AGUA HEDIONDA LAGOON
HYDRODYNAMIC STUDIES

by

Hany Elwany, Ph.D.
Reinhard Flick, Ph.D.
Martha White, M.S.
Kevin Goodell

Prepared for

Tenera Environmental
141 Suburban Road, Suite A-2
San Luis Obispo, California 93401

Prepared by

Coastal Environments
2166 Avenida de la Playa, Suite E
La Jolla, CA 92037

25 October 2005
CE Reference No. 05-10

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

APPENDIX FIGURES

LIST OF TABLES

AGUA HEDIONDA LAGOON
HYDRODYNAMIC STUDIES

1.0 INTRODUCTION

The purpose of this report is to evaluate the hydrodynamics of Agua Hedionda Lagoon, which is located in Carlsbad, California (Figure 1-1). The lagoon consists of three basins, the Outer, Middle, and Inner Basins (Figure 1-2). The lagoon is connected to the Pacific Ocean through an inlet channel protected by two jetties.

The results of this study will be used to estimate entrainment mortality on a bay or lagoon population caused by the operation of the Encina Power Station (EPS). The EPS is located adjacent to Agua Hedionda Lagoon. The five power-generating units withdraw about 635 to 670 million gallons of water per day (mgd) from the lagoon to the power plant condenser systems for cooling purposes. The heated water is discharged through a channel across the beach. Figure 1-3 shows the configurations of the inlet and discharge channels.

The main questions for this study are:

1. What are the general hydrodynamics of Agua Hedionda Lagoon?
2. What are the volumes of the three lagoon basins at various elevations?
3. What is the tidal prism, defined in this study as the volume of water in the lagoon between maximum and minimum water level per tidal cycle?
4. What is the residence time of water in the lagoon and its basins?

Chapter 1 describes the purpose of the study and outlines the required tasks. Chapter 2 describes the lagoon and the tidal cycles that control the water level in the lagoon. Chapter 3 provides information about the water level, velocity, salinity, and temperature measurements in the lagoon that were conducted between 1 June 2005 and 7 July 2005. Chapter 4 describes the method used to estimate the residence time of water in the lagoon and provides the results. Chapter 5 gives a brief summary of the results; a list of the references used in this study is given in Chapter 6. The appendices provide a summary of the results obtained from the fieldwork conducted during the study.

Our efforts during this study included:

1. Site visits to Agua Hedionda Lagoon;
2. A review of the existing oceanographic data and literature;
3. Installation of instruments at four temporary data collection stations;
4. Collection of data for a one-month period, including water level, water velocity, salinity, and temperature measurements;
5. Computation of the tidal prism; and
6. Presentation of our findings in this report.

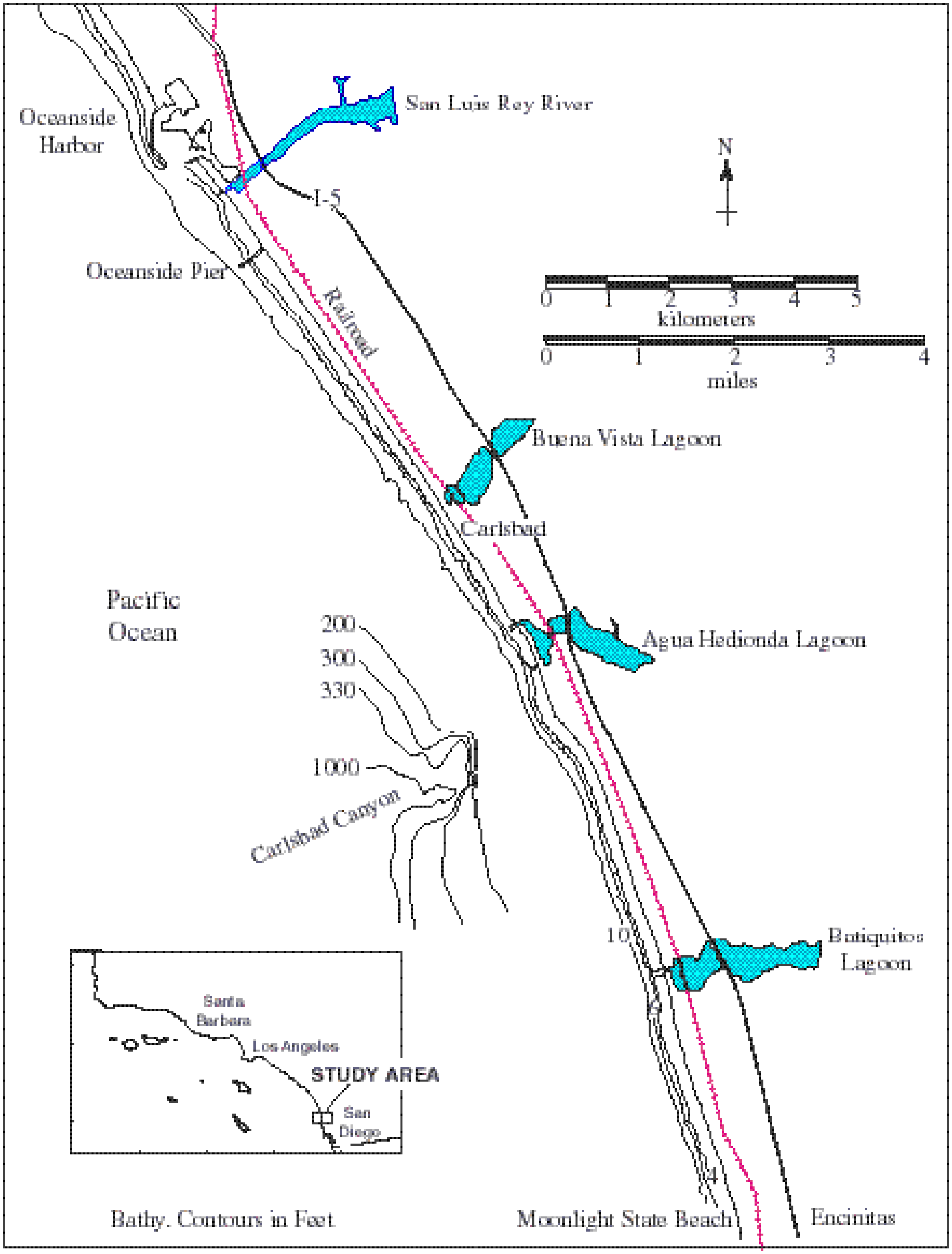

Figure 1-1. Map showing the location of Agua Hedionda Lagoon

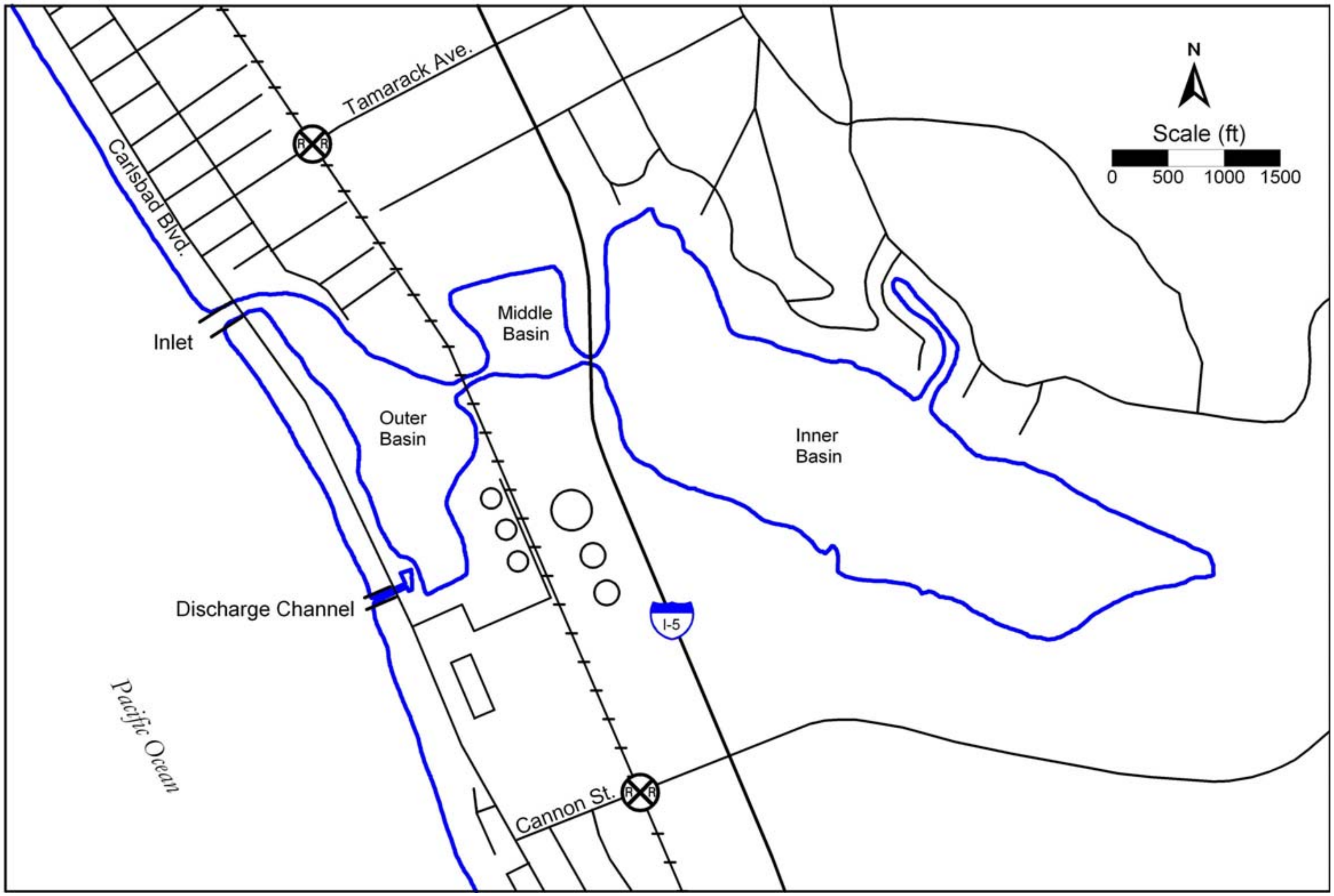

Figure 1-2. Map of Agua Hedionda Lagoon showing the locations of its three basins: the Outer, Inner, and Middle Basins.

