Technical Memorandum

Carmel River Lagoon

Subject:	**Hydrographic Survey and Stage-Volume Relationship**
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1 Introduction

The analysis contained herein is part of an ongoing study being conducted with the intent of understanding the complex interactions between environmental processes, human interests, and natural habitats of the Carmel River Lagoon (Lagoon). The intent of this technical memorandum is to present the results of a stage-volume relationship developed for the Lagoon.

1.1 Background

The Carmel River Lagoon is immediately adjacent to and affects Critical Coastal Watershed Area No. 44 (also known as Carmel Bay). Low-lying structures near the Lagoon are subject to flooding from both the Carmel River and ocean waves, filling the Lagoon when the sandberm at the mouth of the Lagoon is closed. Historically, the Monterey County Department of Public Works has breached the sandbar to protect surrounding residences and public infrastructure. Often, this activity takes place during the fall and early winter months when initial storms and runoff from the Carmel River raise the level of water in the Carmel River lagoon, but are not high enough to naturally breach the sandbar.

1.2 Previous Studies

Monterey County, NOAA Fisheries, California Department of Fish and Game (CDF&G), and California Department of Parks and Recreation (CDPR) have relied on information and analyses of lagoon hydrodynamics collected since 1990 by Monterey Peninsula Water Management District (MPWMD). Since 1990, substantial information has been collected, but not completely analyzed. In addition, the Lagoon has undergone two major projects to increase the volume and restore wetland and riparian habitat. A comprehensive topographic survey and analysis has not been completed since 2004 when the second of these projects was implemented.

In 1997, MPWMD retained Graham Mathews & Associates to develop a stage-volume relationship for the Lagoon based on 1988 photogrammetric data and a 1994 field survey conducted by MPWMD staff. These data were utilized to create a single, complete topographic model to be used in the stage-volume analysis. The result was an estimated 285.8 acre-feet (AF) of storage at a stage elevation of 10.0 feet based on the National Geodetic Vertical Datum (NGVD) of 1929 (Table 2). In 2004, a detailed stage-volume study estimated 89.4 acre-feet of storage at a stage of 10 feet in the newly constructed South Arm.

2 Approach

Meridian Surveying and Engineering, in conjunction with Radman Aerial Survey, was subcontracted by RMC to complete a topographic and bathymetric survey of the active portions of the lagoon. The “active

portion" is defined by sand-bottom channels, and areas adjacent to those channels, at the mouth of the Carmel River that have historically been susceptible to natural and artificially induced changes. RMC used these datasets as well as topographic information published by the Association of Monterey Bay Area Governments (AMBAG) to develop stage-volume information up to 15 feet above NGVD 29 mean sea-level.

2.1 Survey Data

The data used to create the current stage volume relationship was based on three data sources:

1. A bathometric survey of the Main Stem supplemented with aerial photogrammetry. These surveys were conducted in May of 2006.
2. A bathometric survey of the South Arm conducted in September of 2007
3. 2003 AMBAG LIDAR data used for areas outside of the Main Stem and South Arm (see Figure 2).

The accuracy of each of these sources of information is summarized in Table 1.

Table 1: Data Accuracy

Data Source	Vertical Accuracy	Horizontal Accuracy
Bathometric survey, 2007[a]	0.1 feet (+/-)	0.1 feet (+/-)
Bathometric survey, 2006[a]	0.1 feet (+/-)	0.1 feet (+/-)
Aerial Survey 2006	0.5 feet (+/-)	0.5 feet (+/-)
AMBAG Data	1.0 foot (+/-)	2.0 feet (+/-)

[a] Hydrographic Survey according to Class 1 survey methods and accuracies outlined in the Corps of Engineers' manual. The survey incorporated a sounding precision of 0.5 feet, a sounding interval every 5 to 10 feet, and a maximum interval of 25 feet.

