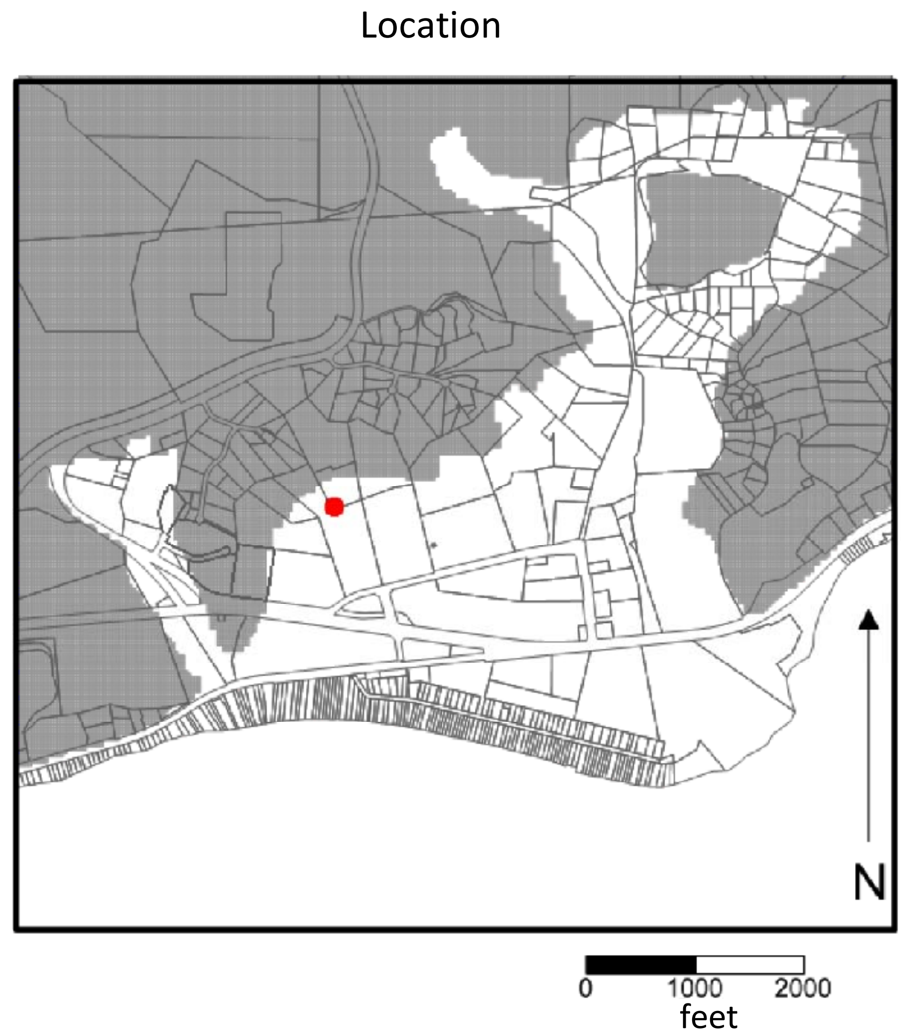
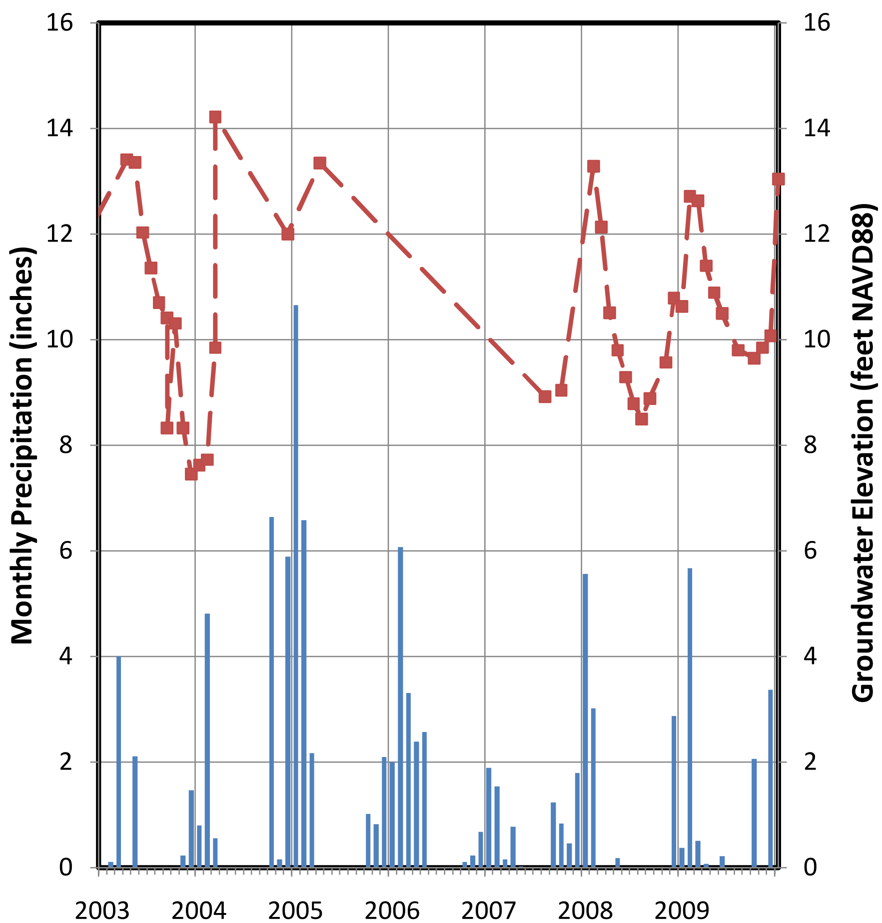


Figure 2.16a. Hydrograph showing groundwater levels at SMBRP-9, west side of the alluvium and precipitation during the period 2003-2009.

McDonald Morrissey ASSOCIATES, Inc.

Monthly Precipitation and Groundwater Level

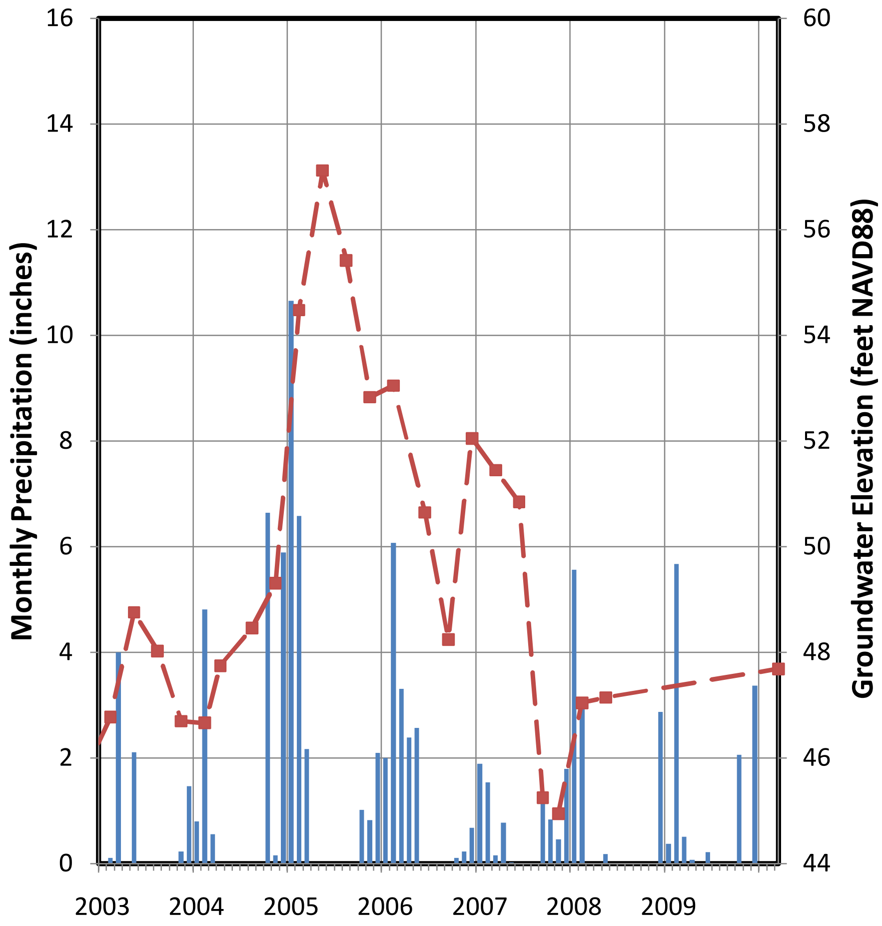


Location

Figure 2.16b. Hydrograph showing groundwater levels at SMBRP-10C west side of the alluvium and precipitation during the period 2003-2009.

McDonald Morrissey ASSOCIATES, Inc.

Monthly Precipitation and Groundwater Level



Location

Figure 2.16c. Hydrograph showing groundwater levels at Well-03 in Winter Canyon and precipitation during the period 2003-2009.

McDonald Morrissey ASSOCIATES, Inc.

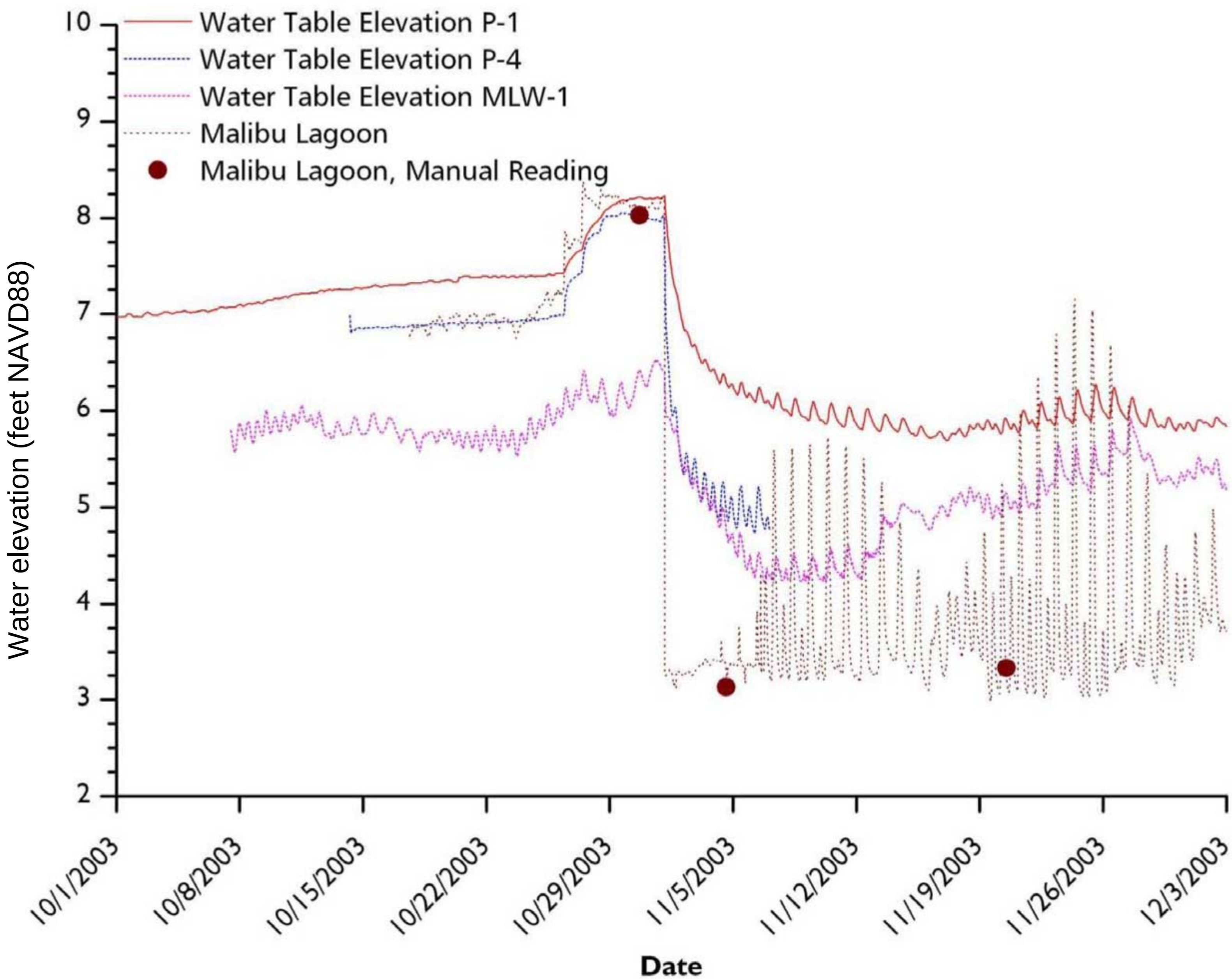


Figure 2.17. Graph showing lagoon stage and the groundwater levels in wells, P-9, and P-4 during a period when the lagoon transitions from a flooded to breached condition (modified from Stone Environmental, Inc., 2004).

McDonald Morrissey ASSOCIATES, Inc.

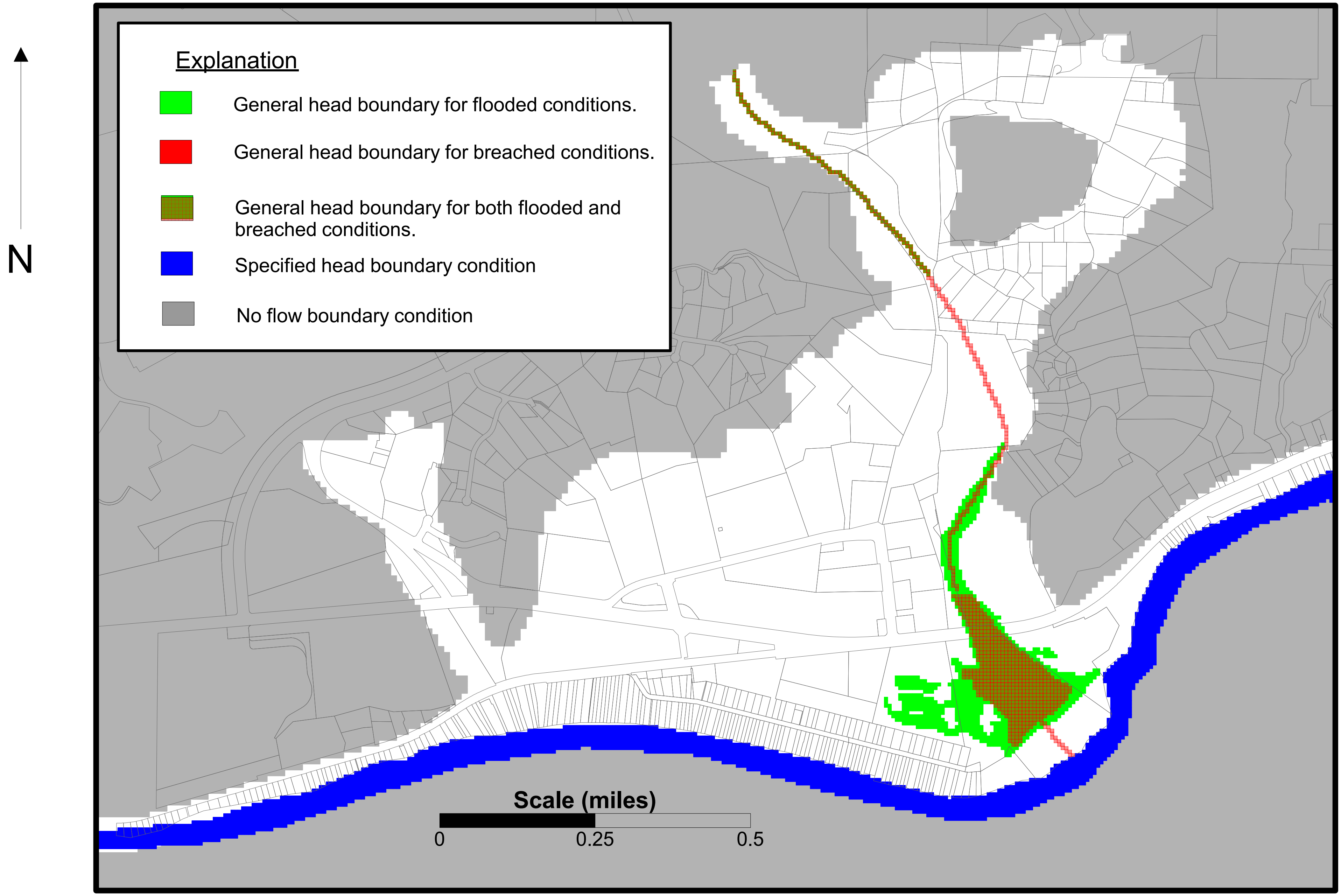
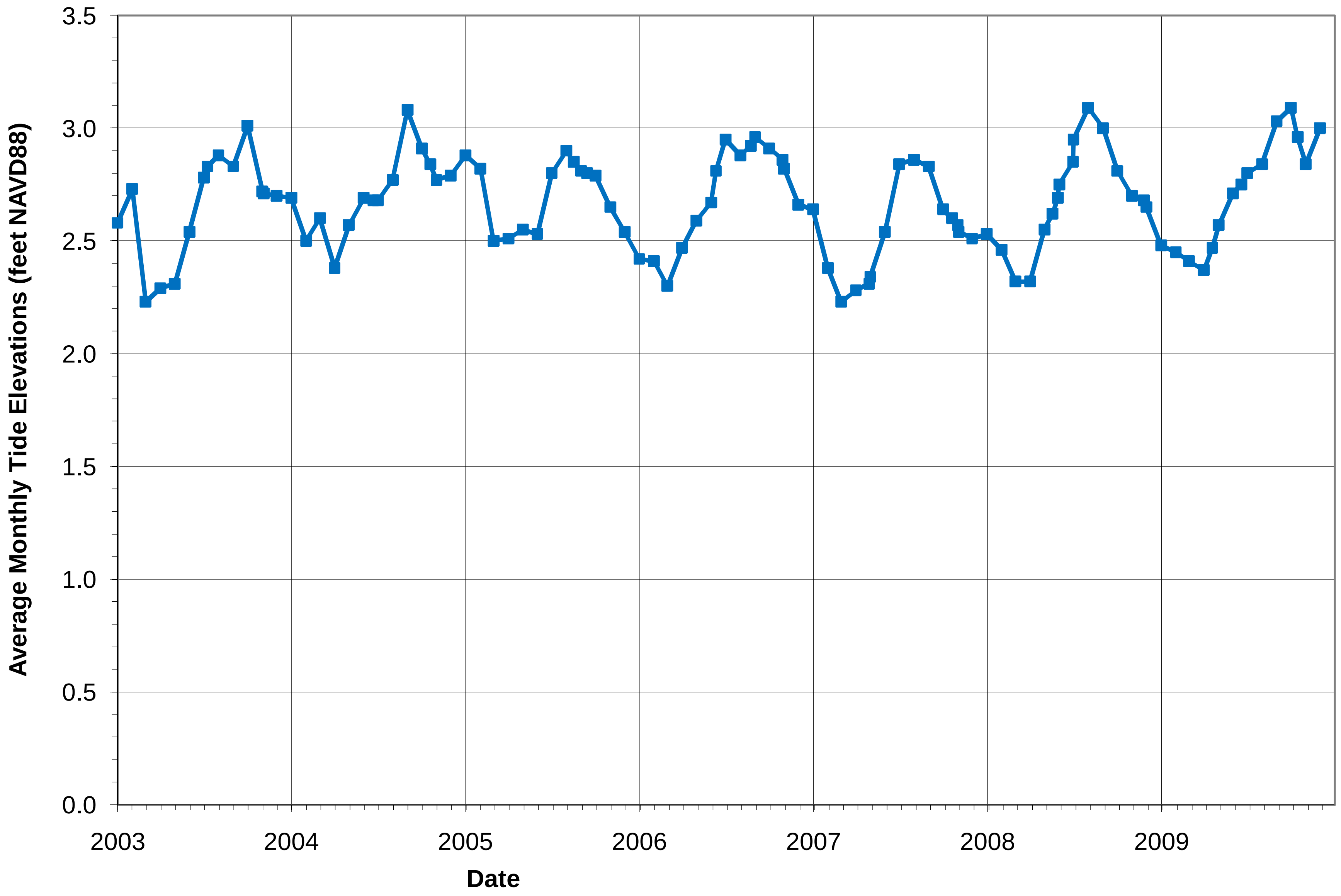


Figure 3.1. Map showing numerical model extent and boundary conditions for model layer 1.

McDonald Morrissey ASSOCIATES, Inc.



Source: http:\\tidesandcurrents.noaa.gov

Figure 3.2. Graph showing average monthly tide elevation at Santa Monica, CA - Station ID 9410840.

McDonald Morrissey ASSOCIATES, Inc.

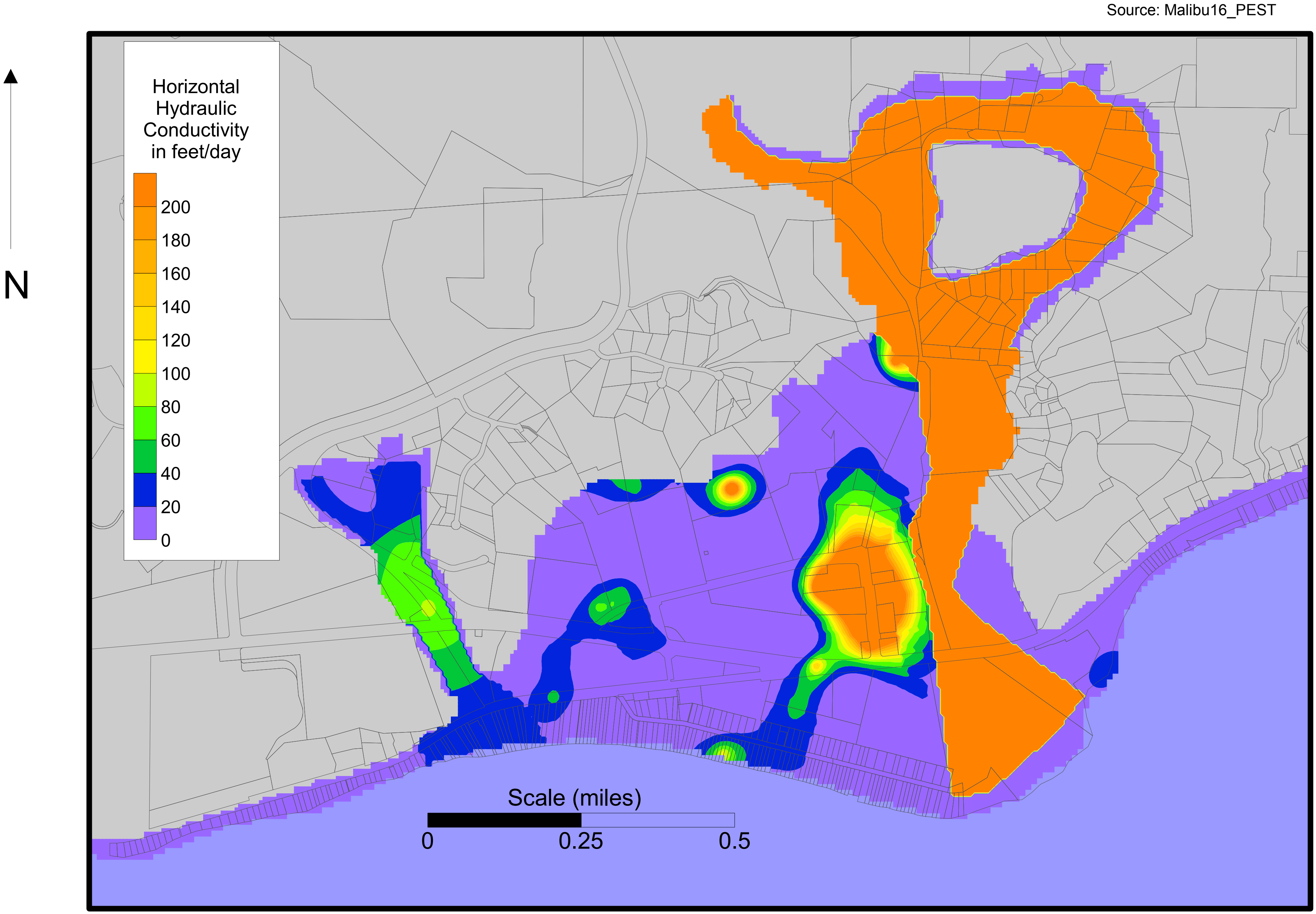


Figure 3.3. Map showing hydraulic conductivity values for model layer 1, in feet/day.

McDonald Morrissey ASSOCIATES, Inc.

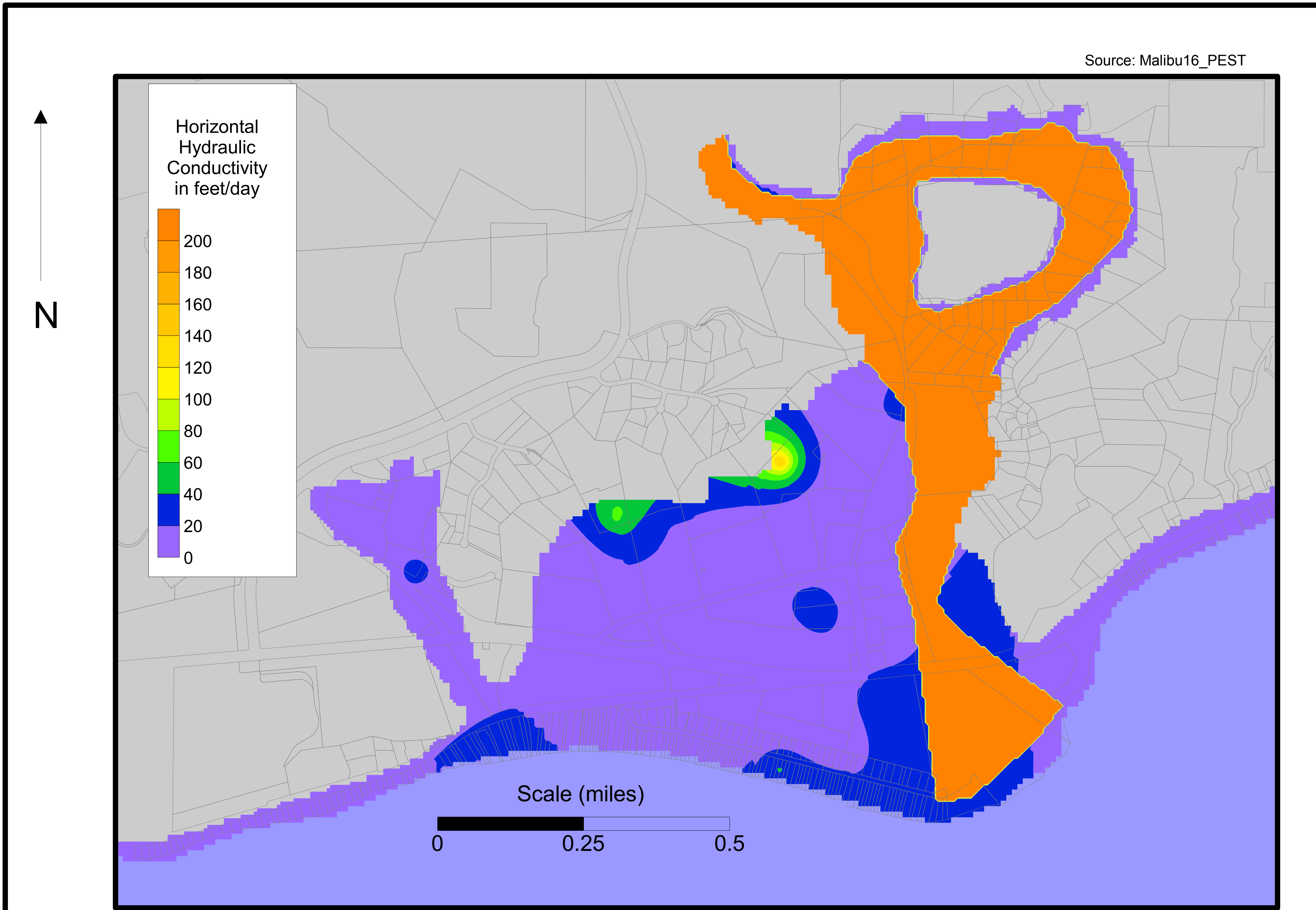


Figure 3.4. Map showing hydraulic conductivity values for model layer 2, in feet/day.

McDonald Morrissey ASSOCIATES, Inc.

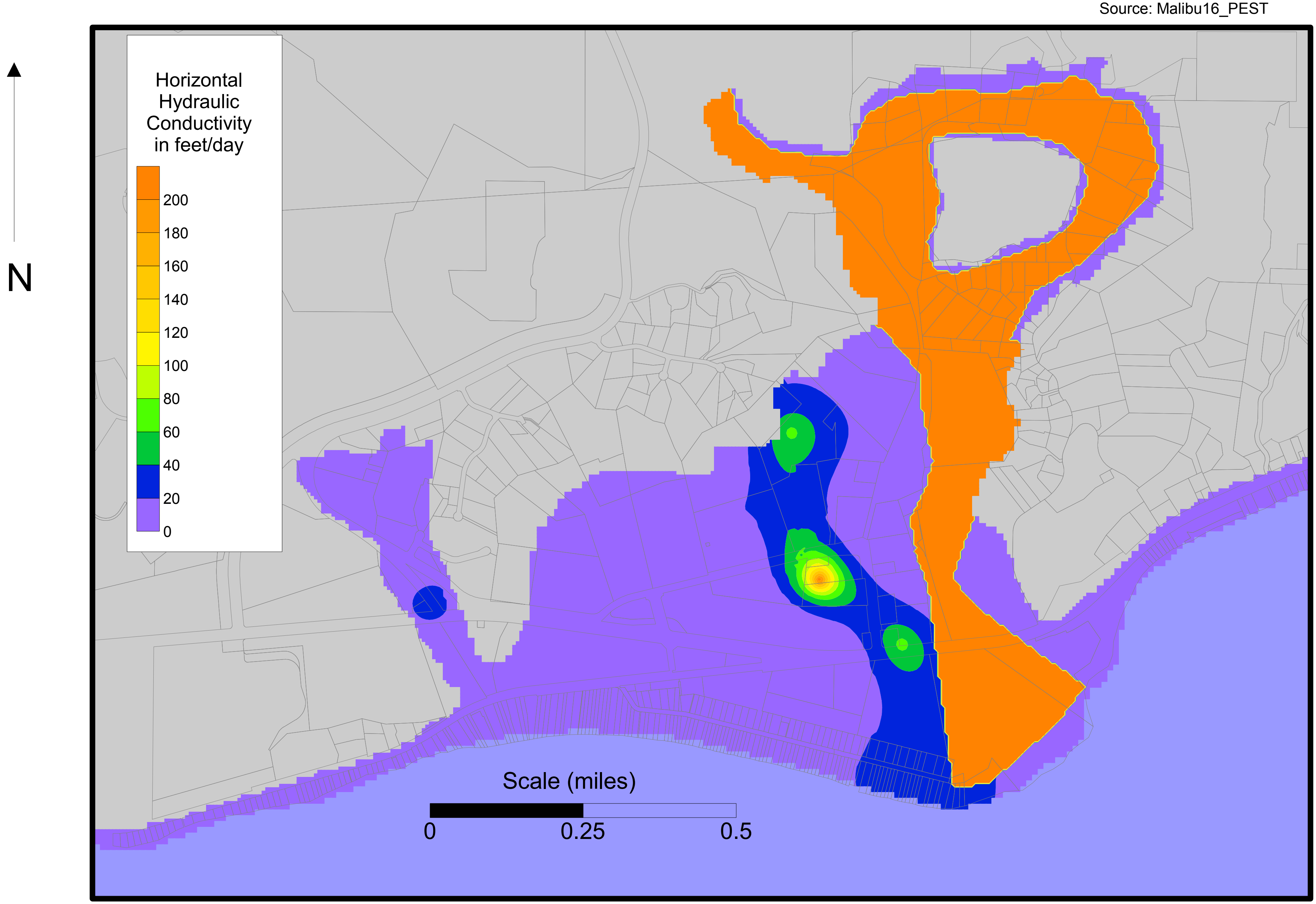


Figure 3.5. Map showing hydraulic conductivity values for model layer 3, in feet/day.

McDonald Morrissey ASSOCIATES, Inc.

Source: Malibu16_PEST

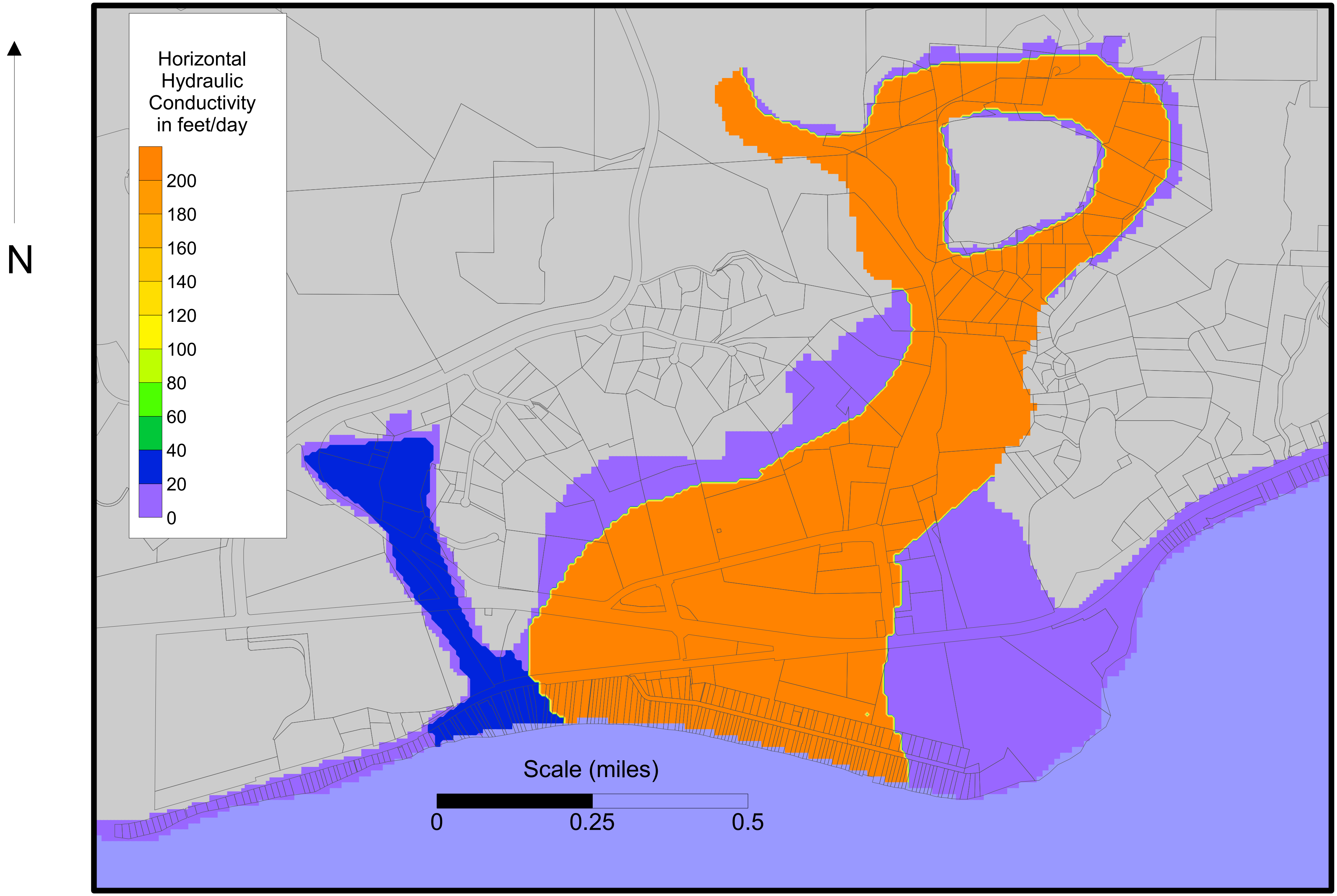


Figure 3.6. Map showing hydraulic conductivity values for model layer 4, in feet/day.

McDonald Morrissey ASSOCIATES, Inc.

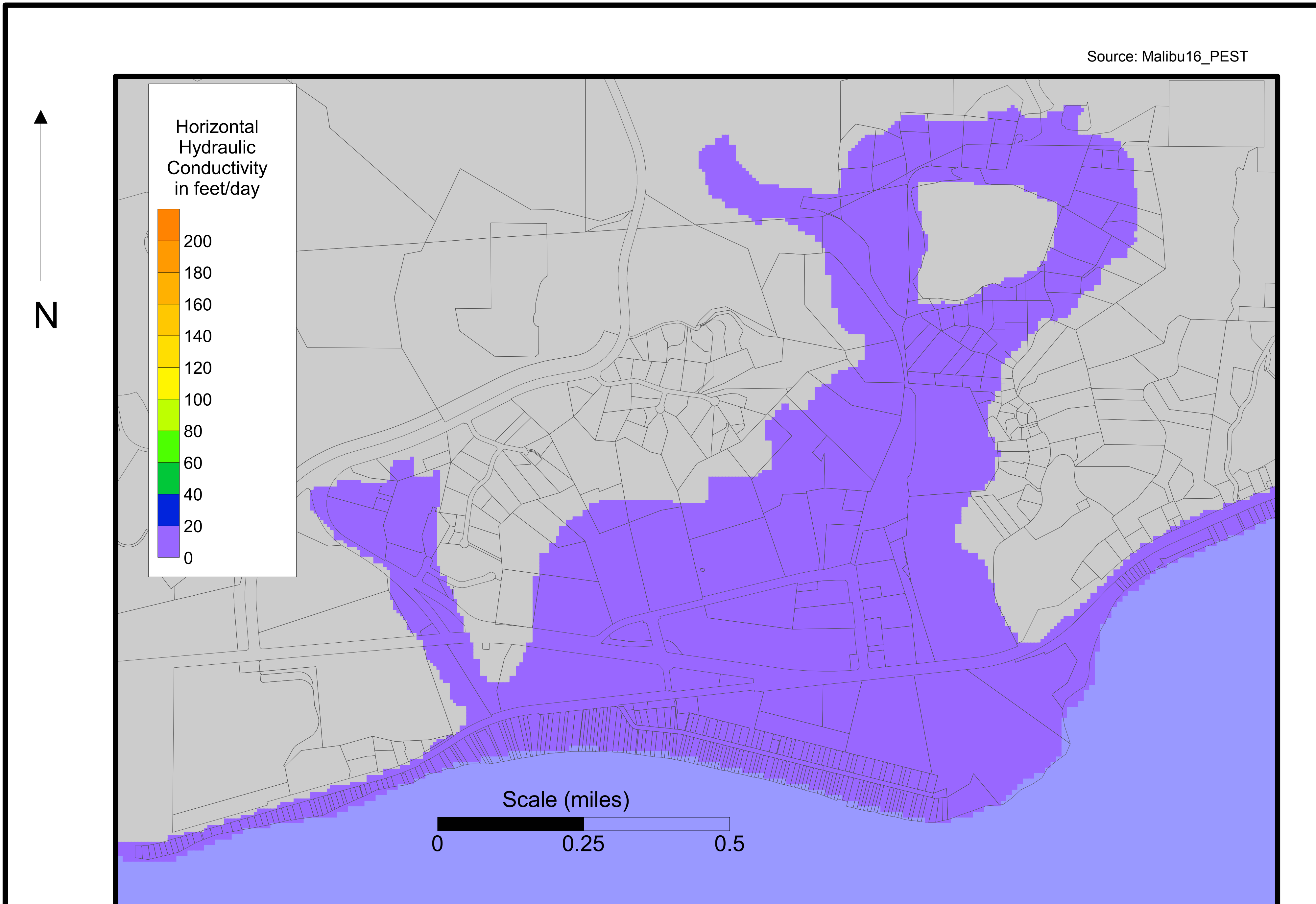


Figure 3.7. Map showing hydraulic conductivity values for model layer 5, in feet/day.

McDonald Morrissey ASSOCIATES, Inc.

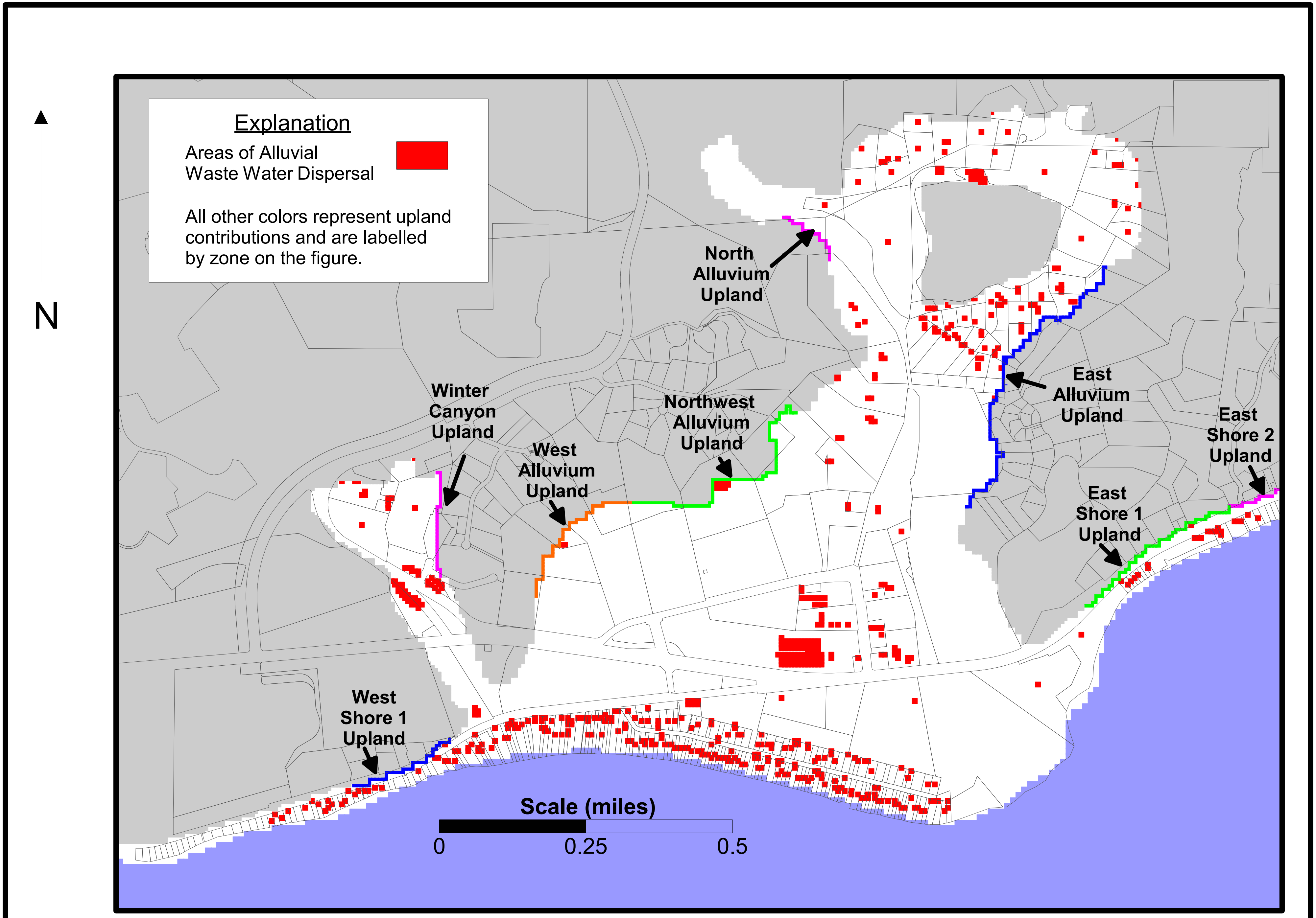


Figure 3.8. Map showing locations where subsurface waste water dispersal was simulated in the model using the WELL package in MODFLOW.