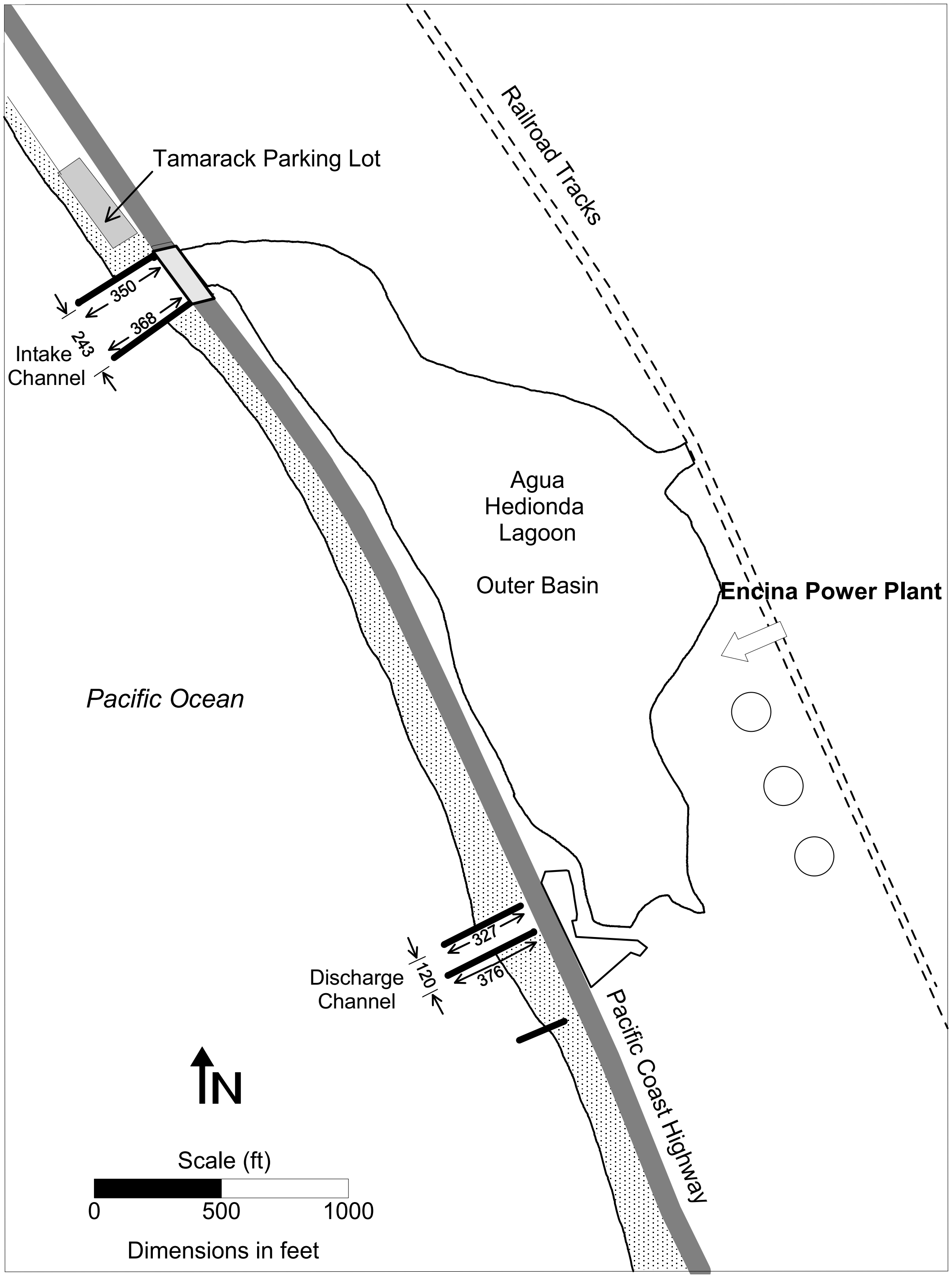

Figure 1-3. Configurations of intake and discharge channels of Agua Hedionda Lagoon.

Several studies have previously been conducted to determine the effect of the operation of the cooling system of Encina Power Station on lagoon sedimentation (Ellis, 1954; Bhogal et al., 1989; EA Engineering Science and Technology, 1997; Jenkins and Wasyl, 2001). Studies to determine the impact on marine environments have been presented by Jenkins and Skelly (1998) and Jenkins et al. (1989). Elwany et al. (1999) described the oceanographic conditions (waves and tides) at Agua Hedionda Lagoon in detail. A bibliography of pertinent research on existing conditions and monitoring studies in the vicinity of Agua Hedionda lagoon is given in Coastal Environments (1998).

2.0 DESCRIPTION OF AGUA HEDIONDA LAGOON

Agua Hedionda Lagoon is located within the City of Carlsbad, California. The lagoon is bounded on the west by the Pacific Coast Highway (called "Carlsbad Boulevard" in this area), on the north by the City of Carlsbad residential community, and on the east and south by undeveloped hill slopes and bluffs. On the south side above the bluffs lie cultivated fields and the EPS.

The Santa Fe Railroad and Interstate 5 freeway ("I-5") divide Agua Hedionda Lagoon into three sections, the Inner, Middle and Outer Basins, which have areas of 186, 22, and 50 acres, respectively. The natural resources of Agua Hedionda Lagoon have been described in Bradshaw et al. (1976).

In 2004 and 2005, the Encina Power Station conducted topographic surveys in the lagoon. Surveys of the Outer, Middle, and Inner Basins were conducted in March 2005, November 2004, and May 2005, respectively. Figure 2-1 is a bathymetric map of the lagoon. There is a cooling water intake channel and an effluent discharge channel offshore from the lagoon. The intake jetties are located west of the Coast Highway bridge and have lengths of about 350 ft (north) and 368 ft (south). The distance between the centerline of the two jetties is about 243 ft. The jetties at the discharge channel are about 327 and 376 ft long, with the south jetty extending longer than the north jetty. The distance that the intake and discharge jetties extend varies with the changing location of the shoreline.

Figures 2-2 through 2-4 show the bathymetry of the Outer, Middle and Inner Basins. The bottom elevations in the basins range from about −42 ft (NGVD 29), in the deepest portion of the Outer and Middle Basins, to about 10 ft NGVD along the shoreline of the Inner Basin. The Outer Basin and the channel leading to the Inner Basin are the deepest areas of the lagoon. The Middle and Inner Basins are shallower at −16 ft, NGVD, in comparison to the majority of the Outer Basin, which is at a depth of −20 to −32 ft, NGVD. From these maps, cumulative surface area (in acres) and cumulative water volume (in acre-ft) were obtained. The potential tidal prism (in acre-ft) versus elevation (ft, NGVD) was computed.

The surface area of the lagoon at 6 ft, NGVD is about 350 acres. The surface area of the lagoon is reduced to about 225 acres at mean low lower water (MLLW). At MLLW, the volume of water in the lagoon is about 1750 acre-ft. The majority of the area and volume come from the large Inner Basin (Figure 2-5).

The potential tidal prism, as a function of lagoon water level elevation, is shown for the Outer, Middle, and Inner Basins and for the total lagoon (Figure 2-6). The tidal prism of the lagoon is defined as the volume of water in the lagoon between the maximum and minimum water levels. Here we assume the minimum water level to be -1 ft, NGVD, for the purpose of computation. Tidal prism is referred to as "potential tidal prism," because we assume that the water level in the entire lagoon is the same, with no friction losses (i.e., no tidal muting). Figure 2-6 shows that the tidal prism of the Inner Basin constitutes the largest portion of the lagoon tidal prism.

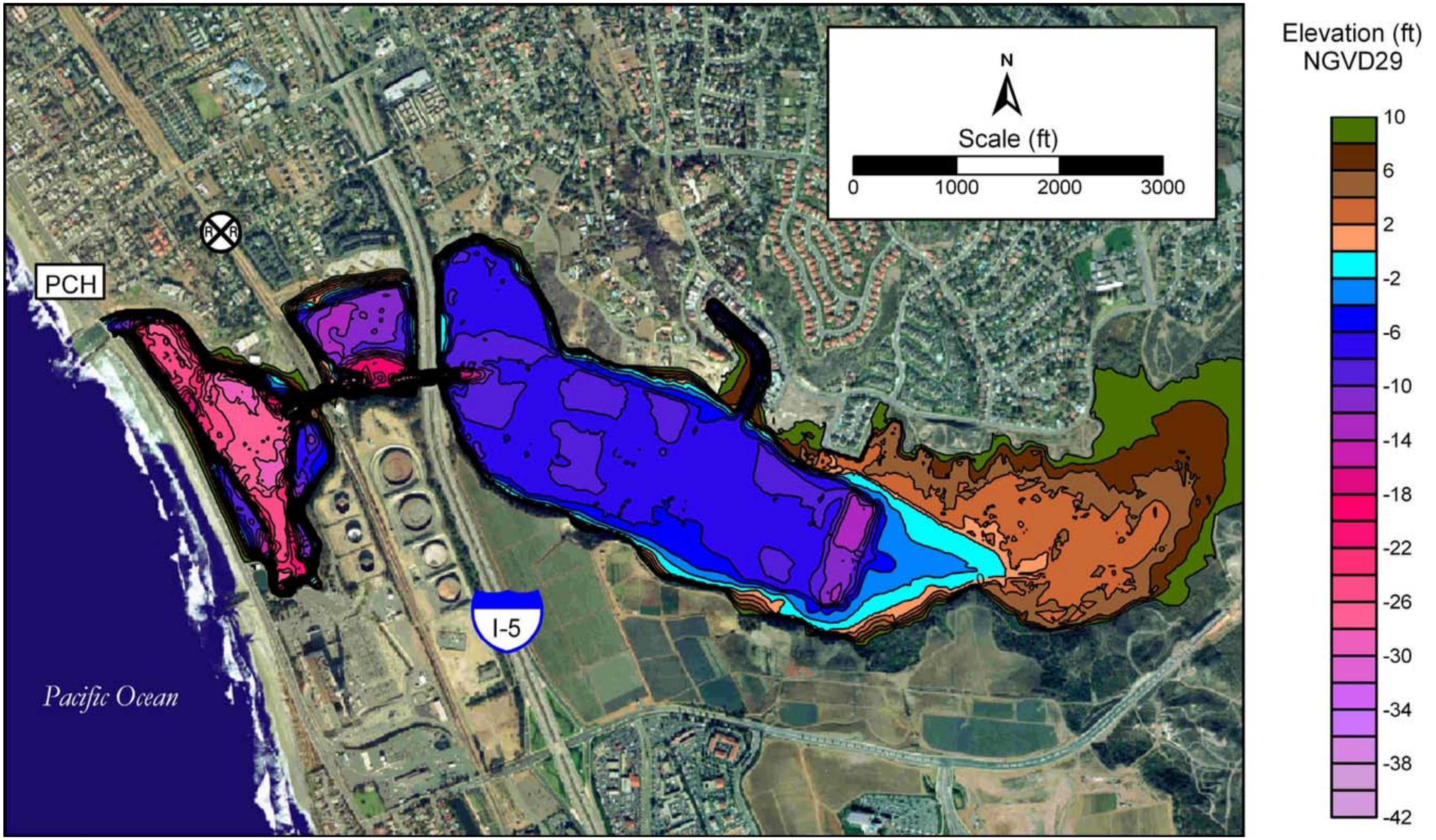

Figure 2-1. Bathymetry map of Agua Hedionda Lagoon.