2.2 Developing the Stage-Volume

Sand dunes typically build up in the Carmel River Lagoon during spring and summer months, creating a barrier behind which Carmel River inflows are impounded until the dunes are anthropogenically or naturally breached. To simulate the same kind of obstruction, one that would cause water levels to rise to an elevation of 15 feet, an artificial barrier was assumed at the mouth of the Lagoon (see Figure 3 and Figure 4). This also restricted the stage-volume analysis to the lagoon areas (instead of including water surfaces that would otherwise extend along the beaches to the north and south).

Assuming the lagoon is initially dry, as water moves down the Carmel River and into the Lagoon it will begin filling up in two equivalent low points in the lagoon: 1) immediately behind the artificial barrier; and 2) a low point at the month the South Arm. From these areas, it is assumed, the water surface will swell and eventually extend deep into the South and North Arms of the Lagoon.

2.3 GIS Approach

The survey data was compiled into a single topographic dataset and ArcGIS was used to create a triangulated irregular network (TIN) as a terrain model. The following steps outline how stage-volume relationships were calculated.

1. TINs were created that correspond to vertical, one-foot increments from -2 to 15 feet (NGVD 29) with each TIN representing a unique elevation plane. The lowest elevation in the survey was -2.0 feet.

2. Where each elevation plane intersected the Lagoon terrain model or TIN, ArcMap clipped the elevation planes.
3. Each resulting water surface was inspected for hydrographic continuity. Isolated "pools" that were not connected to the main body of water were removed and were not considered as a contribution to volume.
4. ArcGIS was used to calculate the volume below the planes, but above the lagoon basement surface.

2.4 Limitations

The survey data used in this analysis are generally good. The most accurate data occurs at lower elevations, typically below 7 feet because these areas were surveyed more recently using exceptionally accurate methods. Stages above 7 to10 feet extend into areas surveyed by AMBAG in 2003; these data are older and less accurate. Cross-checking of data where the more recent surveys overlap the 2003 data indicates that the AMBAG data are within 1.0-foot accuracy. However, care should be taken when using this analysis for flood protection planning or any other engineering analysis requiring precise information because of the uncertainty of water surface elevations at higher stages.

The only portion of the AMBAG data where there is significant uncertainty is along the North-Western boundary of the mouth of lagoon. Here, there is a very active dune region where geomorphologic processes such as wind and water erosion are constantly changing the landscape. This area has undoubtedly undergone substantial changes since the 2003 data was collected. However, the "artificial barrier" assumed in this analysis (see section 2.2) prevents water from extending very far into this area, and thus the introduction of uncertainty into the stage-volume analysis is largely avoided.

3 Results

The GIS analysis described above produced a three-dimensional representation of the Carmel River Lagoon, stage-volume data, and a spatial relationship between stage and water surface shape. Based on this output, a general comparison could be made between the current and the 1997 stage-volume. Figure 1 compares the results of these two analyses.

Table 1 shows the results for the current study, Table 2 presents the stage-volume relationship based on data collected between 2003 and 2007, and Table 3 summarizes the results from the 1997 study.

Table 2: Stage-Volume Relationship based on Survey Data Collected Between 2003 and 2007

Elevation NGVD 29[a] (ft)	Incremental Stage Volume acre-ft	Cumulative Volume (acre-feet)
-2.0	1.5	1.52
-1.0	1.2	2.76
0.0	1.8	4.61
1.0	3.3	7.90
2.0	5.8	13.68
3.0	10.6	24.31
4.0	16.8	41.12
5.0	23.2	64.36
6.0	35.6	99.98
7.0	49.4	149.35
8.0	62.9	212.25
9.0	76.3	288.58
10.0	93.9	382.48
11.0	117.9	500.39
12.0	140.8	641.19
13.0	162.8	803.96
14.0	187.8	991.80
15.0	225.3	1,217.14

[a] All survey data were originally in NAVD 88. The VERTCON conversion calculator provided by the National Geodetic Survey (NGS) recommended a shift of -2.736 feet to convert from NAVD 88 to NGVD 29.