McDonald Morrissey ASSOCIATES, Inc.

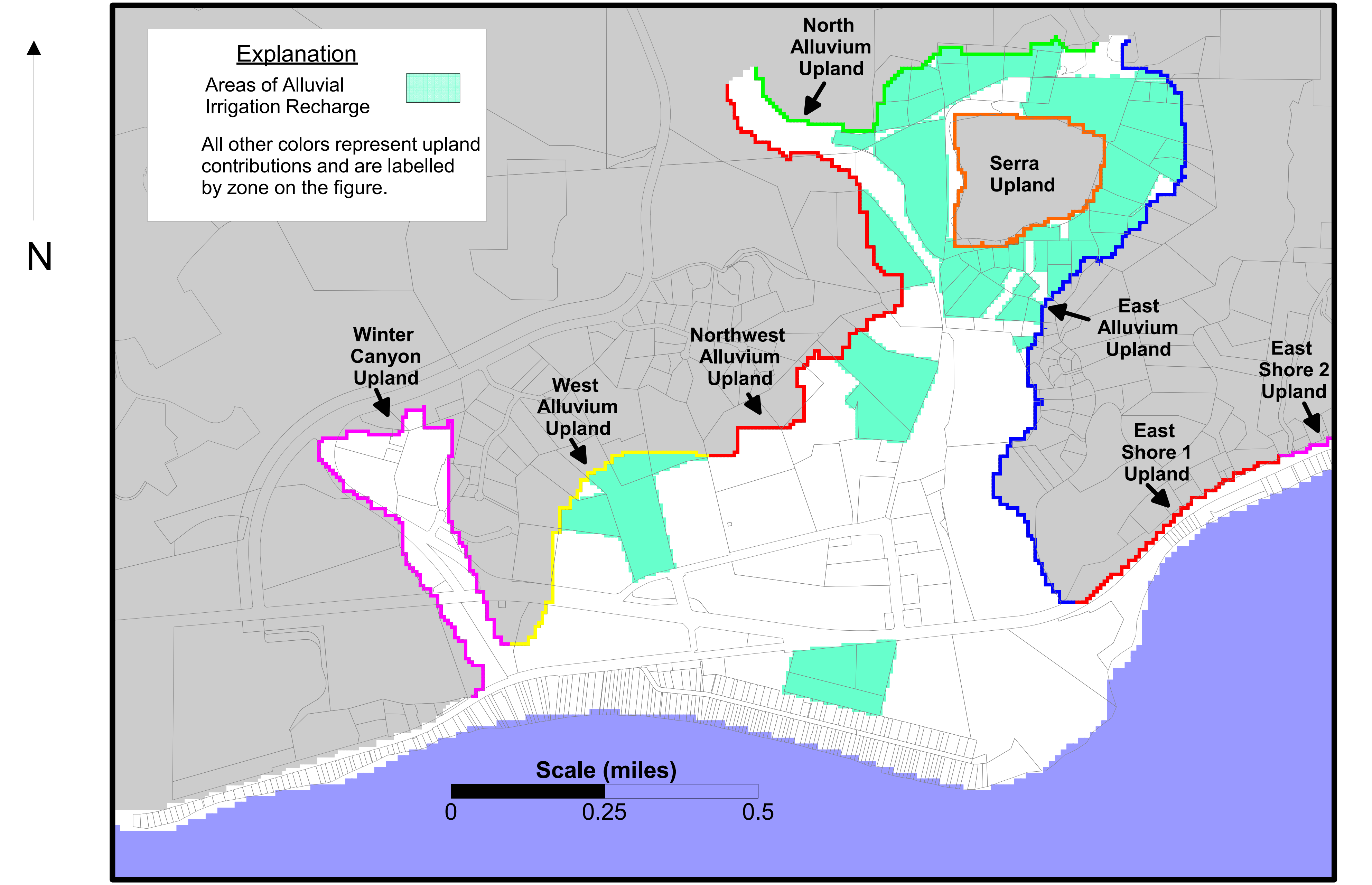


Figure 3.9. Map showing locations where recharge from excess irrigation was simulated in the model using the RIVER package in MODFLOW.

McDonald Morrissey ASSOCIATES, Inc.

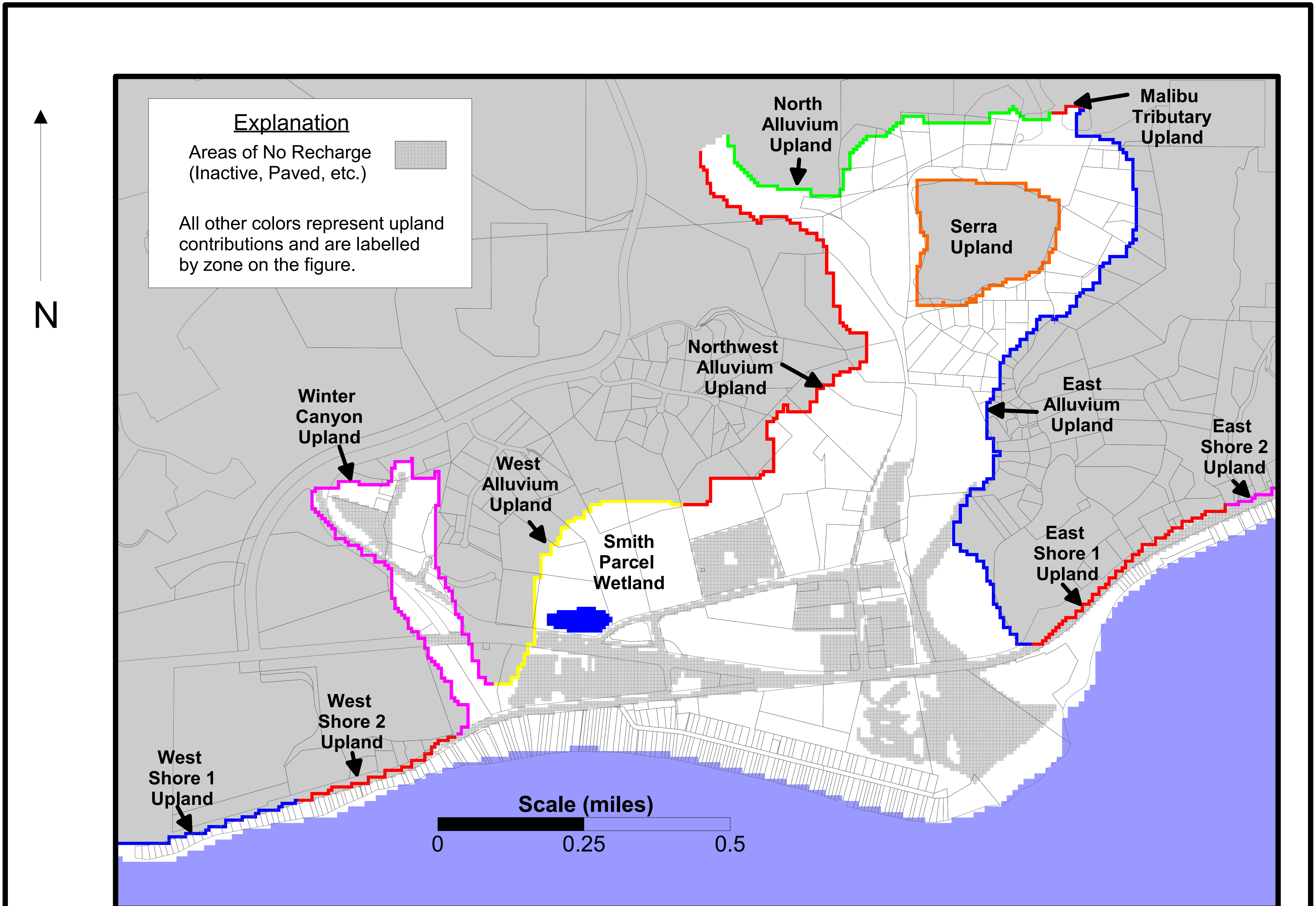


Figure 3.10. Map showing locations where recharge from infiltration of precipitation on the alluvial deposits and from runoff originating in upland areas was simulated in the model using the RECHARGE package in MODFLOW.

McDonald Morrissey Associates, Inc.

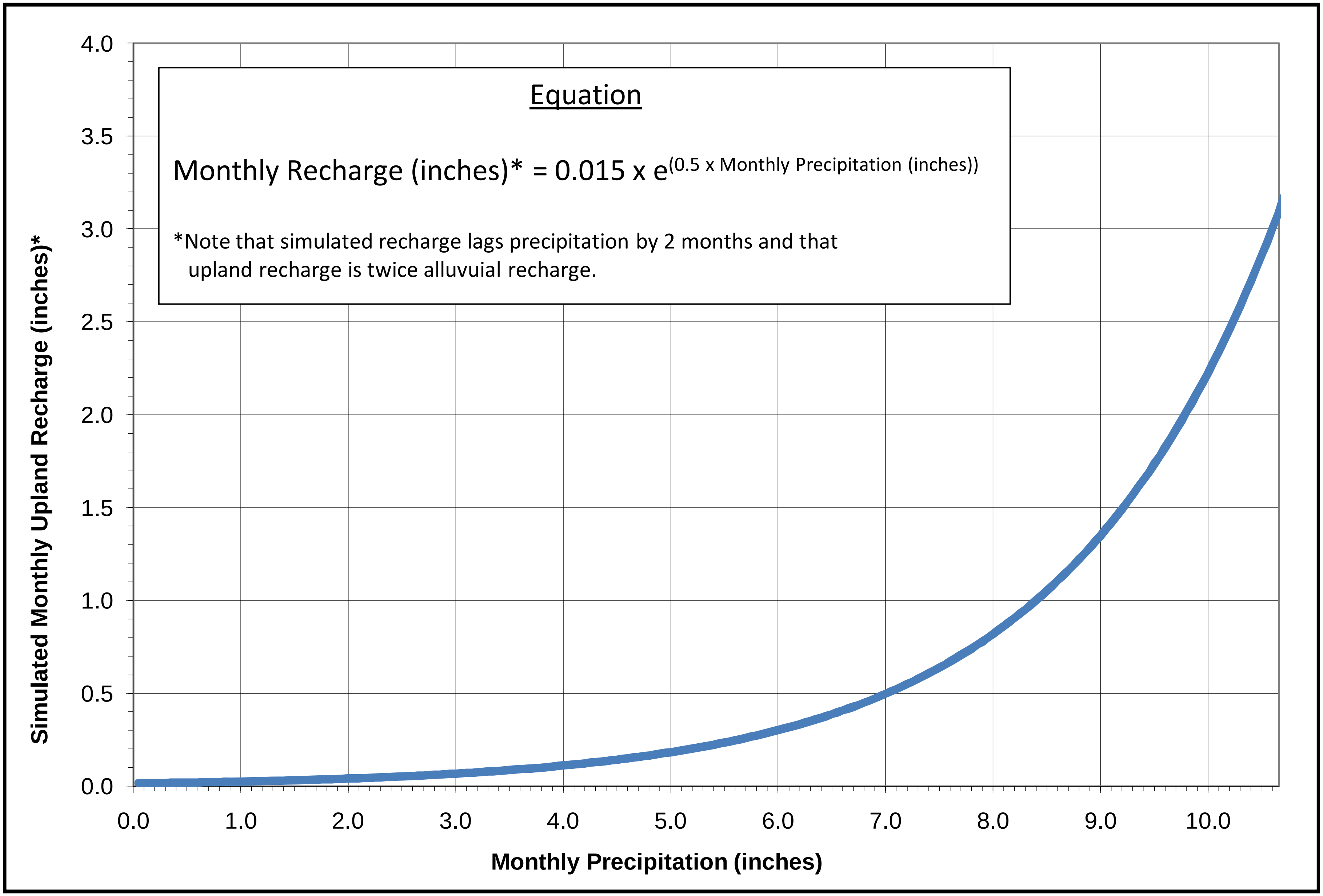


Figure 3.11. Graph showing simulated relationship between monthly precipitation and monthly recharge from infiltration of precipitation and upland runoff.

McDonald Morrissey ASSOCIATES, Inc.

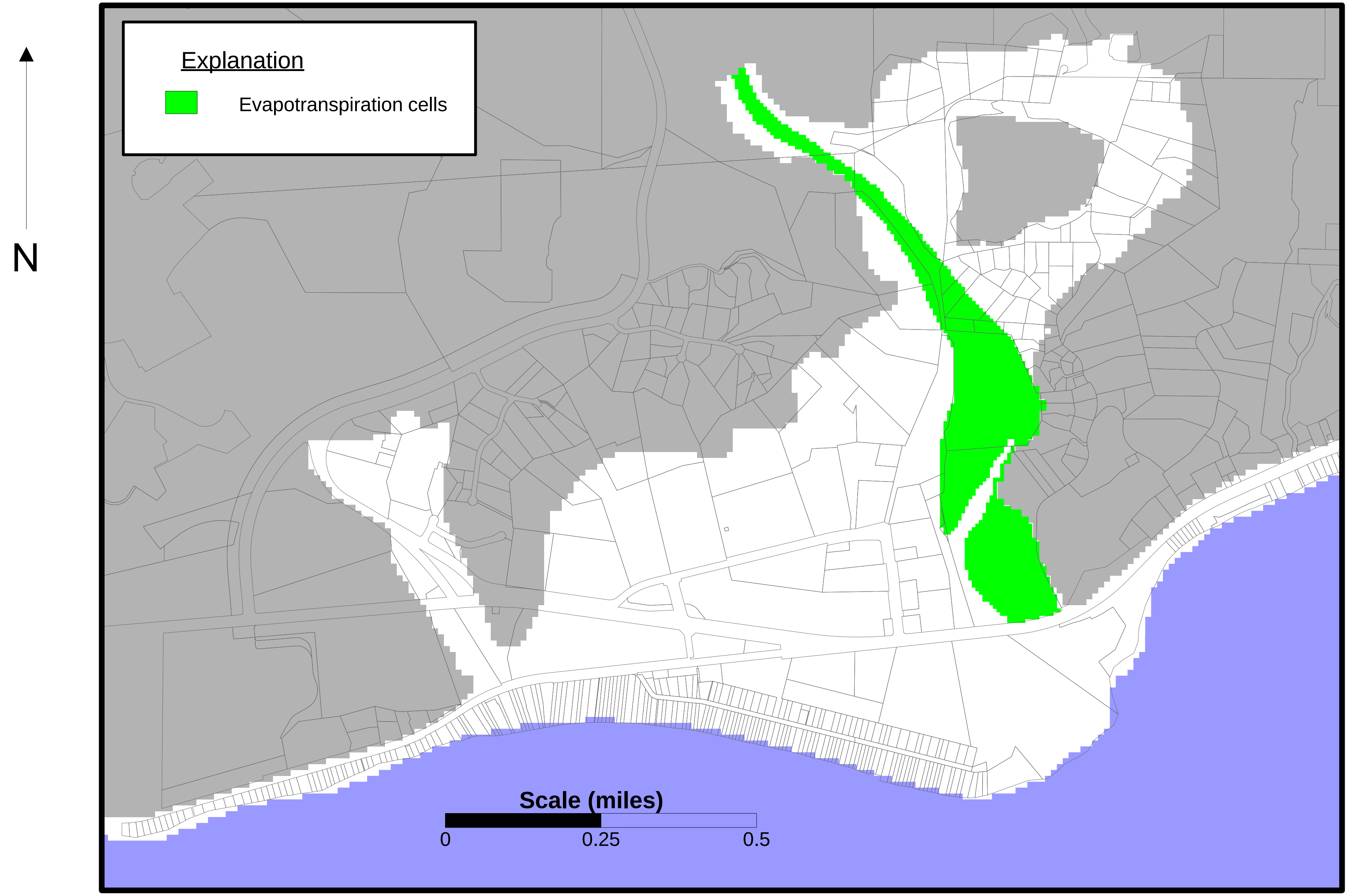
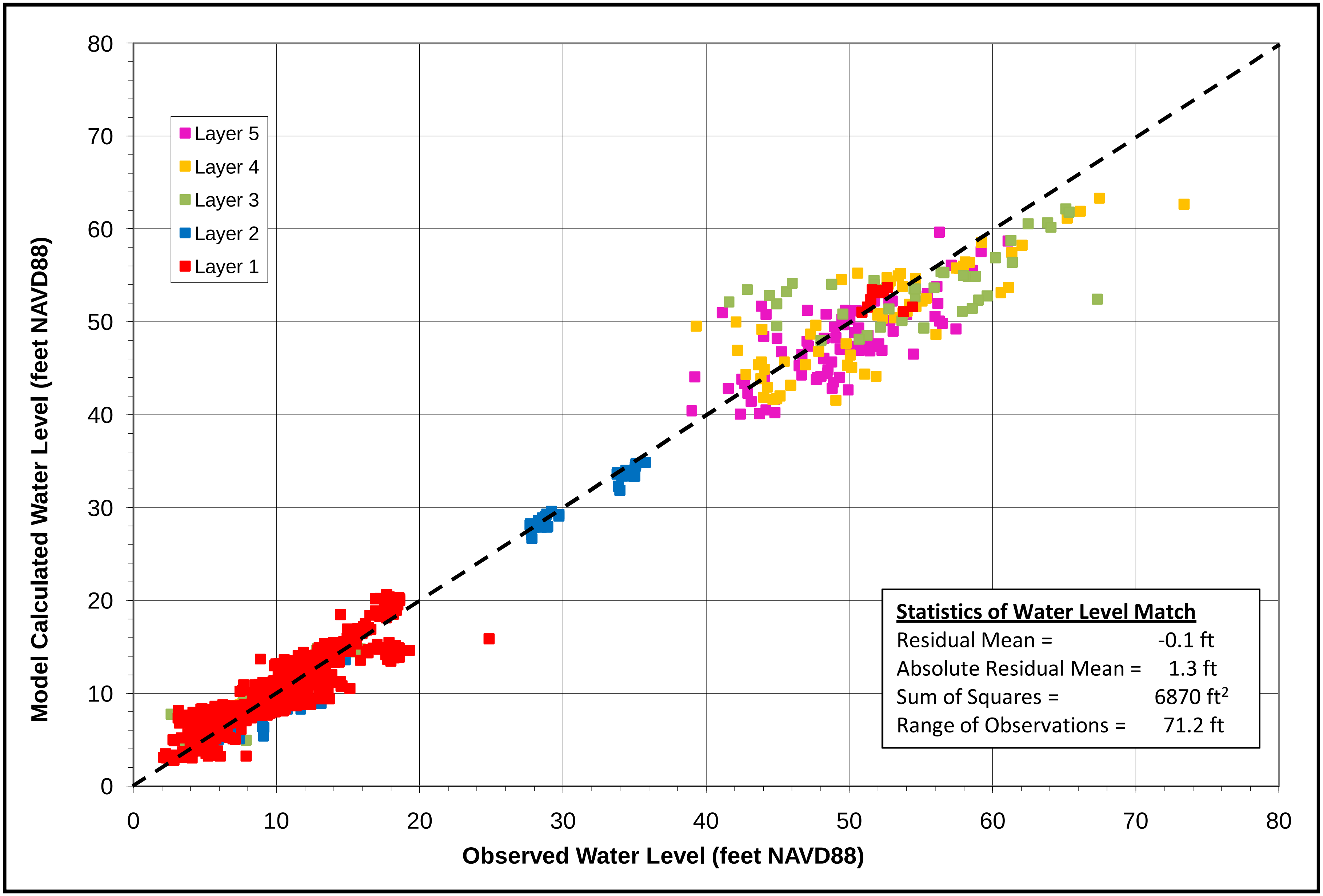


Figure 3.12. Map showing locations where groundwater evapotranspiration was simulated in the model with the ET package in MODFLOW.

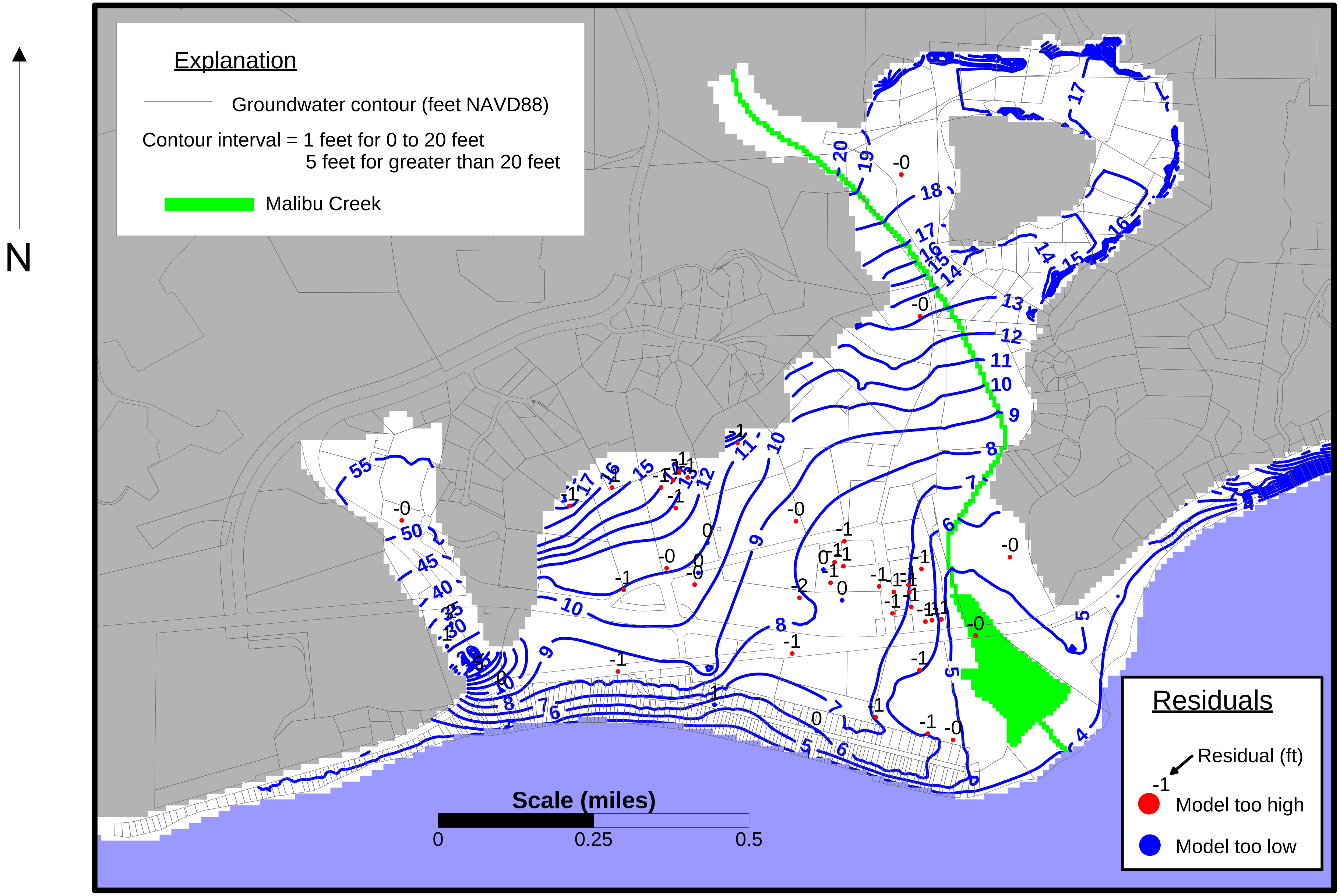
McDonald Morrissey ASSOCIATES, Inc.



Run: Malibu16_PEST

Figure 3.13. Scatter plot showing comparison of model calculated water levels with observed water levels.

McDonald Morrissey ASSOCIATES, Inc.



Source: Malibu16_PEST

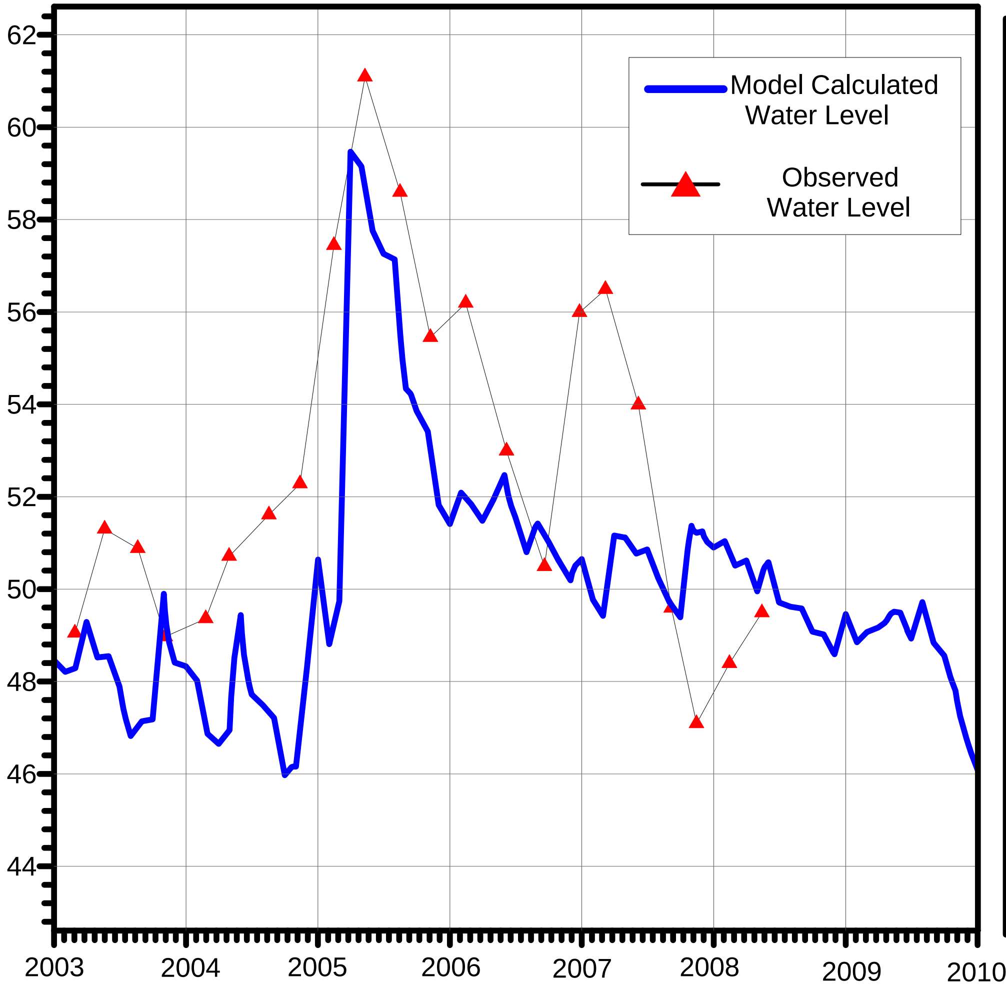
Figure 3.14. Map showing model calculated shallow groundwater levels and distribution of residuals in feet for the December 8, 2009 synoptic water level measurement.

McDonald Morrissey ASSOCIATES, Inc.

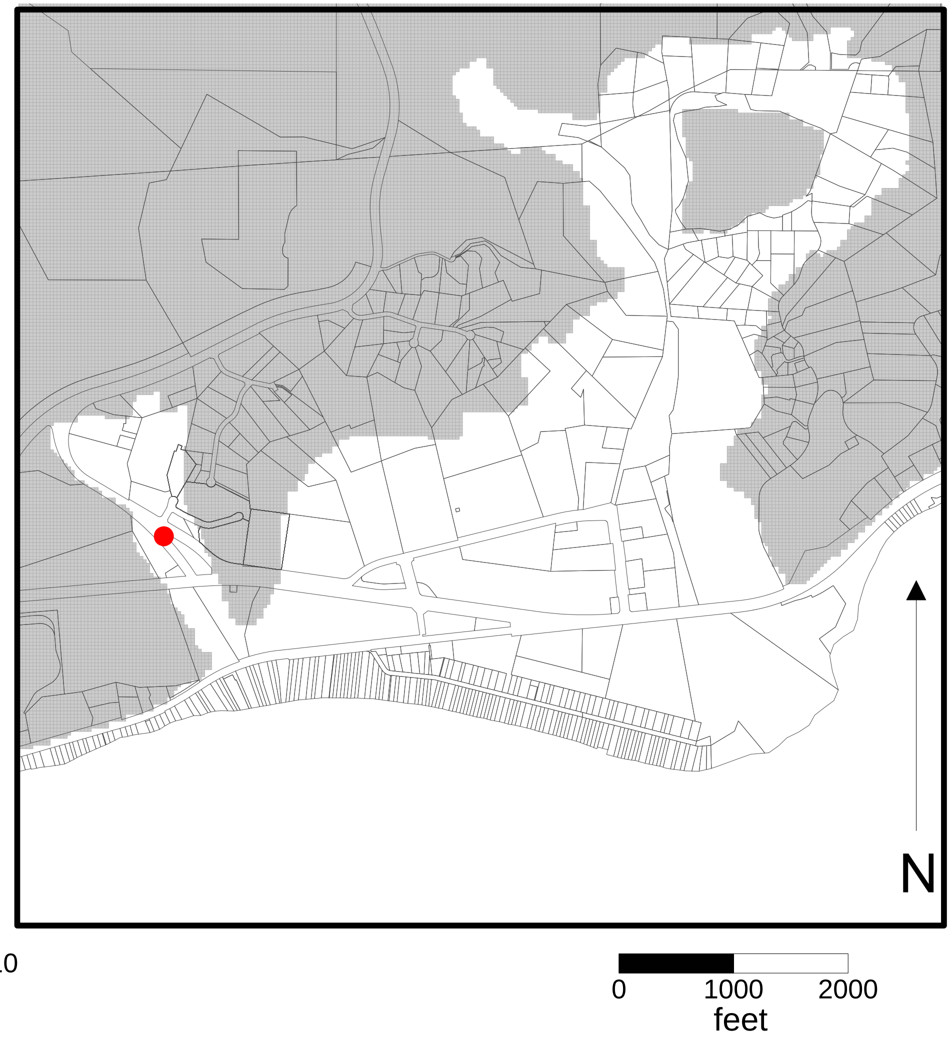
Malibu Hydrograph

Well02_4458028020

Water Level Elevation (feet NAVD88)



Model Layer **5** Screen Info: **Depth Only**



Number of Measurements	22
Range of Elevation	47.09 to 61.09
Average Elevation	52.61

Observed Data From: Malibu Wells gdb from A. Macrellis 5/10/2010
Modelled Data From: Malibu16_PEST 7/10/2010

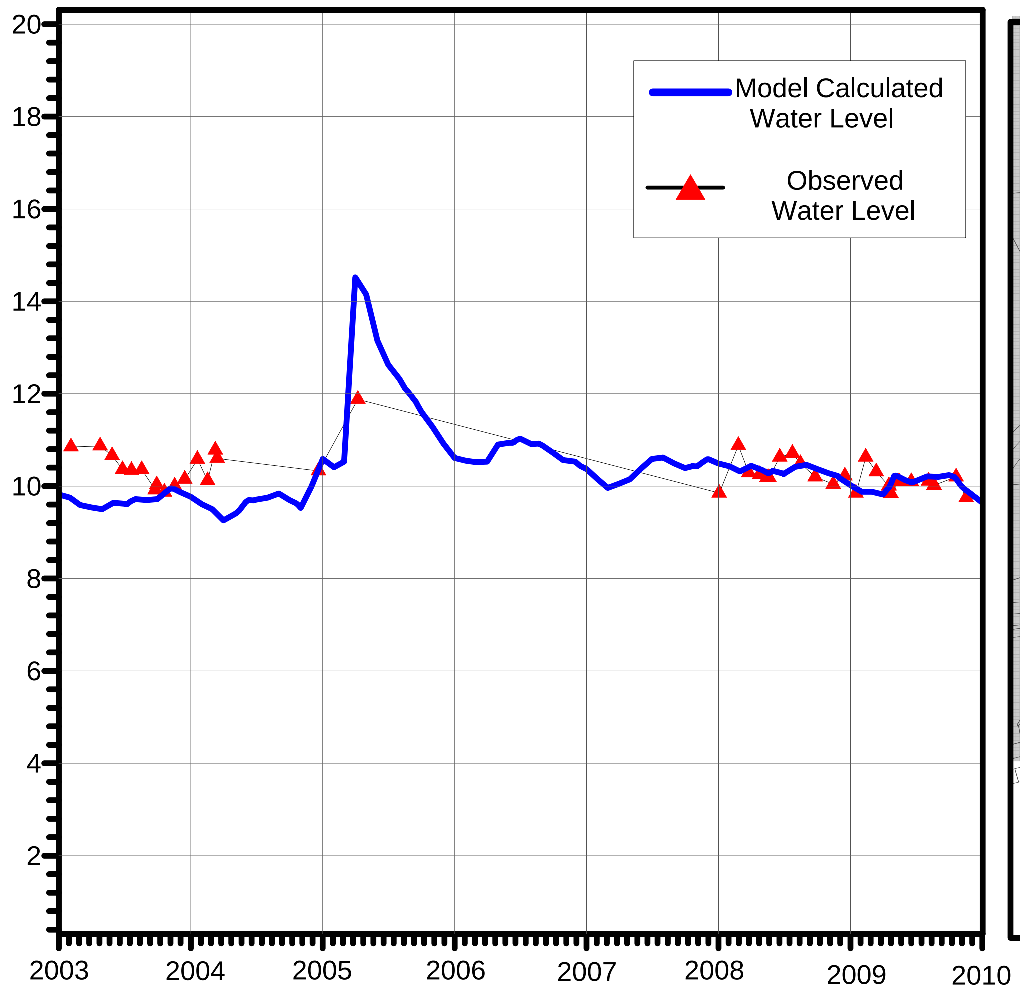
Figure 3.15a. Hydrograph showing model calculated and observed water levels at well Well02 in Winter Canyon.

McDonald Morrissey ASSOCIATES, Inc.

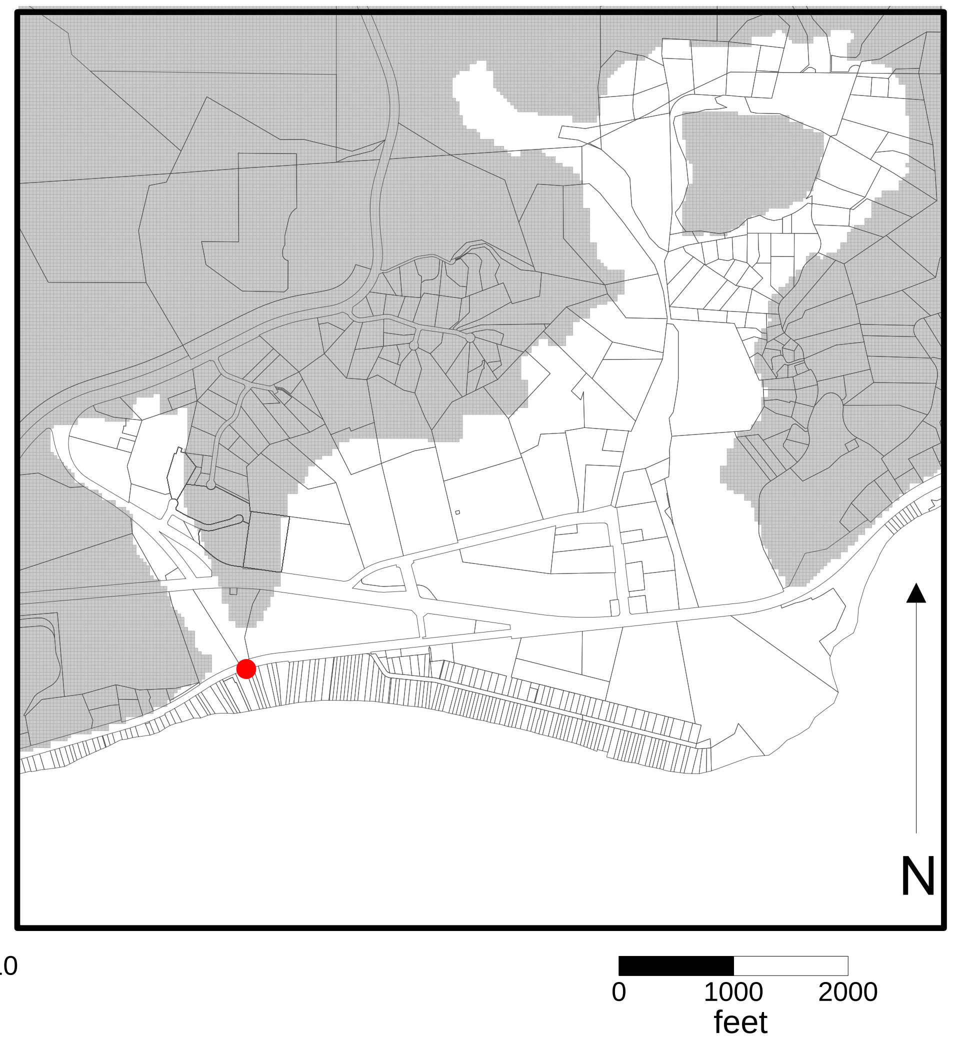
Malibu Hydrograph

SMBRP-11_4458007018

Water Level Elevation (feet NAVD88)



Model Layer **1** Screen Info: **Yes**



Number of Measurements	41
Range of Elevation	9.75 to 11.88
Average Elevation	10.31

Observed Data From: Malibu Wells gdb from A. Macrellis 5/10/2010
Modelled Data From: Malibu16_PEST 7/10/2010

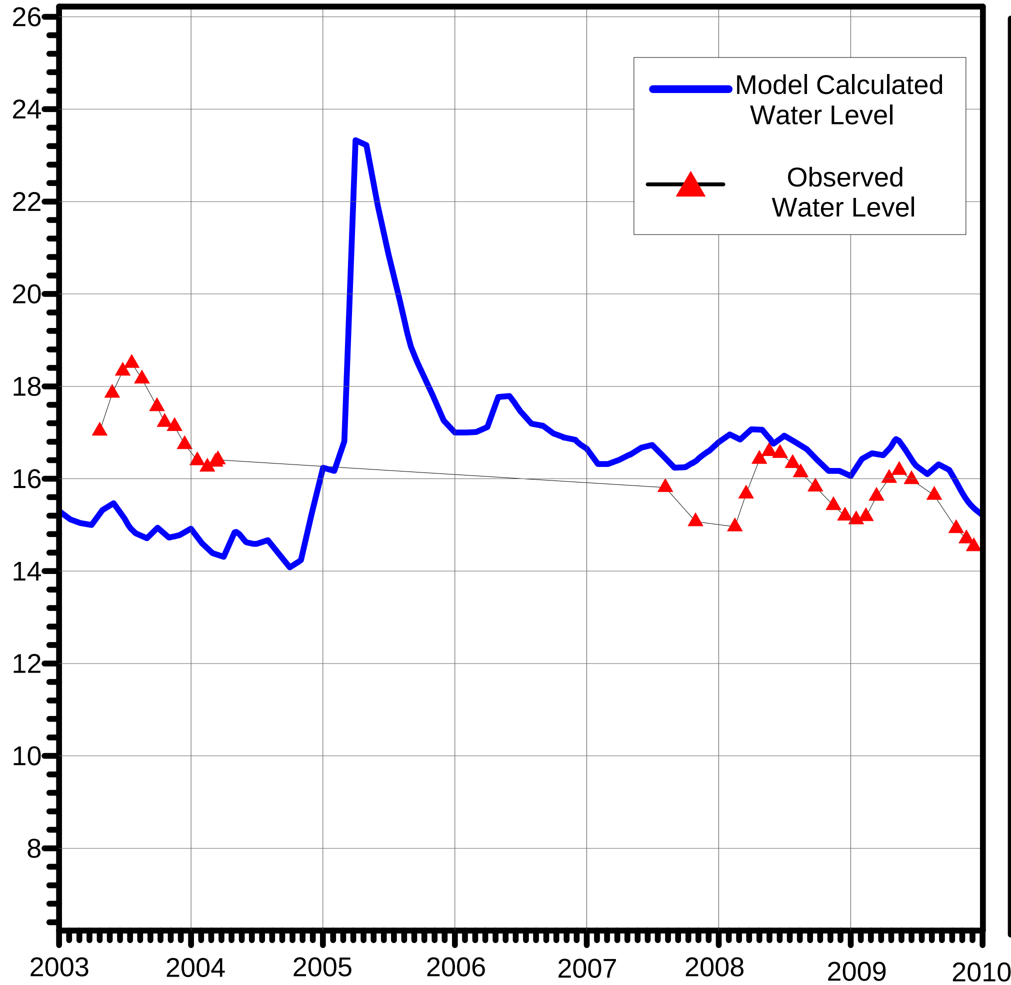
Figure 3.15b. Hydrograph showing model calculated and observed water levels at well SMBRP-11 at the base of Winter Canyon.