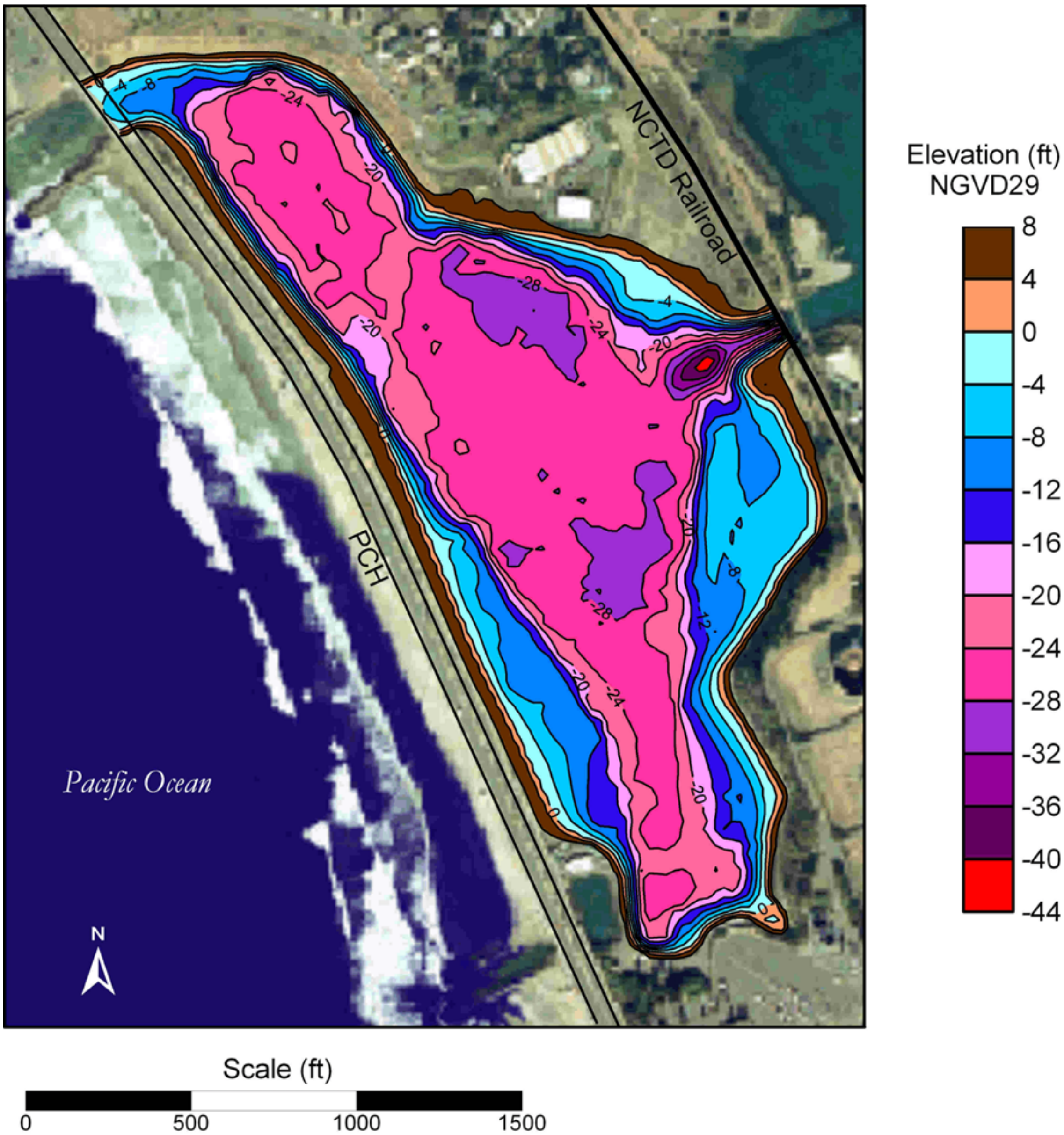

Figure 2-2. Bathymetry map of Outer Basin.

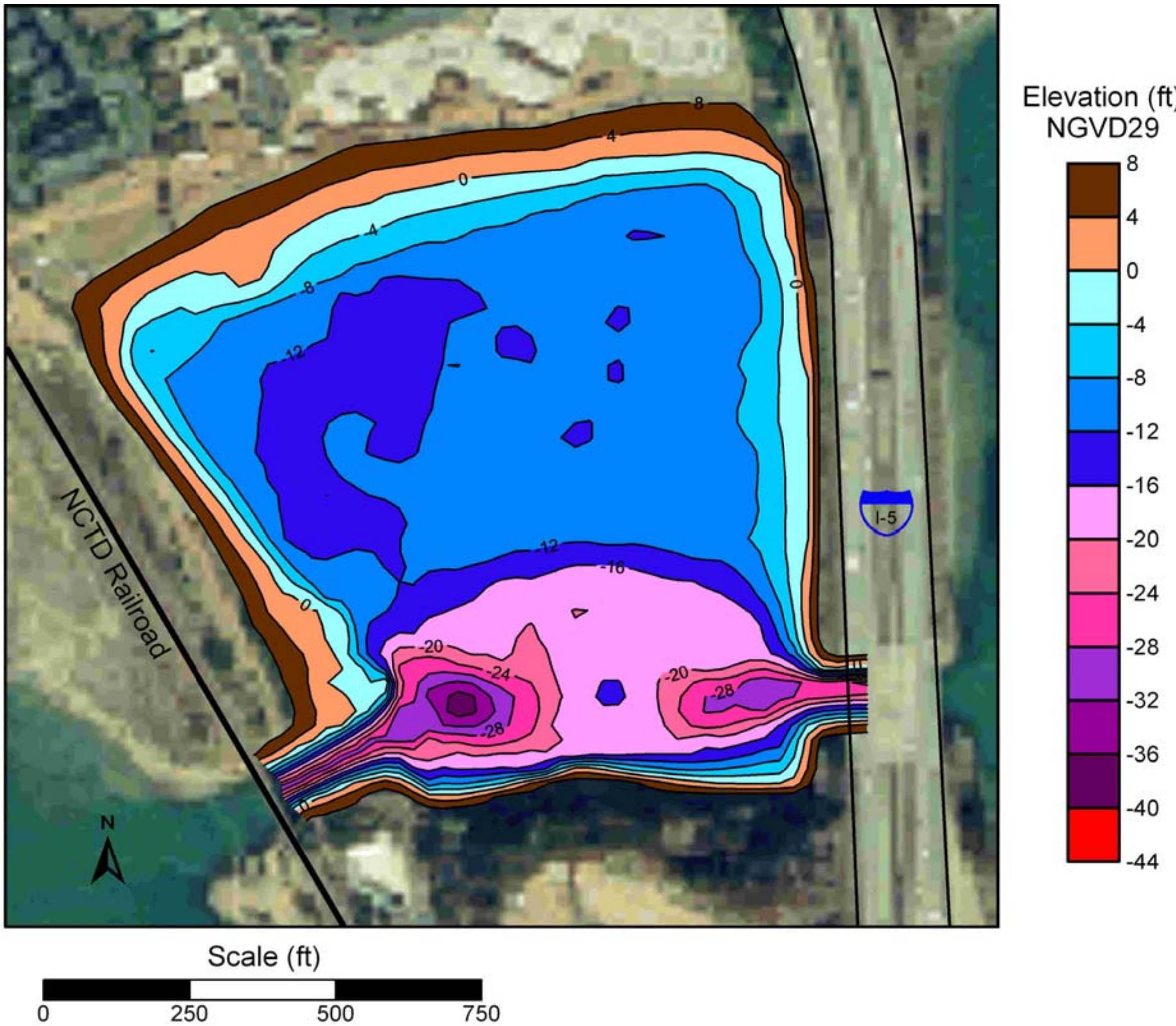

Figure 2-3. Bathymetry map of Middle Basin.

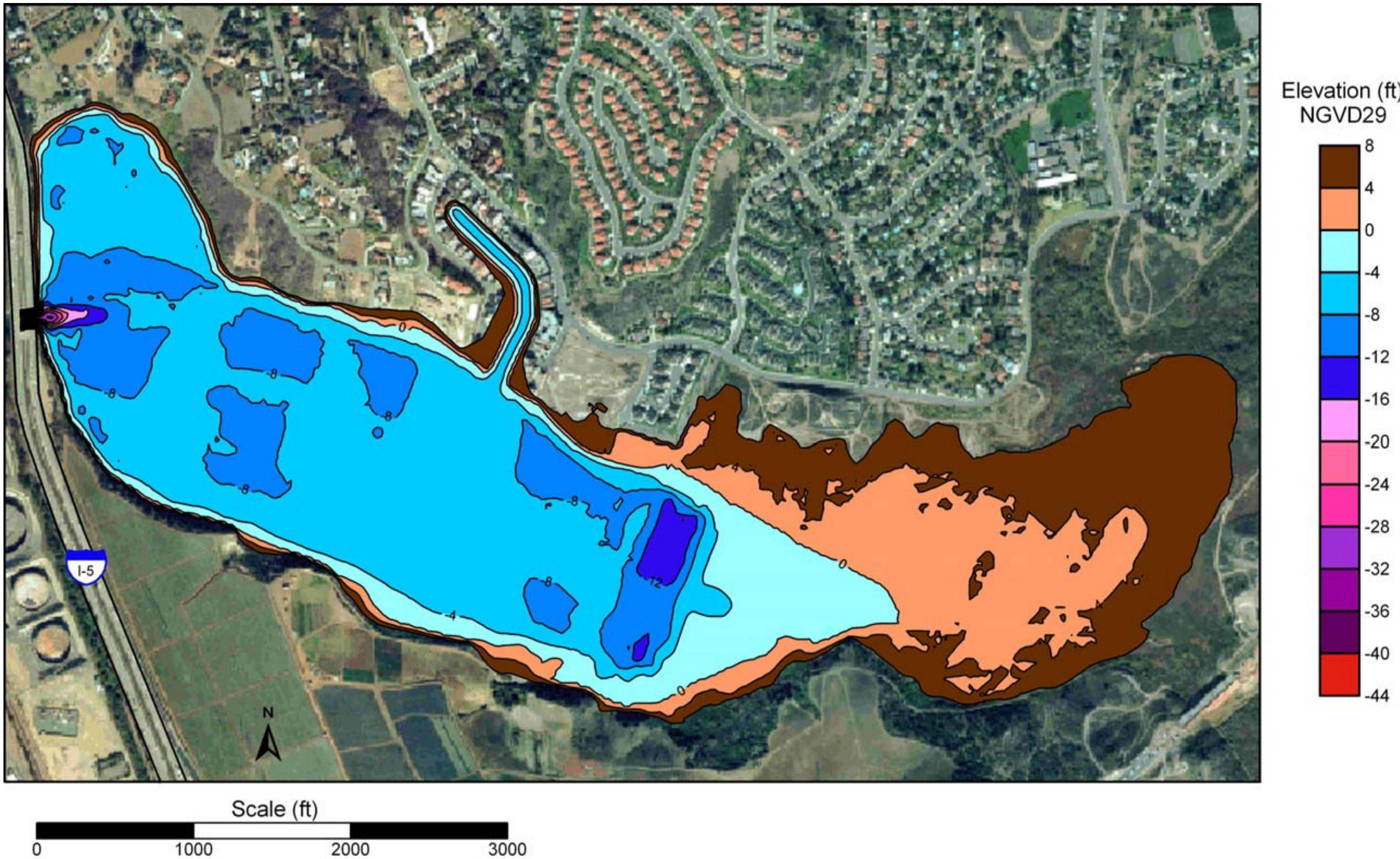

Figure 2-4. Bathymetry map of Inner Basin.