Table 3: 1997 Stage-Volume Analysis[a]

Elevation (ft, NGVD 29)	Cumulative Volume (acre-feet)
-2.00	0.002
-1.00	0.04
0.00	0.19
1.00	0.50
2.00	1.50
3.00	4.57
4.00	12.55
5.00	30.18
6.00	60.58
7.00	103.31
8.00	155.77
9.00	217.25
10.00	285.77

a. Source: MPWMD Technical Memorandum 05-01, “Surface Water Dynamics at the Carmel River Lagoon. Water Years 1991 through 2005” (October, 2005).

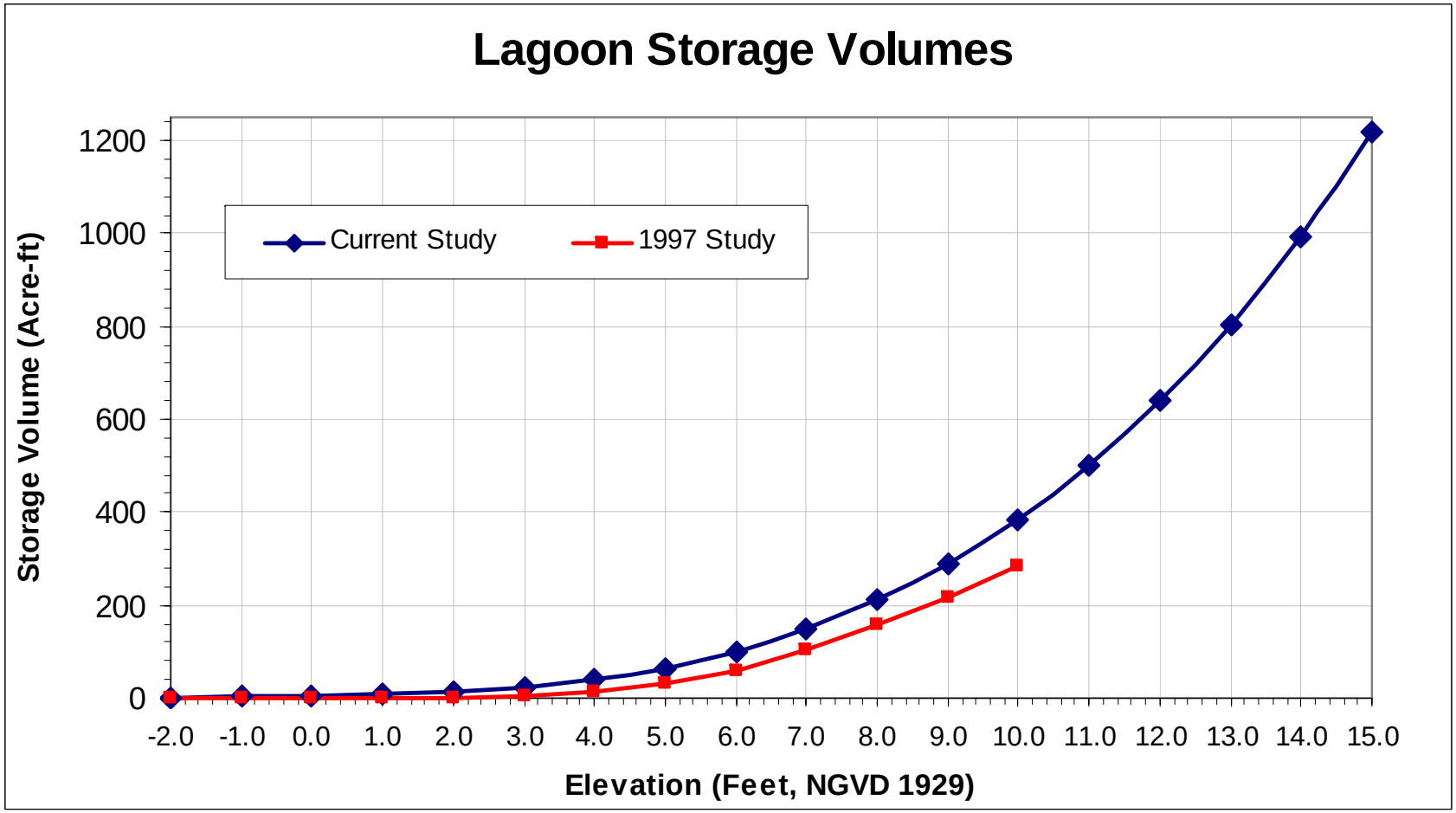

Figure 1: Comparison of the 1997 and Current Stage-Volume Analysis

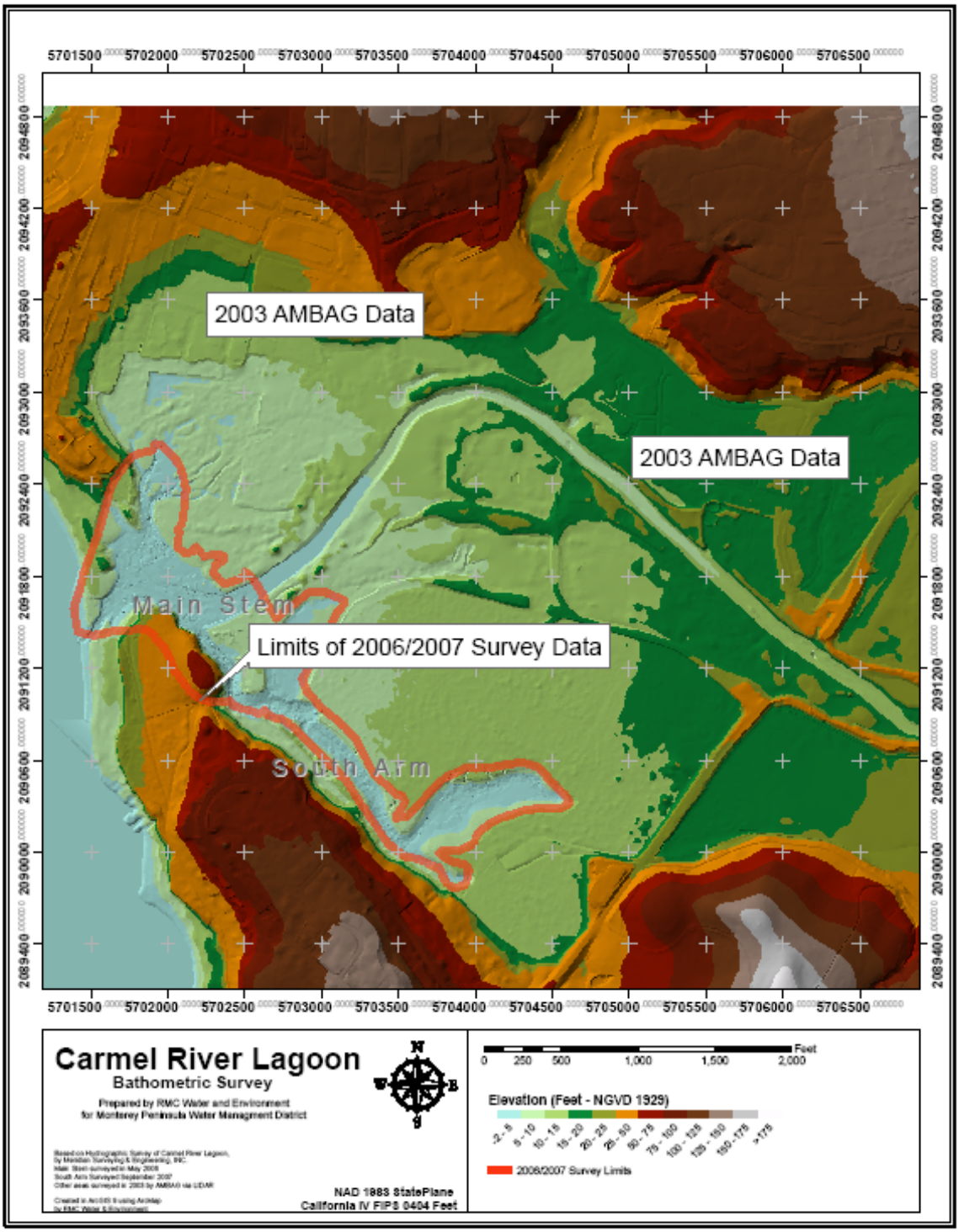

Figure 2: Lagoon Elevations and Survey Limits