McDonald Morrissey ASSOCIATES, Inc.

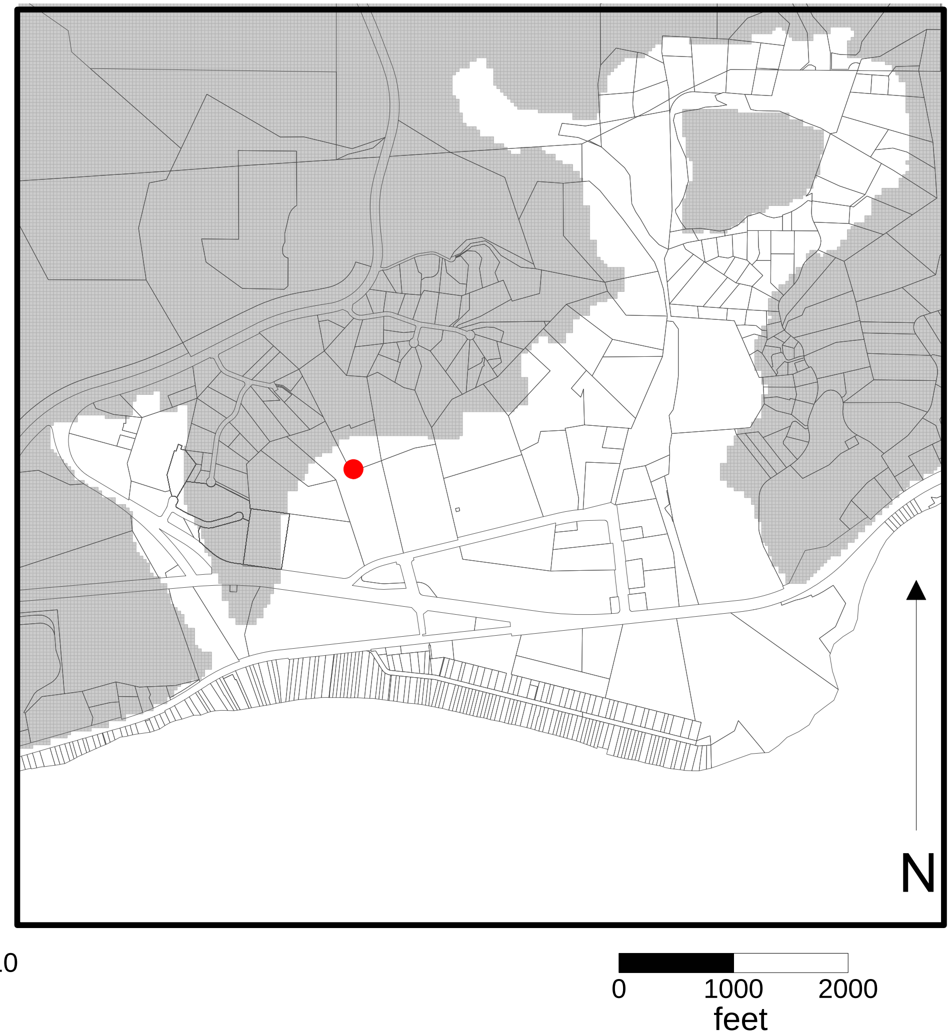
Malibu Hydrograph

SMBRP-9_4458021173

Water Level Elevation (feet NAVD88)



Model Layer 1 Screen Info: Yes



Number of Measurements	35
Range of Elevation	14.53 to 18.50
Average Elevation	16.22

Observed Data From: Malibu Wells gdb from A. Macrellis 5/10/2010
Modelled Data From: Malibu16_PEST 7/10/2010

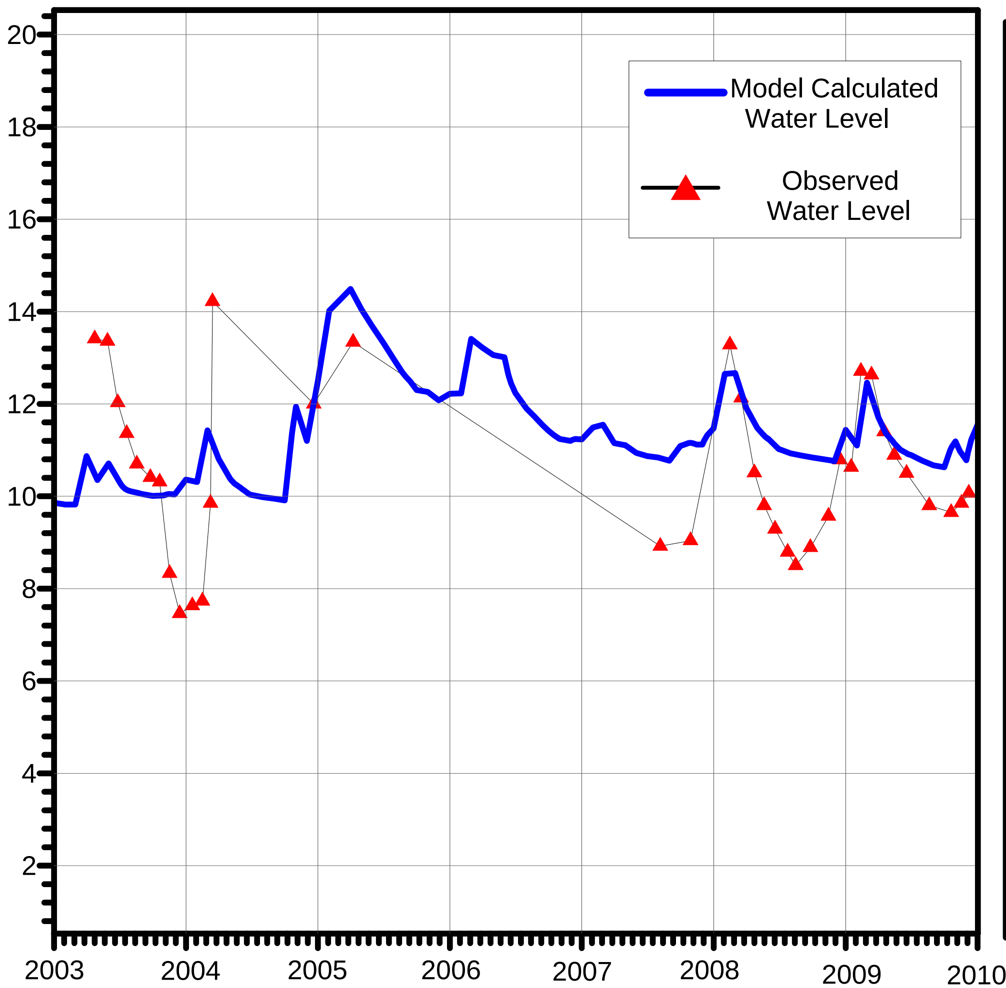
Figure 3.15c. Hydrograph showing model calculated and observed water levels at well SMBRP-9 at the edge of the alluvium near the upland.

McDonald Morrissey ASSOCIATES, Inc.

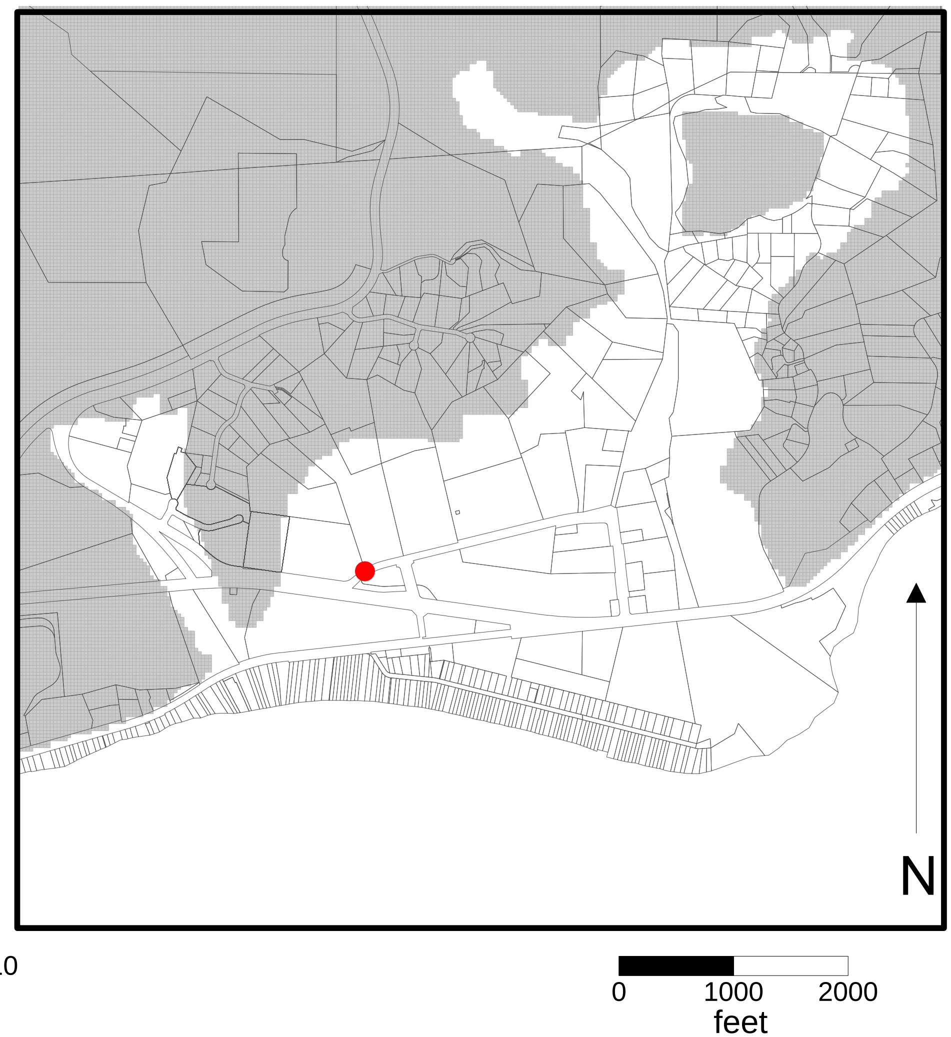
Malibu Hydrograph

SMBRP-10C_4458021007

Water Level Elevation (feet NAVD88)



Model Layer **2** Screen Info: **Yes**



Number of Measurements	37
Range of Elevation	7.46 to 14.22
Average Elevation	10.53

Observed Data From: Malibu Wells gdb from A. Macrellis 5/10/2010
Modelled Data From: Malibu16_PEST 7/10/2010

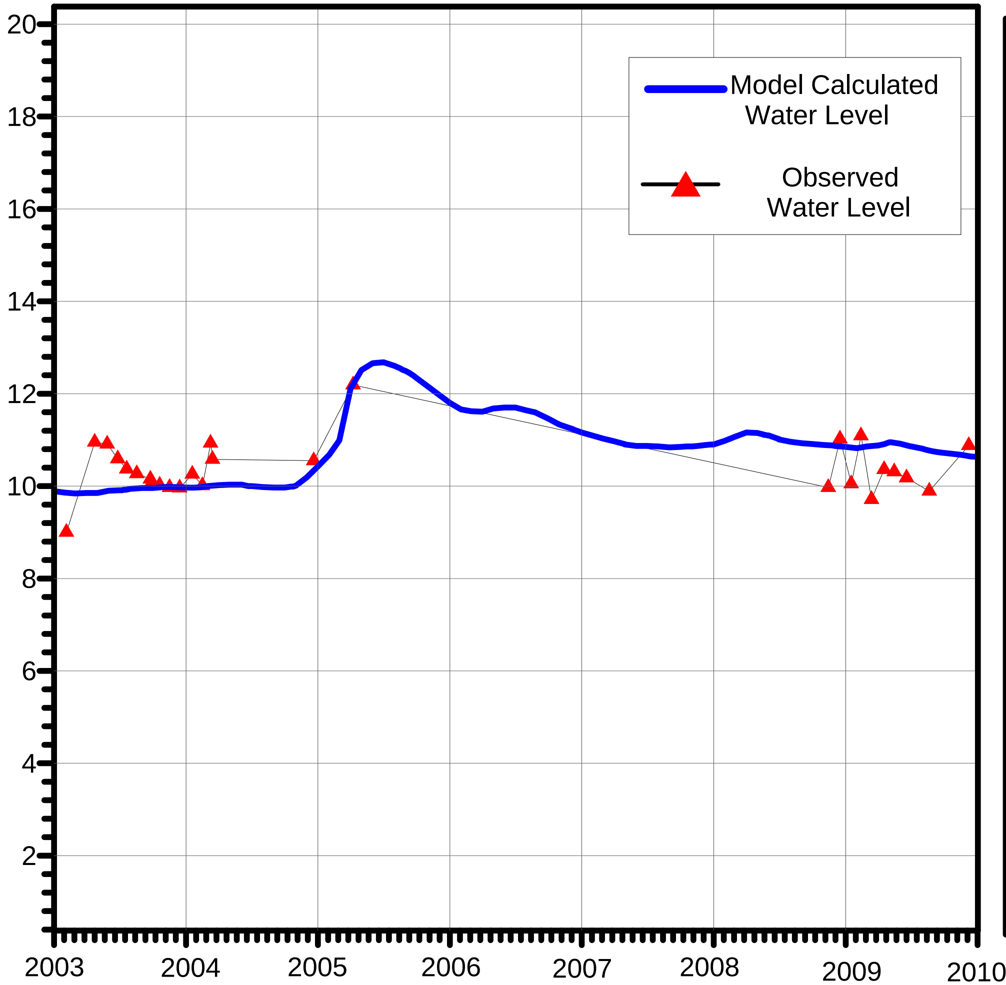
Figure 3.15d. Hydrograph showing model calculated and observed water levels at well SMBRP-10C at the edge of the alluvium near the Smith Parcel artificial wetland.

McDonald Morrissey ASSOCIATES, Inc.

Malibu Hydrograph

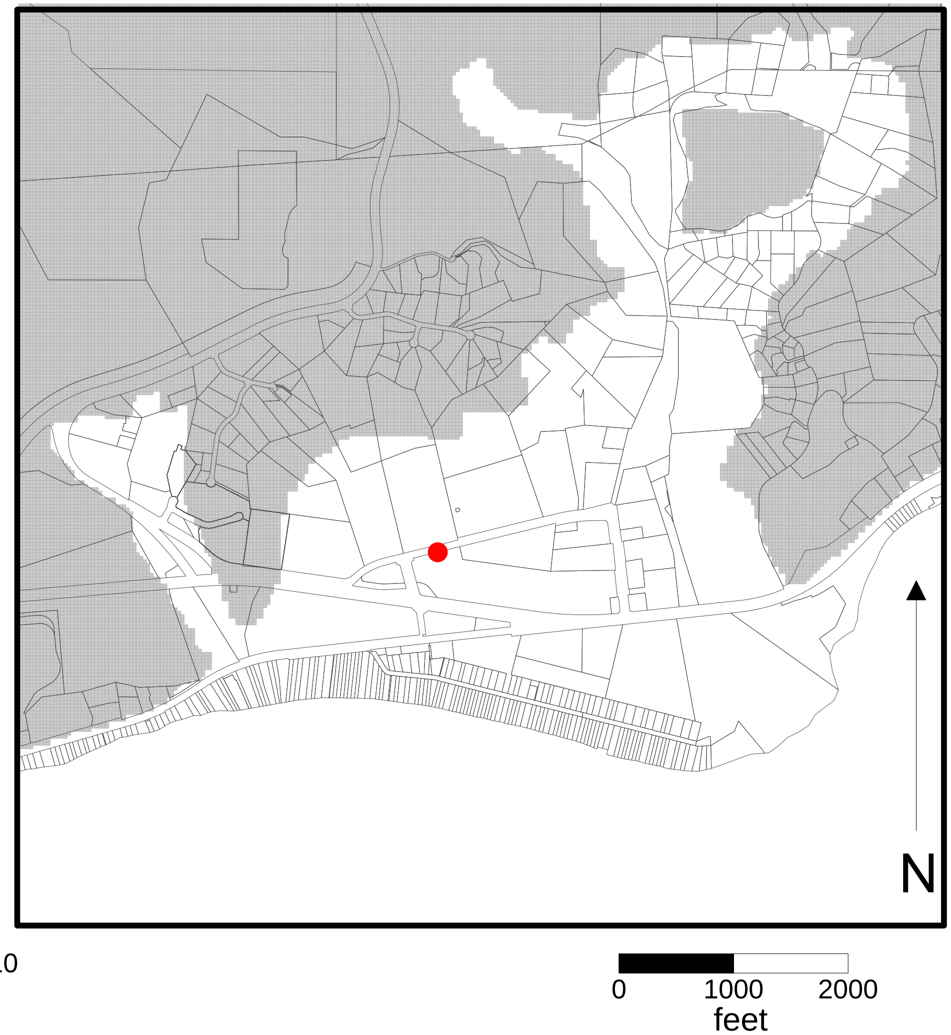
SMBRP-16_4458020016

Water Level Elevation (feet NAVD88)



Model Layer **1**

Screen Info: **Yes**



Number of Measurements	27
Range of Elevation	9.00 to 12.19
Average Elevation	10.38

Observed Data From: Malibu Wells gdb from A. Macrellis 5/10/2010
Modelled Data From: Malibu16_PEST 7/10/2010

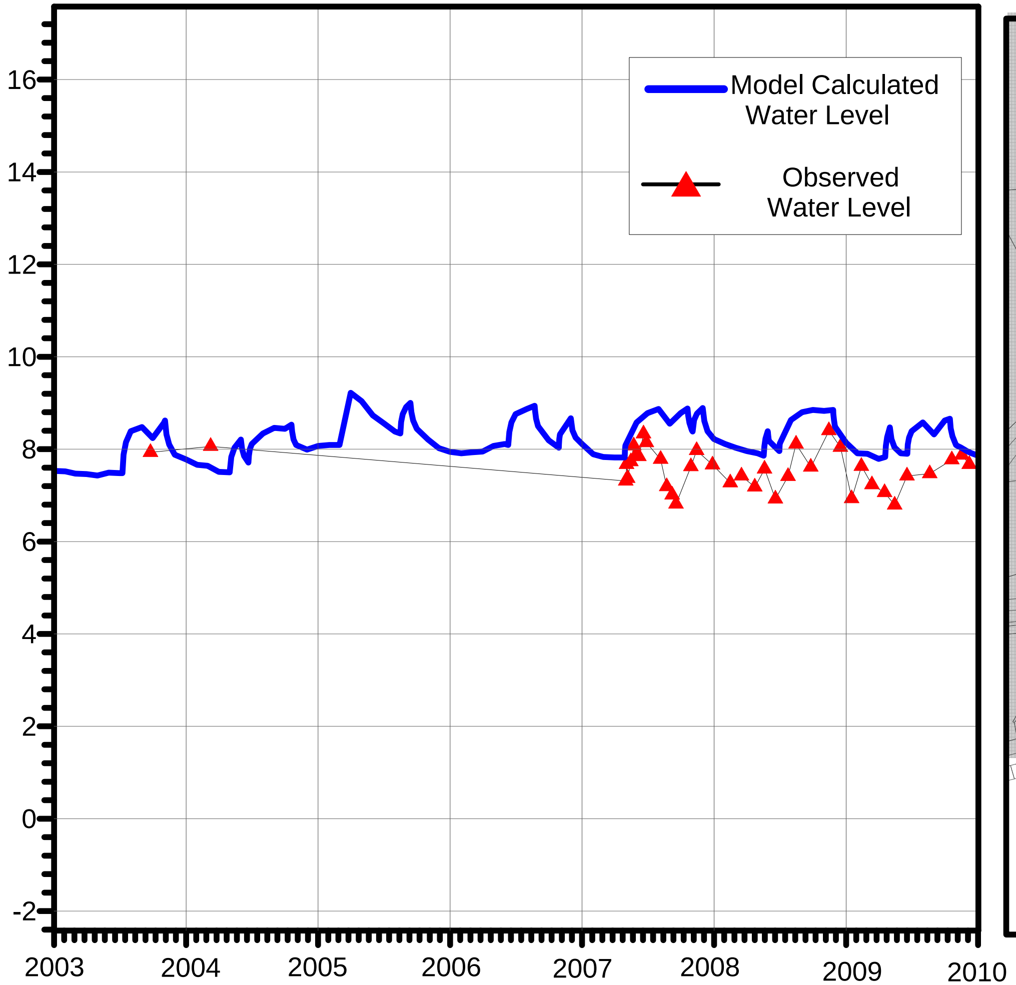
Figure 3.15e. Hydrograph showing model calculated and observed water levels at well SMBRP-16 in the center of the alluvium.

McDonald Morrissey ASSOCIATES, Inc.

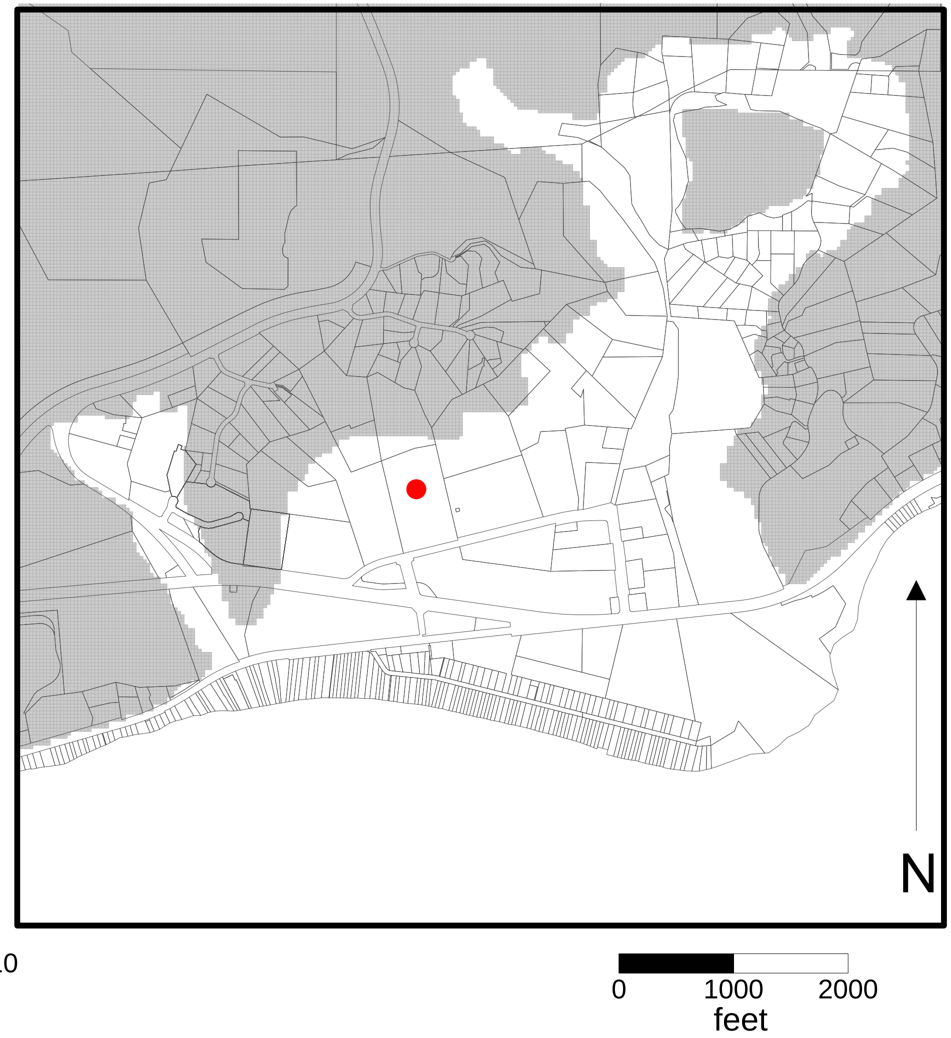
Malibu Hydrograph

MW-6_4458022011

Water Level Elevation (feet NAVD88)



Model Layer **4** Screen Info: **Yes**



Number of Measurements	38
Range of Elevation	6.79 to 8.40
Average Elevation	7.58

Observed Data From: Malibu Wells gdb from A. Macrellis 5/10/2010
Modelled Data From: Malibu16_PEST 7/10/2010

Figure 3.15f. Hydrograph showing model calculated and observed water levels at well MW-6 in the Civic Center gravels.

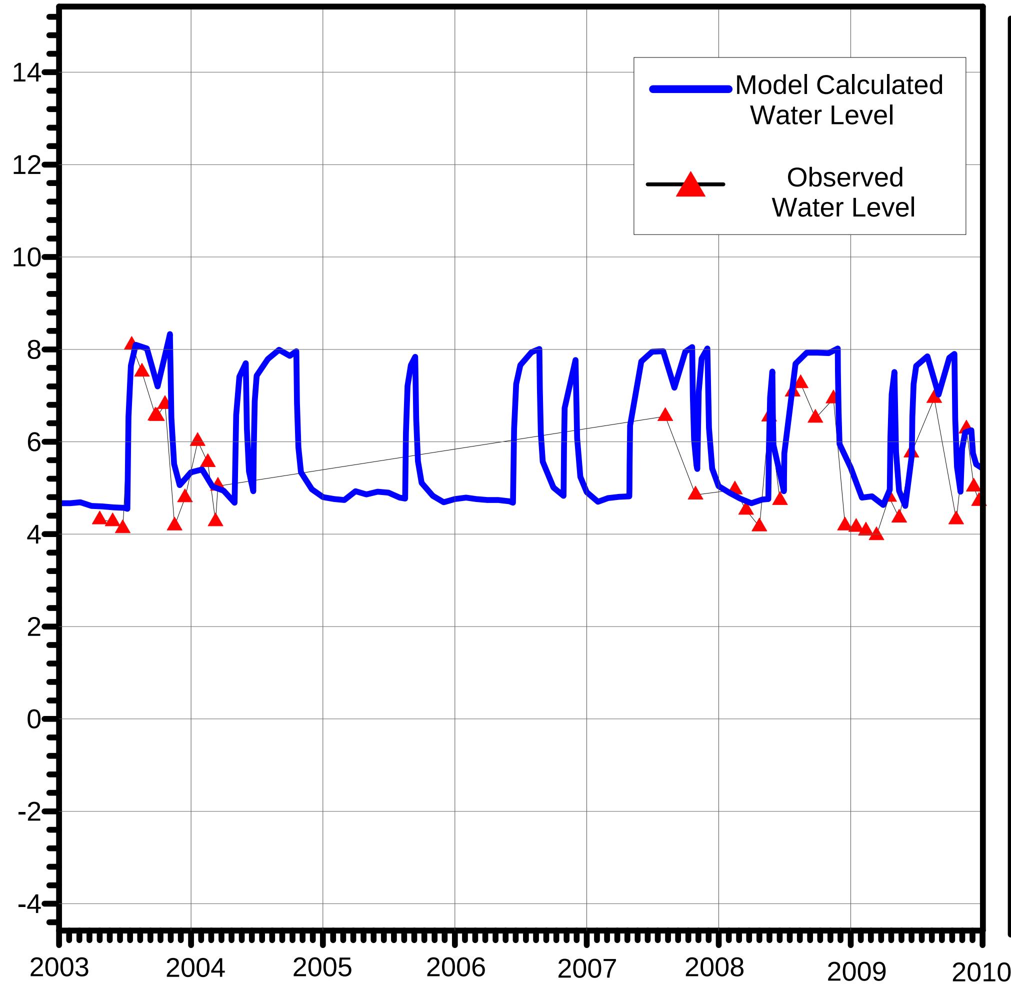
McDonald Morrissey ASSOCIATES, Inc.

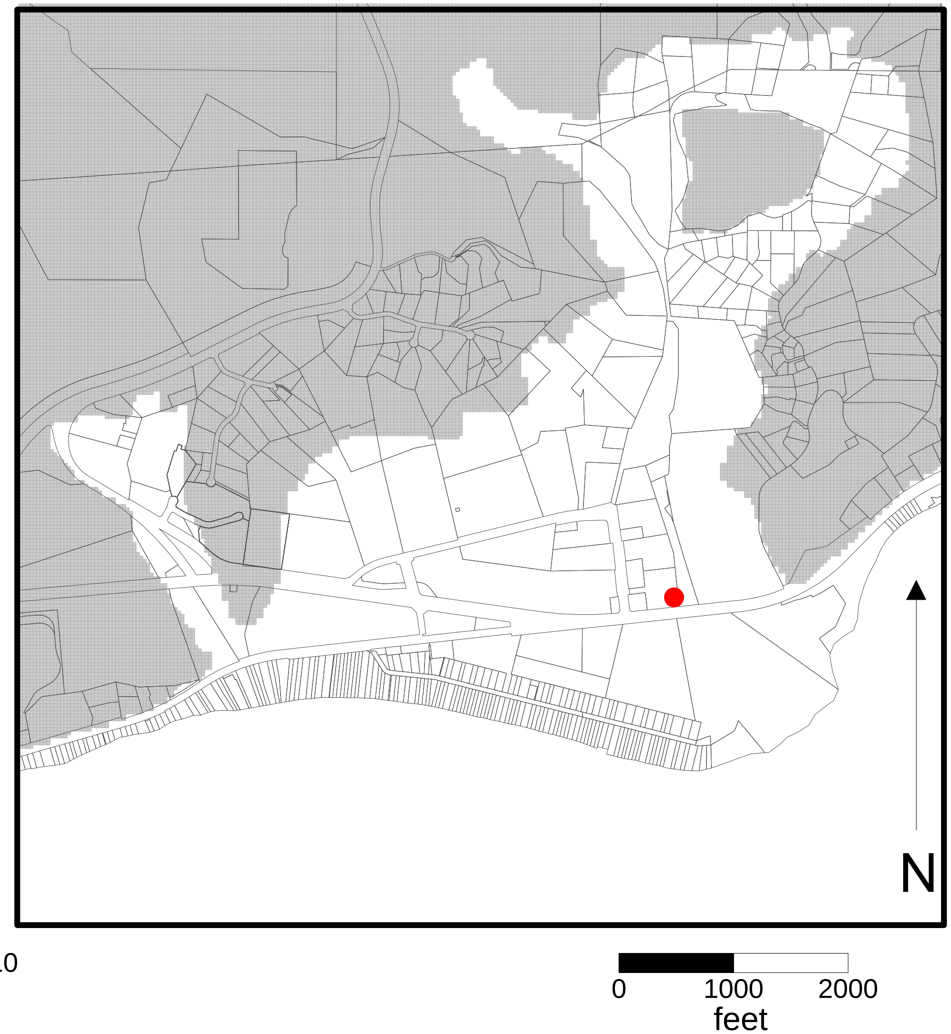
Malibu Hydrograph

P-9_4452011043

Water Level Elevation (feet NAVD88)

Model Layer **1** Screen Info: **Yes**





Number of Measurements	37
Range of Elevation	3.97 to 8.09
Average Elevation	5.42

Observed Data From: Malibu Wells gdb from A. Macrellis 5/10/2010
Modelled Data From: Malibu16_PEST 7/1/2010

Figure 3.15g. Hydrograph showing model calculated and observed water levels at well P-9 near the lagoon.

McDonald Morrissey Associates, Inc.

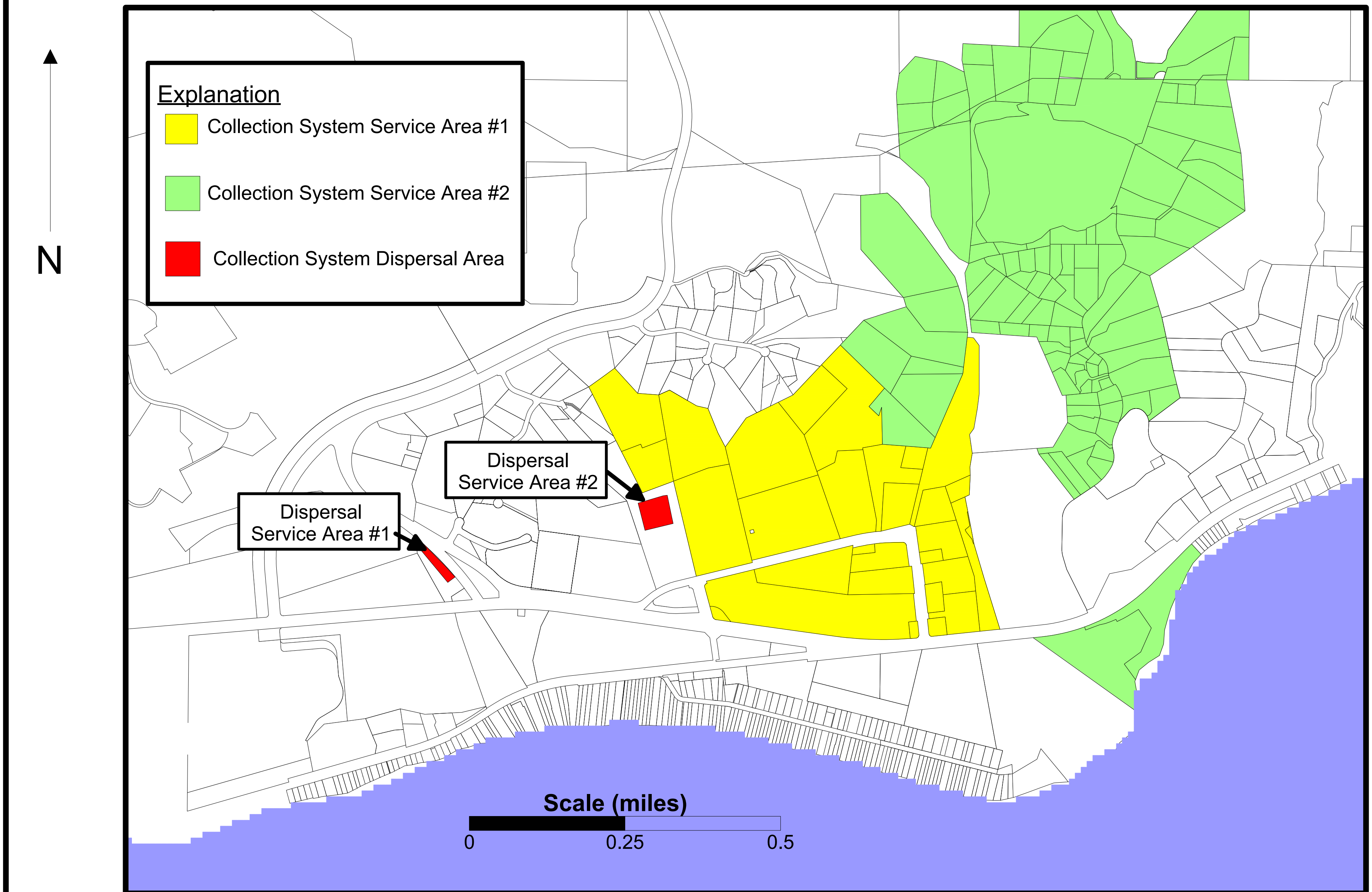
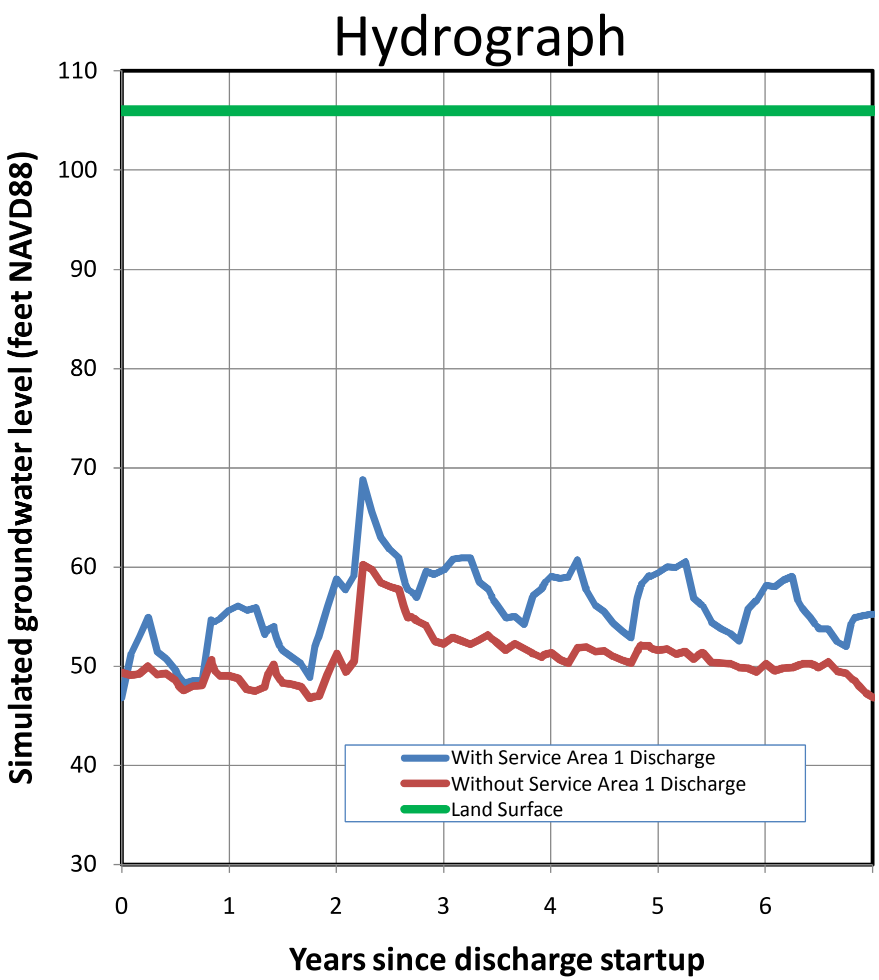


Figure 3.16. Map showing collection system service areas and dispersal locations.

McDonald Morrissey ASSOCIATES, Inc.

Hydrograph



Location

Figure 3.17. Hydrograph showing simulated groundwater levels beneath the Malibu Bay Company Waste Water Dispersal Site with and without Service Area 1 discharge.

McDonald Morrissey ASSOCIATES, Inc.

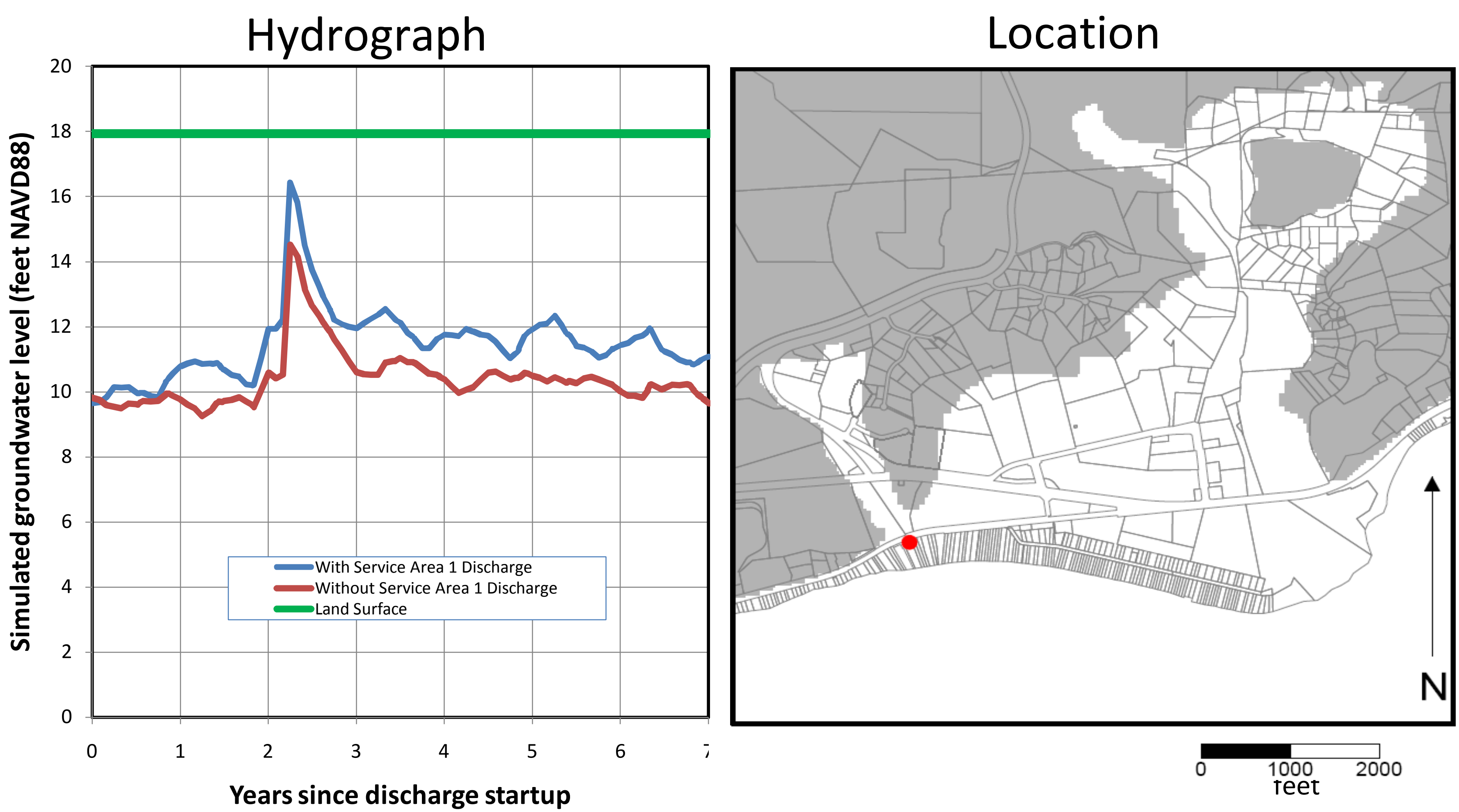


Figure 3.18. Hydrograph showing simulated groundwater levels at SMBRP-11 down gradient of the Malibu Bay Company Waste Water Dispersal Site with and without Service Area 1 discharge.

McDonald Morrissey ASSOCIATES, Inc.