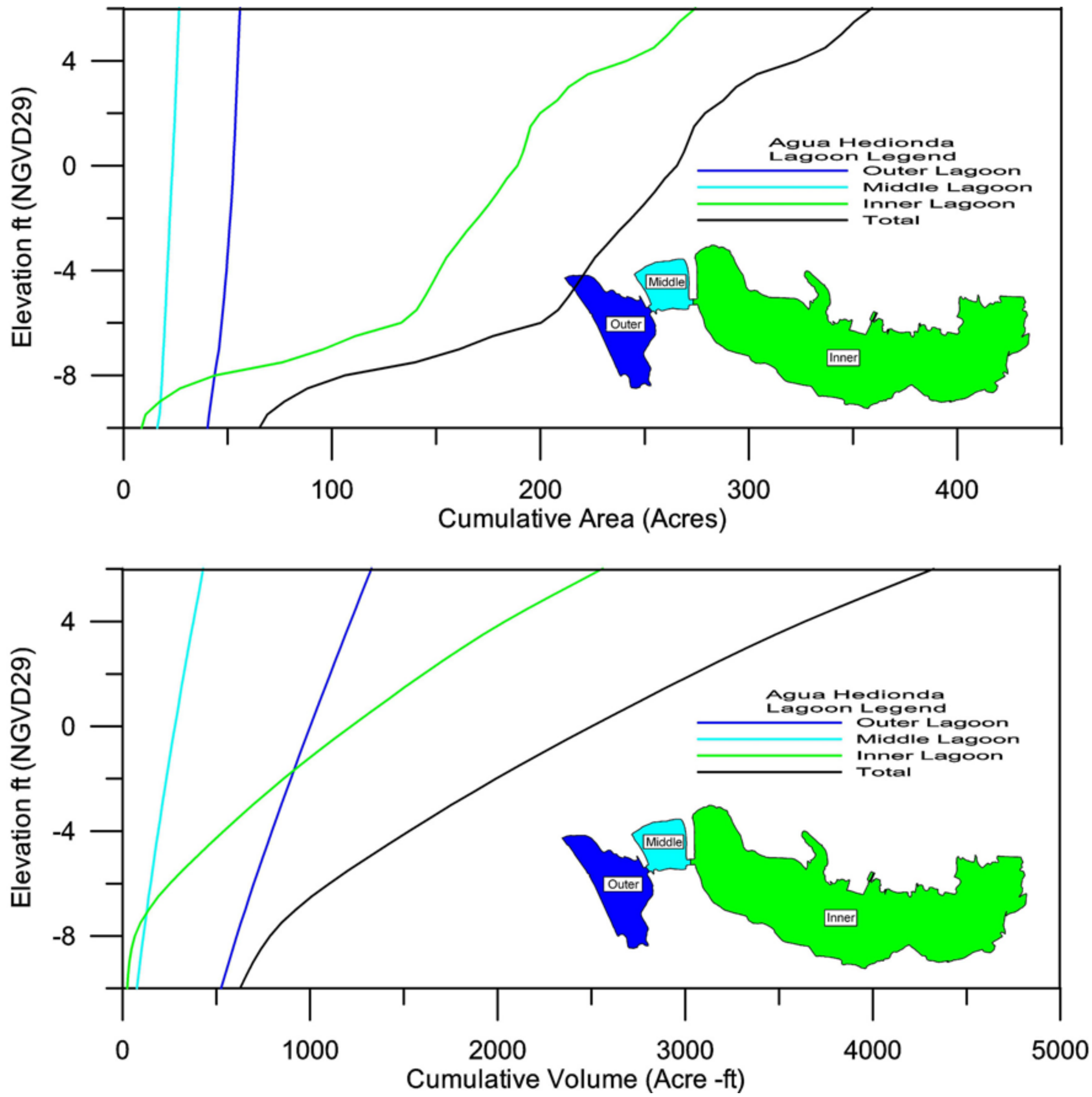

Figure 2-5. Agua Hedionda Lagoon surface area (top) and water volume (bottom).

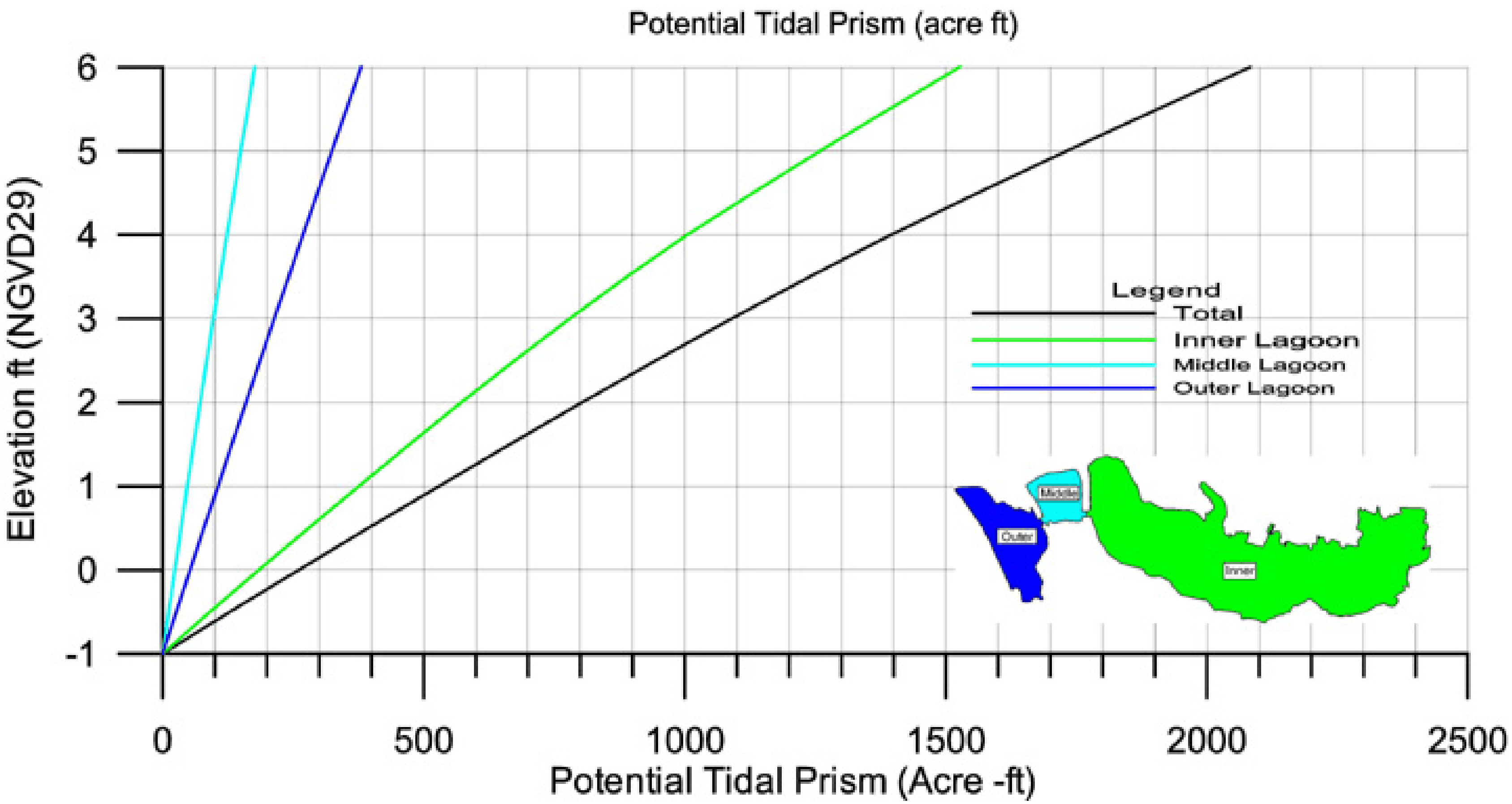

Figure 2-6. Potential tidal prism for the Outer, Middle, and Inner Basins and for the lagoon (total).

2.1 OCEAN TIDES

Ocean tides force water fluctuations in the lagoon. The tide is the change of ocean water level caused by the astronomical forces of the moon and sun. Tides are predictable and can be decomposed into a set of constituent frequencies near one and two cycles per day, each having a given amplitude and phase at any location. Longer period fluctuations in amplitude occur at two cycles per month and two cycles per year, every 4.4 and 18.6 years.

On the San Diego coast, the tide is mixed and has nearly equal semi-daily and daily components (Zetler and Flick, 1985). The highest monthly tides in the winter and summer are higher than the highest monthly tides in the spring and fall as a result of lunar and solar declination effects. Also, the extreme monthly higher-high tide in the winter tends to occur in the morning.

The tidal fluctuations are superimposed at sea level. Seasonal sea level in the San Diego area tends to be highest in the fall and lowest in the spring, with differences of about 0.5 ft. Local warming or cooling resulting from offshore shifts in water masses can alter the average sea level by several tenths of a foot over periods lasting several months (e.g., El Niño years) (Reid and Mantyla, 1976).

Tidal elevations are usually referenced to Mean Lower Low Water (MLLW), which is defined as the average elevation of the lowest water level readings of each day over a specified 19-year interval. In the study area, the maximum tidal range is about 9 ft (7.2 ft above MLLW to 1.8 ft below MLLW). Tidal elevations can be converted to other vertical datum using the appropriate conversion values. Table 2-1 gives some of these datum with respect to MLLW and NGVD.

2.2 POWER PLANT INTAKE FLOW RATES

Figure 2-7 shows the hourly flow rates of the power plant intake between 1 June 2005 and 7 July 2005. Plant diversion of lagoon waters reduces the outflow water from the lagoon to the ocean. Actual plant inflow rates during high-use periods are typically 635 to 670 million gallon per day (mgd). This is about 26 to 28 million gallons per hour.

Table 2-1. Tidal levels with respect to MLLW and NGVD (1960-1978).

Parameters	Mean Lower Low Water (MLLW) ft	National Geodetic Vertical Datum (NGVD) ft
Mean Higher High Water (MHHW)	5.37	2.81
Mean High Water (MHW)	4.62	2.06
Mean Sea Level (MSL)	2.75	0.19
NGVD	2.56	0
Mean Lower Low Water (MLLW)	0	2.56