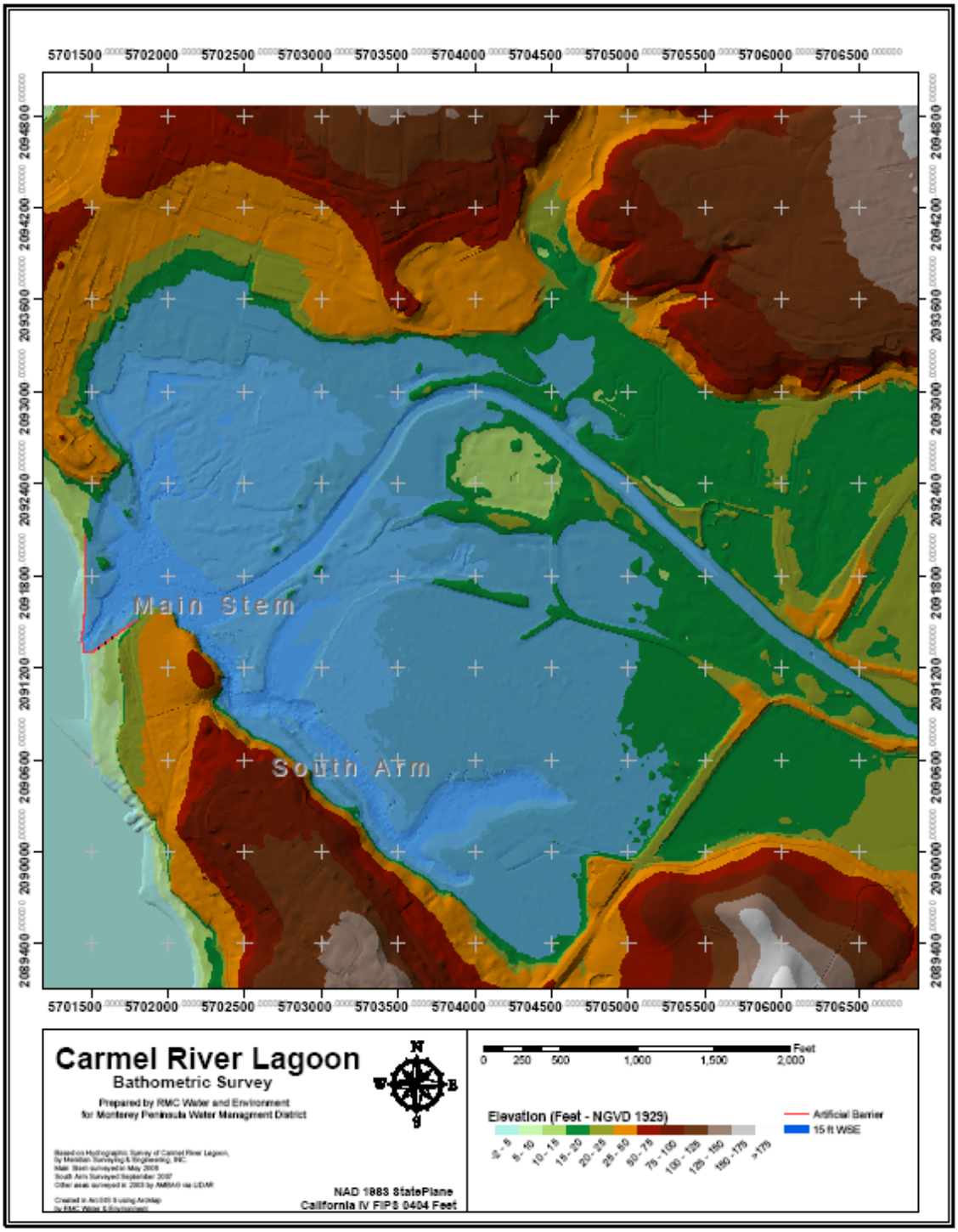

Figure 3: Lagoon Elevations and Water Surface at 15 feet

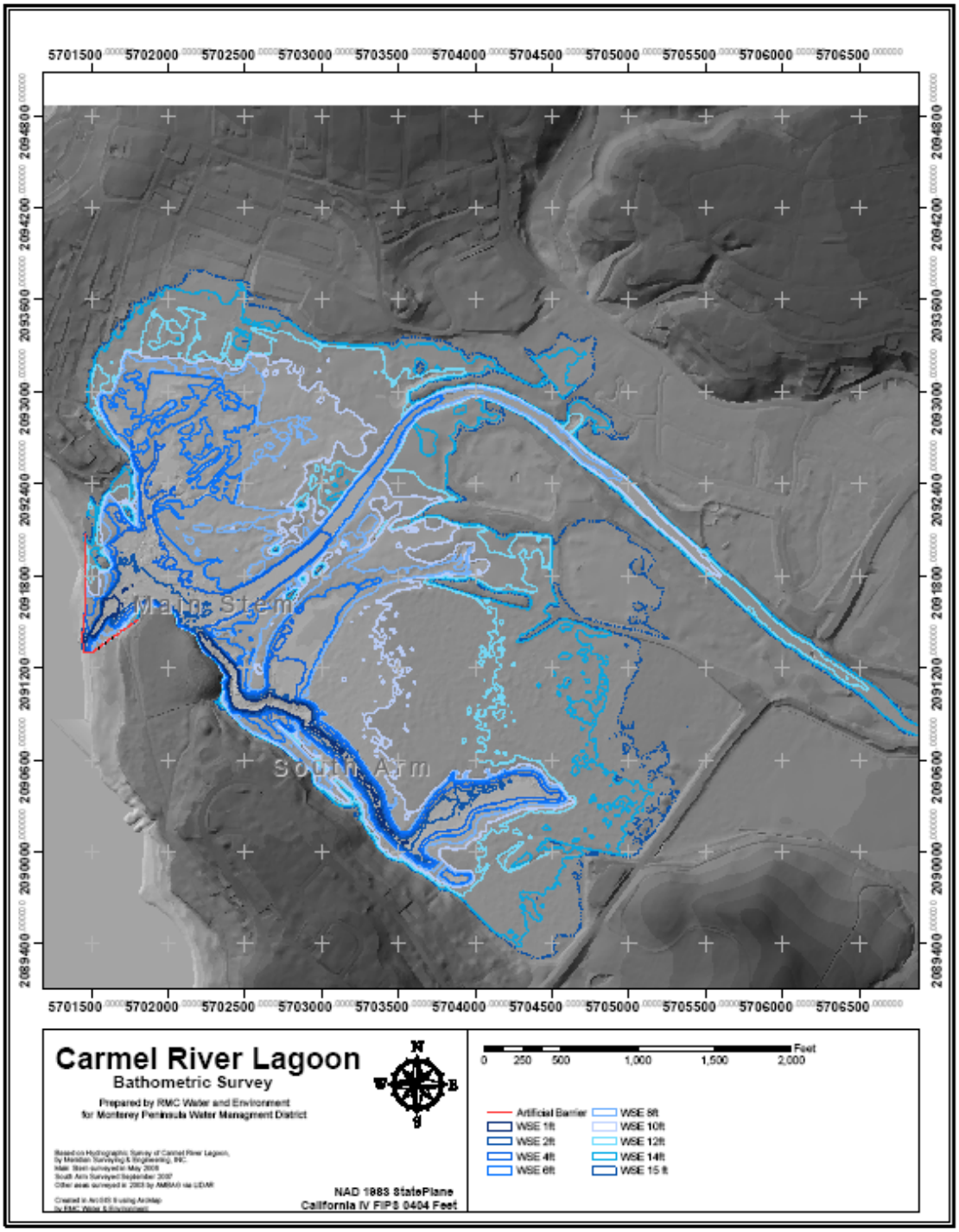

Figure 4: Water Surface Elevations