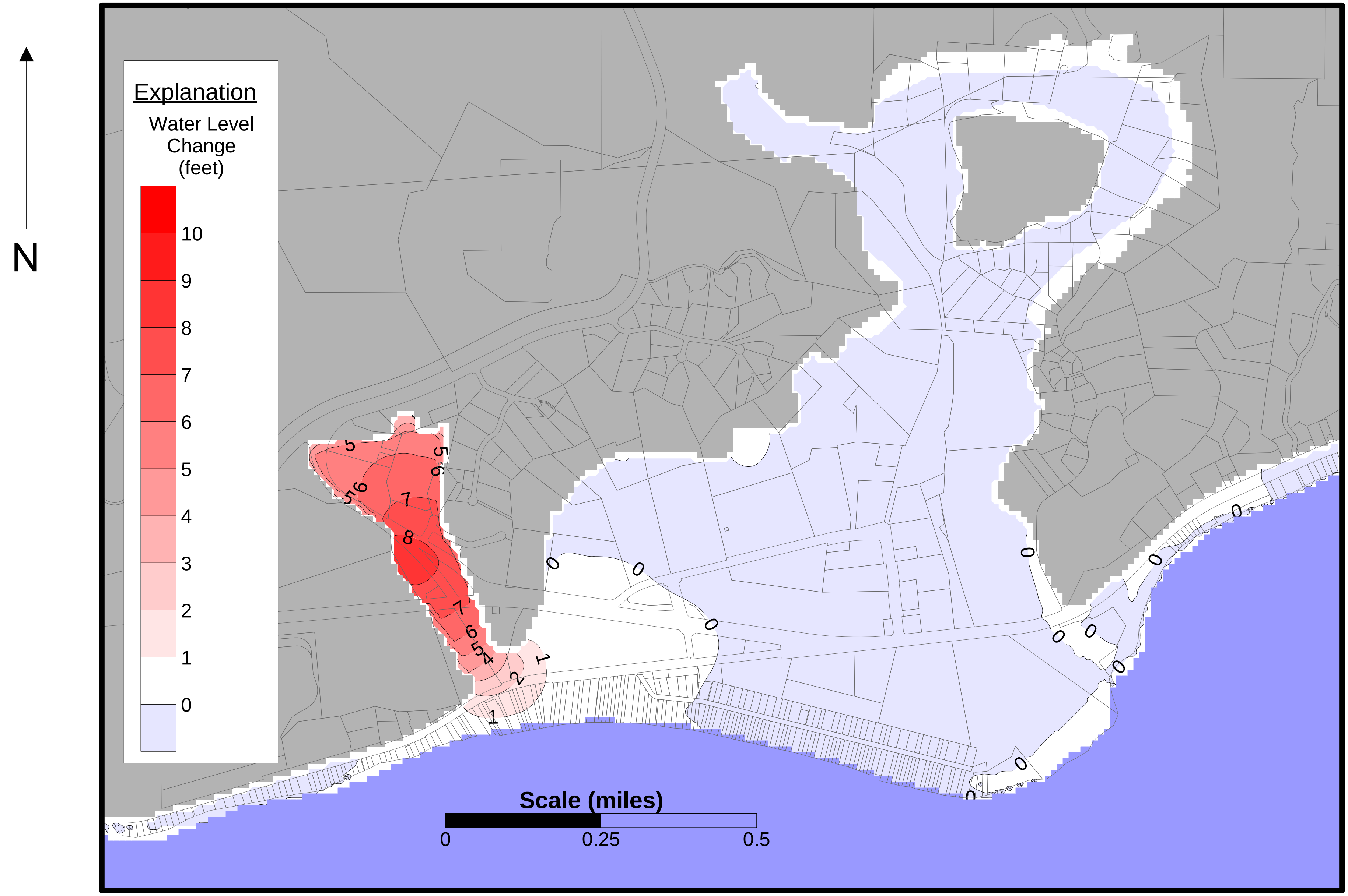
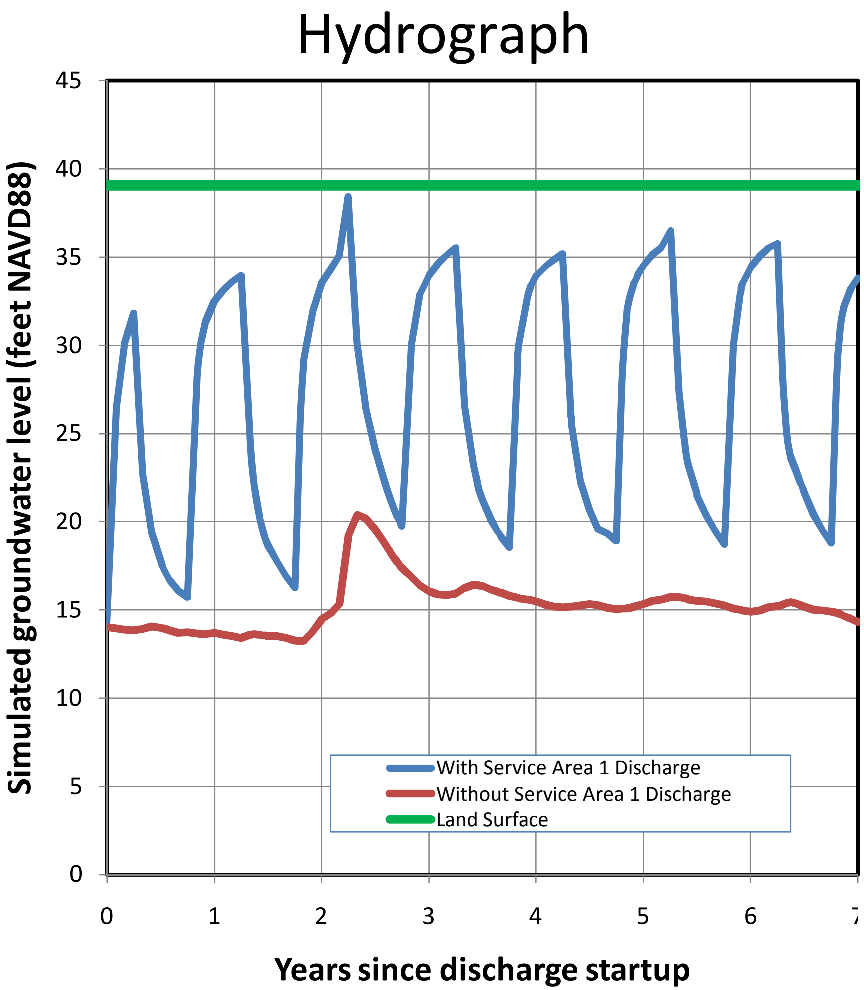


Figure 3.19. Map showing groundwater level changes caused by Service Area #1 Scenario at high water condition.

McDonald Morrissey ASSOCIATES, Inc.



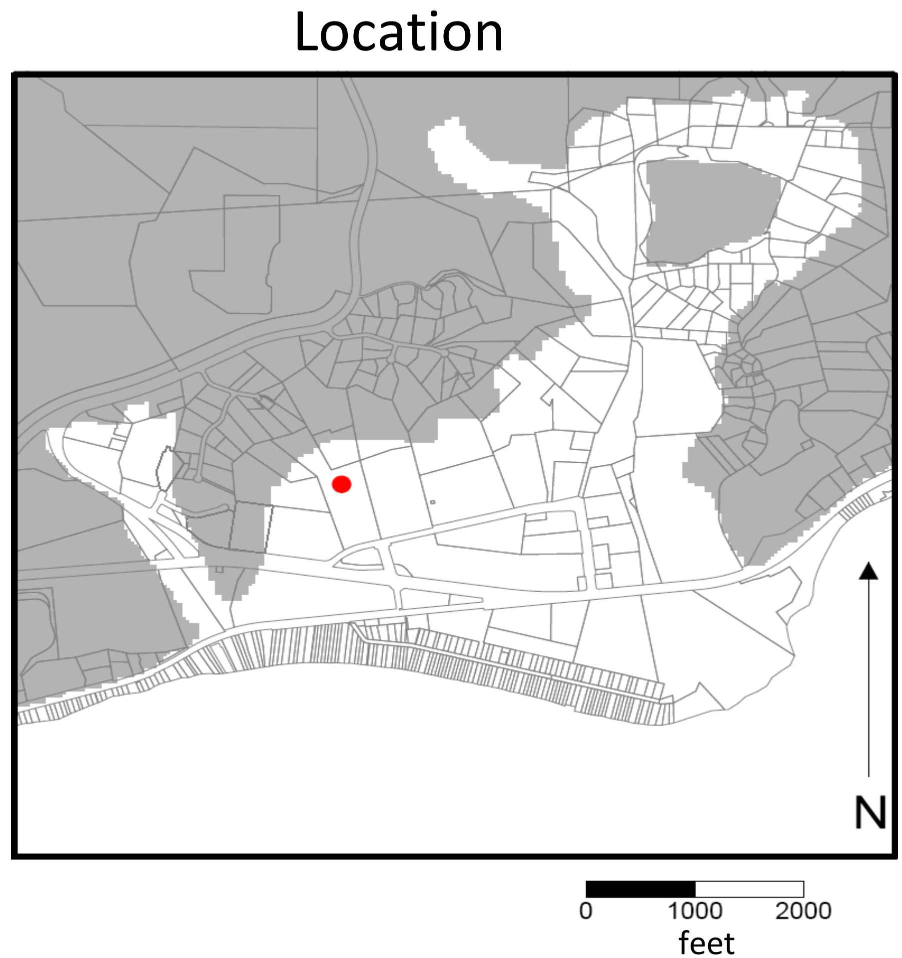
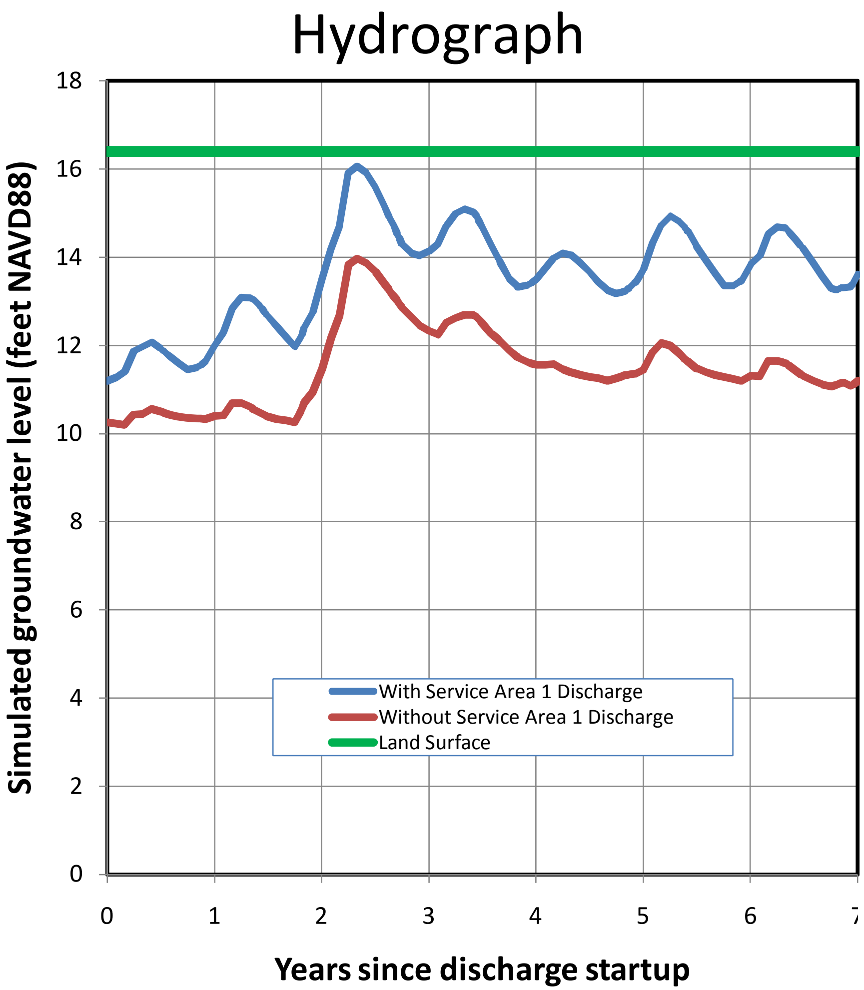


Figure 3.20. Hydrograph showing simulated groundwater levels beneath the Yamaguchi Waste Water Dispersal Site with and without Service Area 2 discharge.

McDonald Morrissey ASSOCIATES, Inc.



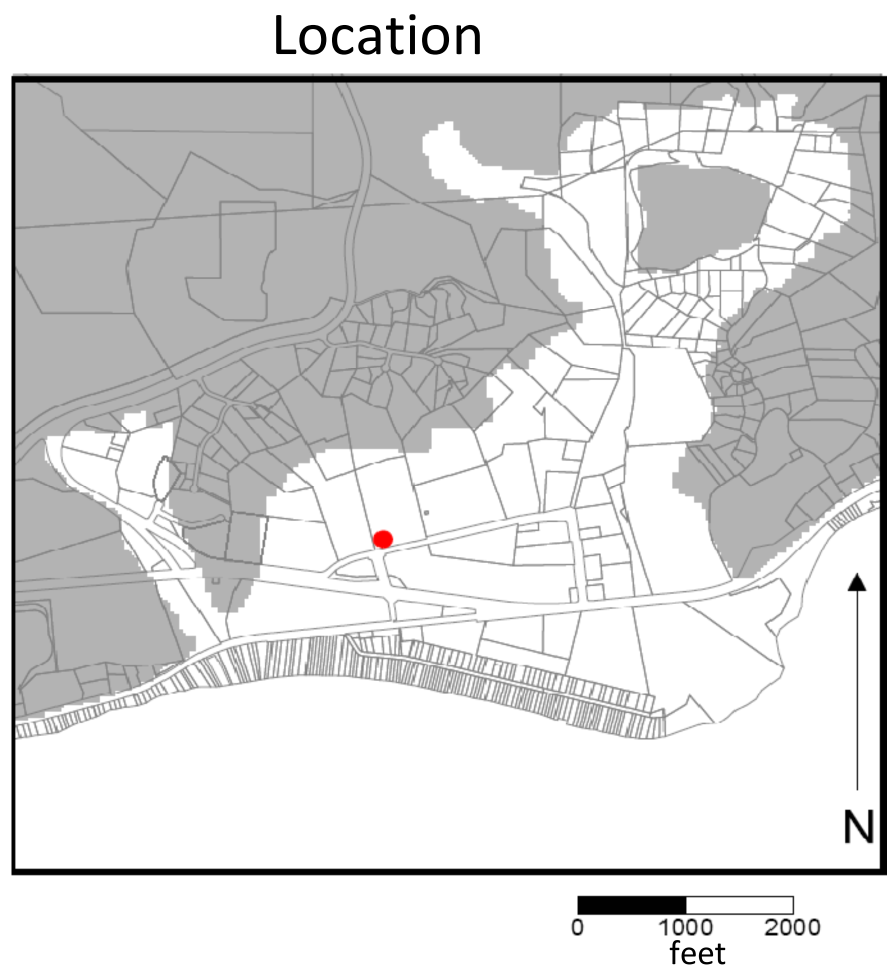


Figure 3.21. Hydrograph showing simulated groundwater levels at M6-2 down gradient of the Yamaguchi Waste Water Dispersal Site with and without Service Area 2 discharge.

McDonald Morrissey ASSOCIATES, Inc.

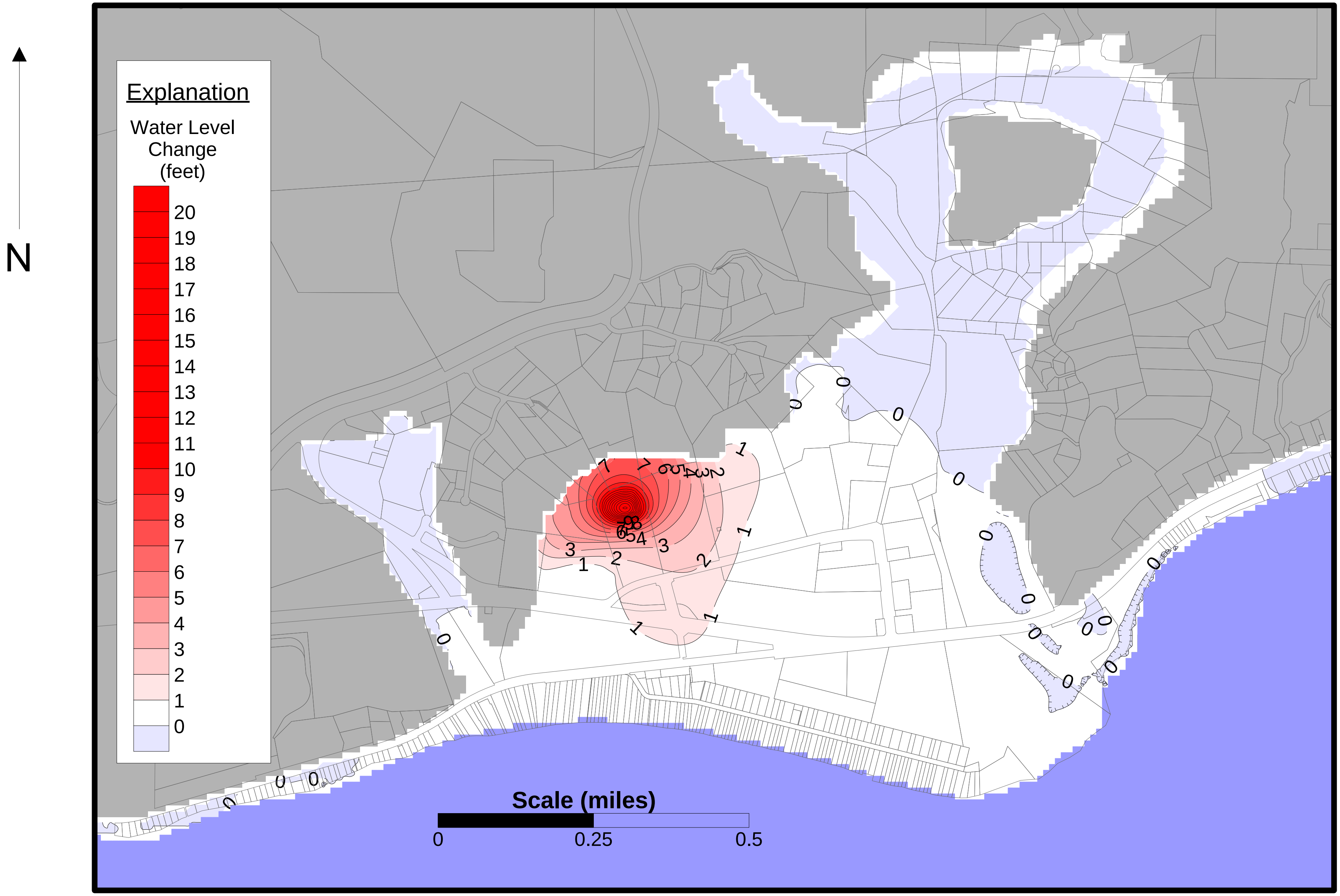


Figure 3.22. Map showing groundwater level changes caused by Service Area #2 at high water condition.

McDonald Morrissey Associates, Inc.

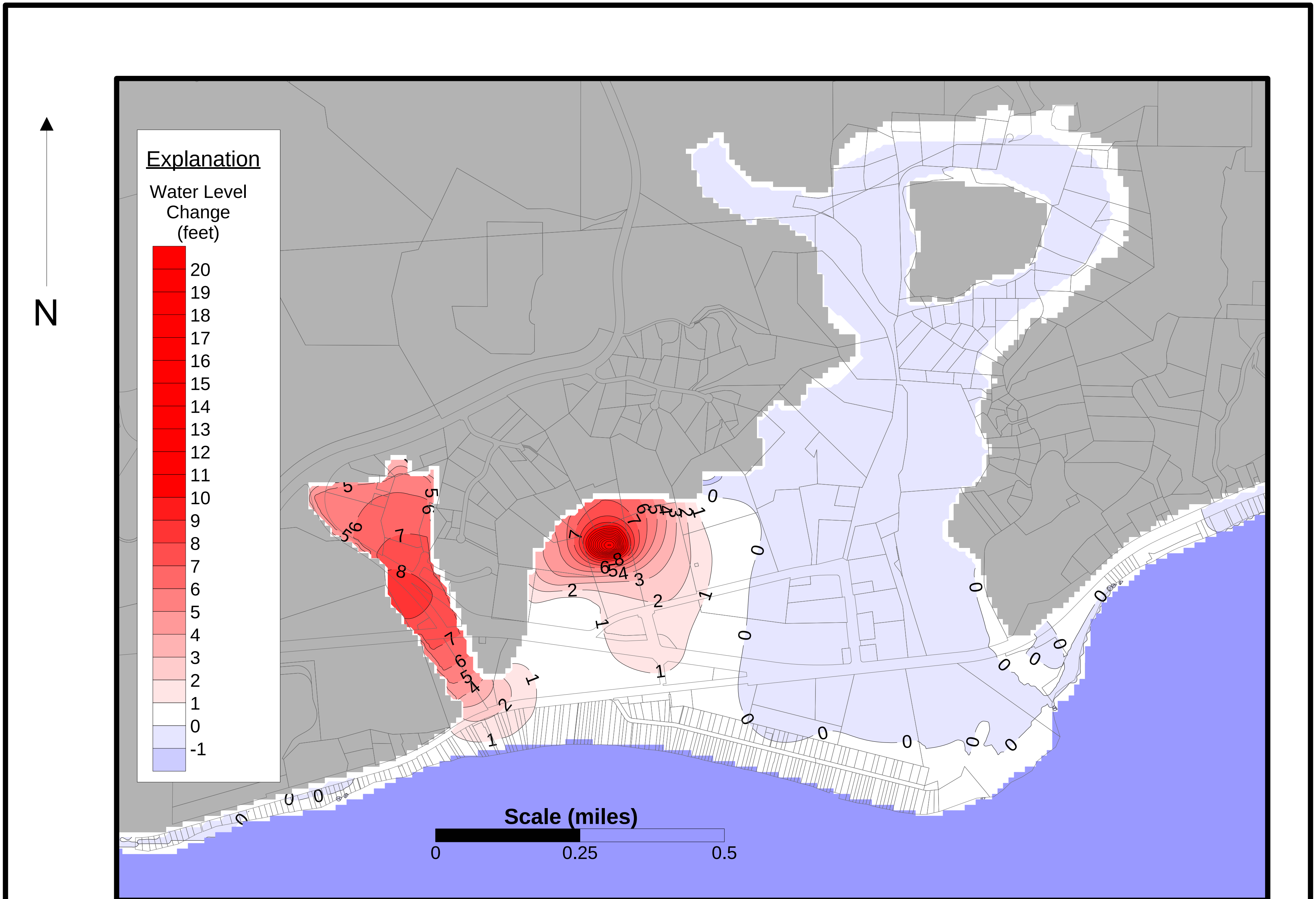


Figure 3.23. Map showing groundwater level changes caused by combined Service Area #1 and Service Area #2 Scenario at high water condition.

McDonald Morrissey ASSOCIATES, Inc.

Report on the MASW Survey for the City of Malibu

JULY 2010

ENTRIX PROJECT NUMBER: 02667001.00

PREPARED BY

John Jansen
Senior Managing Hydrogeologist

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Summary

A geophysical survey was conducted consisting of a Multi-channel Analysis of Surface Waves (MASW) survey along two survey lines March 8 to 10, 2010 in the City of Malibu, California. The survey was conducted for Stone Environmental in support of a groundwater modeling effort for the City. The survey was intended to provide depth to bedrock information in areas of the City where the depth to bedrock was greater than the depth of the borings that had been previously conducted. The MASW survey was selected due to the difficult site conditions. The survey area is developed with strong traffic noise from the Pacific Coast Highway that made other geophysical methods impractical.

The survey area lies above a bedrock valley that appears to deepen toward the Pacific Ocean. The depth to bedrock as determined by the MASW survey ranged from about 20 to 200 feet below land surface. The elevation of the bedrock surface ranged from about 100 ft msl to about -200 feet msl.

The results of the geophysical survey filled in critical data gaps in the understanding of the bedrock surface. The data will assist Stone Environmental in preparing a groundwater flow model of the unconsolidated aquifer in the area. The results presented in this report are based on indirect sensing methods subject to multiple sources of interference. The results of the survey should be verified with test borings or other direct methods of investigation.

S E C T I O N A

Introduction

A geophysical survey was conducted consisting of a Multi-channel Analysis of Surface Waves (MASW) survey along two survey lines March 8 to 10, 2010 in the City of Malibu, California. The survey was conducted for Stone Environmental in support of a groundwater modeling effort for the City. The survey was intended to provide depth to bedrock information in areas of the City where the depth to bedrock was greater than the depth of the borings that had been previously conducted.

The MASW survey was selected due to the difficult site conditions. The survey area is densely developed in places and has high seismic noise levels from the Pacific Coast Highway. These conditions severely limit the types of geophysical methods that can be used to image the bedrock in the study area. Previous efforts to use the more common methods of seismic refraction and seismic reflection reportedly produced such noisy data that they could not be interpreted. We had previously suggested using electrical resistivity to map the top of bedrock and the thickness of a gravel unit above bedrock. The USGS collected limited resistivity data in 2008 in conjunction with research they were conducting on groundwater discharge to the Pacific Ocean. The resistivity survey conducted by the USGS was limited by the amount of open land suitable for resistivity data collection. Only one resistivity line was on a site large enough to accommodate an electrode spread long enough to achieve adequate penetration to image the bedrock surface. Inspection of the survey area indicated that it may be possible to image the bedrock on a few more sites using a modified electrode array. However, the sites suitable for resistivity data collection were very limited due to development and cultural interference.

Based on this history, it was decided that the MASW method was the only method capable of imaging the bedrock in the study area. The MASW method is normally used for foundation analysis at shallow depths. However, by using a longer geophone spread and taking advantage of the low frequency seismic energy produced by waves along the coast line, we believed it would be possible to push the MASW method to the depths needed to image the bedrock surface in much of the study area.

The survey area lies above a bedrock valley that appears to deepen toward the Pacific Ocean. The depth to bedrock as determined by the MASW survey ranged from about 20 to 200 feet below land surface. The elevation of the bedrock surface ranged from about 100 ft msl to about -200 feet msl.

The results of the geophysical survey filled in critical data gaps in the understanding of the bedrock surface. The data will assist Stone Environmental in preparing a groundwater flow model of the unconsolidated aquifer in the area. The results presented in this report are based on indirect sensing methods subject to multiple sources of interference. The results of the survey should be verified with test borings or other direct methods of investigation.

S E C T I O N B

Site Description

Geologic Setting

The area of interest is approximately 1 mile by 1.5 miles and contains several major roadways and buildings. Portions of the area are generally undeveloped and available for survey work. **Figure 1** shows the study area.

The available site information provided to ENTRIX indicates that the site is covered with approximately 100 to 200 feet of unconsolidated material, consisting primarily of silt, clay, and sand and gravel, over siltstone and claystone bedrock of the Sespe Formation. A bedrock valley lies near the center of the study area. Bedrock outcrops on the northern, western and eastern edges of the study area. The depth of the bedrock valley was not well understood but was known to exceed the depth of numerous borings drilled between City Hall and the Pacific Ocean, many of which exceeded 60 to 70 feet in depth. A single boring in the southwest corner of the study area encountered bedrock at a depth of about 100 feet. A smaller tributary bedrock valley is present in the Winter Canyon area in the western portion of the study area.

The shallow unconsolidated material in the study area consists of stiff clay that forms steep slopes in outcrop. The bedrock consists of claystone and sandstone that is relatively soft and tends to have a thick weathered zone. A sand and gravel unit is present in the deeper portion of the bedrock valley below the clay layer. The sand and gravel units are commonly called dense to medium dense on boring logs. The stratigraphic sequence of stiff clay soil over soft weathered bedrock does not provide a sharp velocity contrast for seismic methods and made it more difficult to distinguish stiff soil from weathered bedrock in some areas.

The cost of drilling through these sediments is significant due to the depth of penetration required, the nature of the sediments, and the difficulty of gaining site access for drilling. The number of borings that can be drilled in practical terms is considerably lower than the number that would be needed to adequately characterize the subsurface in the study area. Geophysical surveys can provide information on the depth to bedrock for lower costs and with more complete coverage than is possible by test drilling.

S E C T I O N C

Description of Methods

MASW Survey

MASW is a seismic method that uses the dispersion of surface waves of different frequencies to determine the change in shear wave velocity (Vs) with depth. The Vs of geologic materials is a function of the stiffness of the material. Dense, rigid materials (like hard rock) have high Vs values while loose, poorly consolidated materials (like loose soil) have low Vs values. The Vs value is a good predictor of the suitability of a material to support structural foundations, resist liquefaction or collapse in earth quakes, and can be used to distinguish bedrock from unconsolidated material. **Table 1** provides typical Vs ranges for common geologic materials. In general, material with Vs values below 1,200 ft/sec (366 m/sec) are considered to be unconsolidated soils, material above 2,500 ft/sec (762 m/sec) are considered to be consolidated rock, Materials between 1,200 to 2,500 ft/sec (366 to 762 m/sec) can either be very dense soil or soft rock. These values are general ranges only. Local geologic conditions can vary and some discretion based on local knowledge is needed to assign velocity ranges for unconsolidated or consolidated material.

MASW measurements are made using arrays of low frequency geophones (usually 4.5 Hz.) on the ground surface to measure the variation in Vs of surface waves at different frequencies. Several different array geometries can be used, but linear geophone arrays are the most common for roadside applications due to space limitations. The depth of investigation of surface waves varies and is a function of the frequency of the wave with lower frequency waves being affected by deeper material than higher frequency waves. The change in Vs with frequency through a section of the earth is known as the seismic dispersivity and can be used to determine the change in Vs with depth.

MASW measurements can be conducted in two modes: an active mode that uses a hammer source, and a passive mode that uses ambient surface waves from traffic, waves, power plants, industrial machinery, and other incidental sources of seismic energy. The active source method can be used to produce high resolution images of the subsurface by calculating lateral variations at each geophone but is usually limited in penetration to about 30 to 50 feet. Passive methods, also called the Refraction Micro-Tremor Method, can achieve greater penetration, often 100 to 300 feet. The Passive method can only calculate a single dispersion curve that represents the average conditions for the spread and is arbitrarily assigned to the center of the geophone spread. The depth of penetration of the passive methods is limited by the frequency range of the ambient seismic energy and the length of the geophone spread. Geophone spreads of about 120 to 240 feet are common for road side surveys producing typical depths of penetration of about 100 to 200 feet.

Passive MASW data is collected by recording a series of long records of the ambient seismic energy crossing the geophone array. The seismic records are processed using a Fourier transform to measure the change in Vs with frequency (dispersion curves). The dispersion curve is modeled to fit a 1-dimensional velocity model for the spread location. The orientation of the source to the geophone spread is important when using a linear roadside array. The optimal data quality comes from a seismic source (traffic) that is located several geophone spread lengths off either end of the spread in the same line as the geophones.

Sources that are out of the line of the geophones cause the incident seismic energy to propagate across the line at an angle to spread and create geometric factors that create anomalous apparent Vs readings. An extreme example of this phenomenon occurs when the source is perpendicular to the geophone spread and the seismic energy hits all of the geophones simultaneously. This and creates nearly infinite apparent Vs values. The apparent phase velocity measured in these conditions will always be higher than the true Vs values for the subsurface. Because of this phenomenon it can be difficult to collect meaningful passive source MASW data with linear geophone arrays if the source is at the wrong orientation to the spread. If space is not a factor this problem can be eliminated by changing the orientation of the geophone spread or using non-linear arrays. This is often not possible for roadside surveys where the working space is limited to linear stretches along the roadway.

Field Procedures for MASW Data

The MASW data was collected using a Geometrics Geode 24 channel seismograph. The geophone array consisted of 4.5 Hz geophones mounted on a land streamer with a phone spacing of 10 feet. Data was collected using traffic along the Pacific Coast Highway and other roadways as the predominant seismic source. Wave energy from the Pacific Ocean provided an additional source of energy in the lower frequency range. Data was collected for 20 records at each station. Each record had a listening period of 30 seconds.

Data was collected along seven transects as shown on **Figure 1**. With the exception of Line 1, the transects were conducted along roadways or sidewalks. Part of Line 1 was conducted in undeveloped fields west of the City Hall building. Lines 1 though 5 were advanced as a series of seismic stations. Each station consisted of a single geophone spread of 24 channels. Stations were advanced by dragging the land streamer to position the first geophone of the new spread at the location of the last geophone of the previous spread. In many cases the spacing of the stations had to be modified to avoid roadways, driveways, and other obstacles. The land streamer was often moved from one side of a road to another as needed along a transect to avoid obstacles. Lines 6 and 7 were limited to single geophone spreads due to limited land availability. The ends of each seismic station were recorded with a handheld GPS unit for positional control. The elevation of each station was estimated using topographic maps from LIDAR images of the area.

The data from each station was interpreted using the SeisImager/SW package. The velocity model from each station was combined with the data from the rest of each seismic line to produce two dimensional profiles of the Vs distribution with elevation along each line. The velocity dispersion curves for each station are presented in **Appendix A**. Please note that the data below about 150 to 200 feet on some stations appears to be erratic and was not used for interpretation.

S E C T I O N D

Results

MASW Survey Results and Discussion

The Pacific Coast Highway and Pacific Ocean provided strong seismic signals down to approximately 1 to 2 Hz. This is lower than is typically produced by traffic noise and made it possible to get a greater depth of penetration as was needed to image the bedrock in the center of the bedrock valley.

When processing the data it became apparent that some of the lines suffered from strong apparent phase velocity problems and produced anomalously high near surface velocity data. After closer examination, it was concluded that Lines 4 and 5 were orientated at too much of an angle from the Pacific Coast Highway and were receiving energy at an oblique angle to the geophone spread. This produced erroneous apparent seismic velocity measurements because the waves were striking the geophone array from the side rather than down its axis. Lines 4 and 5 were run along the side of the roadways with limited open space. It was not possible to reorient the geophone spreads at these locations, so it was not possible to obtain usable data on these lines without stopping traffic on the Pacific Coast Highway and adding an alternate seismic source in line with the trend of the roadways. Line 1 also suffered from an anomalously high velocity zone in the shallow data. This line produced estimated depth to bedrock values that were deeper than the available drilling data, suggesting that the high velocity zone was impacting the quality of the data inversion. Line 6 was located at the base of a steep slope on the bedrock surface as apparent from the steep bedrock escarpment a short distance to the north of the line. Because of its position at the edge of a steep bedrock scarp, it was unclear how representative a single bedrock depth value from a 240 foot long geophone spread would be and at what point along the line the calculated value would represent.

Lines 2 and 3 lie roughly parallel to the Pacific Coast Highway where traffic noise from along the roadway provided a strong seismic source parallel to the orientation of the line. This reduced the problem of oblique angles of incidence for the seismic waves and produced more reasonable velocity profiles and bedrock depth measurements. Both of these lines are located above the assumed center of the bedrock valley where numerous borings have been drilled but none of the borings were deep enough to encounter bedrock. This area represents the area of greatest interest and the area where the depth to bedrock information is most needed. Given the geometry problems related to Lines 1, 4, and 5, and the limited land available to reorient these lines into more favorable orientations, it was decided to only use the data from Lines 2, 3, 6 and 7 for the analysis in this report.

Figures 2 and 3 present the MASW profiles for Lines 2 and 3 plotted as Vs as a function of elevation for each station along the transects. The subsurface material shows a Vs range of between about 500 to 1,500 m/sec on Line 2 and 300 to 1,500 m/sec on Line 3. **Figures 4 and 5** present the velocity dispersion curves for Lines 6 and 7. The general pattern on all four lines is a low velocity layer of material with Vs of about 500 to 700 m/sec over a higher velocity layer of material with Vs of about 1,000 to 1,500 m/sec. A zone of lower velocity material with Vs of about 300 to 400 m/sec is present in the center of Line 3. This velocity structure is interpreted to represent unconsolidated stiff soil over soft to competent rock. The low velocity zone near the center of Line 3 may represent less dense sand and gravel deposits within the unconsolidated zone.

Based on the velocity distribution and the soil descriptions from boring logs, a velocity of about 900 m/sec was chosen as the boundary between soil and bedrock. The red line on both figures represents the approximate location of the 900 m/sec contour and is intended to represent the approximate elevation of the bedrock surface. This value is slightly higher than the typical ranges presented on Table 1. This is believed to be due to the very stiff nature of the clay units in the area. Using a different Vs value would result in the estimated depth to bedrock being slightly higher or lower. Lines 1, 4, and 5 produced plots with high velocity layers at the surface. These results indicated that the lines were recording anomalously high velocity values in the higher frequency range, probably due to the orientation of the lines to the Pacific Coast Highway that caused the incident seismic energy to propagate across the line at an angle to the spread resulting in inaccurate Vs measurements.

The depth to bedrock as determined by the MASW survey ranged from about 20 to 200 feet below land surface. The elevation of the bedrock surface ranged from about 100 ft msl to about -200 feet msl. **Figure 6** is a bedrock elevation map made from the MASW data from Lines 2, 3, 6, and 7 and from a line of borings that encountered bedrock along the northern edge of the bedrock valley as provided by McDonald Morrissey as summarized on **Table 2** (prepared by McDonald Morrissey). The bedrock surface shows the orientation of the bedrock valley is predominantly west to east. The deepest portion of the bedrock valley appears near the intersection of the Pacific Coast Highway and Civic Center Way. The elevation of the valley floor was initially expected to deepen toward the ocean. Due to the limited area available for survey work, it was not possible to obtain adequate MASW data in the Winter Canyon area to image the shape of the tributary valley believed to be present.

The USGS ran several electrical resistivity lines in the study area as part of a research project to measure groundwater discharge to the Pacific Ocean. Most of the lines were short lines designed to make shallow measurements of the upper portion of the saturated zone. One line was run on undeveloped land between the Pacific Coast Highway and Civic Center Way. **Figure 7** is a plot of this line prepared by the USGS. This line achieved over 200 feet of penetration The line detected three layers: a shallow low resistivity layer that represents the shallow clay layer, an intermediate higher resistivity layer that represents the sand and gravel unit, and a deeper lower resistivity layer that represents the claystone bedrock. The bedrock layer was detected at a depth of about 150 to 160 feet on the resistivity line. The MASW data closest to the resistivity lines, stations 5 to 9 on Line 2 indicated bedrock at a depth of about 150 feet which is in close agreement with resistivity data.

Based on our inspection of the site, we believe that there are additional areas within the study area that are suitable for electrical resistivity survey work. Using modified electrode arrays we believe it would be possible to get reliable depth to bedrock information in areas not suitable for MASW work due to the orientation of the available sites. The resistivity data would also provide better imaging of the shape of the sand and gravel layer above the bedrock surface.

SECTION E

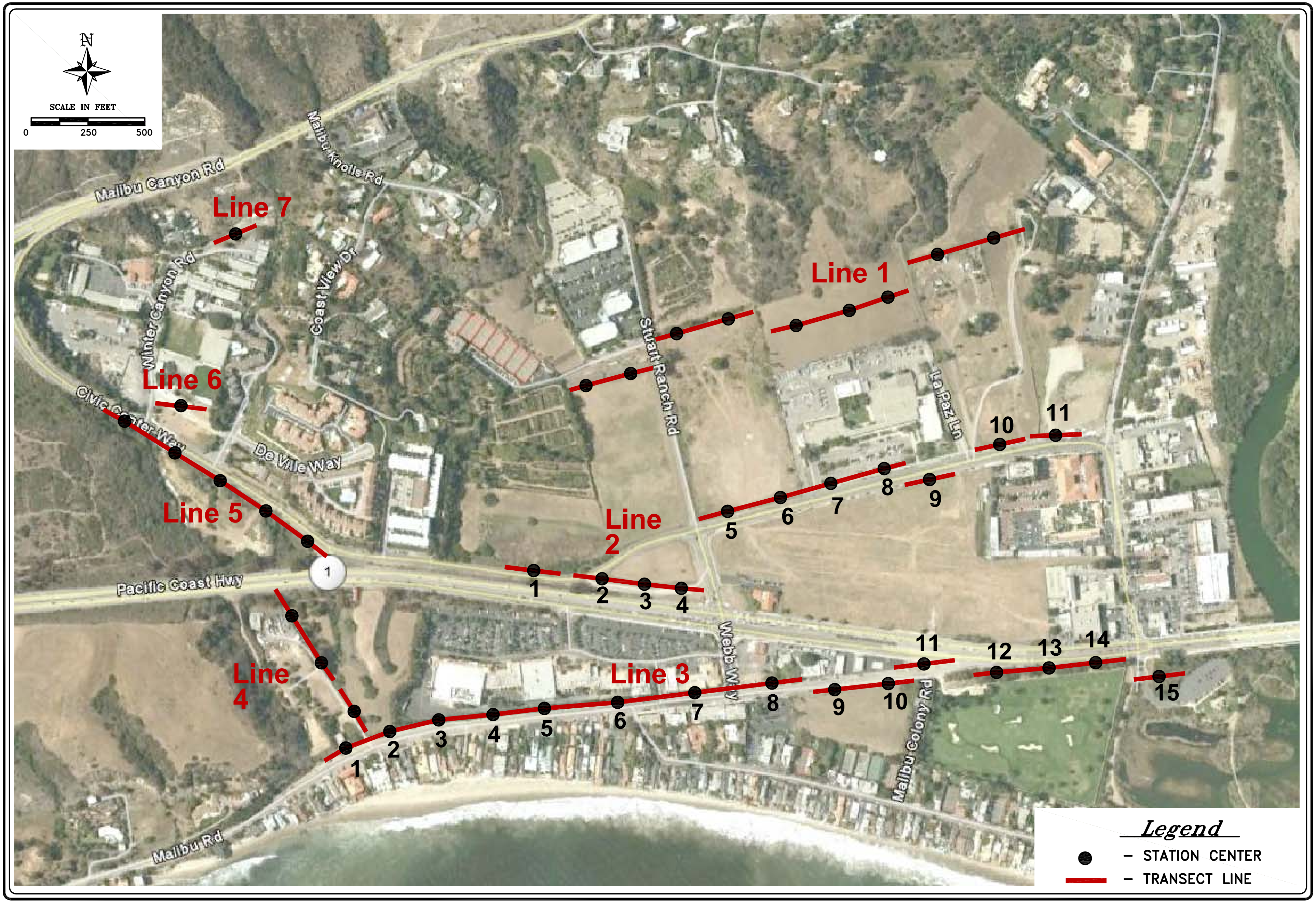
Conclusions

General

- The site conditions in the survey area were unsuitable for most geophysical methods due to the highly developed nature of some areas and the high seismic noise from the Pacific Coast Highway and other roadways.
- Several previous geophysical surveys to map the bedrock surface in the past failed due to the difficult site conditions.
- The MASW method was the only practical means to get depth to bedrock information in many parts of the study area other than drilling.
- The MASW survey was able to map the bedrock surface in the center of the bedrock valley in an area where the bedrock was deeper than existing well borings.
- The deepest portion of the valley was found to be approximately 1,000 feet inland from the Pacific Ocean.
- The data from three lines was not suitable for analysis due to the orientation of the lines relative to the major source of seismic energy in the area.
- The USGS resistivity line near Civic Center Way provided an estimated depth to bedrock nearly identical to the MASW results in the area.
- Several areas within the study area would be suitable for additional electrical resistivity lines using modified arrays to obtain additional depth to bedrock information and provide additional data on the location and thickness of the sand and gravel unit above bedrock.