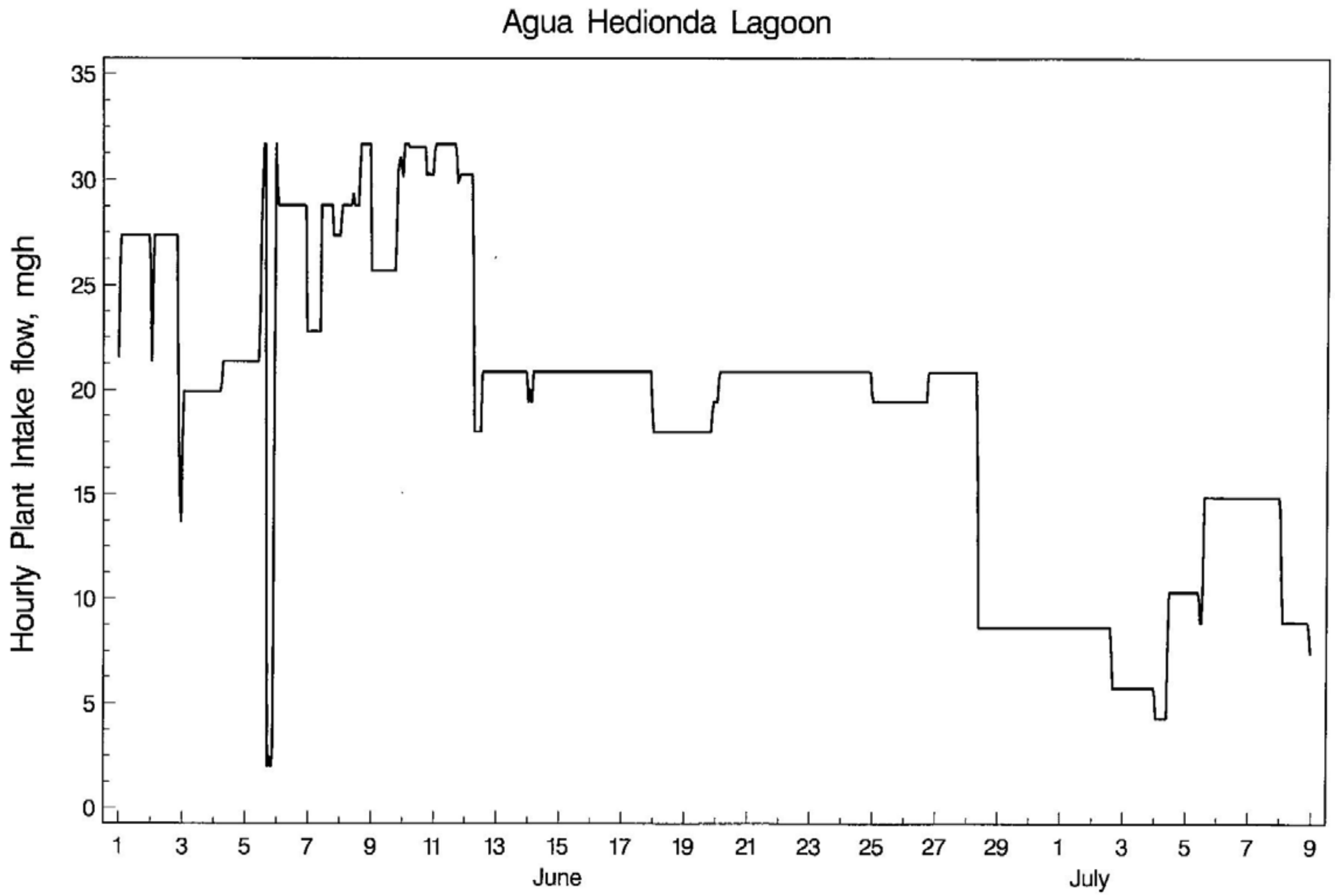

Figure 2-7. Hourly Encina Power Station intake flow.

3.0 WATER LEVEL, VELOCITY, SALINITY, AND TEMPERATURE MEASUREMENTS

3.1 WATER LEVEL

Water level measurements were acquired at four locations throughout the study area (Stations S0, S2A, S2B, and S3) for a period of approximately one month from 1 June 2005 to 7 July 2005. Measurements were taken using self-contained pressure sensors recording water surface elevations at five-minute intervals. Complete results for all locations are shown in Appendix A.

Station S0 is located at the inlet to the Outer Basin; station S2A is located in the northern portion of the Inner Basin; station S2B is located at the inlet to the Inner Basin; and station S3 is located in the southeastern portion of the Inner Basin. The station locations are shown in Figure 3-1, and the benchmarks are shown in Figure 3-2.

Three benchmarks were used during this study to calibrate the pressure data (from the sensors) into water elevations. The process required installing manual tide staffs and taking manual water level elevations for a few hours.

Figures 3-3 through 3-5 show water levels at the four stations during neap, spring, and mean tides, respectively. The measurements presented show that there are only small variations between water level elevations at the four stations during neap tide. There was a time lag between water level at the inlet and water level at the Inner Basin (< 1 hour). During neap tide, water elevation at the entrance to the Outer Basin and water elevation at the interior of the Inner Basin fill to approximately equivalent levels. During spring and mean tides, there is a short time lag and a variation in water elevation (~ 0.25 ft) between the inlet to the lagoon (Station S0) and the interior stations (Figures 3-4 and 3-5).

3.2 WATER VELOCITY

Water velocities were measured at Station S0 during neap, spring, and mean tides (Figures 3-6 through 3-8). Water velocities were high during spring tide (approximately + 4.5 ft to –3.5 ft). The highest water velocity measurements at Station S0 were +5 ft/sec and –3 ft/sec (during spring tide). See Appendix B for further data and figures.

Tidal prism was computed (Figure 3-9) from data collected in the basins during the approximate one-month study period between 1 June and 6 July 2005. During this time period, the cumulative tidal prism for the lagoon ranged from 175 acre-ft to 2075 acre-ft. Water in the Middle and Outer Basins had fewer fluctuations and a much smaller tidal prism (about 50 to 300 acre-ft) than water in the large Inner Basin. The Inner Basin contains the majority of the water in the lagoon (see Appendix C).

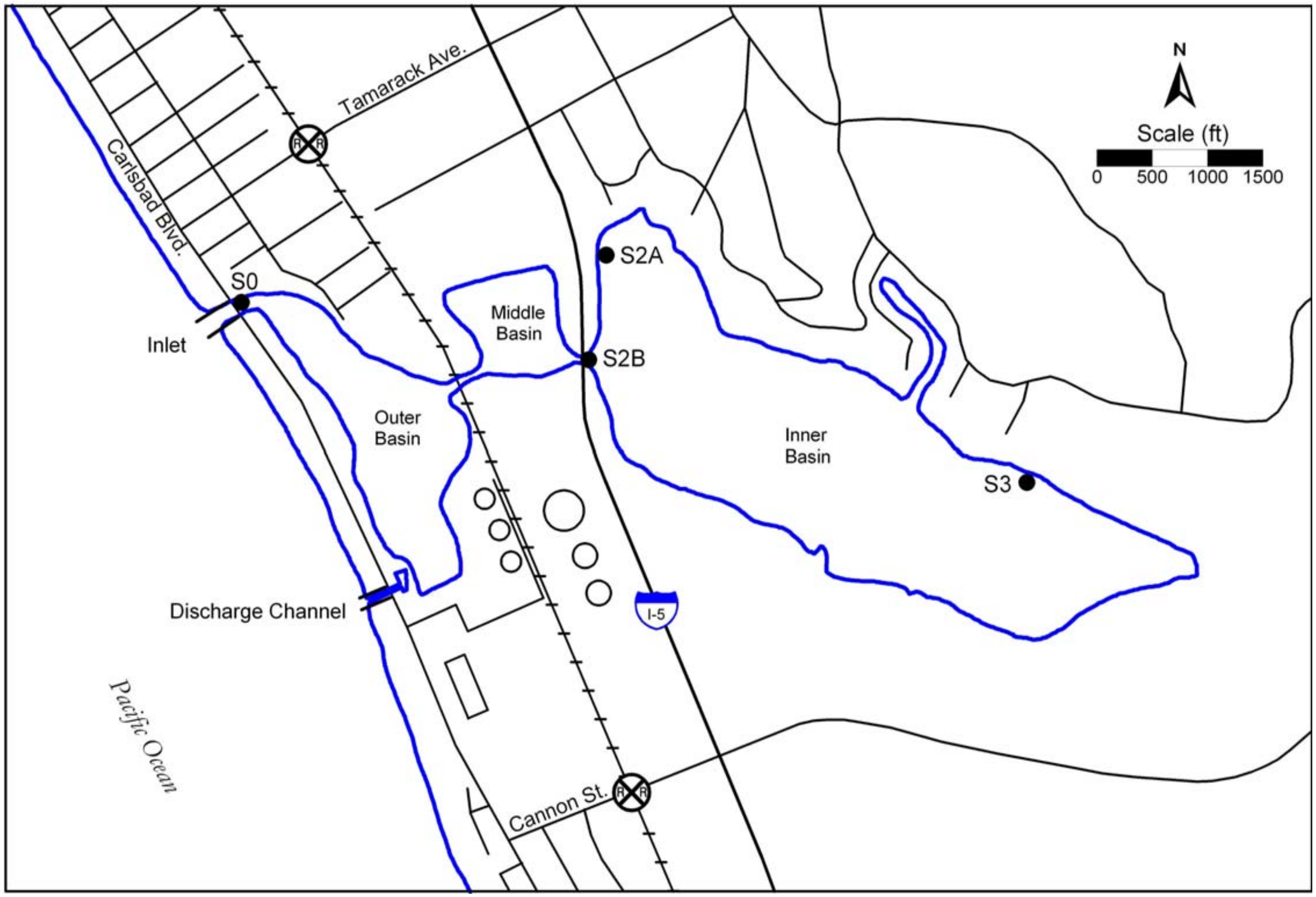

Figure 3-1. Measurement locations for Stations S0 (water level, water velocity, temperature, salinity), S2A (water level), S2B (water level, water velocity, temperature, salinity), and S3 (water level).

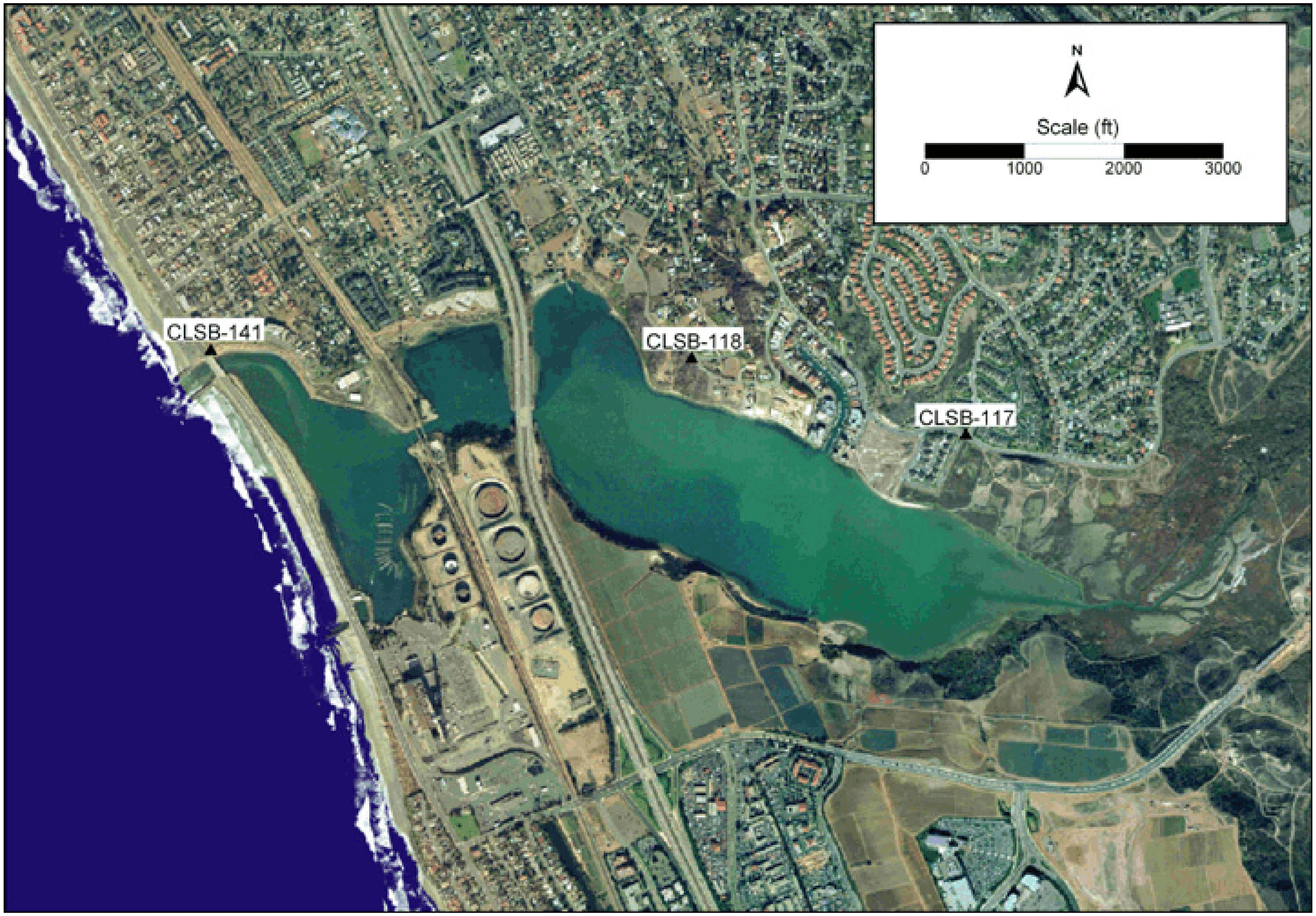

Figure 3-2. Locations of benchmarks used in this study.

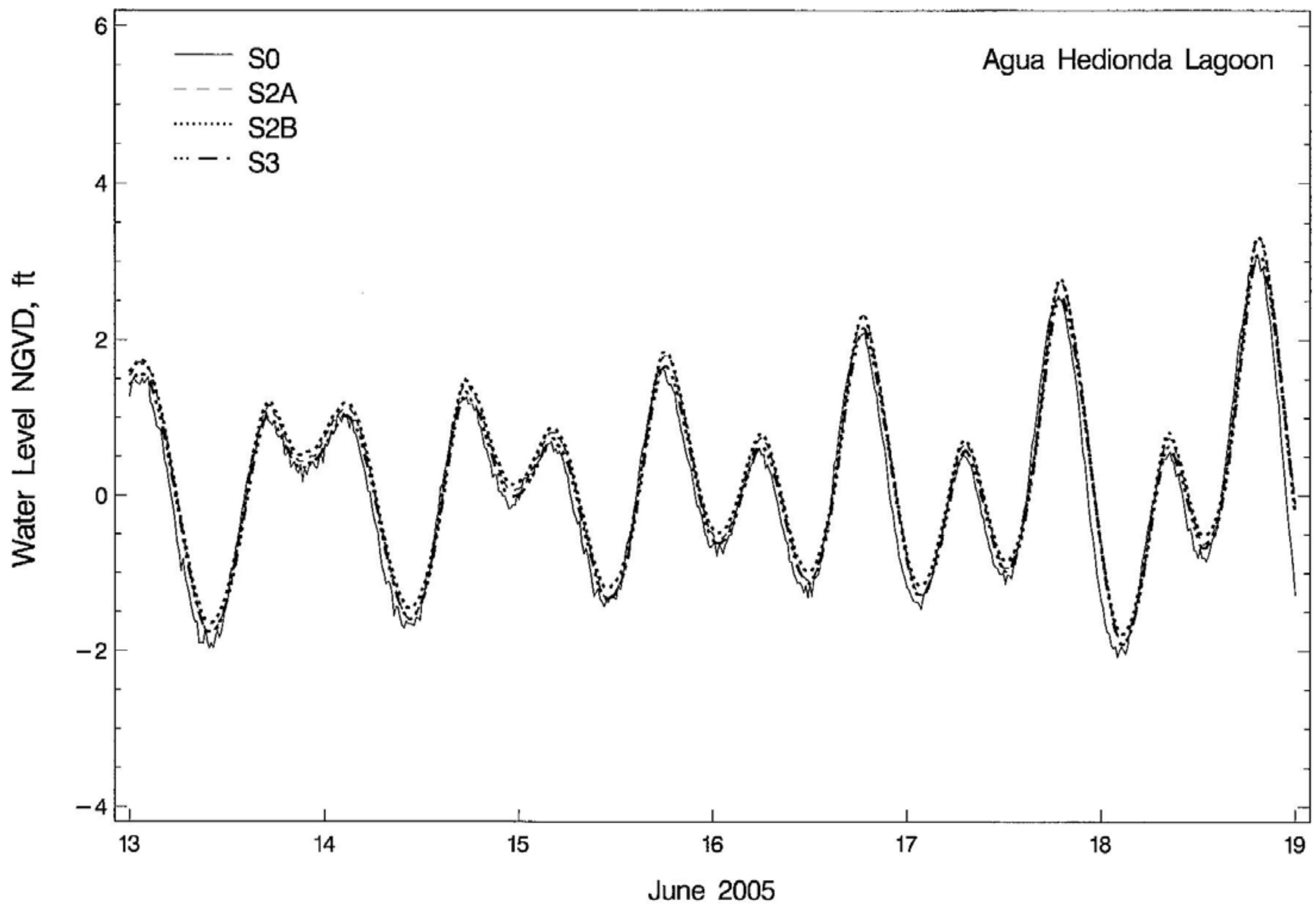

Figure 3-3. Comparison of water level at Stations S0, S2A, S2B, and S3 during neap tide.

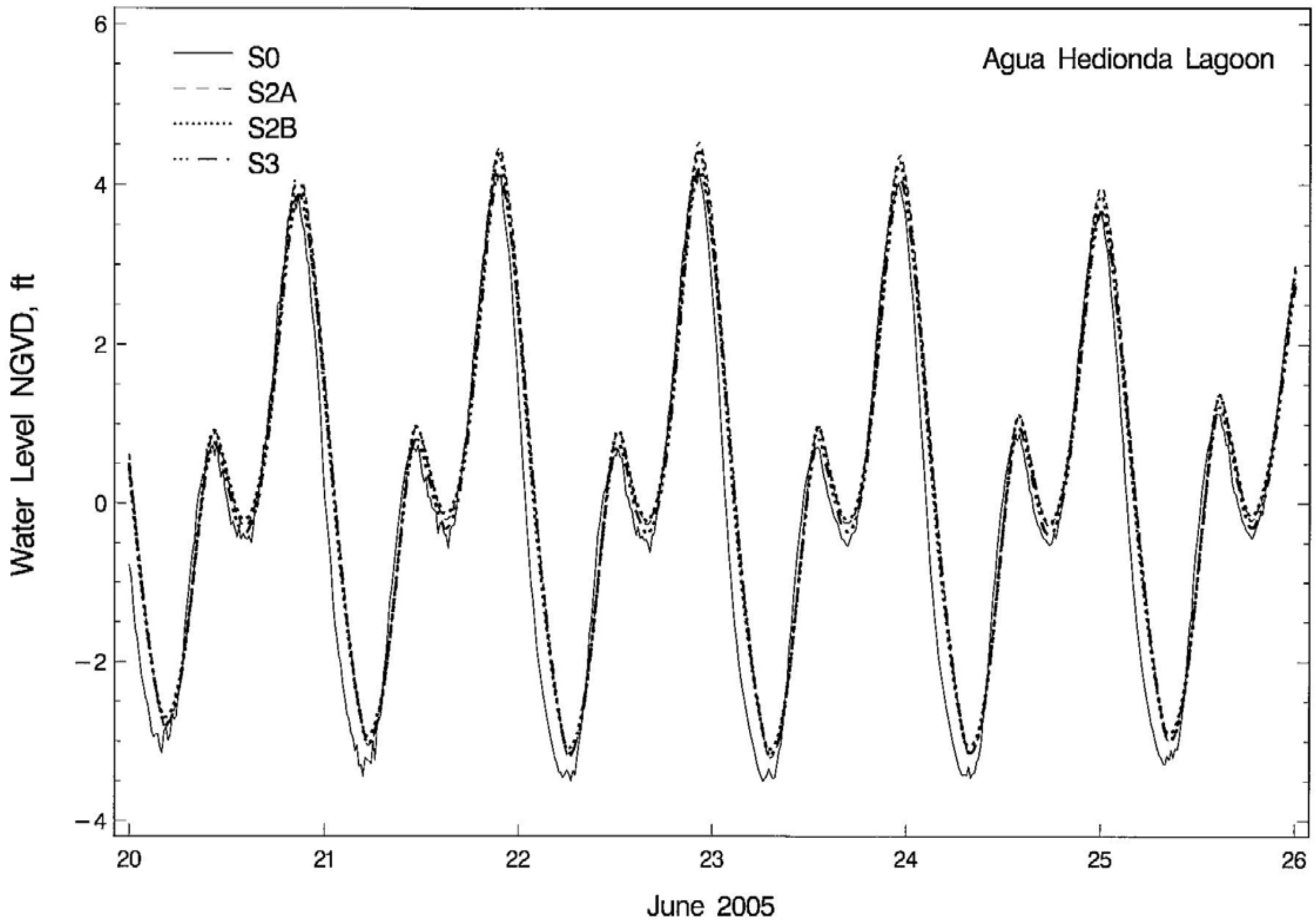

Figure 3-4. Comparison of water level at Stations S0, S2A, S2B, and S3 during spring tide.

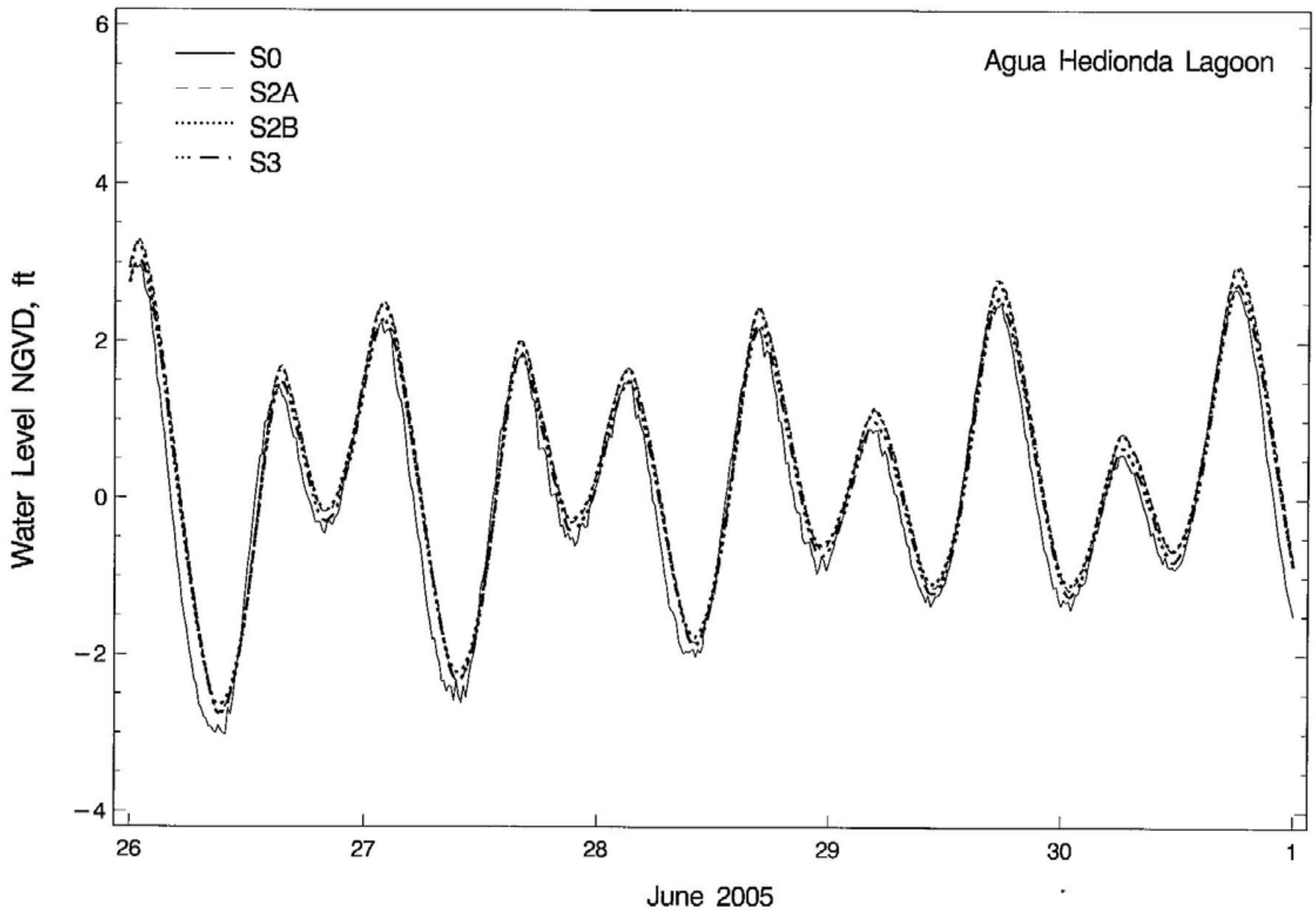

Figure 3-5. Comparison of water level at Stations S0, S2A, S2B, and S3 during mean tide.