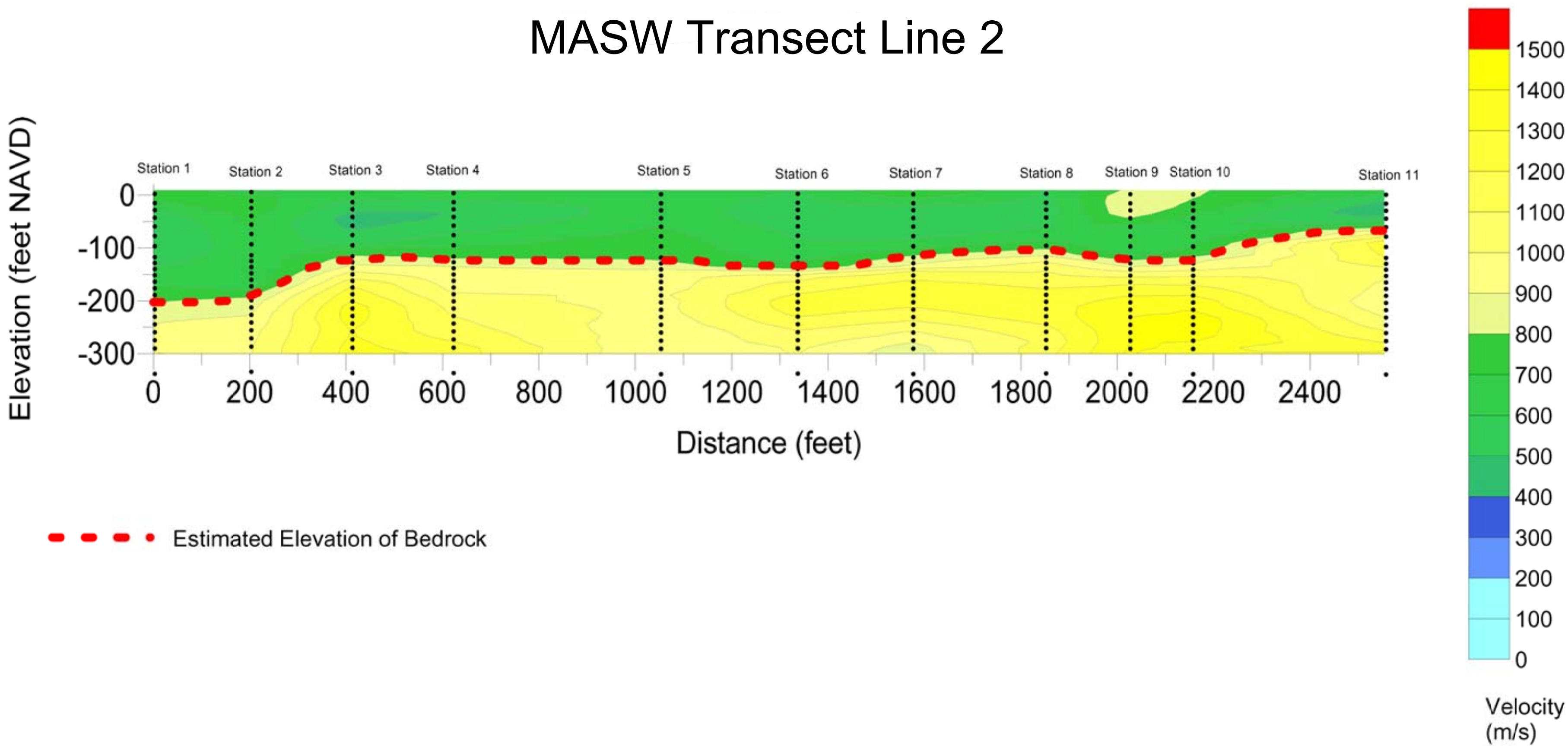
The information provided in this report is an interpretation of remote sensing data. While we strive to use appropriate methods to provide the most reliable interpretation possible, the data are subject to multiple sources of error and uncertainty. As a result we cannot guarantee the reliability of our interpretation without verification from direct methods of investigation such as borings or other methods.

Figures 1 through 7



ENTRIX Down to Earth. Down to Business.	PROJECT NAME: MALIBU	DWG. NUMBER: 02667001je1
	PROJECT NUMBER: 02667001	DATE: 06/03/10

FIGURE 1. MASW STATION LOCATION MAP.



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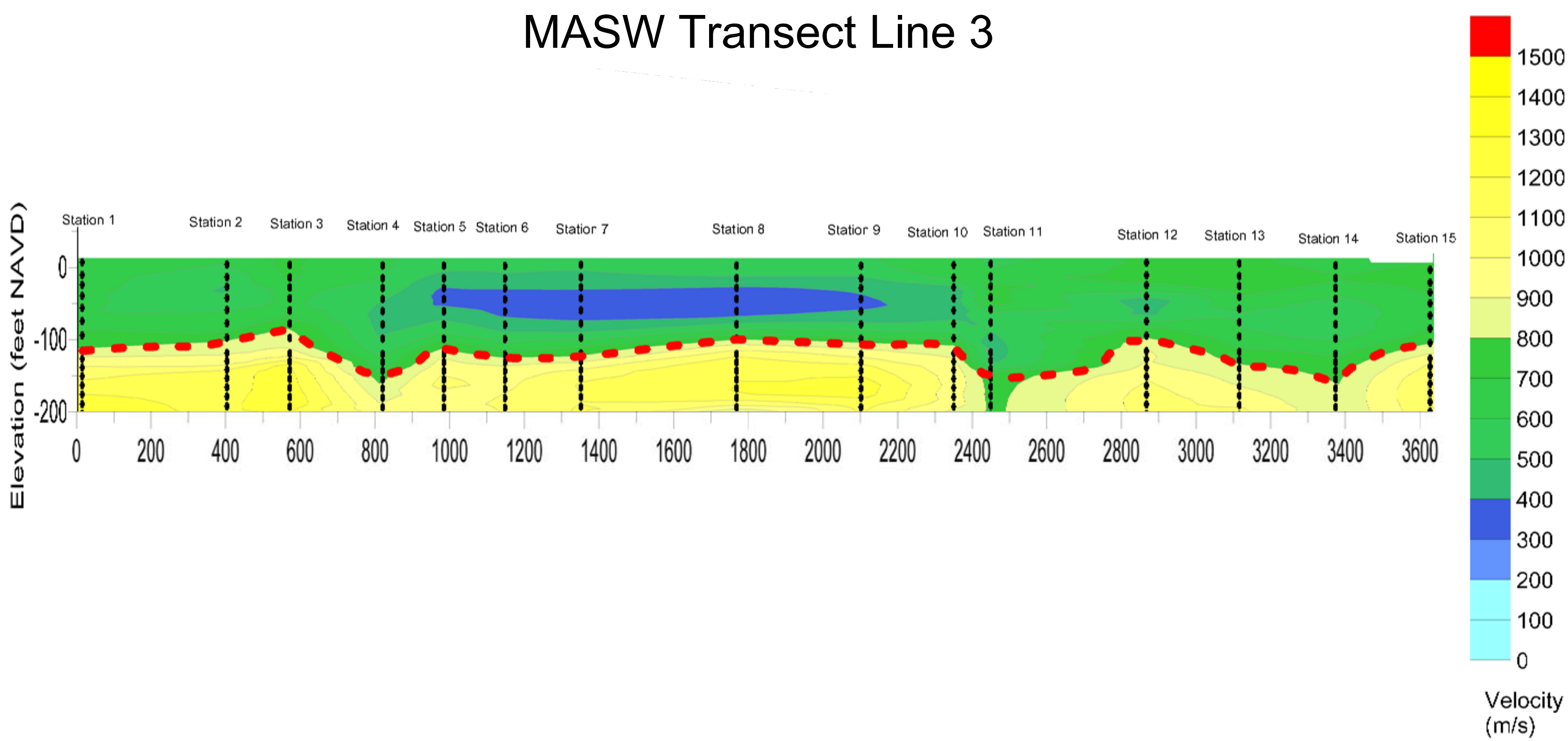
PROJECT NUMBER: 02667001	DATE: 05/21/10

FIGURE 2. MASW TRANSECT LINE 2.



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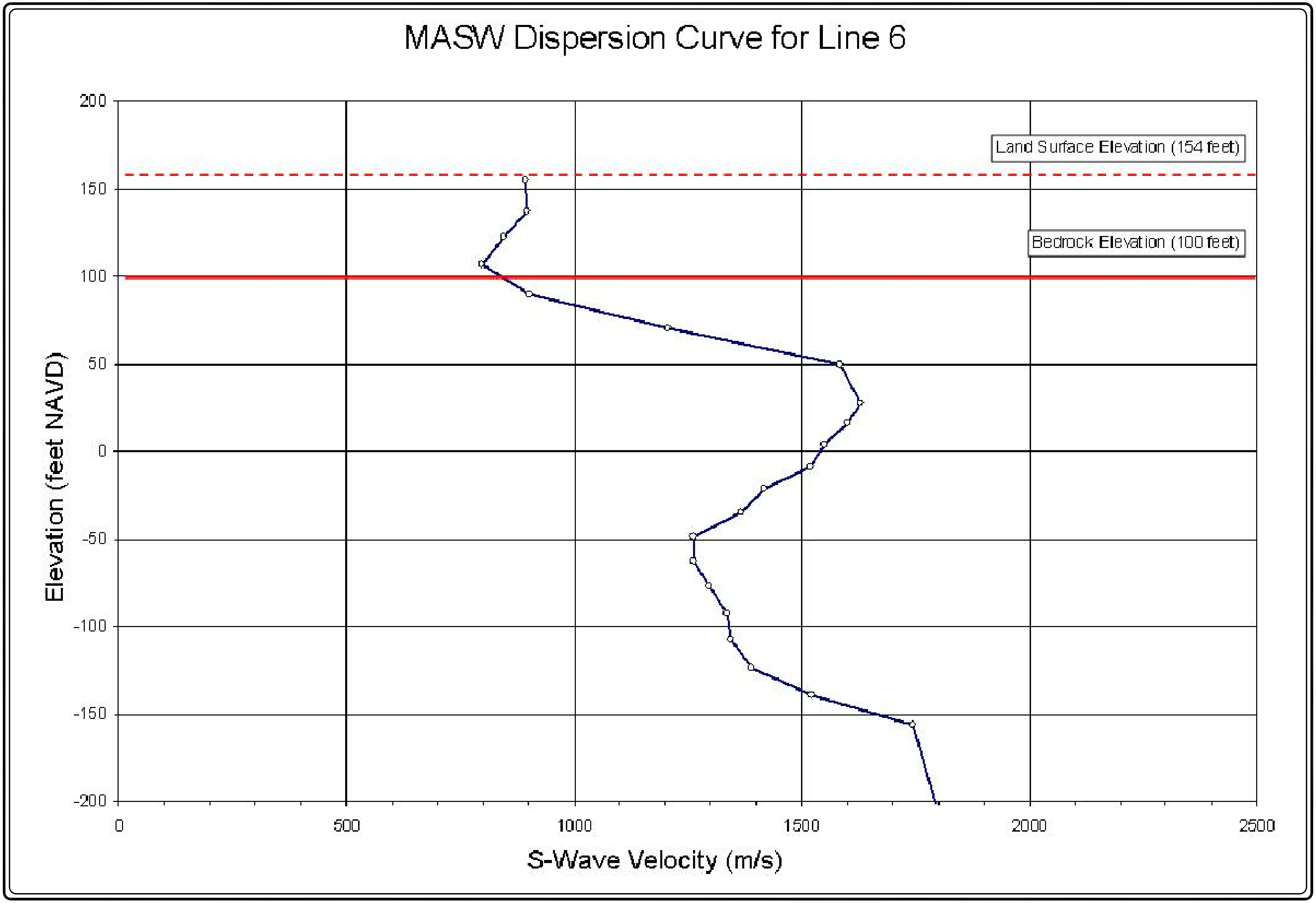
PROJECT NAME: MALIBU
PROJECT NUMBER: 02667001
DWG. NUMBER: 02667001je1
DATE: 05/21/10

FIGURE 3. MASW TRANSECT LINE 3.



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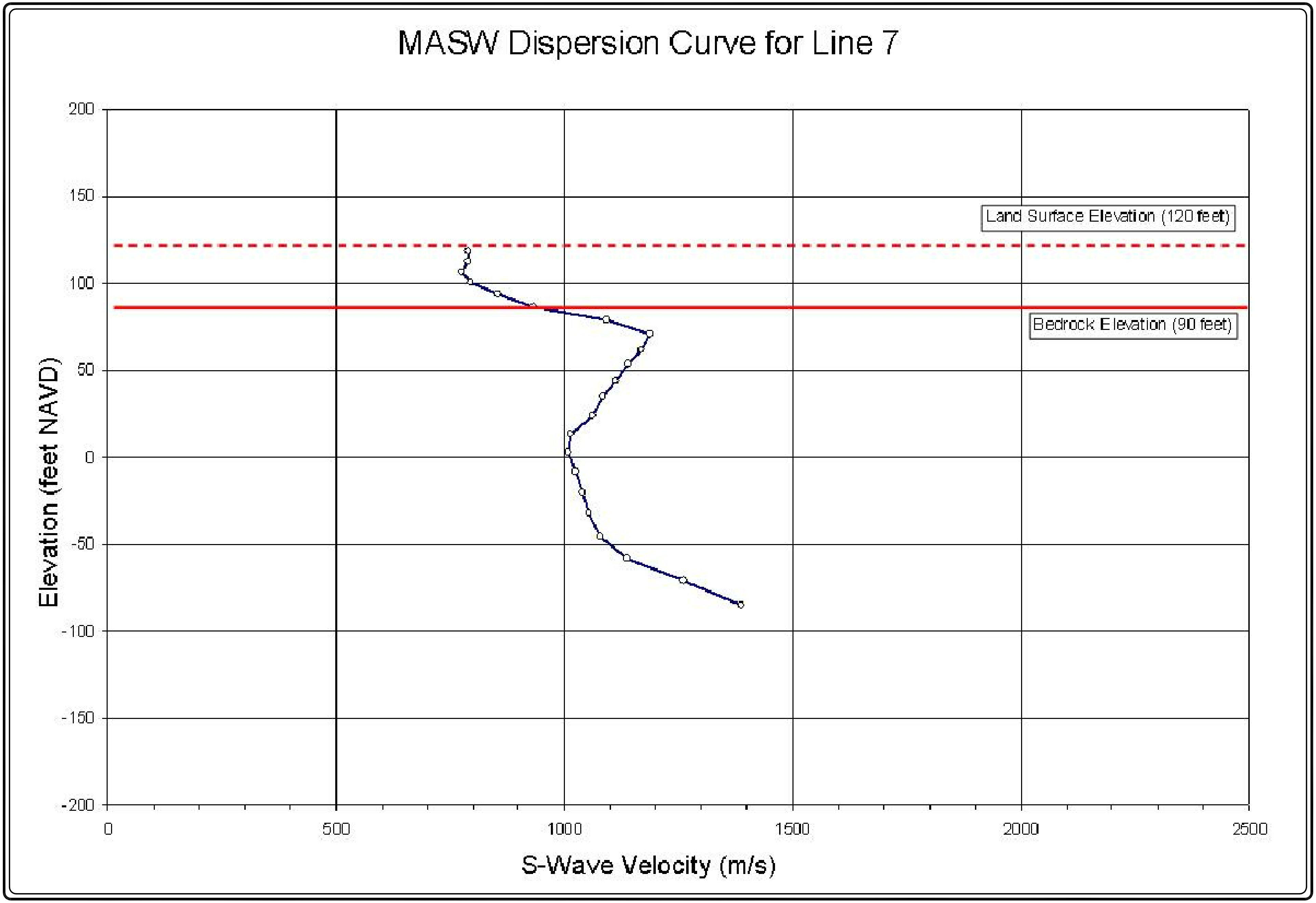
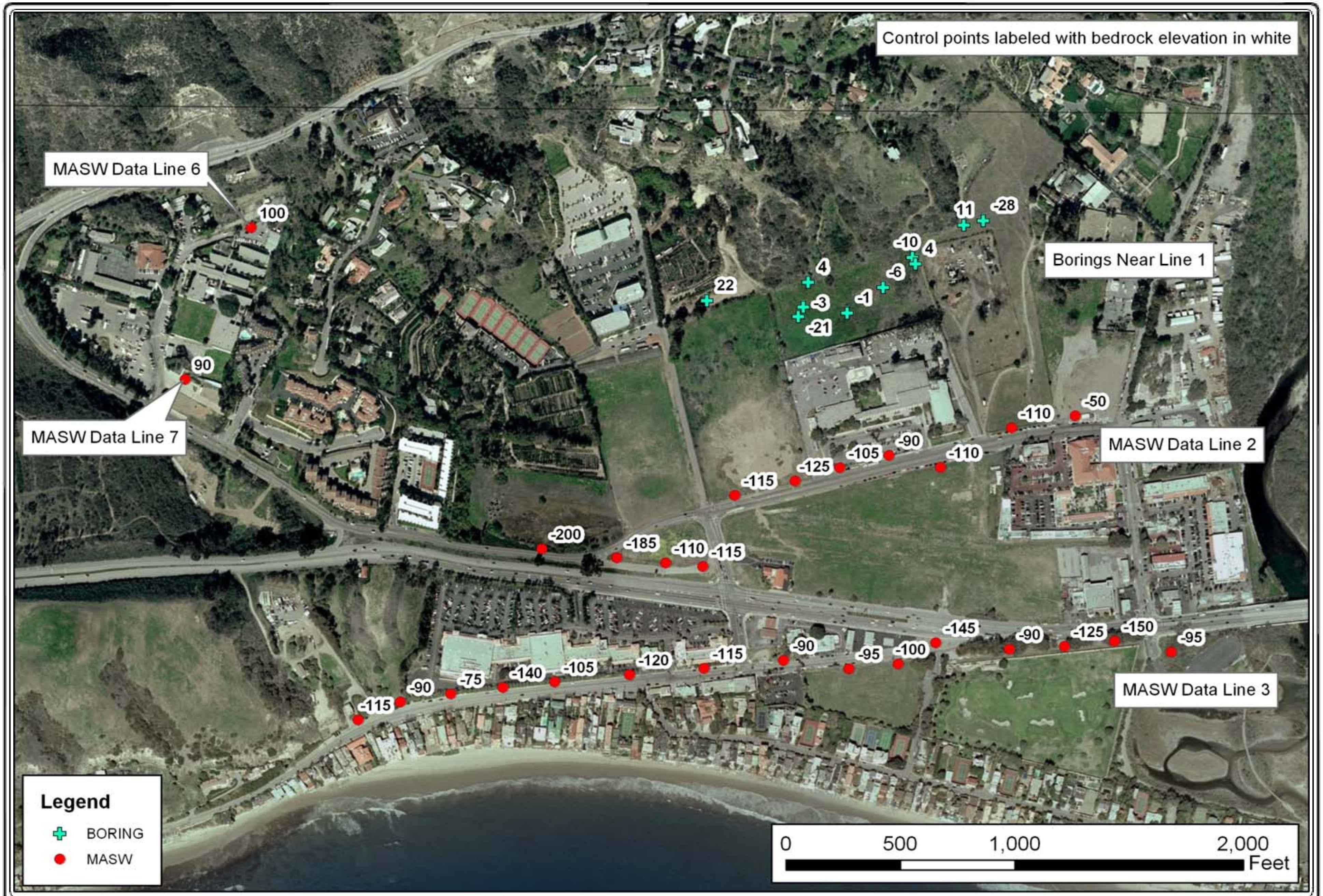
	PROJECT NUMBER: 02667001	DATE: 06/08/10

FIGURE 4. MASW DISPERSION CURVE FOR LINE 6.



ENTRIX Down to Earth. Down to Business.	PROJECT NAME: MALIBU — DWG. NUMBER: 02667001je1
	PROJECT NUMBER: 02667001 — DATE: 06/08/10

FIGURE 5. MASW DISPERSION CURVE FOR LINE 7.



ENTRIX Down to Earth. Down to Business.

PROJECT NAME: MALIBU	DWG. NUMBER: 02667001je1
PROJECT NUMBER: 02667001	DATE: 06/08/10

FIGURE 6. BEDROCK ELEVATION MAP FROM MASW DATA.

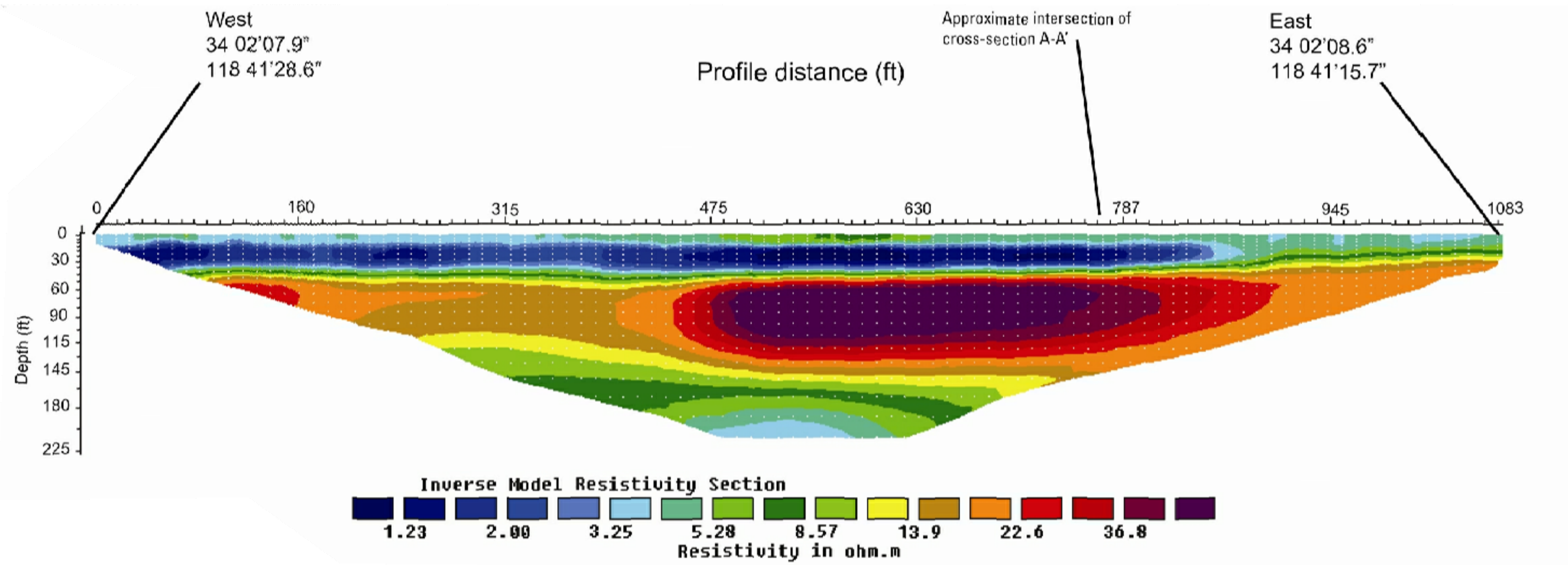


DIAGRAM PROVIDED BY USGS (2008)

ENTRIX Down to Earth. Down to Business.

PROJECT NAME: MALIBU
PROJECT NUMBER: 02667001
DWG. NUMBER: 02667001je1
DATE: 06/08/10

FIGURE 7. USGS RESISTIVITY LINE, MALIBU CIVIC CENTER SITE.

Tables 1 & 2

Table 1. Soil and Rock Shear Wave Velocity Classification

Velocity (ft/s)	Velocity (m/sec)	Classification
> 5,000	>1,524	Hard rock
2,500 to 5,000	762 to 1,524	Rock
1,200 to 2,500	366 to 762	Very dense soil and soft rock
600 to 1,200	183 to 366	Stiff soil
<600	183	Soft soil

Source: ASCE 7-02 and ASCE 7-05

Table 2. Malibu Boring Data From McDonald Morrissey

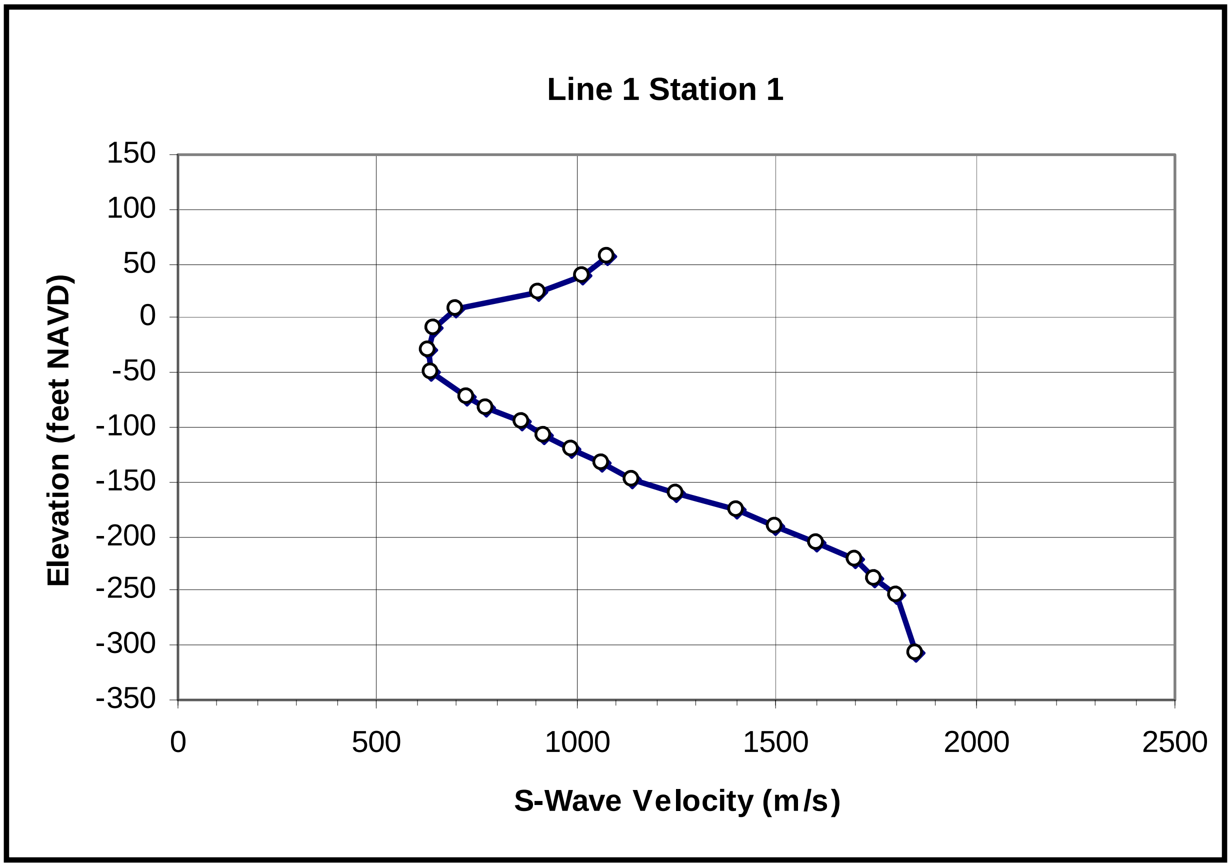
Location ID	Pdf Page(s)	Type	Longitude (Decimal Degrees) (NAD83)	Latitude (Decimal Degrees) (NAD83)	X (California State Plane Zone V FIPS 0405 NAD83 feet)	Y (California State Plane Zone V FIPS 0405 NAD83 feet)	Estimated Land Surface	Land Surface Datum	Bedrock Depth Pick (ft BGS)	Estimated Bedrock Elevation (NAVD88 ft)	Bedrock Elevation Datum
902	4	Miscellaneous Boring			6352573.04	1837055.13	29.56	NGVD88 ft	33.00	-3.44	NGVD88 ft
1696	5-6	Miscellaneous Boring			6353051.76	1837279.41	25.27	NGVD88 ft	35.00	-9.73	NGVD88 ft
1697	7	Miscellaneous Boring			6353063.83	1837250.66	24.00	NGVD88 ft	20.00	4.00	NGVD88 ft
2323	8	Miscellaneous Borings	-118.689059	34.038579	6352922.73	1837142.56	27.62	NGVD88 ft?	34.00	-6.38	NGVD88 ft?
2451	9	Miscellaneous Borings	-118.690140	34.038640	6352595.43	1837166.89	37.24	NGVD88 ft?	33.00	4.24	NGVD88 ft?
2453	10-11	Miscellaneous Borings	-118.690281	34.038209	6352551.59	1837010.35	28.80	NGVD88 ft?	50.00	-21.20	NGVD88 ft?
2458	12	Miscellaneous Borings	-118.689576	34.038260	6352765.32	1837027.55	29.11	NGVD88 ft?	30.00?	-0.89	NGVD88 ft?
2461	13	Miscellaneous Borings	-118.691602	34.038404	6352151.88	1837084.02	49.78	NGVD88 ft?	27.50	22.28	NGVD88 ft?
3289	14	Miscellaneous Borings	-118.687897	34.039362	6353276.83	1837424.96	23.18	NGVD88 ft?	12.00	11.18	NGVD88 ft?
3293	15	Miscellaneous Borings	-118.687621	34.039419	6353360.54	1837445.16	21.89	NGVD88 ft?	50.00	-28.11	NGVD88 ft?

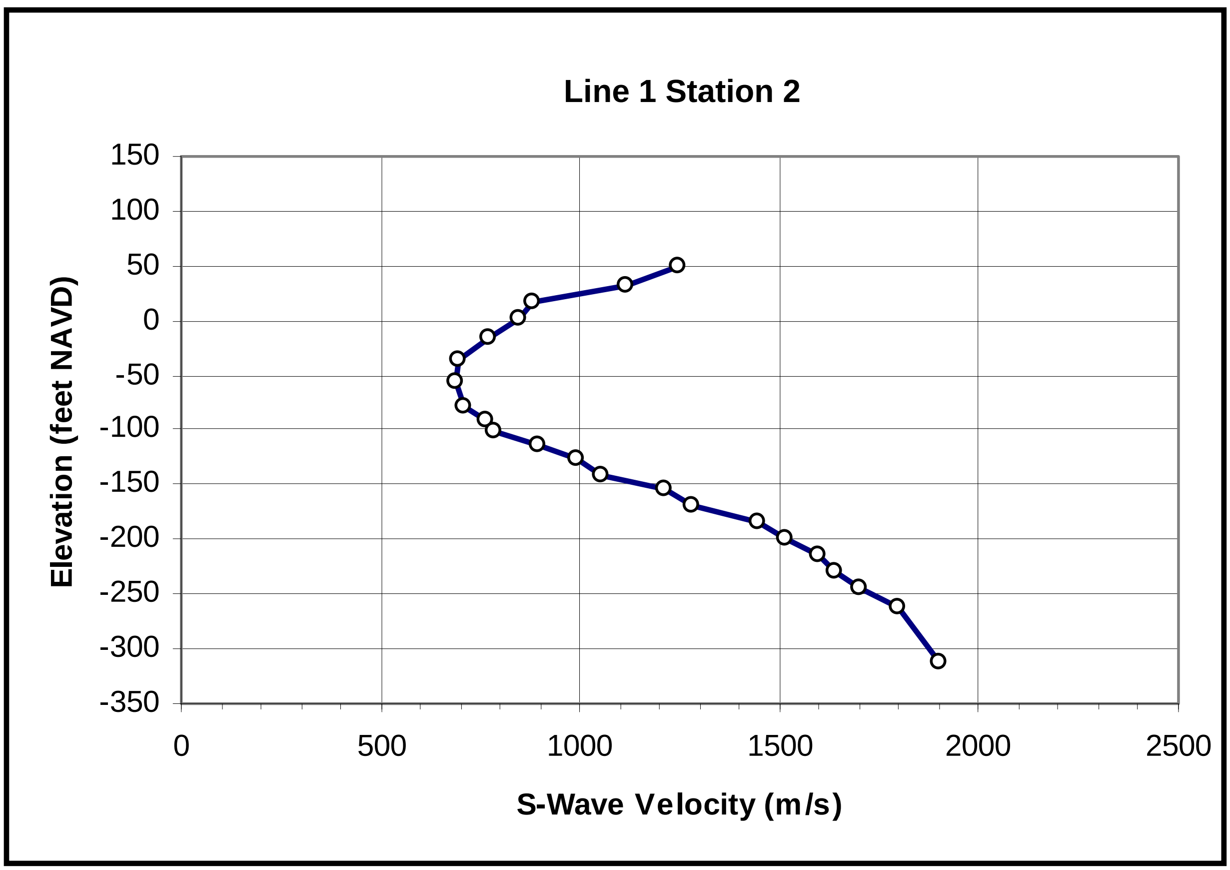
*Page number in Borings Along Jansen Line #1_Final_Set.pdf

APPENDIX A

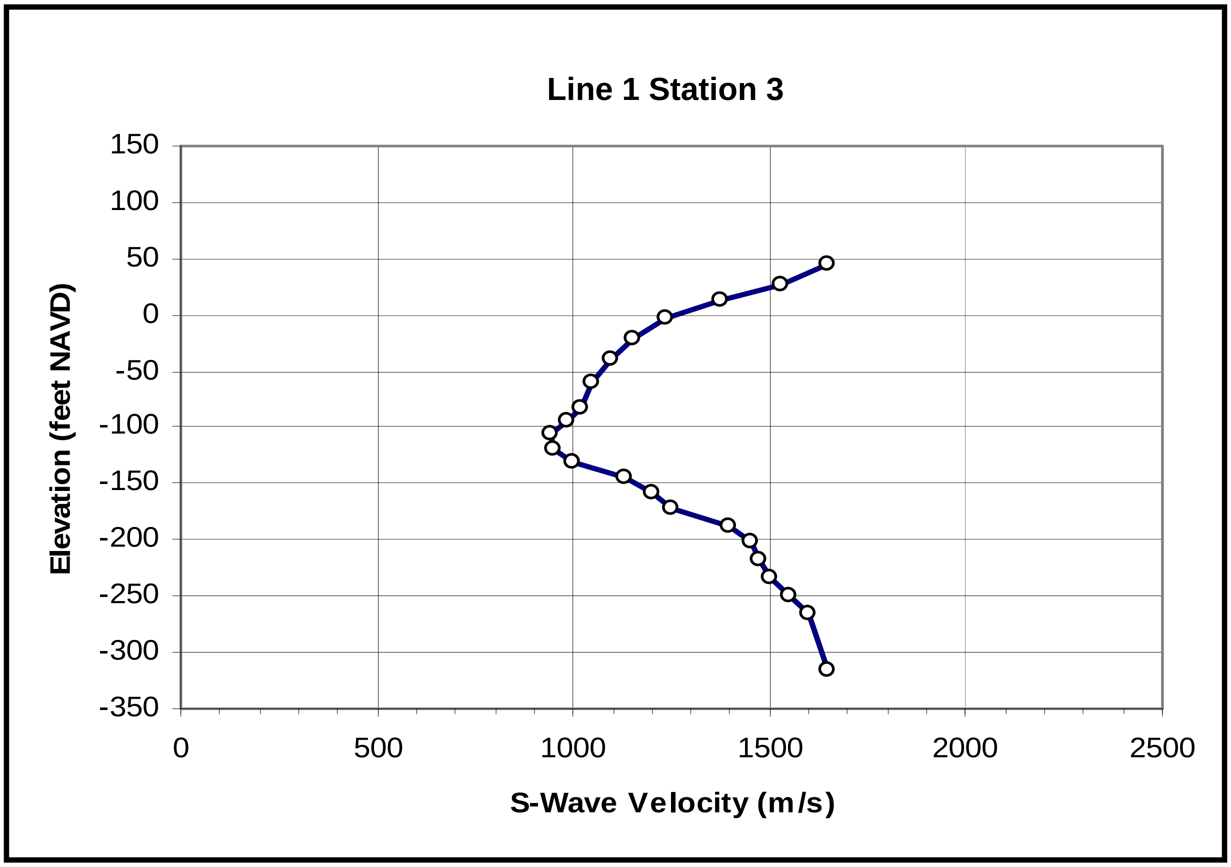
Velocity Dispersion Curves for Each Station