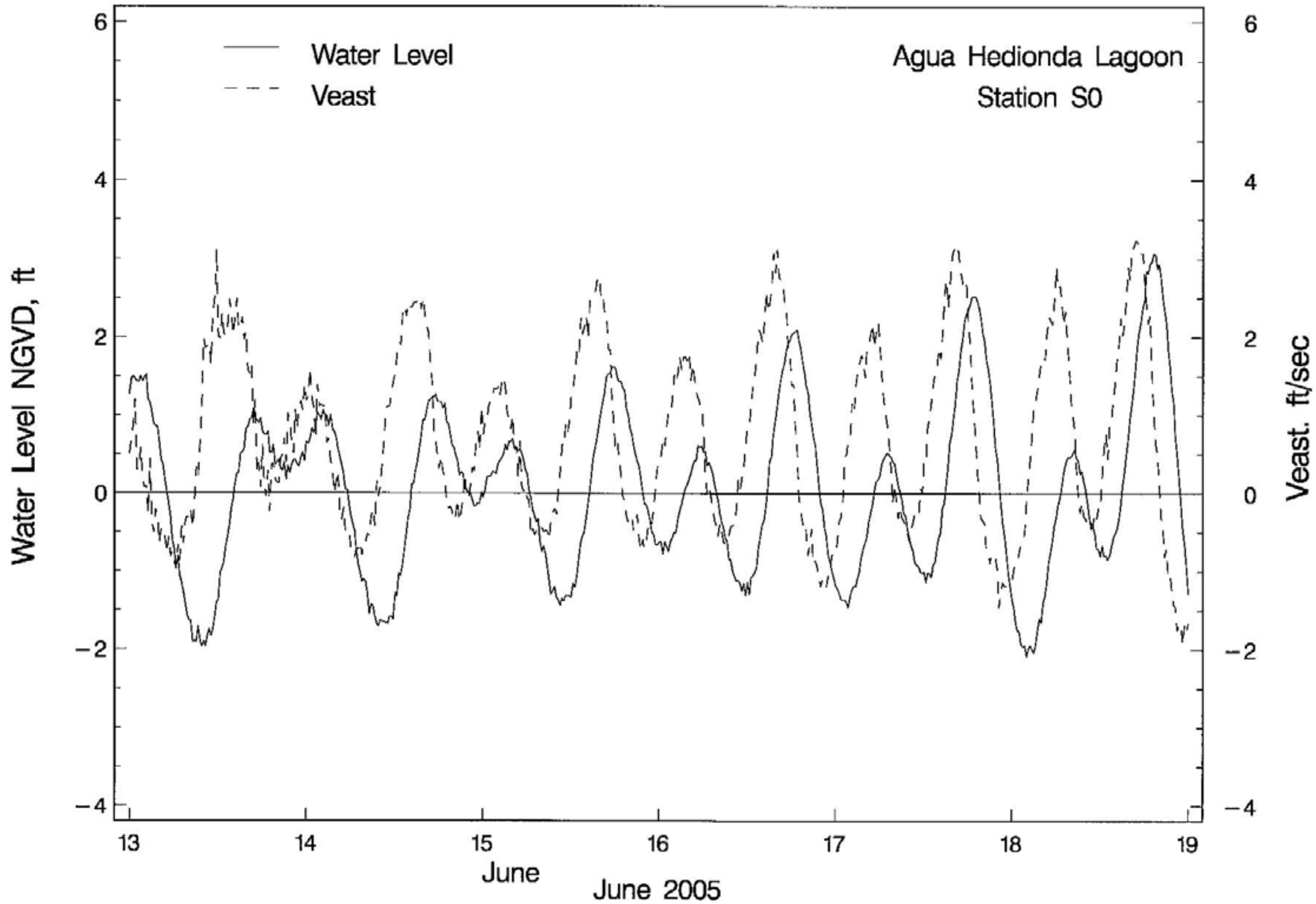

Figure 3-6. Water level and velocity measurements during neap tide.

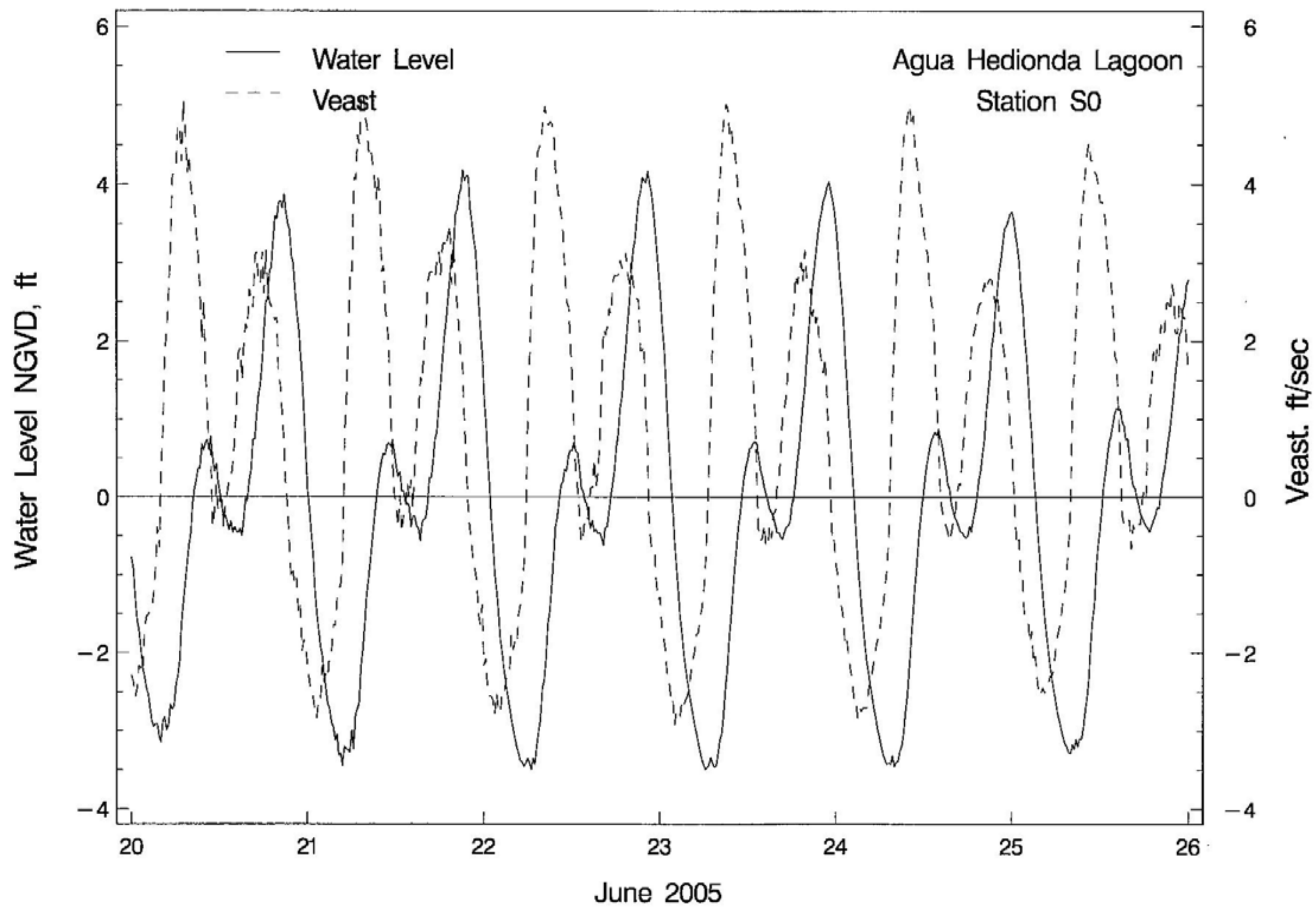

Figure 3-7. Water level and velocity measurements during spring tide.

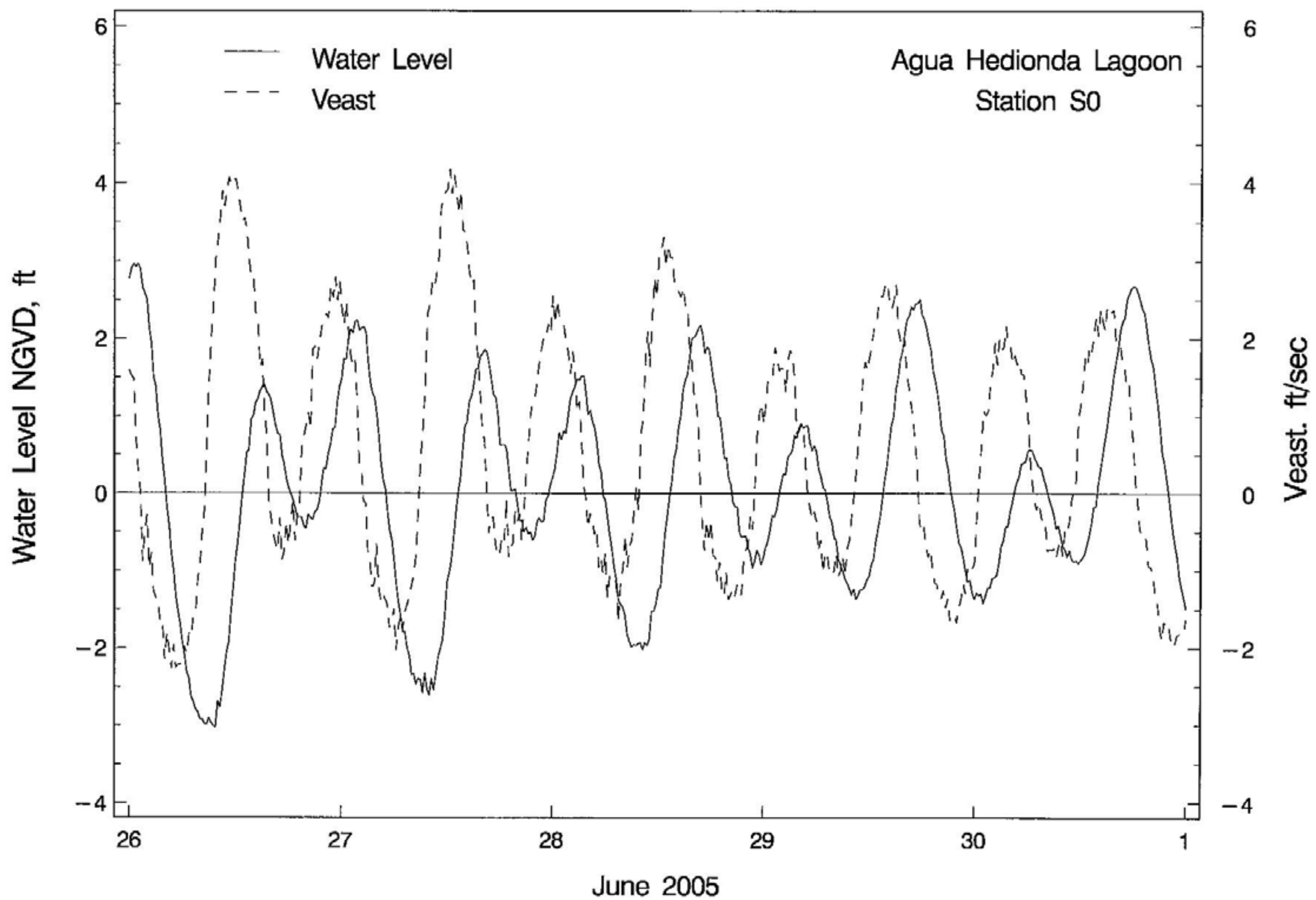

Figure 3-8. Water level and velocity measurements during mean tide.