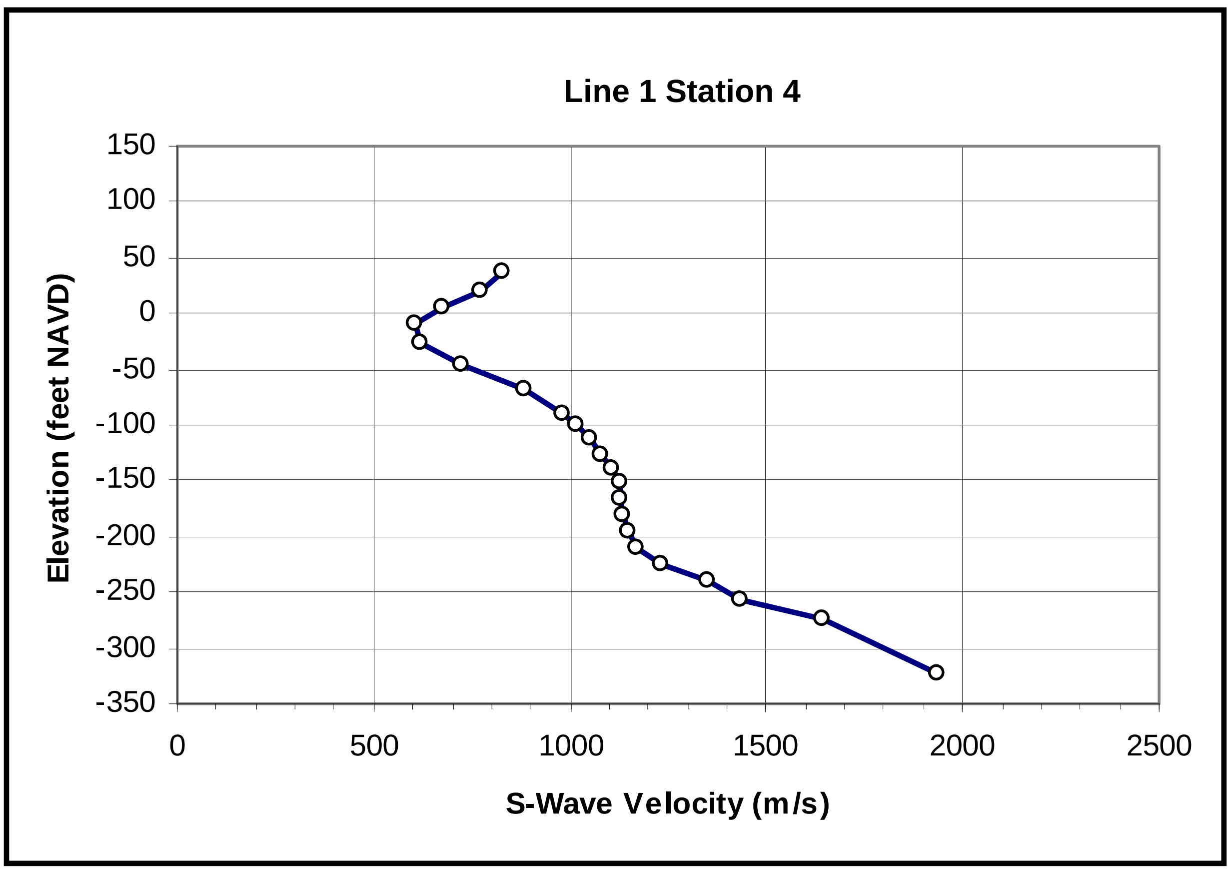
MASW Dispersion Curves: Line 1



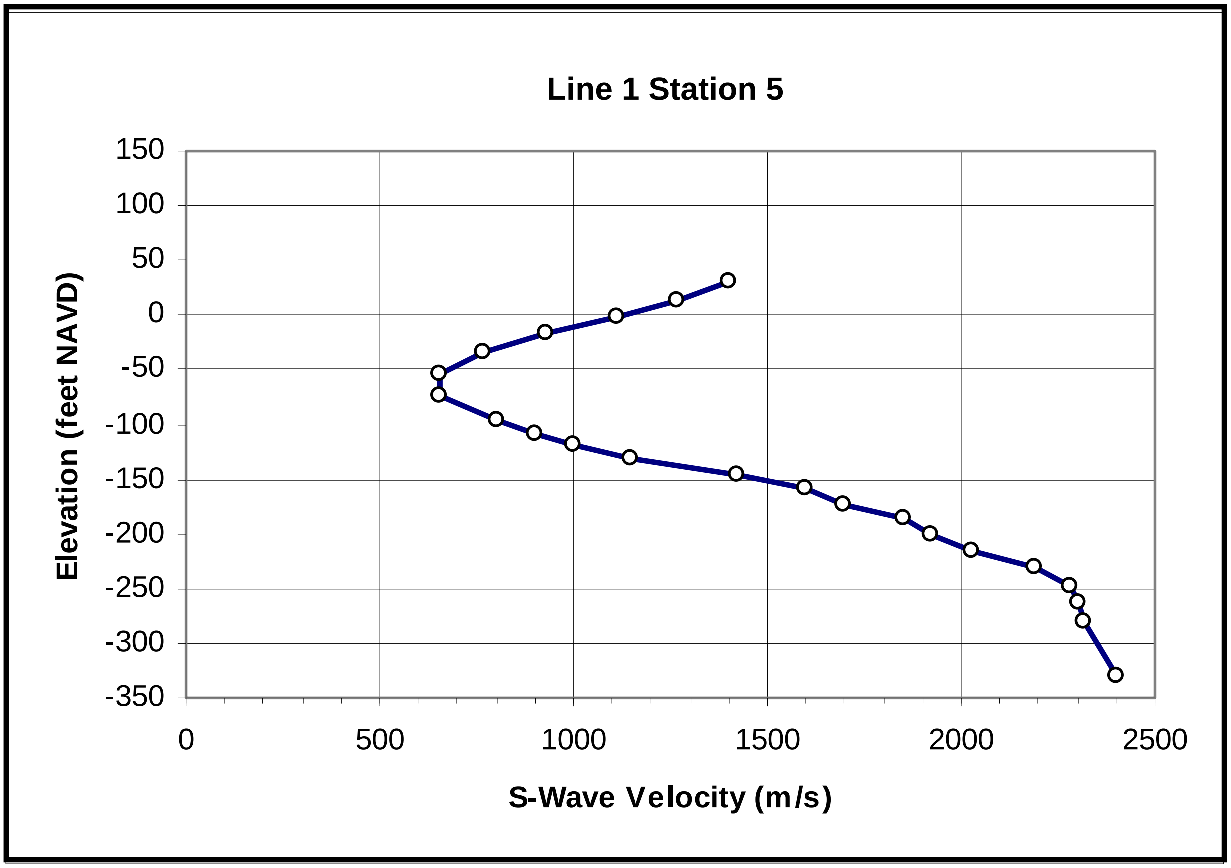


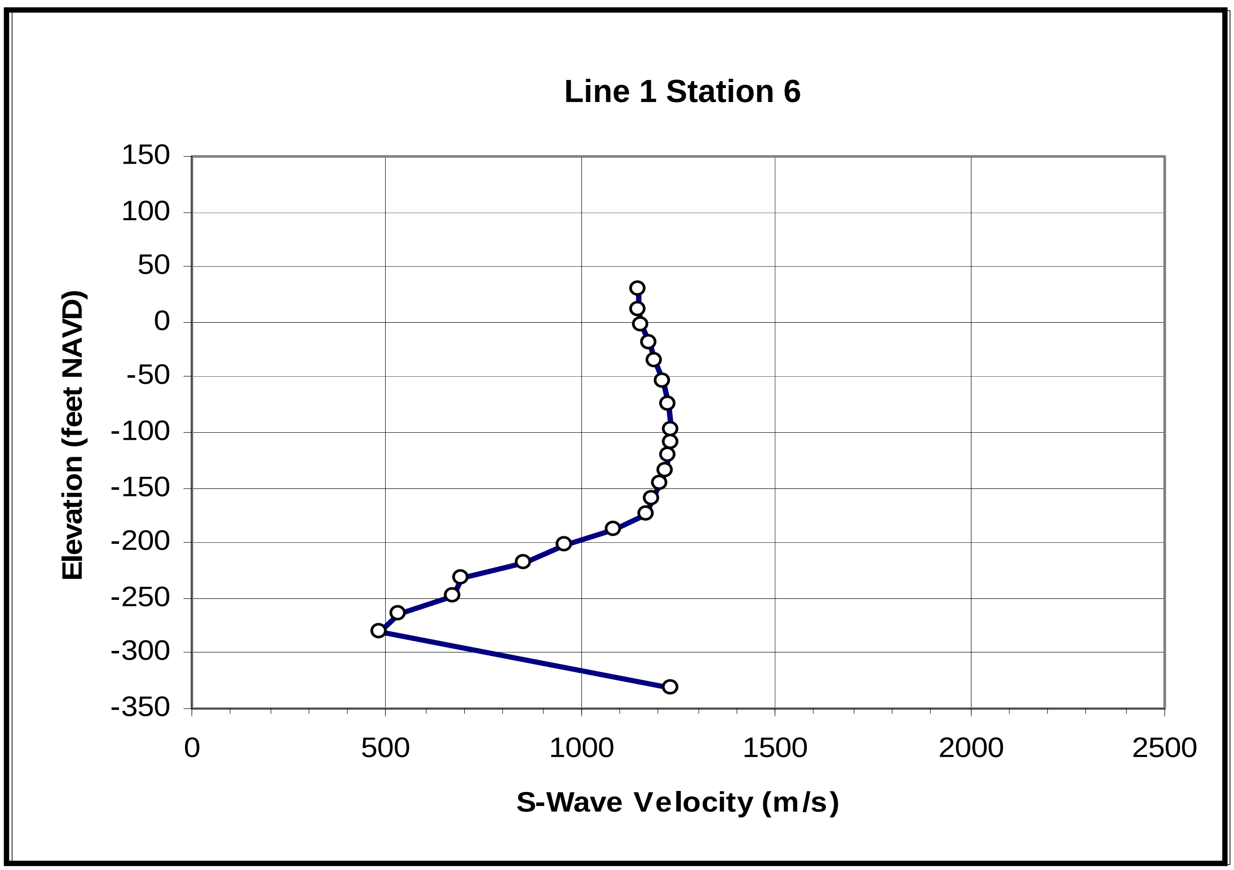
MASW Dispersion Curves: Line 1





MASW Dispersion Curves: Line 1





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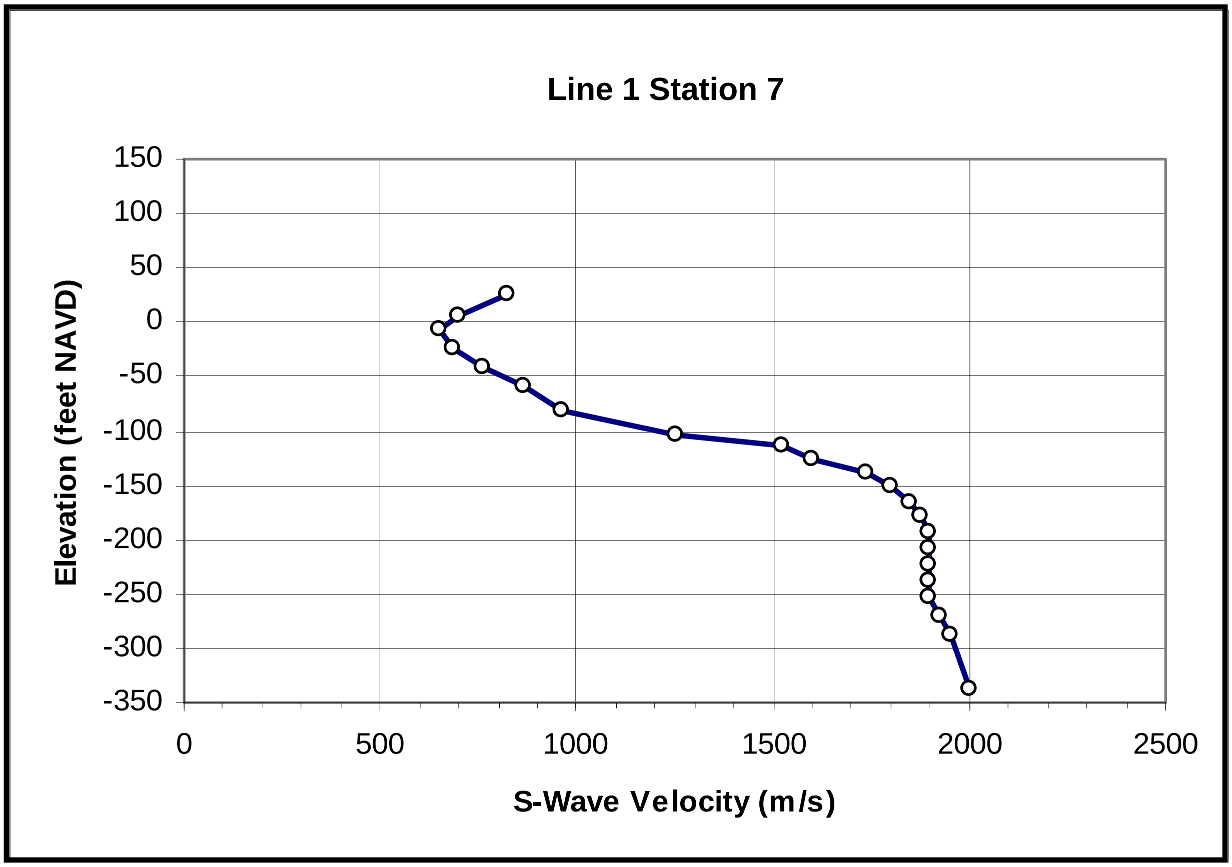
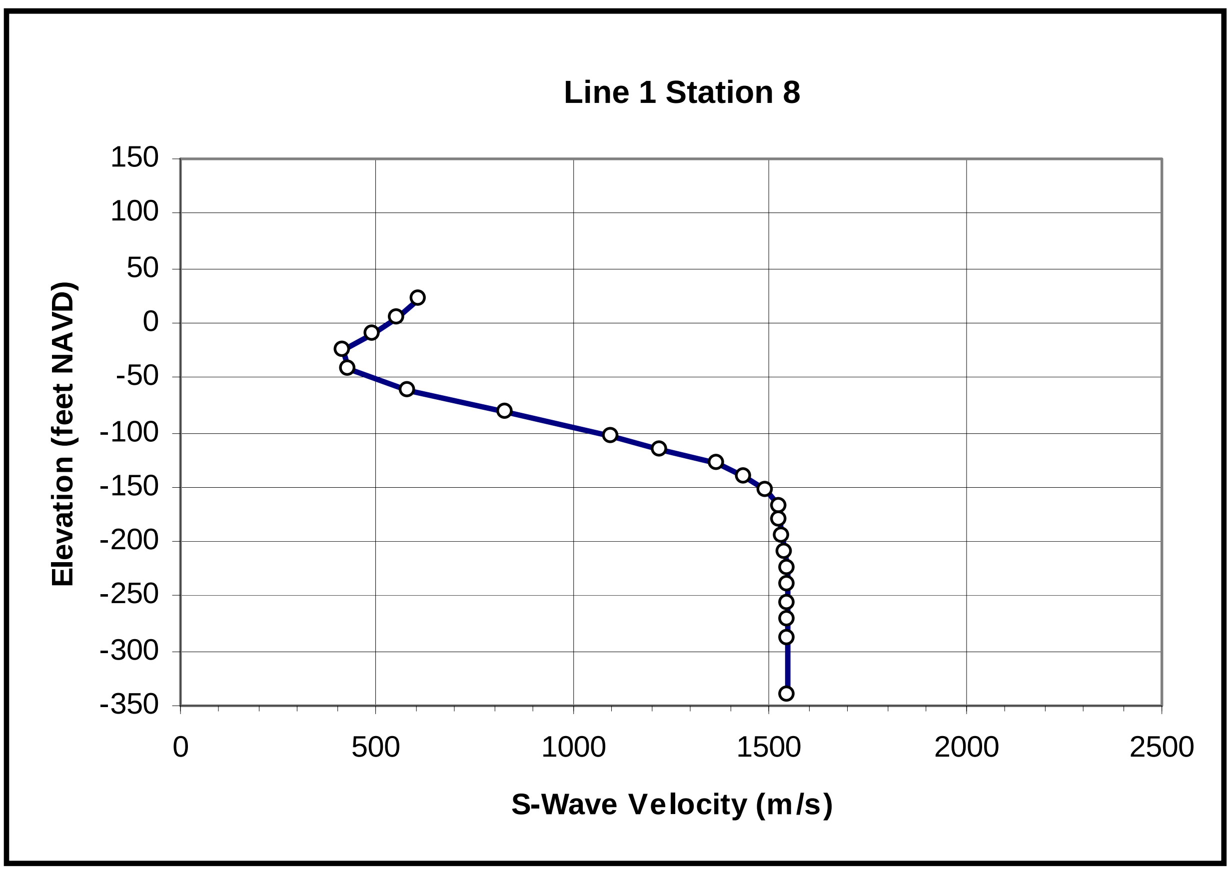
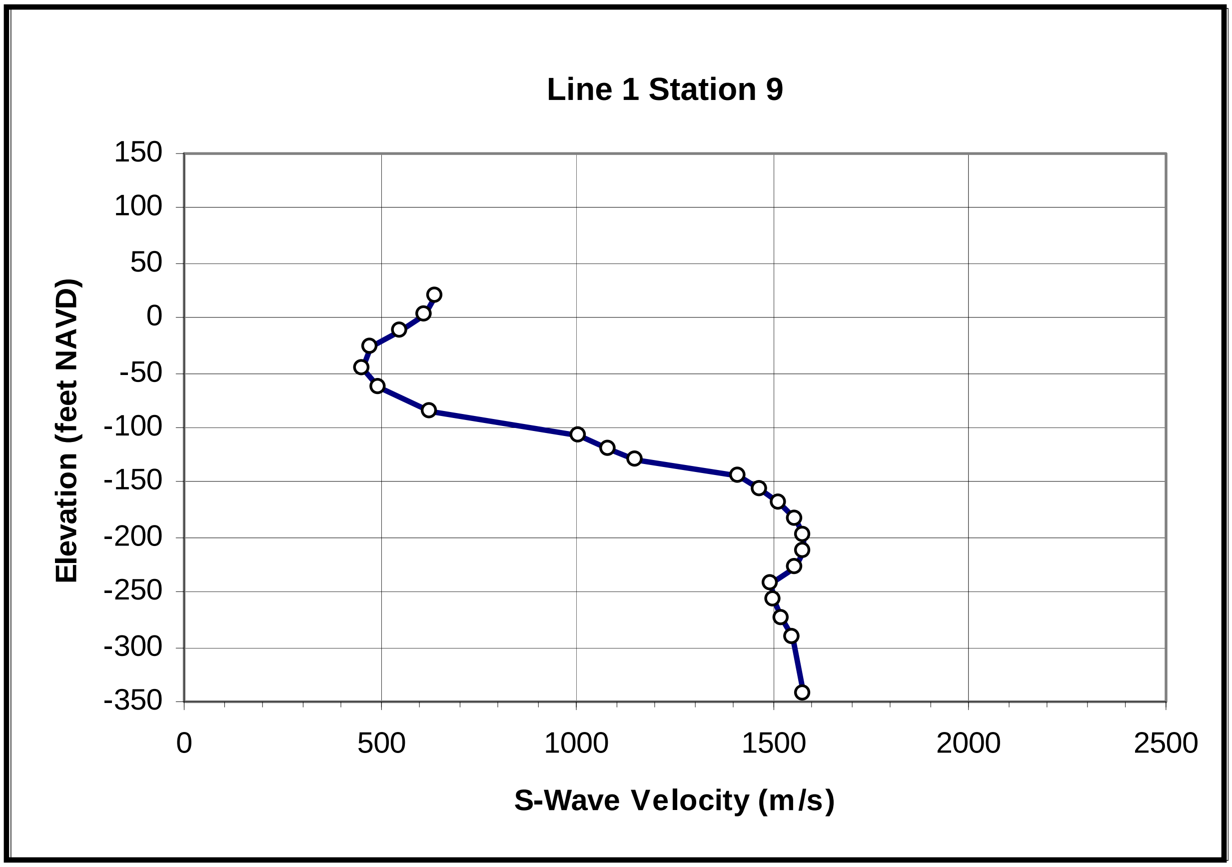




MASW Dispersion Curves: Line 1



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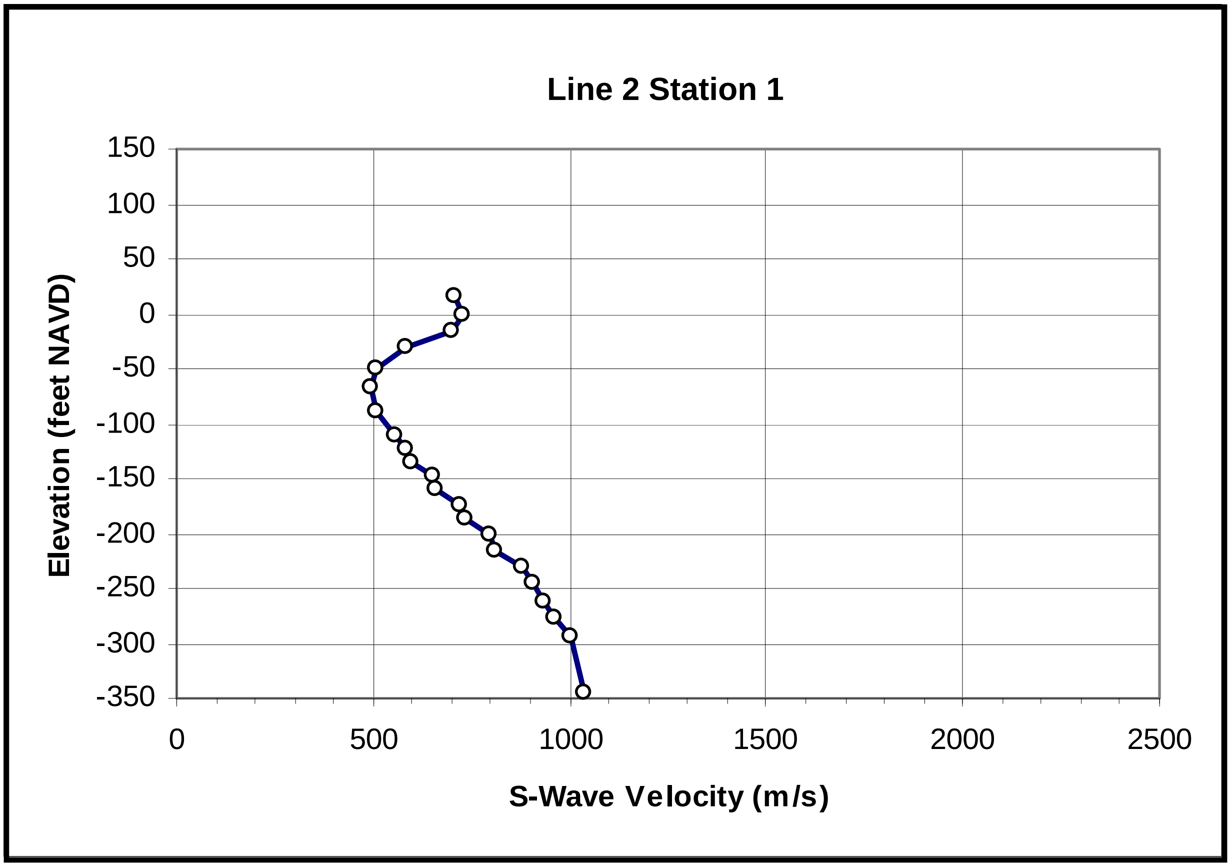

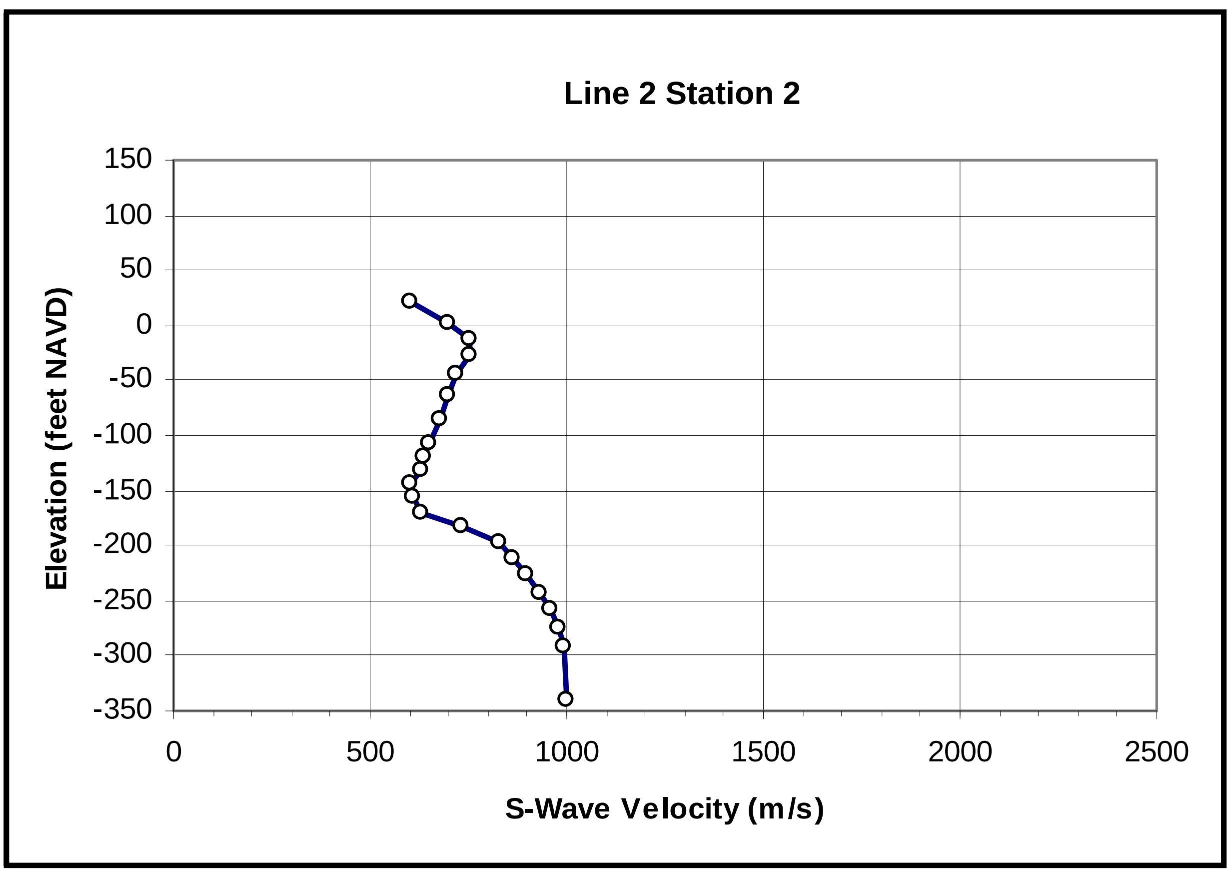

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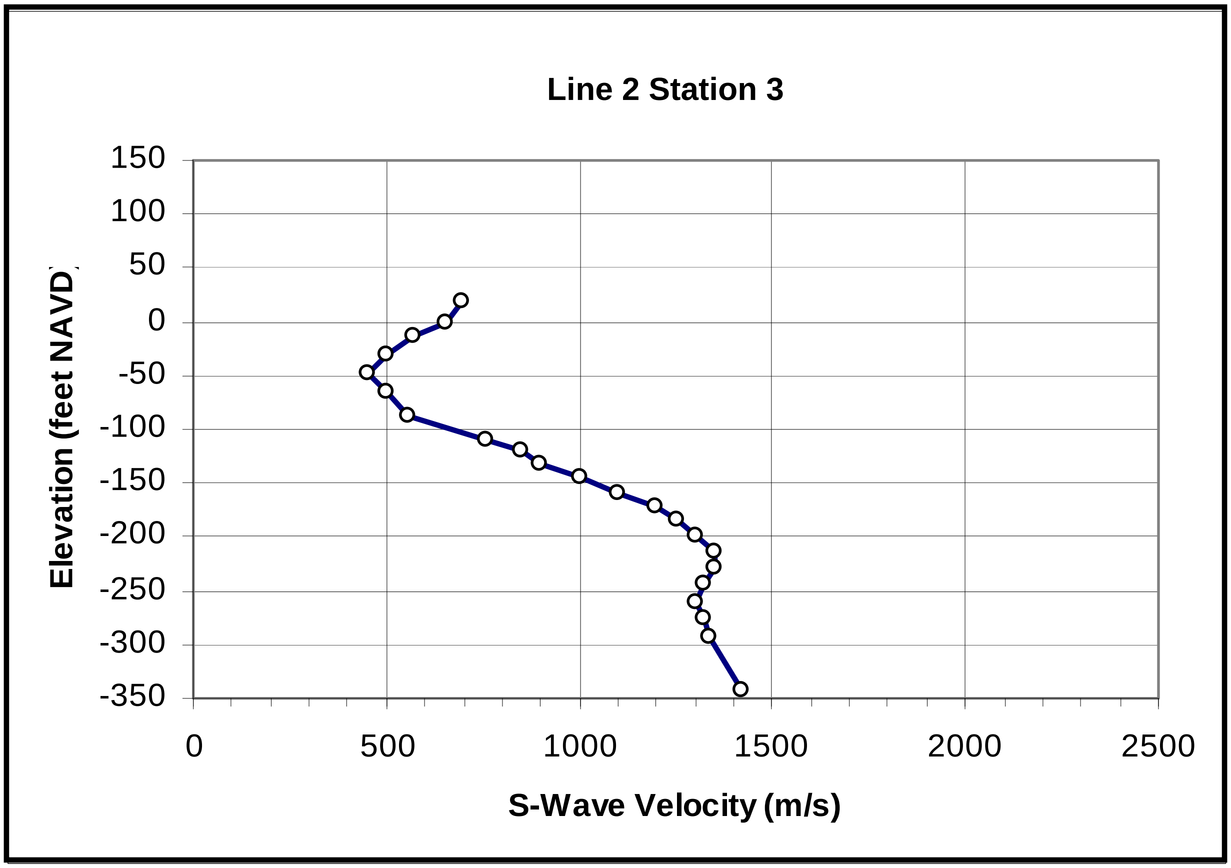

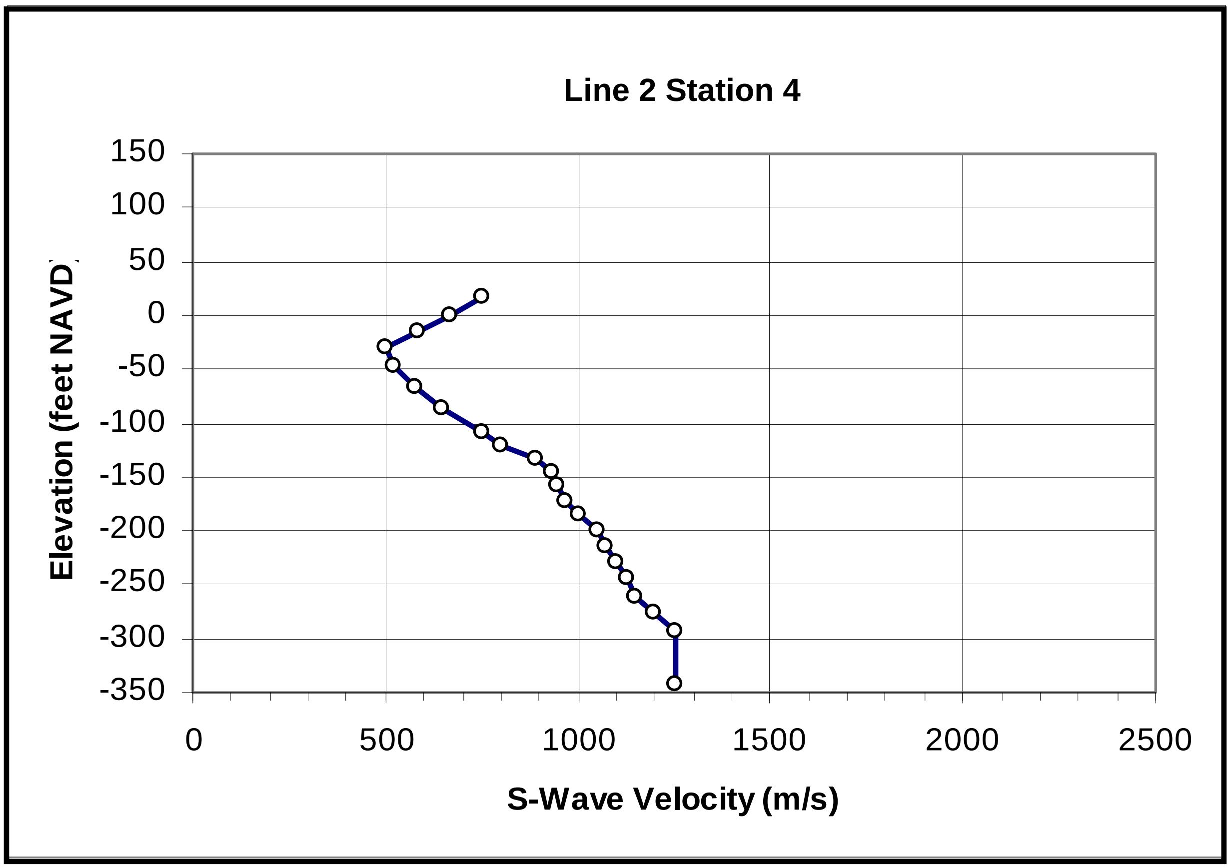

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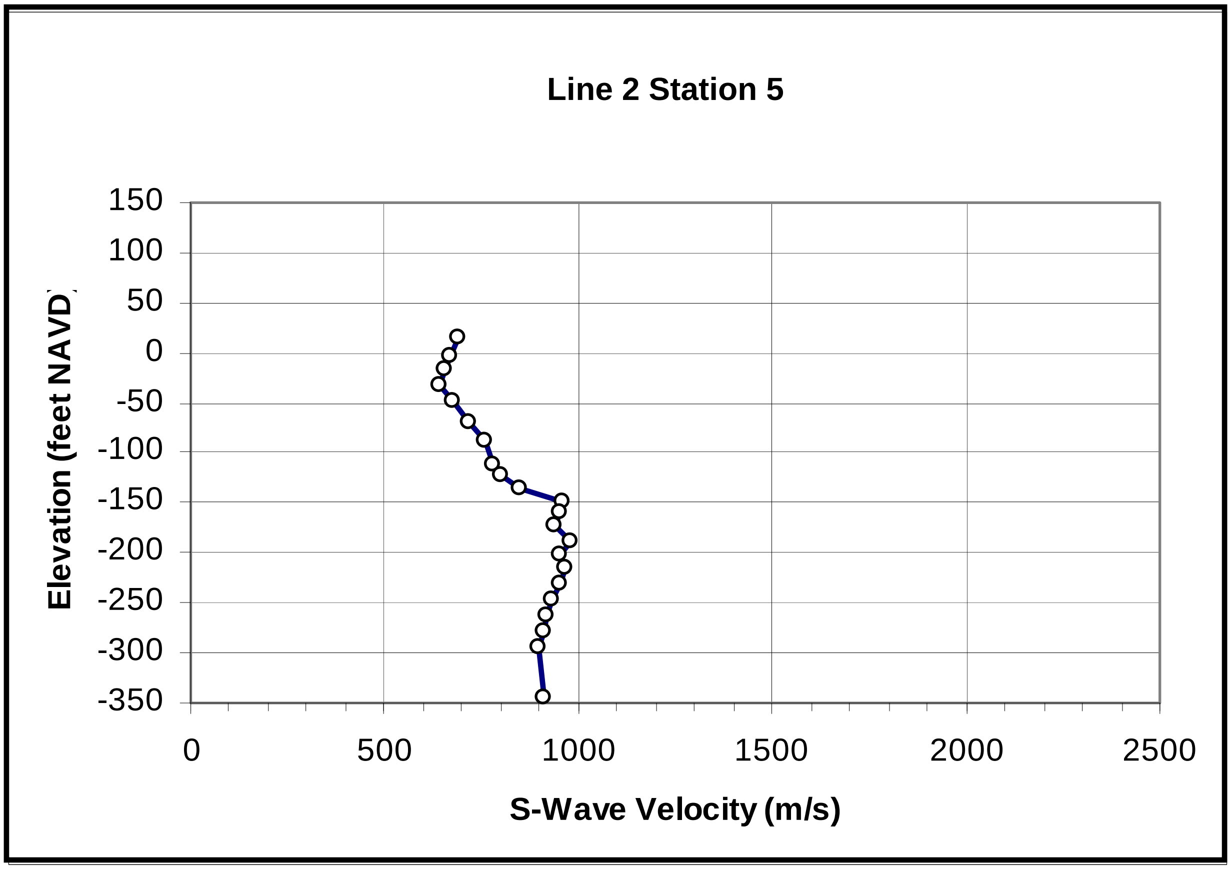

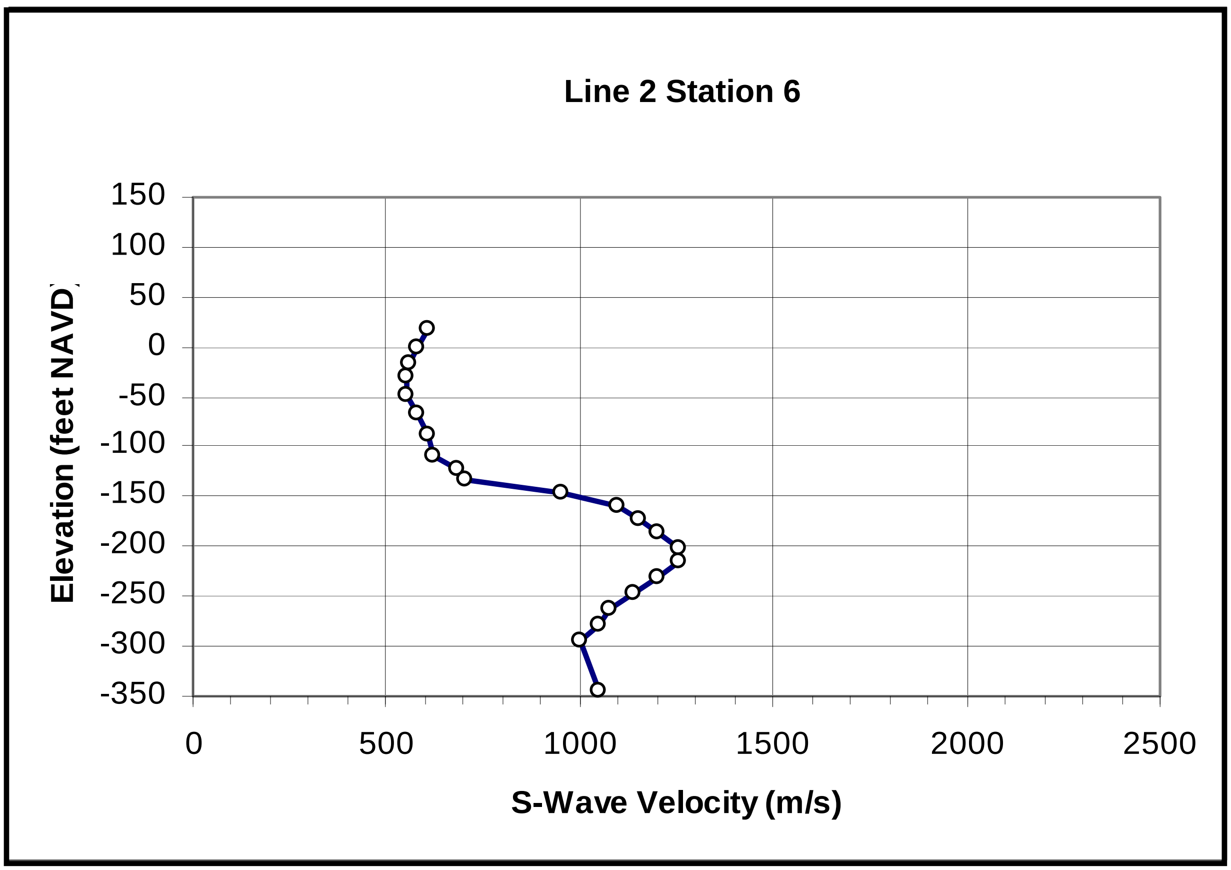

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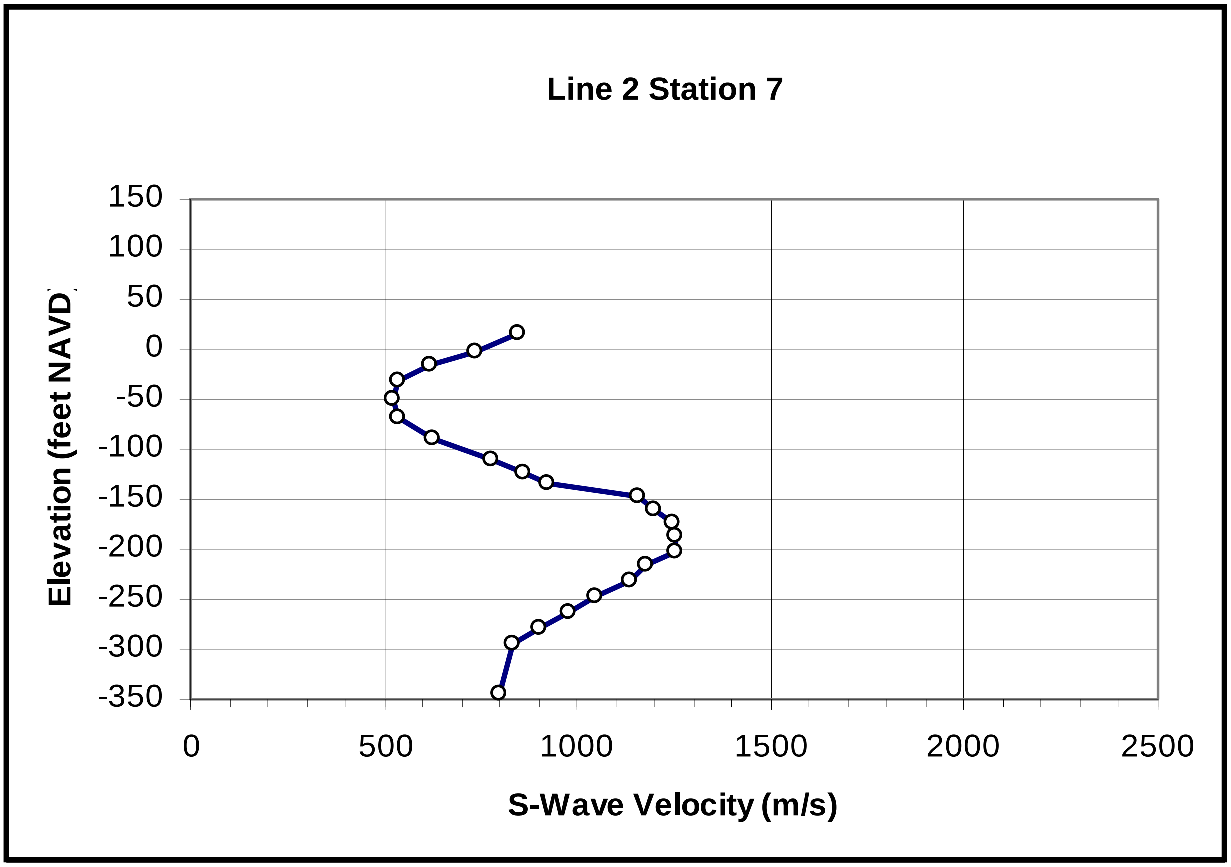

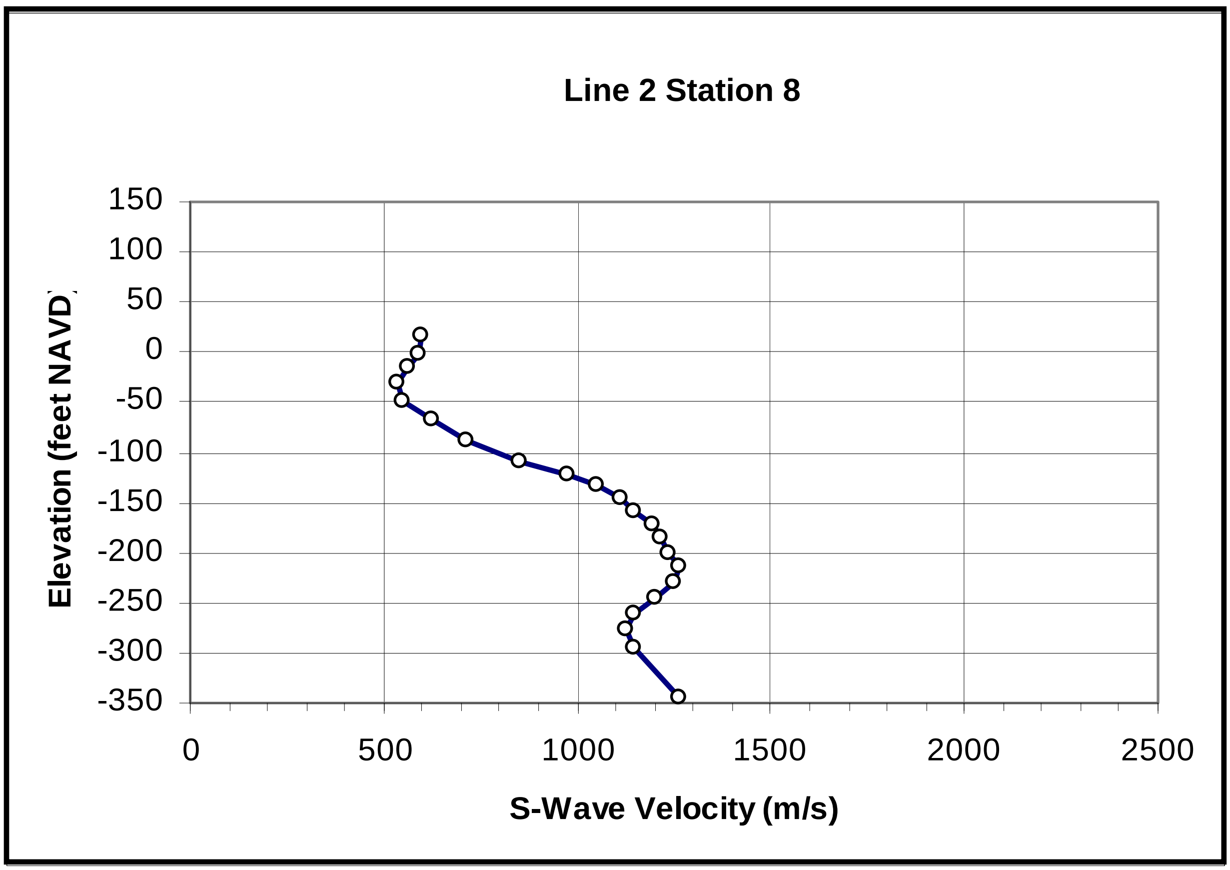

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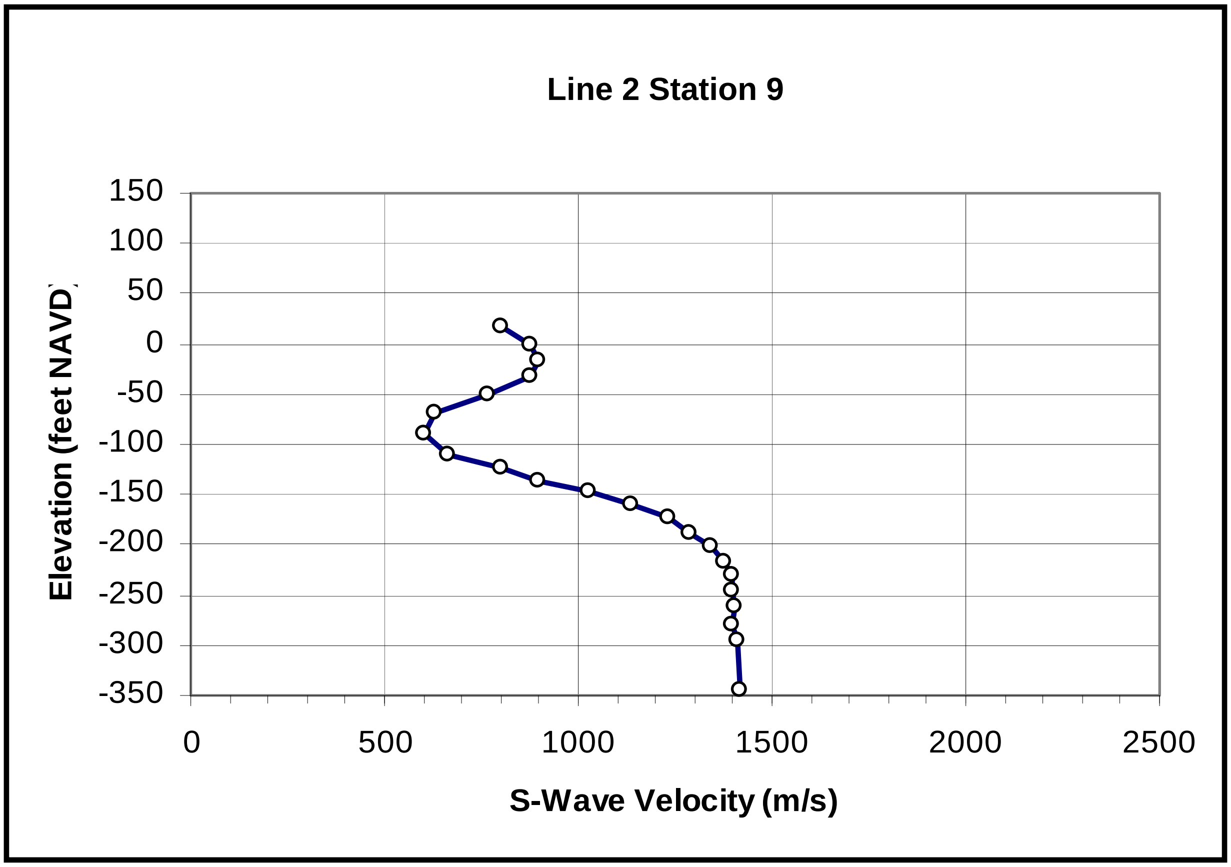

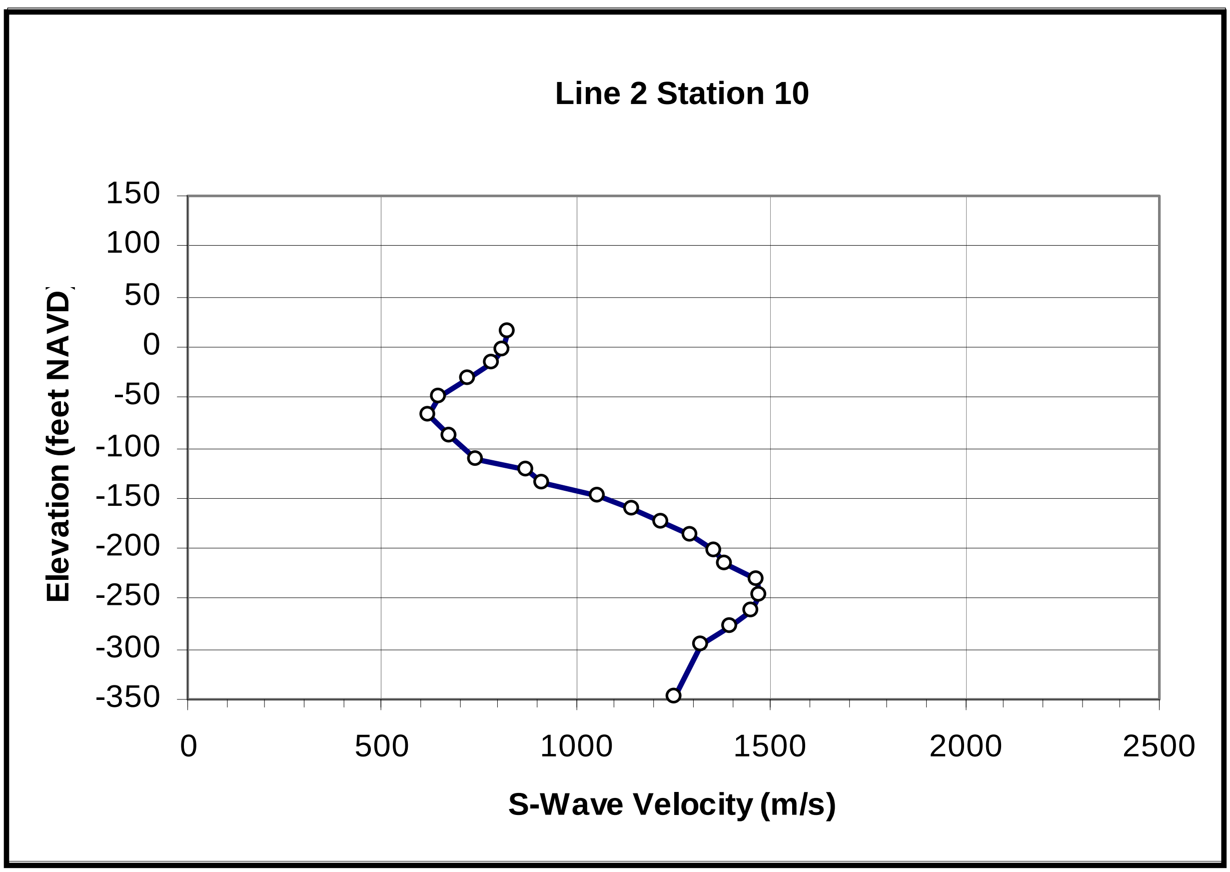

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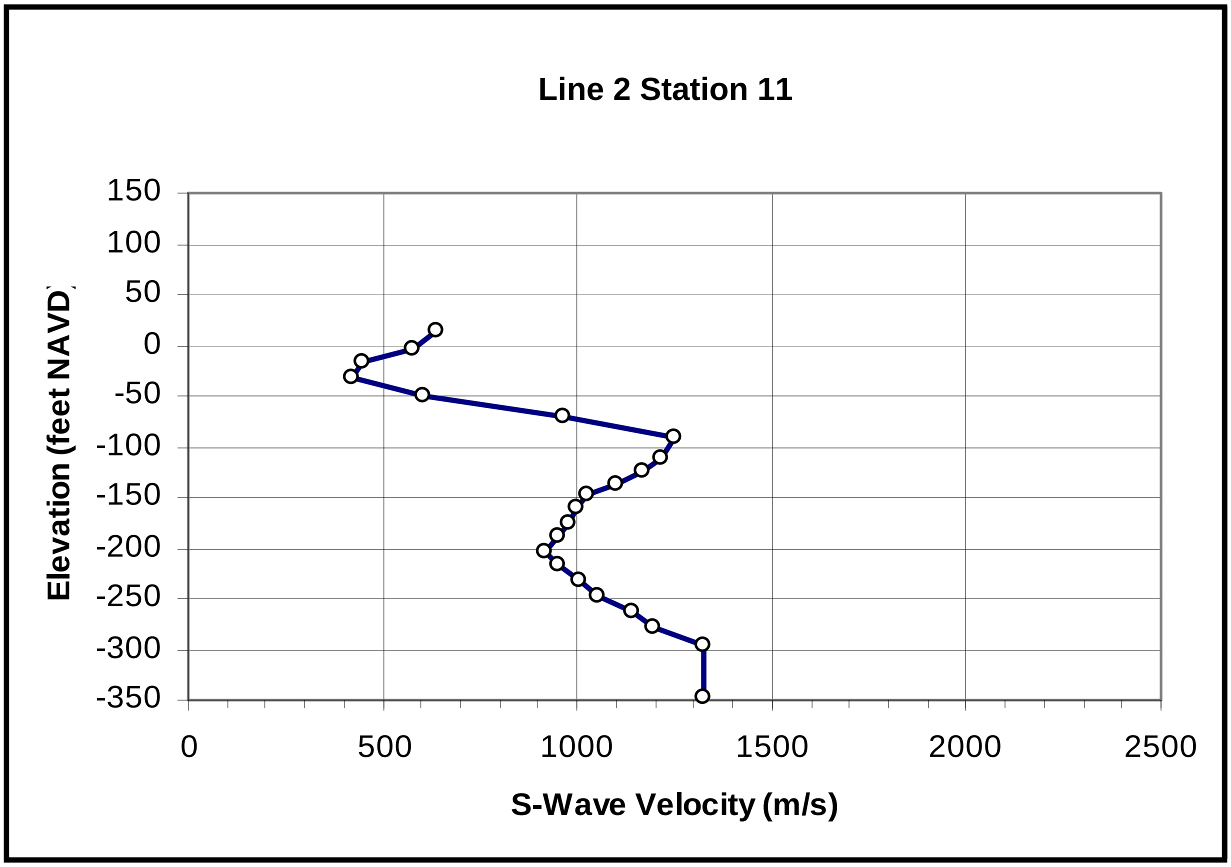

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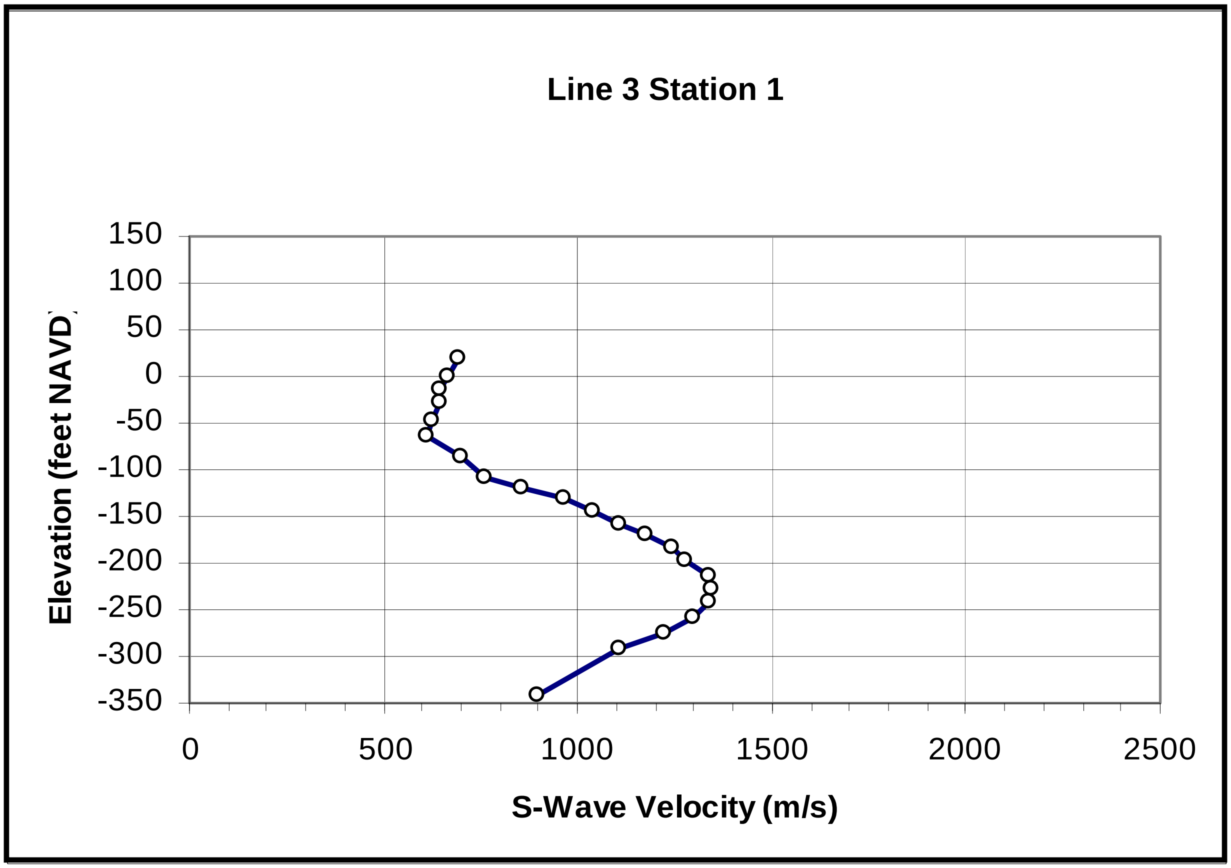

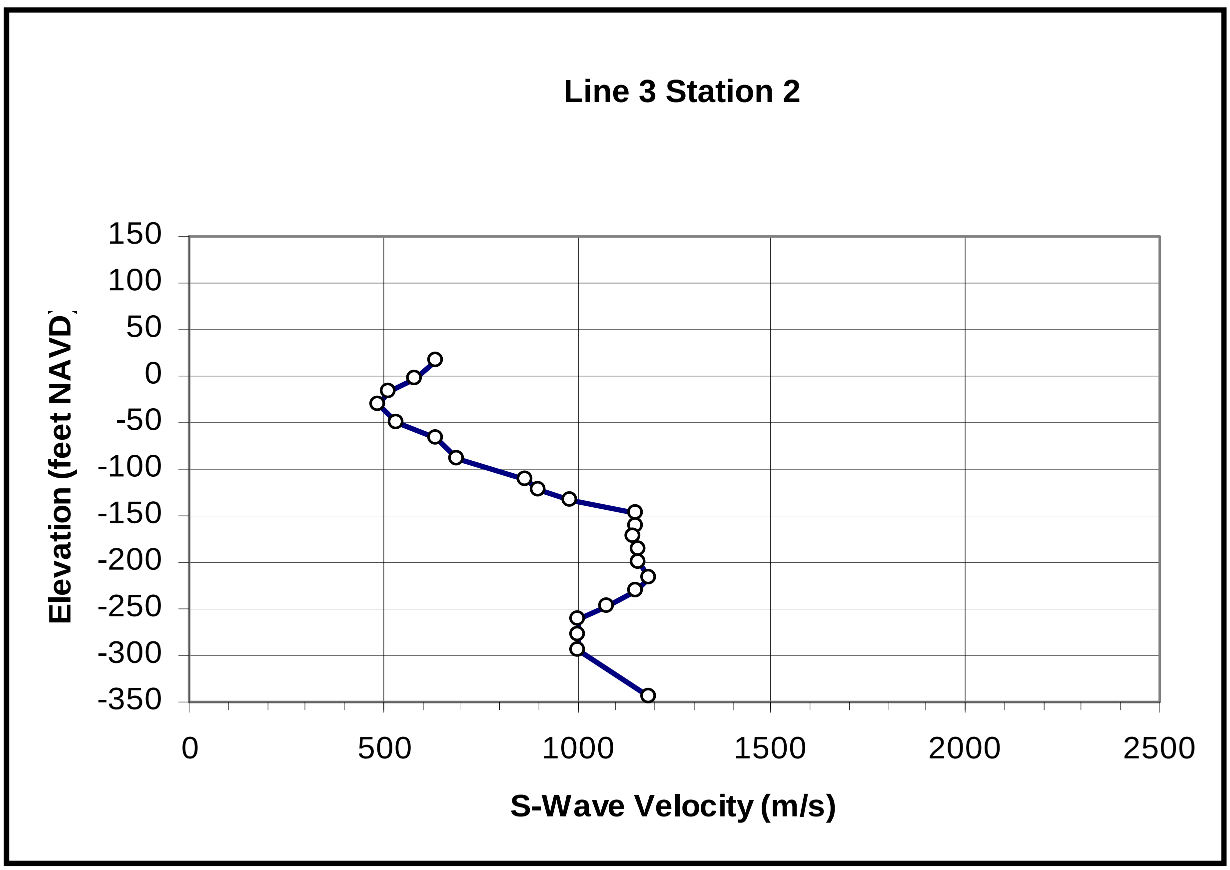

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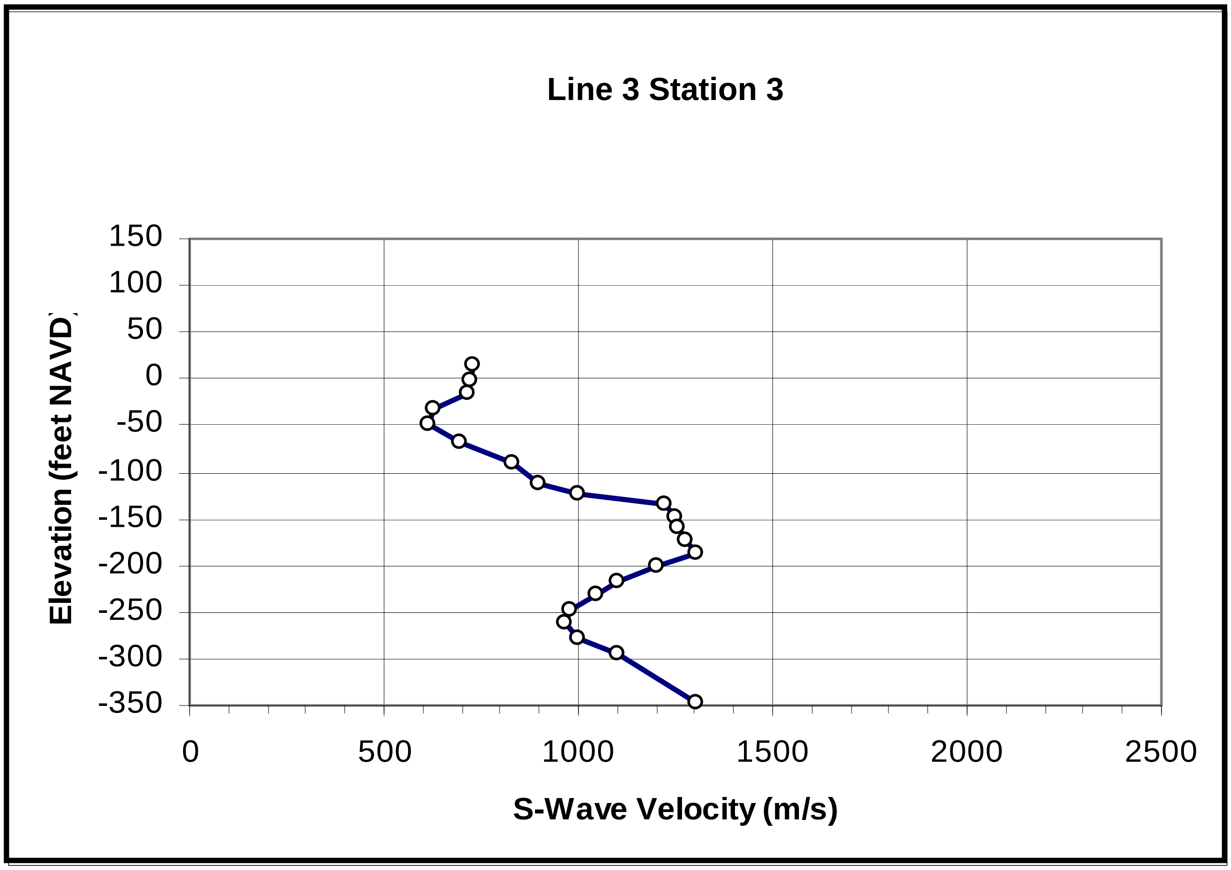

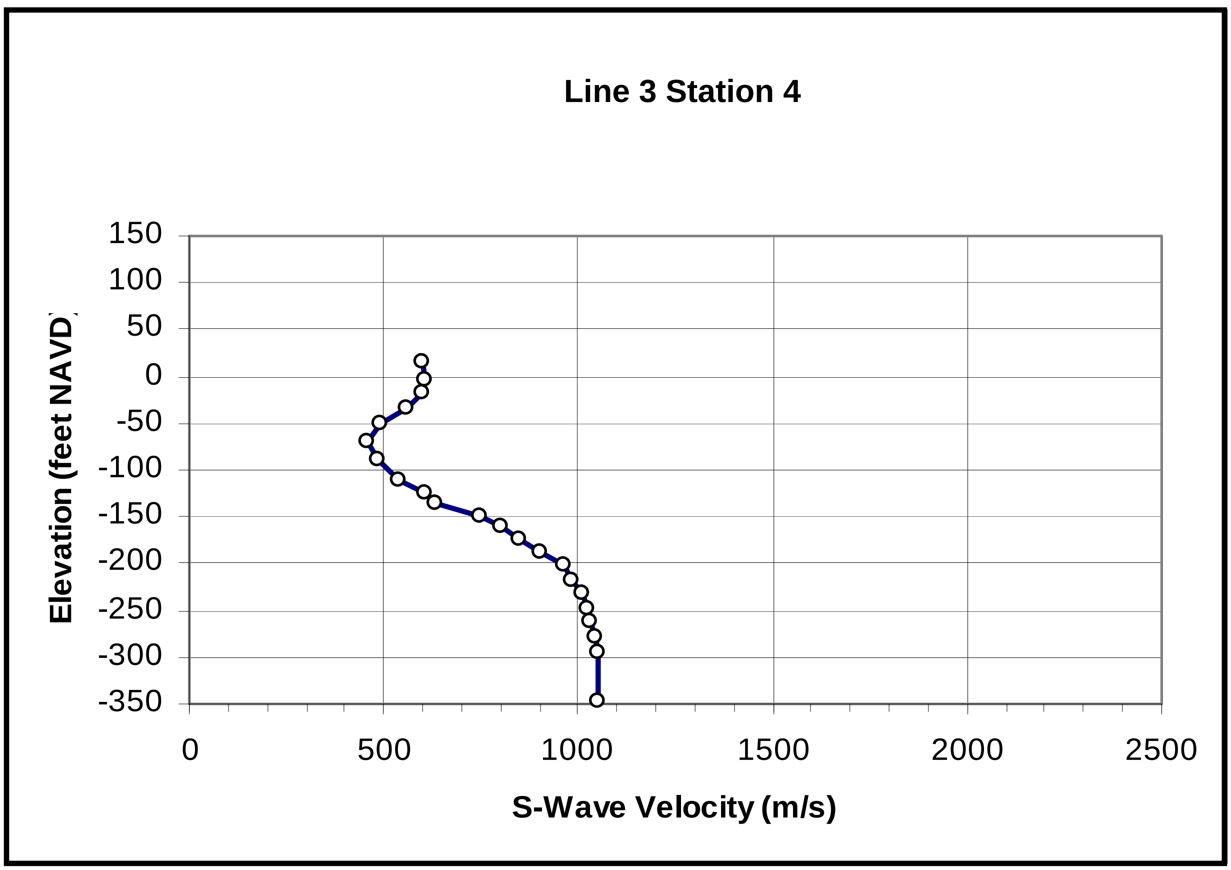

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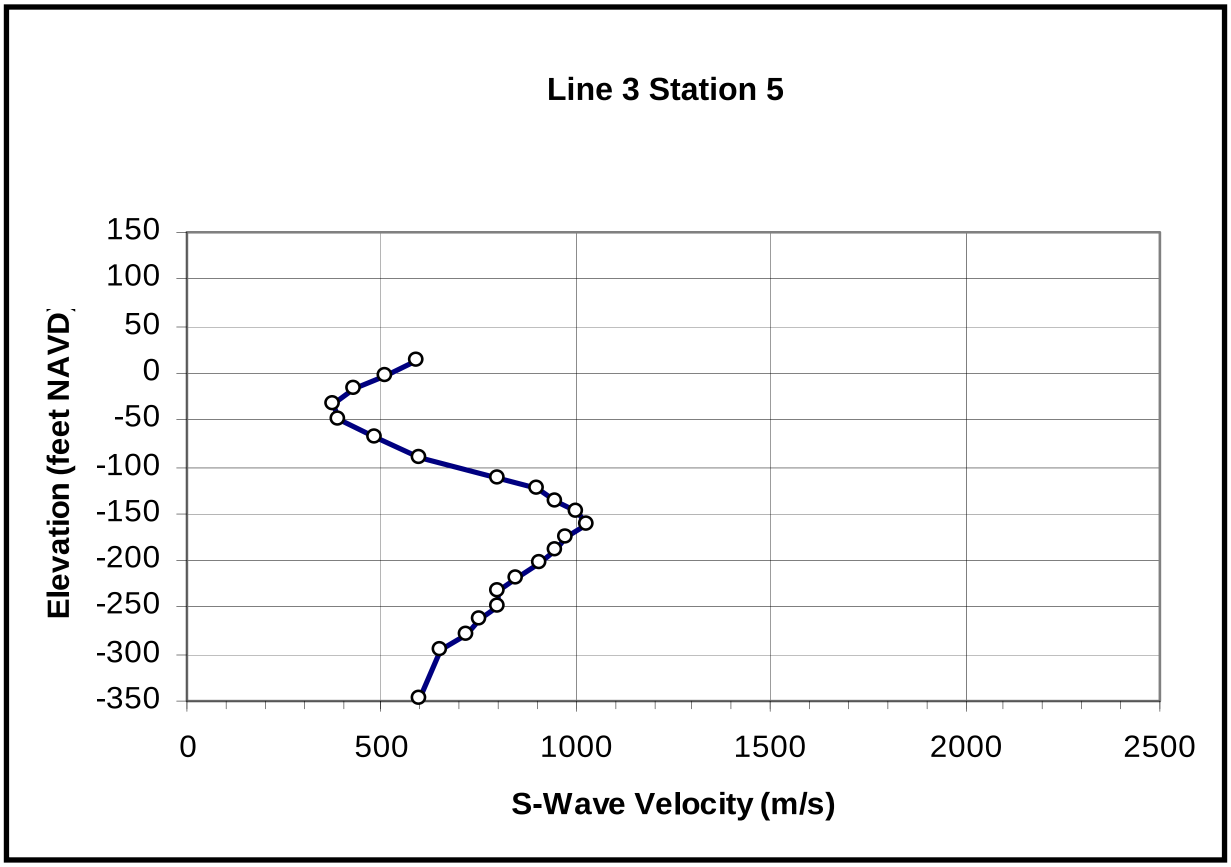

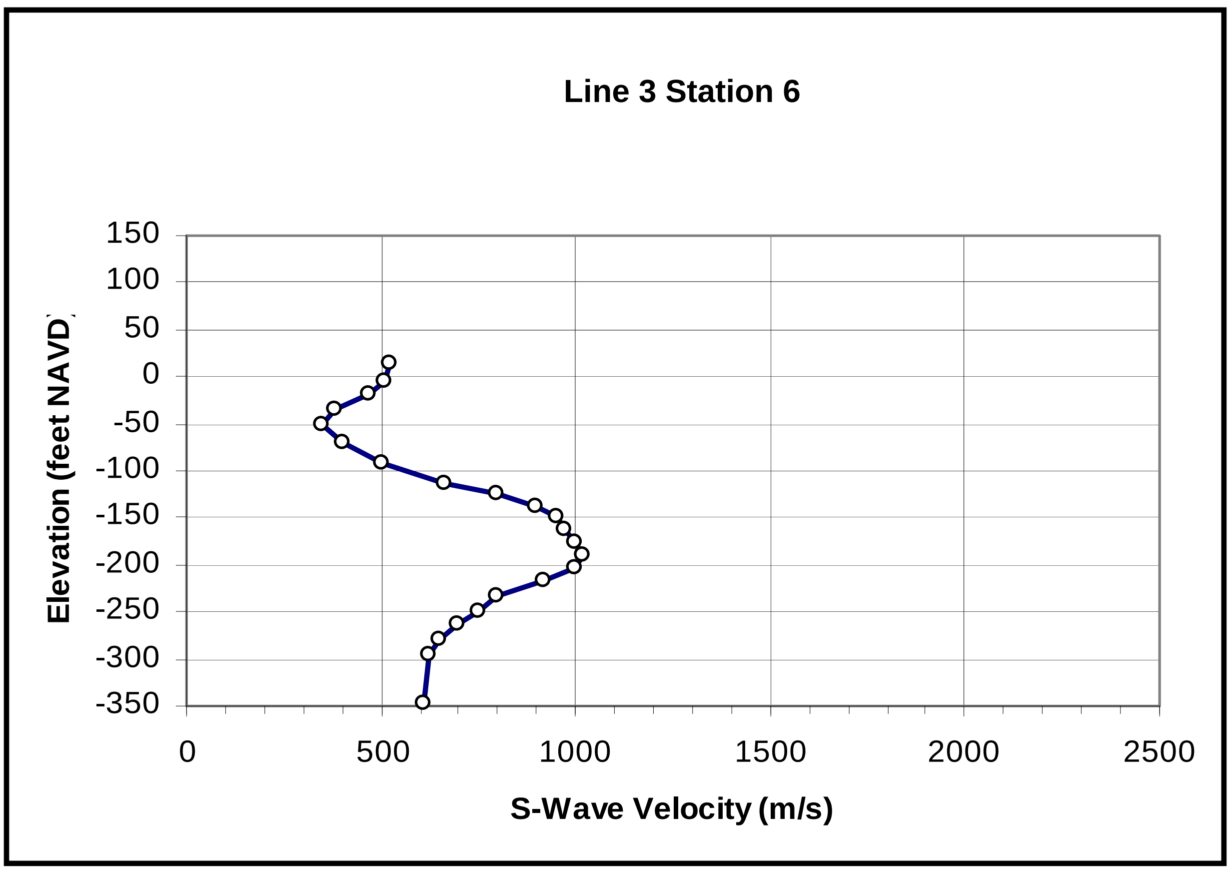

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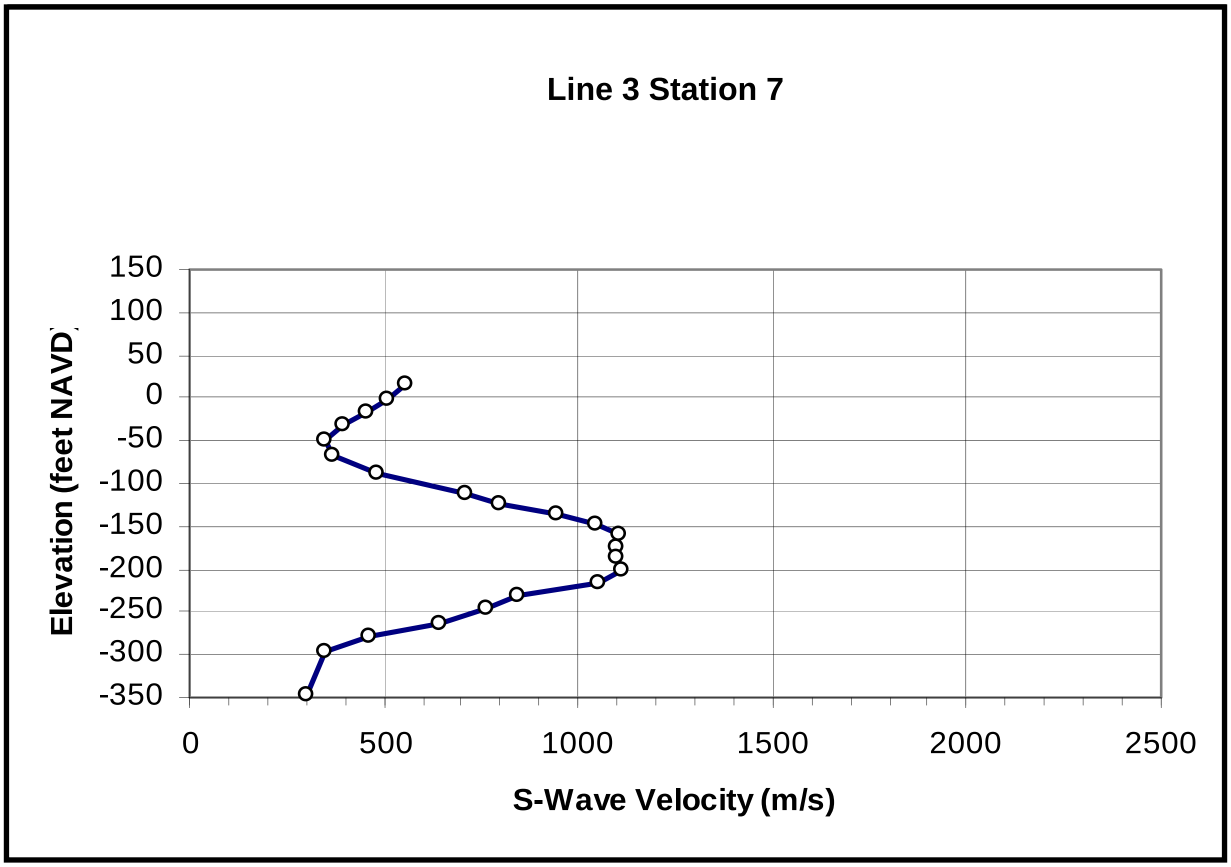

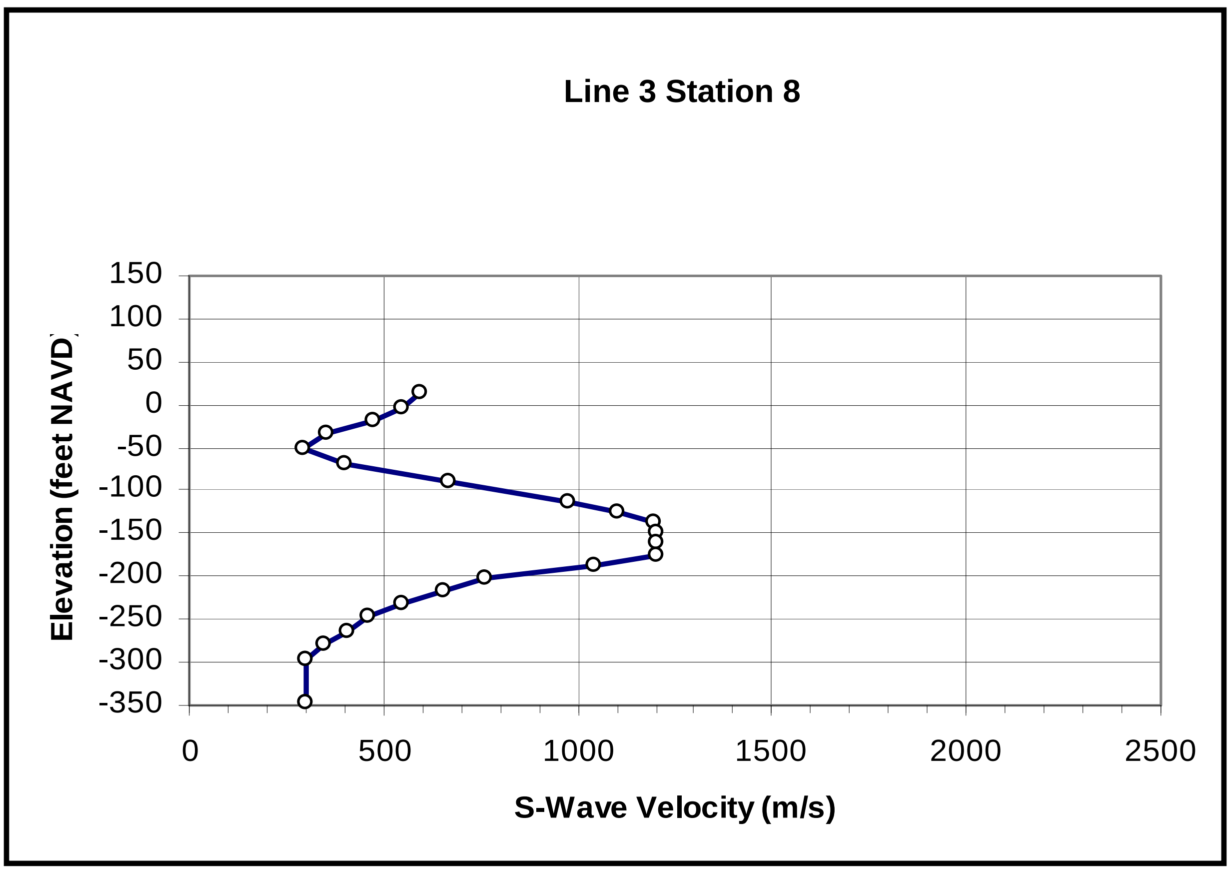

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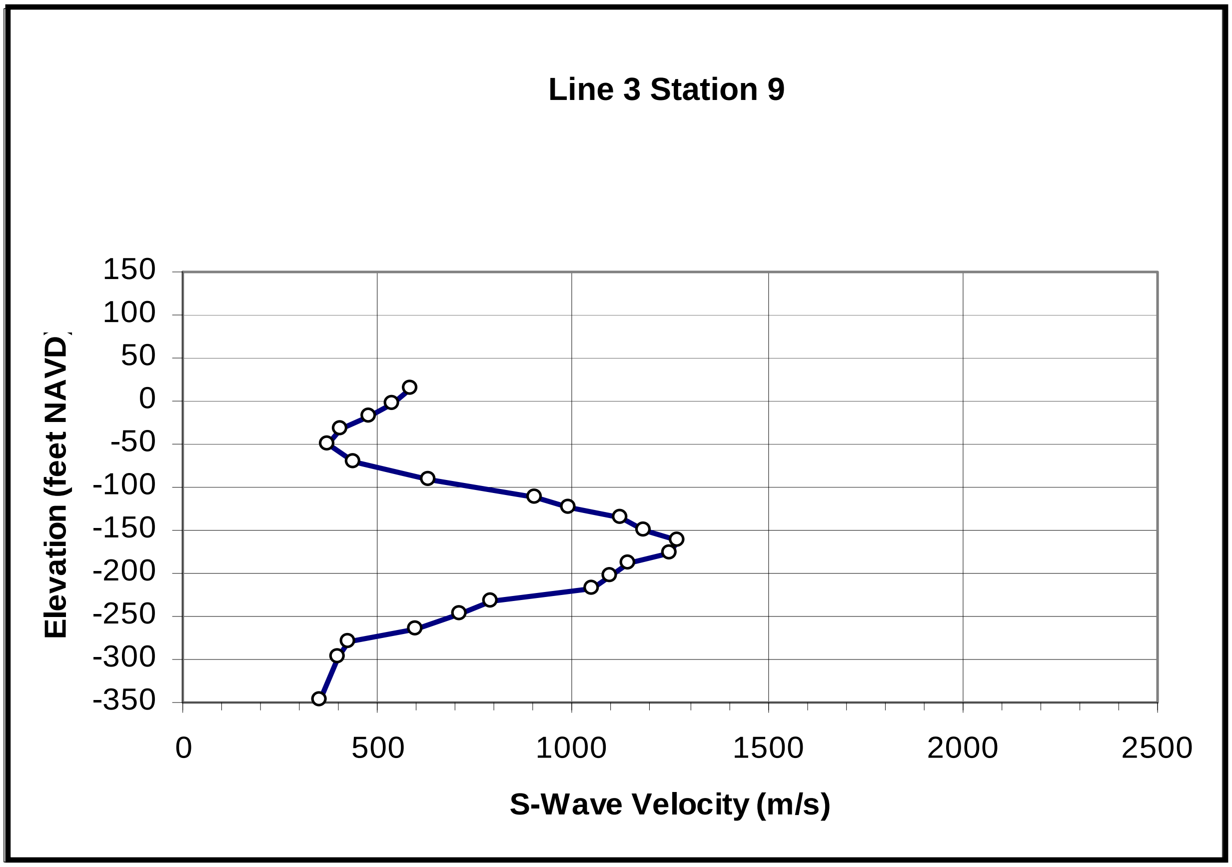

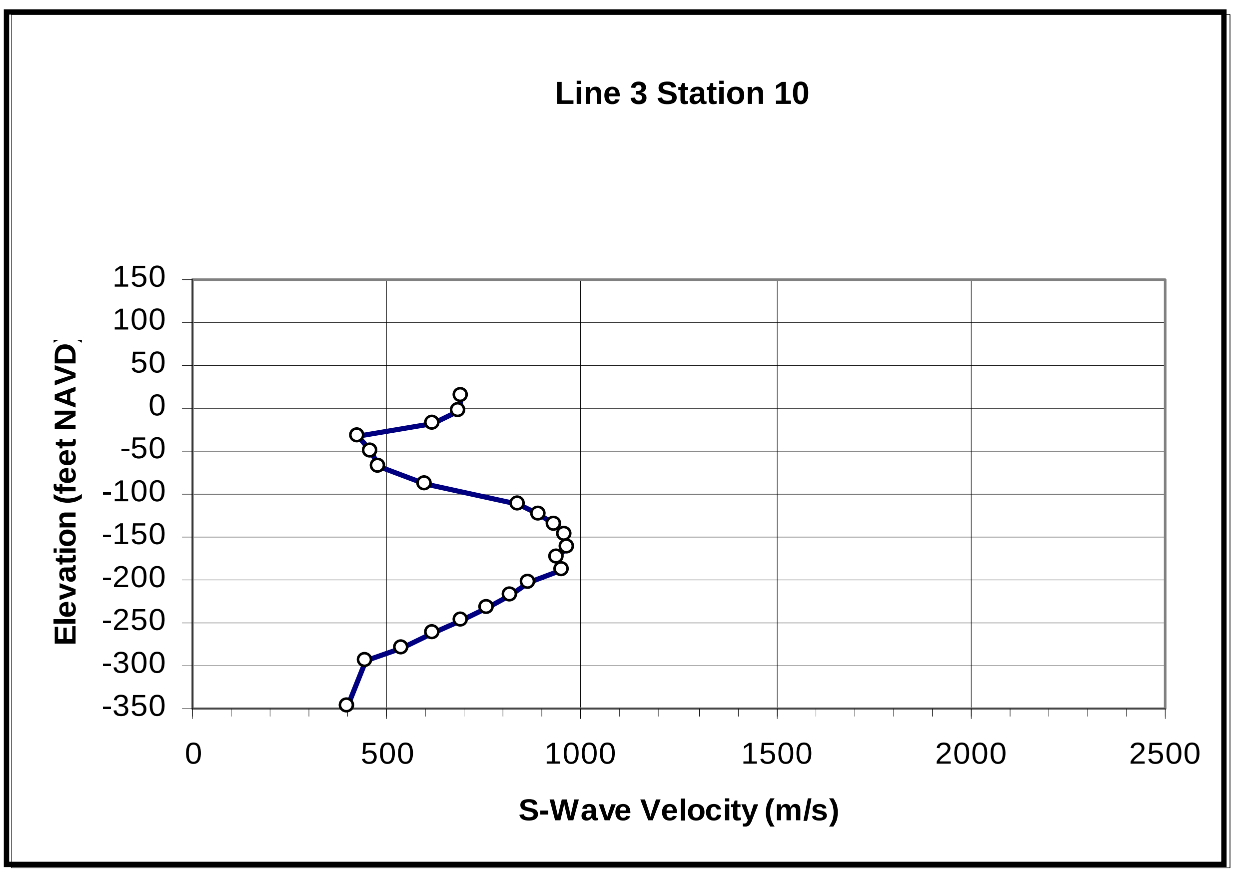

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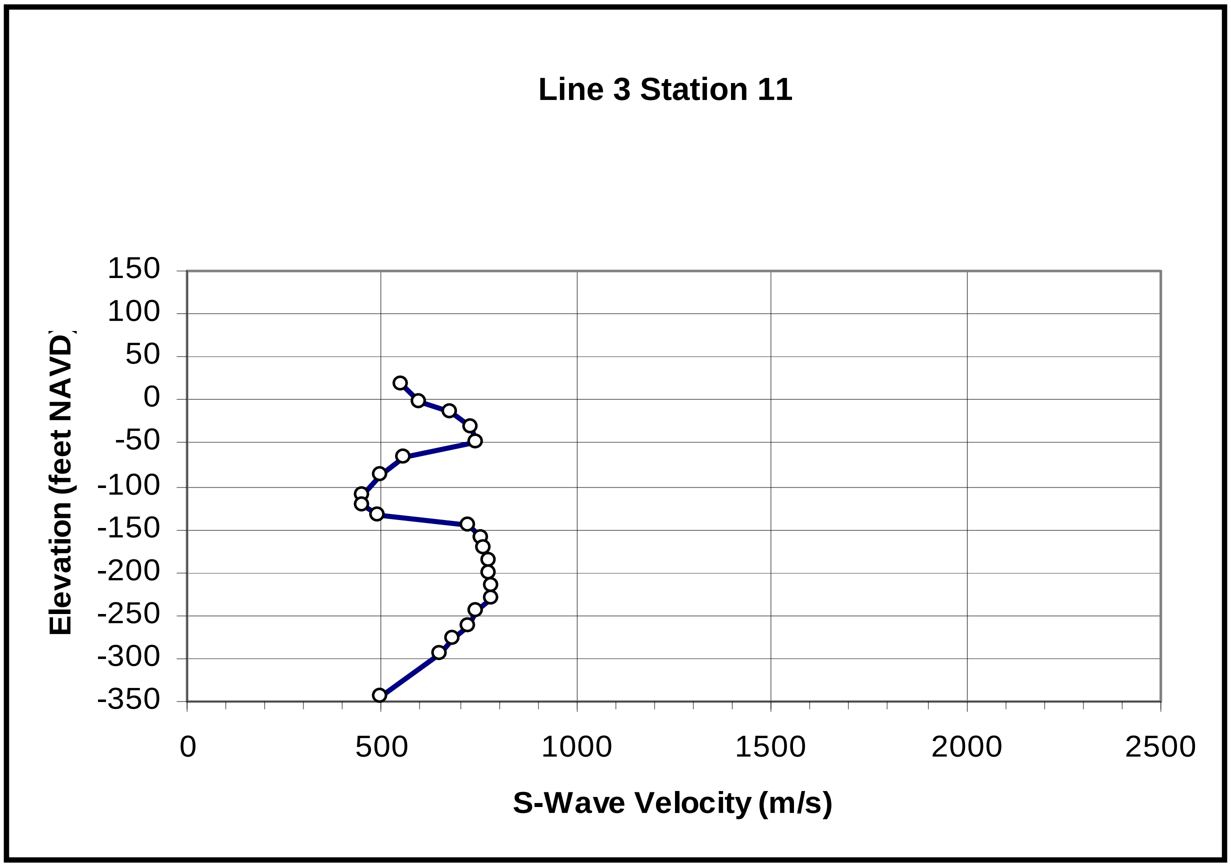

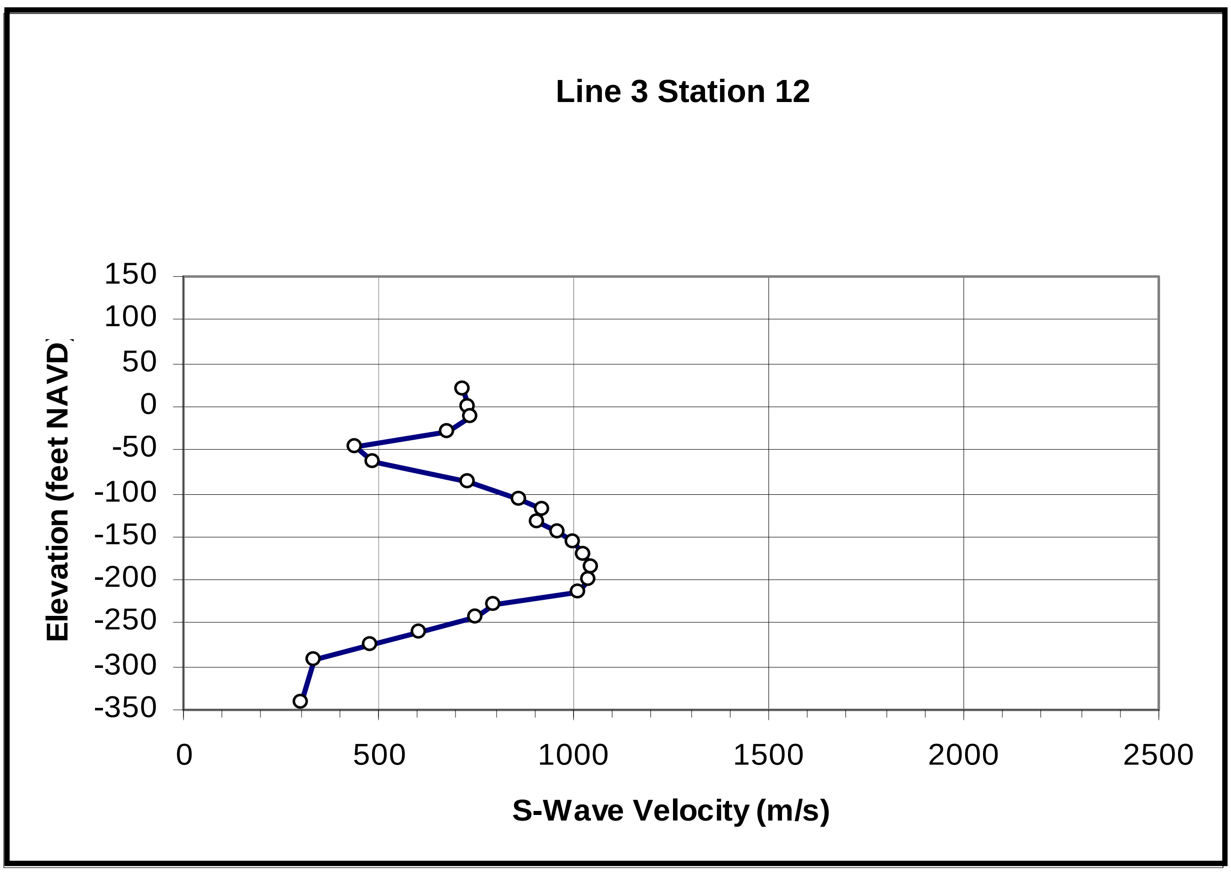

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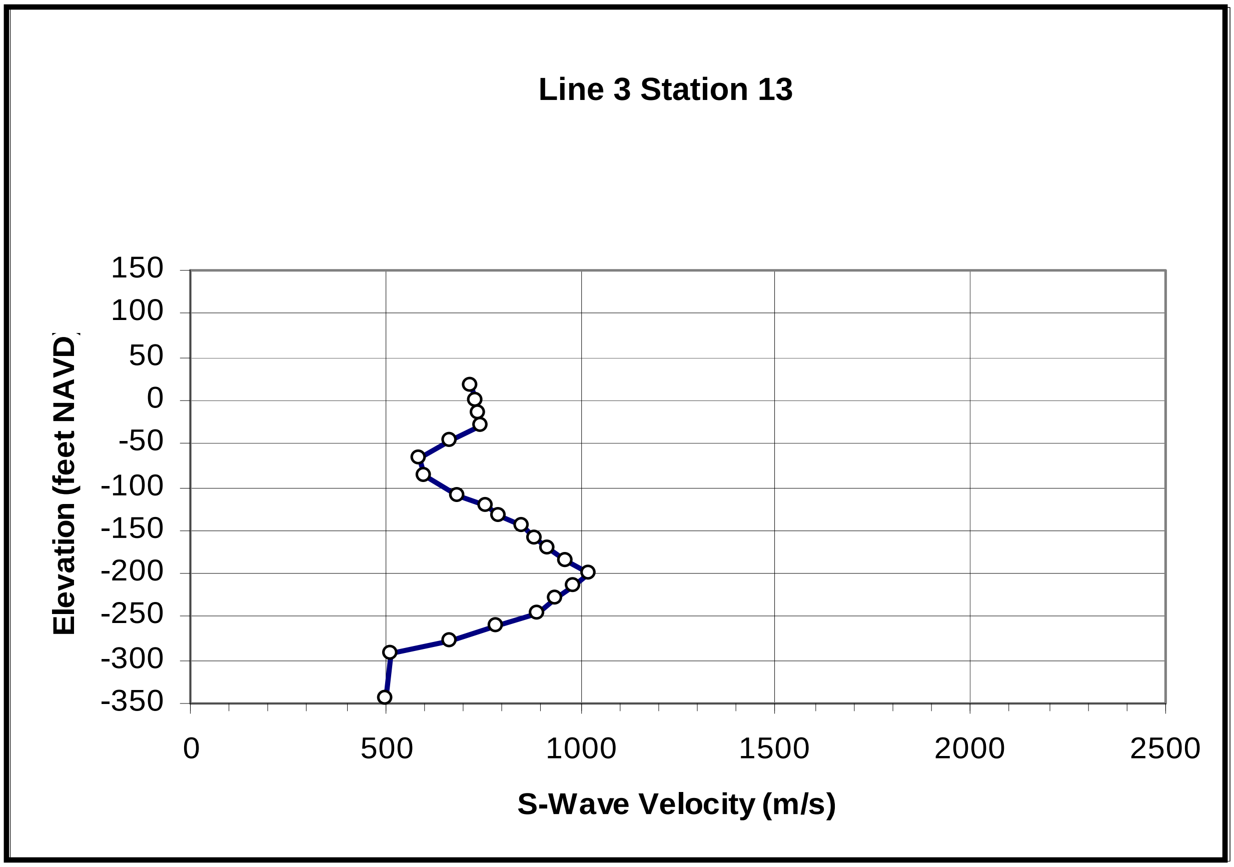

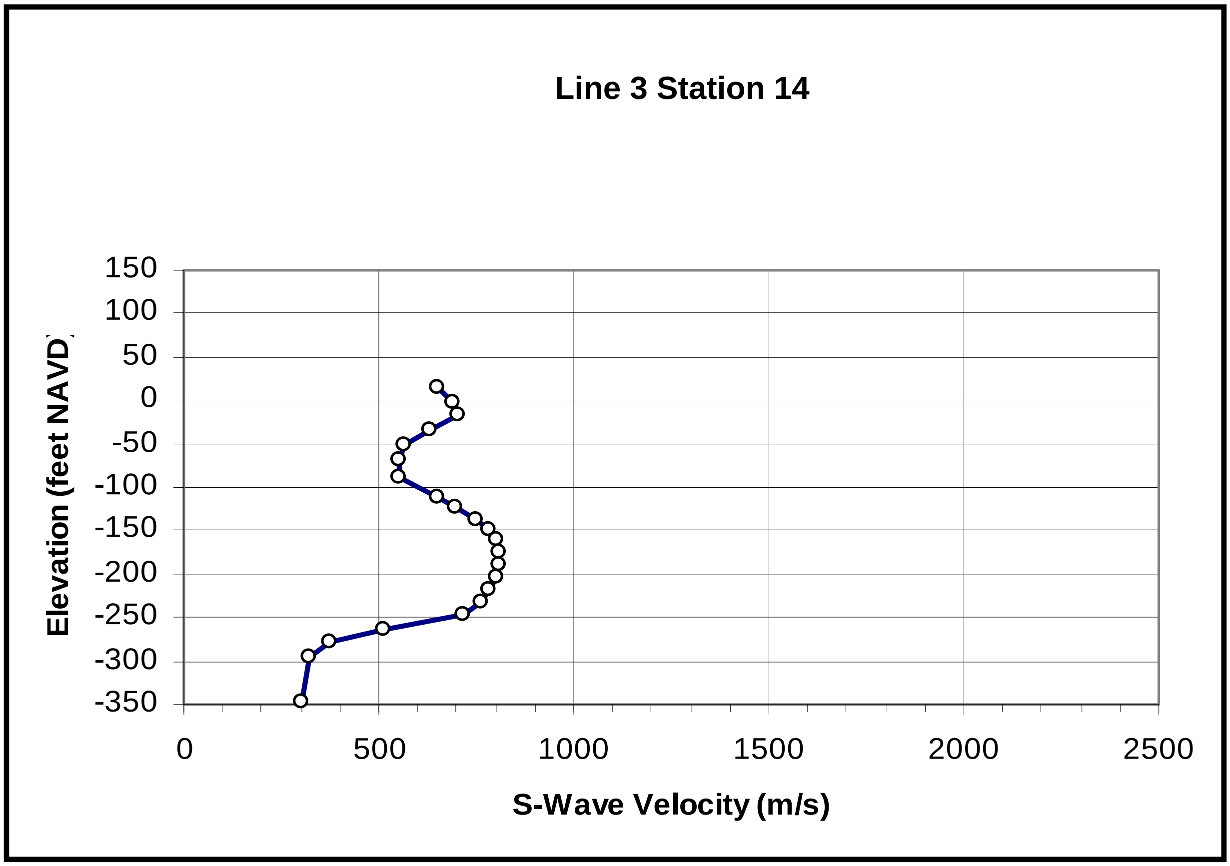

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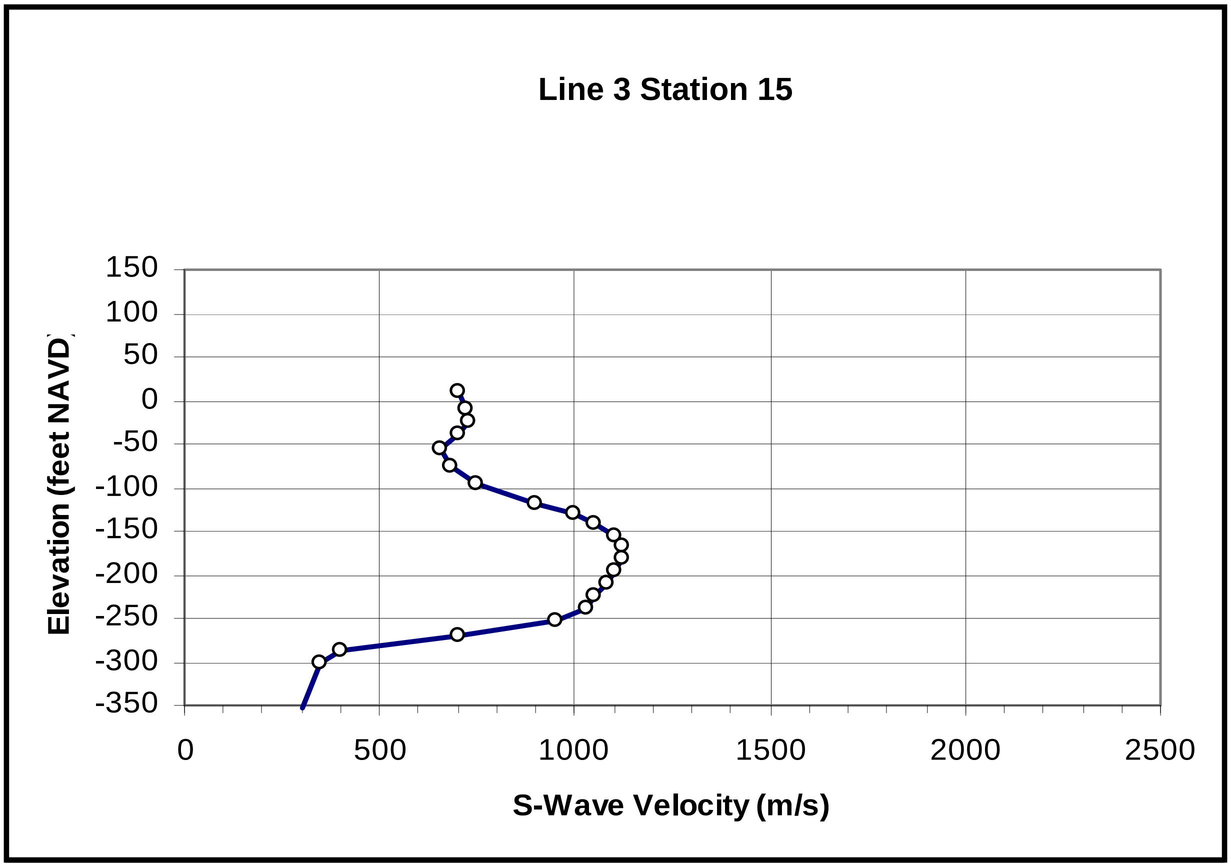

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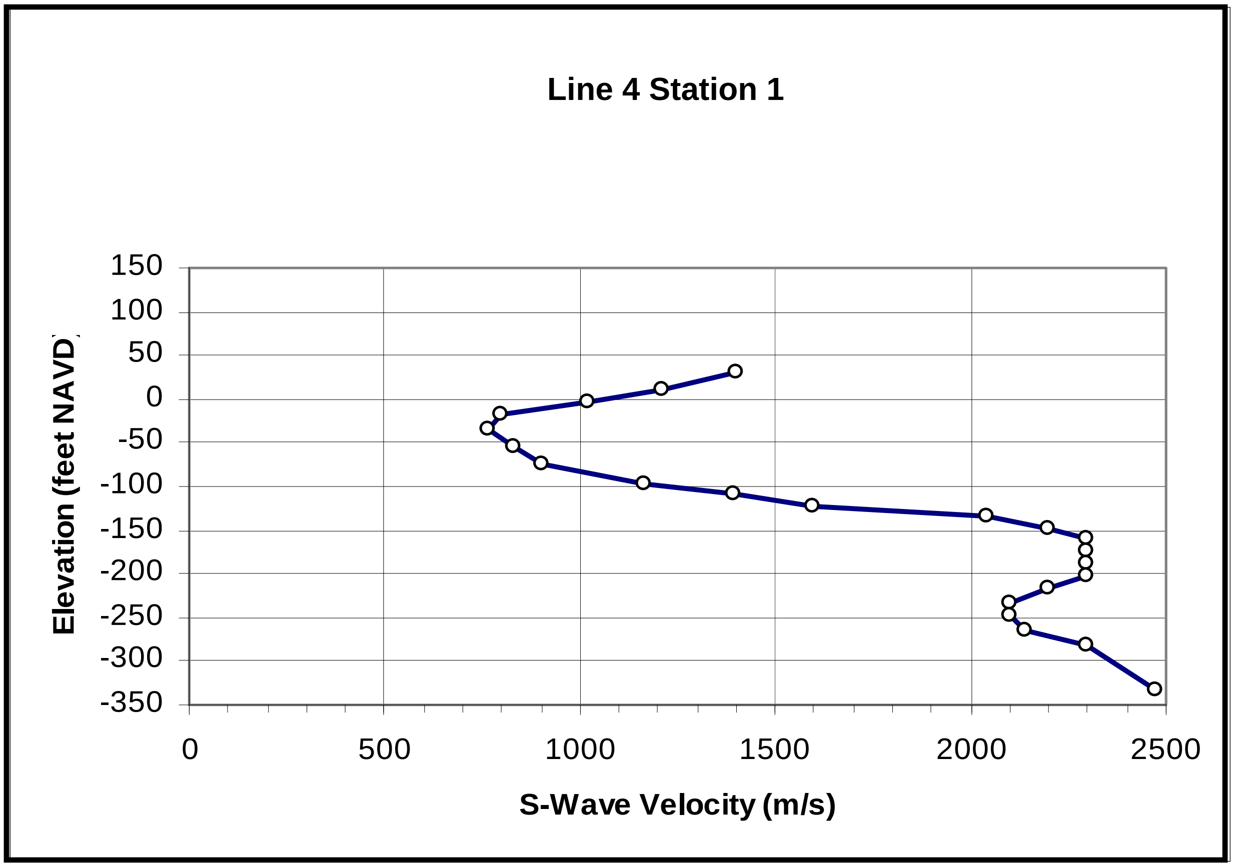

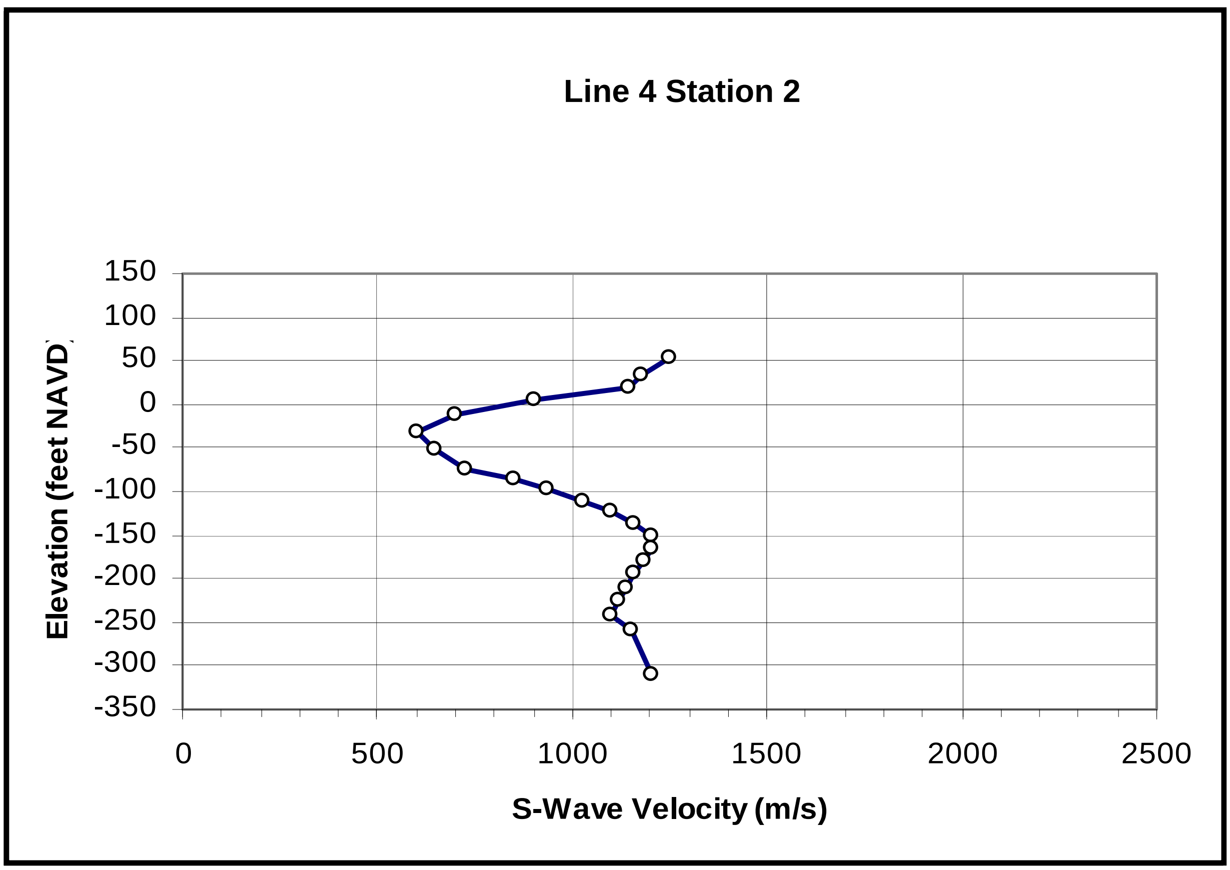

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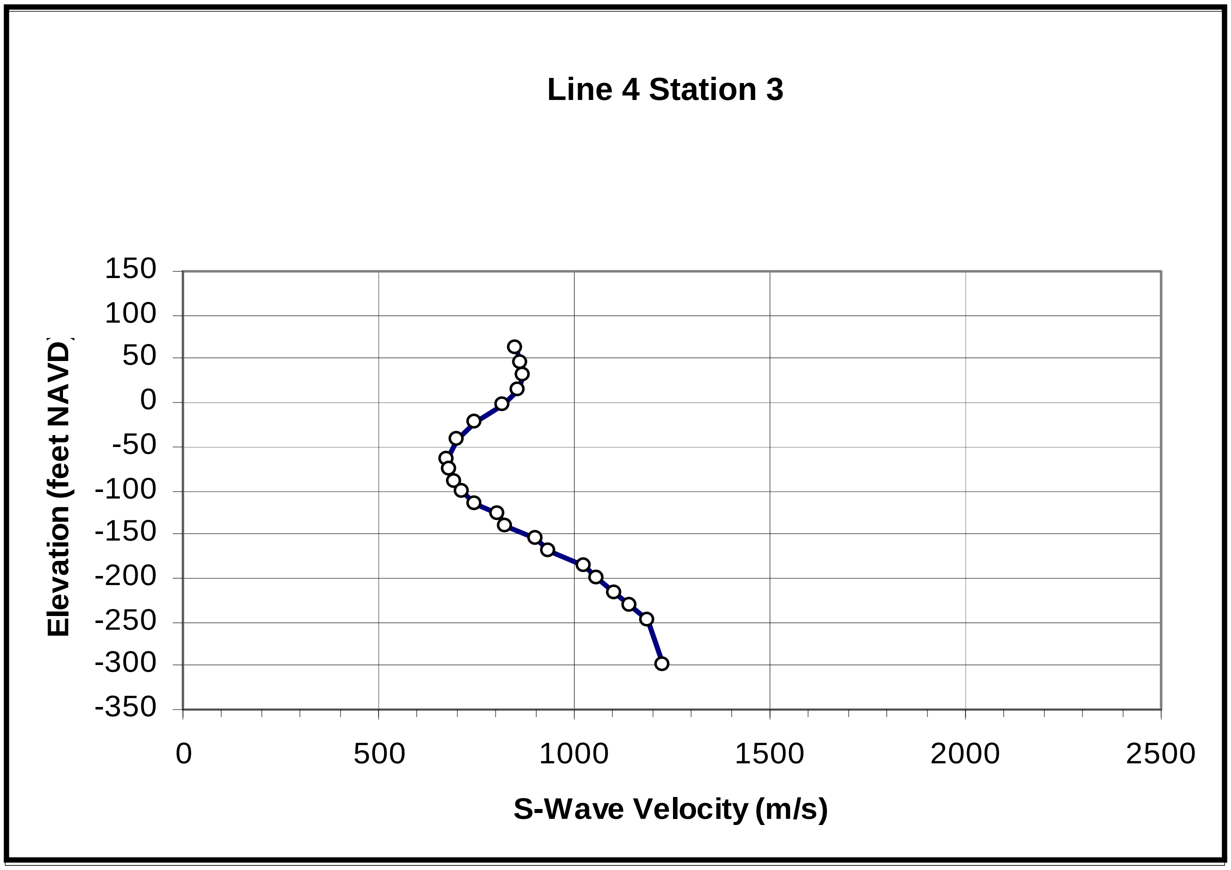

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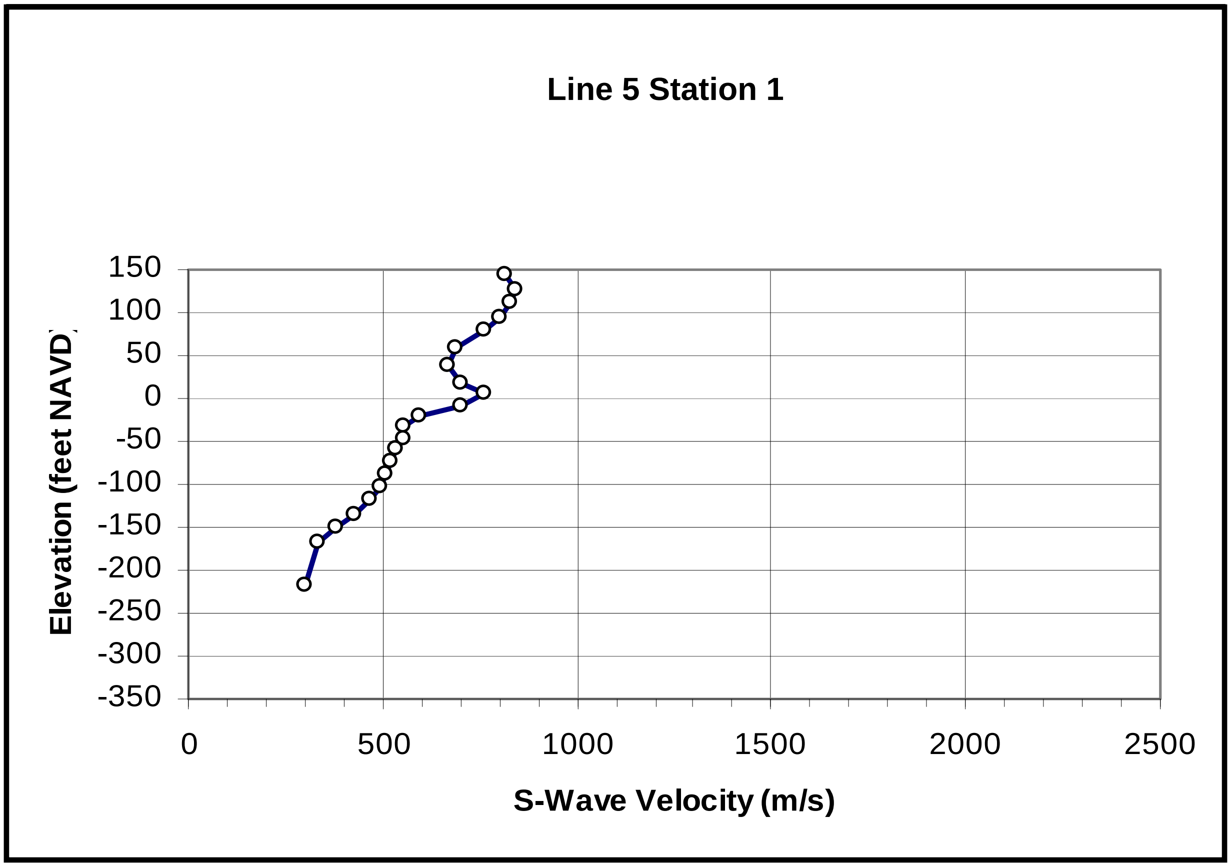

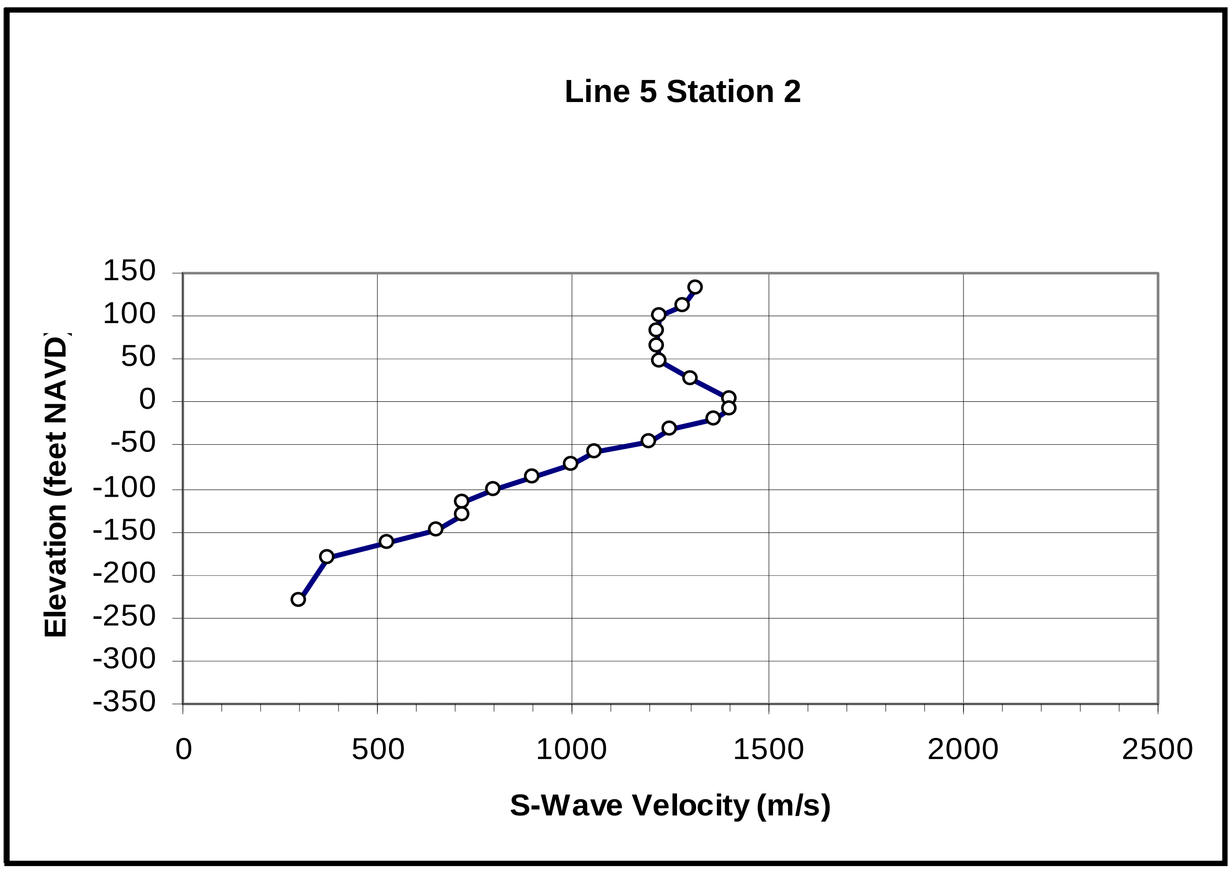

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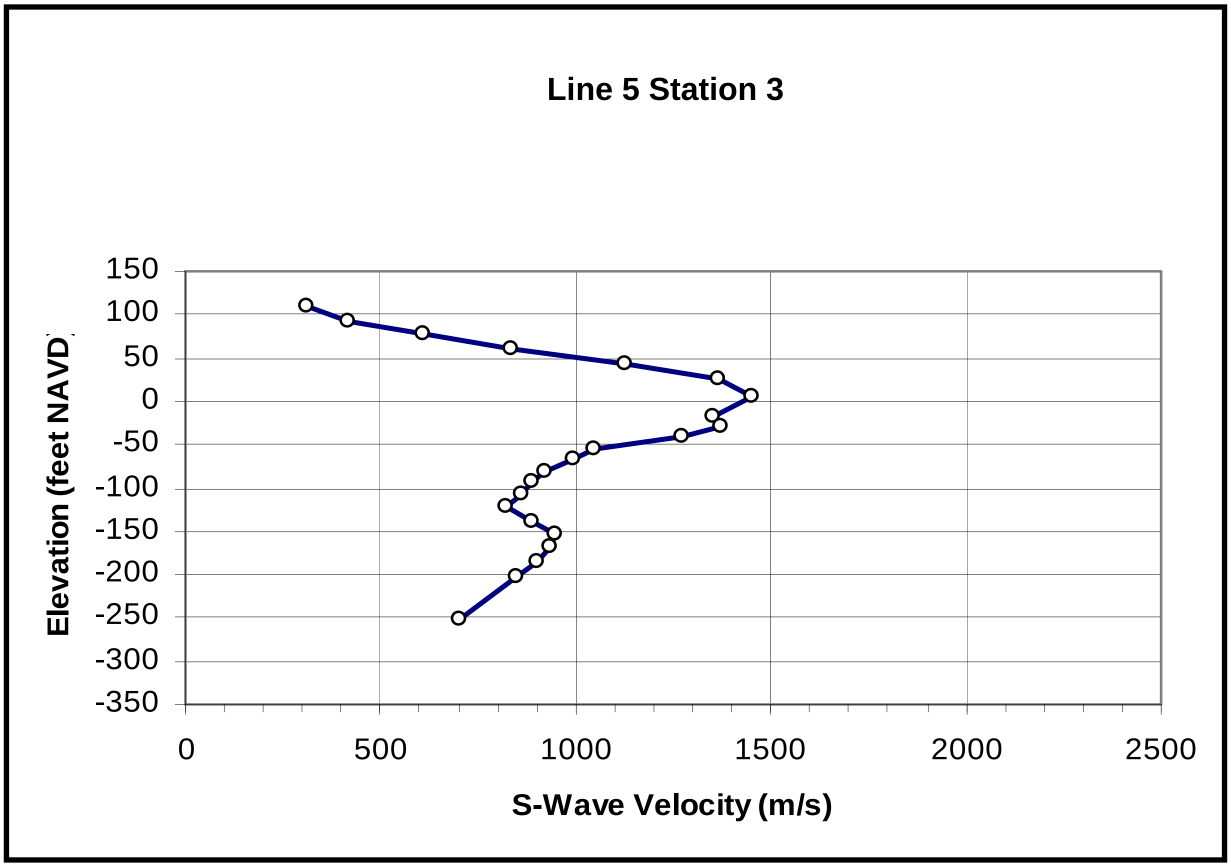

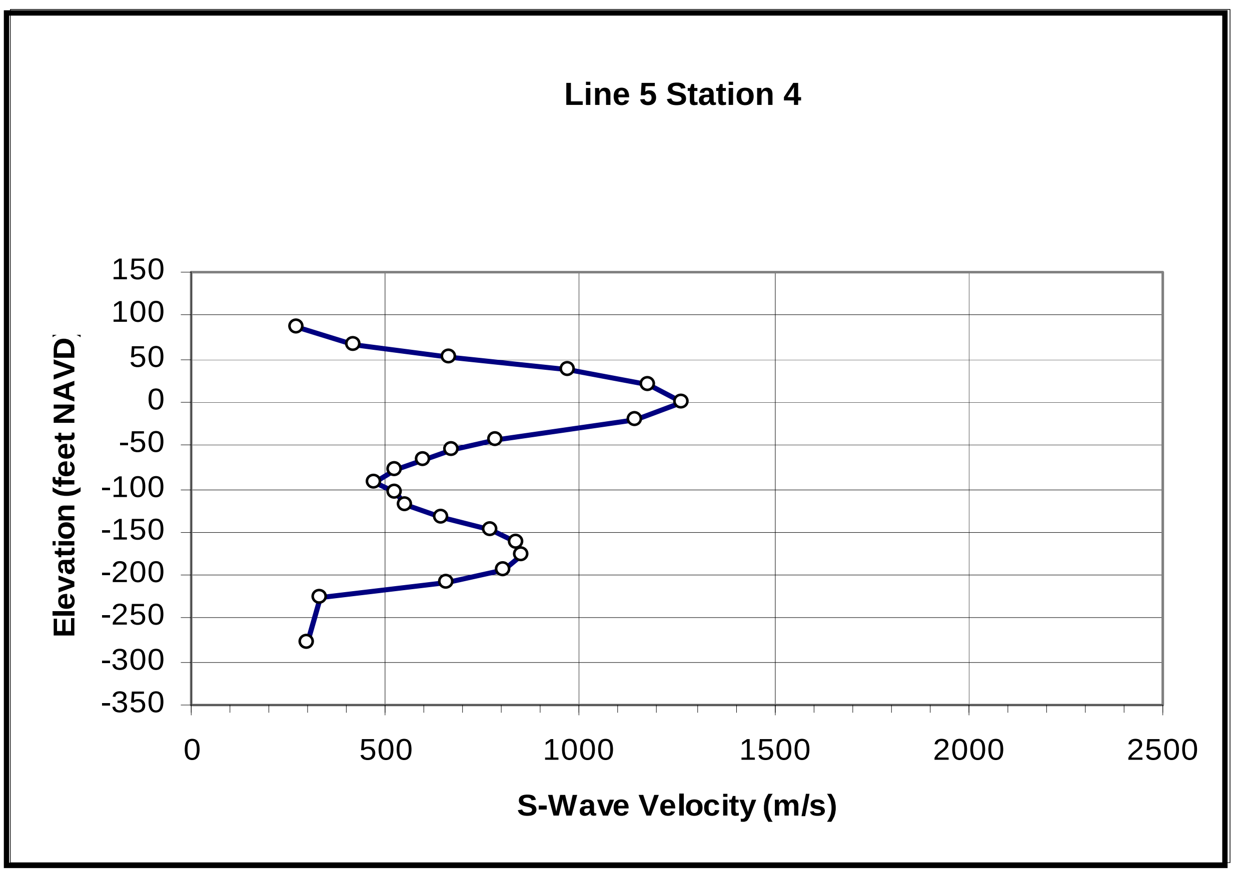

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