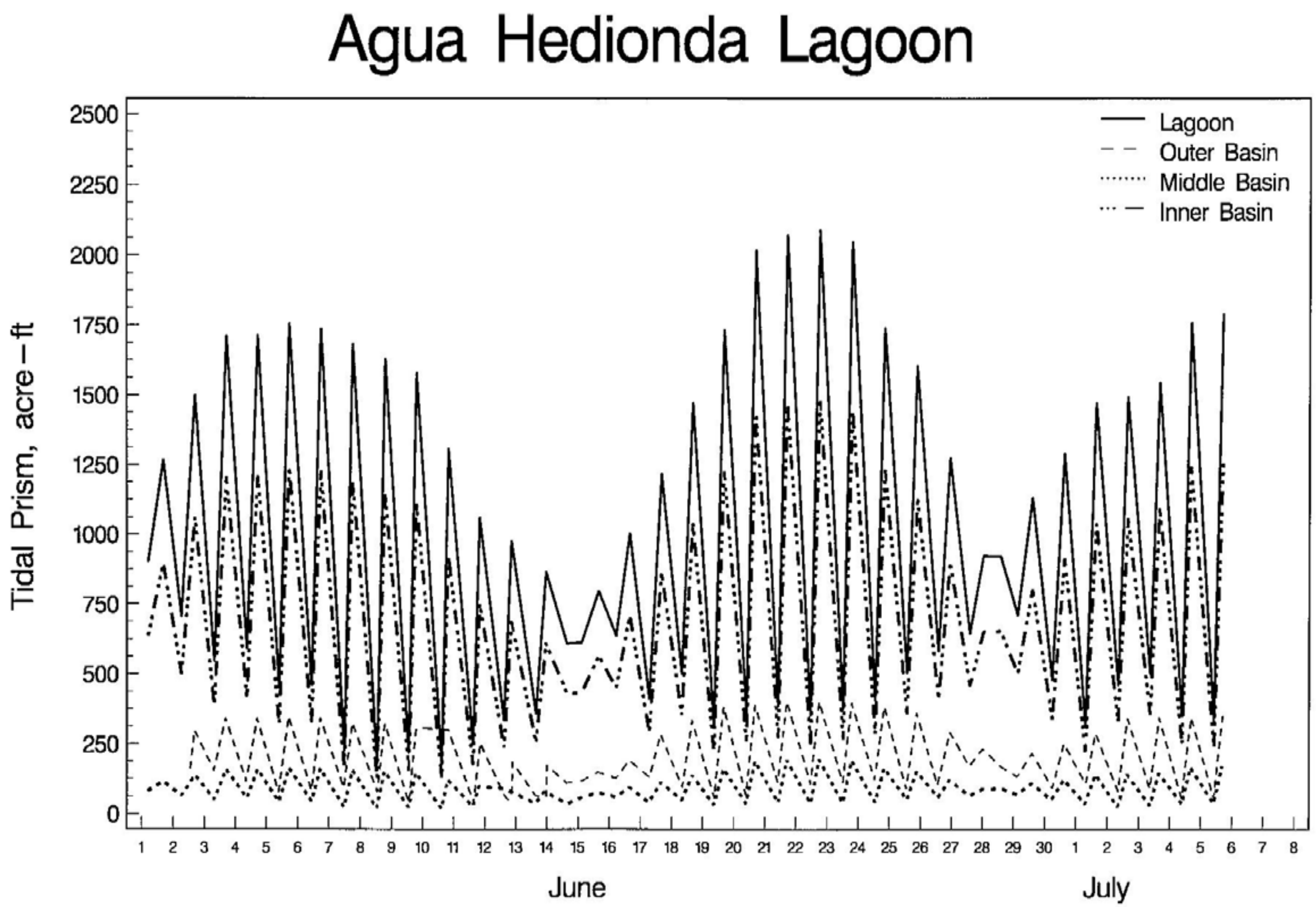

Figure 3-9. Tidal prism of the lagoon between June 1, 2005 and July 6, 2005.

3.3 SALINITY AND TEMPERATURE

Conductivity and temperature measurements were taken at Station S2B over a one-month period in order to compute water salinity. Salinity fluctuated between about 31.5 and 34 PSU (see Appendix D).

Temperature data were collected over a one-month period at Stations S0 and S2B. During the first two weeks of June, the temperature was about 20 to 22º C, while during late June to early July, the temperature decreased and fluctuated significantly, ranging between 14 and 20º C (see Appendix D).

4.0 RESIDENCE TIME OF WATER IN THE LAGOON

The term “old water” is defined here as water that remains in the lagoon system after the water outflow during ebb tide. It is water that has not yet been flushed out of the lagoon. As new water comes into the lagoon during flood tides, the “old water” becomes more diluted with each tidal cycle until all of it is eventually replaced by new water.

A computer program has been written to compute the percentage of remaining old water in the lagoon from the time immediately after the tidal cycle until the time when the remaining old water in the lagoon is less than 2%. The procedure is as follows.

If Q_{min} is the volume of water in the lagoon after the ebb tide, then Q_{min} will be diluted after the first tidal cycle by

$$D_i = (V_{max}(i+1) - V_{min}(i) + I_{pmax}(i+1) / V_{max}(i+1) \tag{1}$$

where D = dilution,
i = the number of the tidal cycle and takes the values 1, 2, 3, ... , n,
V_{max} = the volume of water in the lagoon corresponding to the maximum water level,
V_{min} = the volume of water in the lagoon corresponding to the minimum water level, and
I_{pmax} = the volume of water taken from the lagoon by the power plant intake between the minimum and maximum water levels.

A tidal cycle is defined as the tidal period between two successive upcrossings of water level above the mean water elevation of the lagoon. The computed values of D_i (< 1) are multiplied after each tidal cycle, until the value of $D_i < 0.02$.

$$D_n = D_1 \times D_2 \times D_3 \times \ldots\times D_n \tag{2}$$

The incoming water to the lagoon during a tidal cycle is calculated from the equation:

$$Q_{in} = V_{max} - V_{min} + I_{pmax} \tag{3}$$

while the outgoing water from the lagoon is given by:

$$Q_{out} = V_{max} - V_{min} - I_{pmin} \tag{4}$$

where I_{pmin} is the volume of water taken from the lagoon by the power plant intake between the maximum and minimum water levels.

In performing the computations for the individual basins, we apportioned the power plant intake flows by the volume of the basins at the minimum water level per tidal cycle. Figures 4-1 and 4-2 present the percentage of “old water” in the lagoon vs. the tidal cycles and daily tidal flushing, respectively. The solid lines show the best-fit curve for the data.

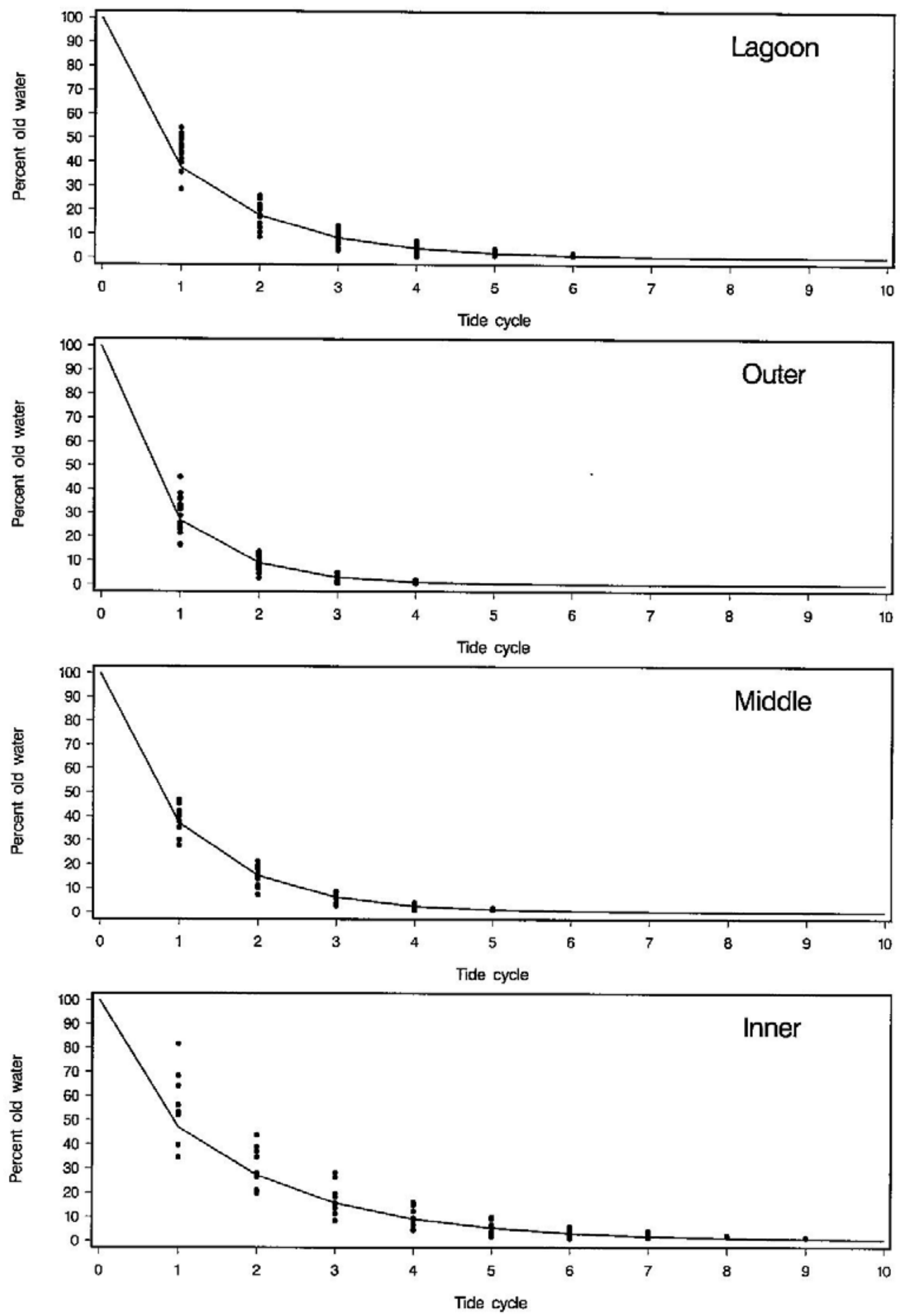

Figure 4-1. Percentage of old water in the lagoon vs. tidal cycles.

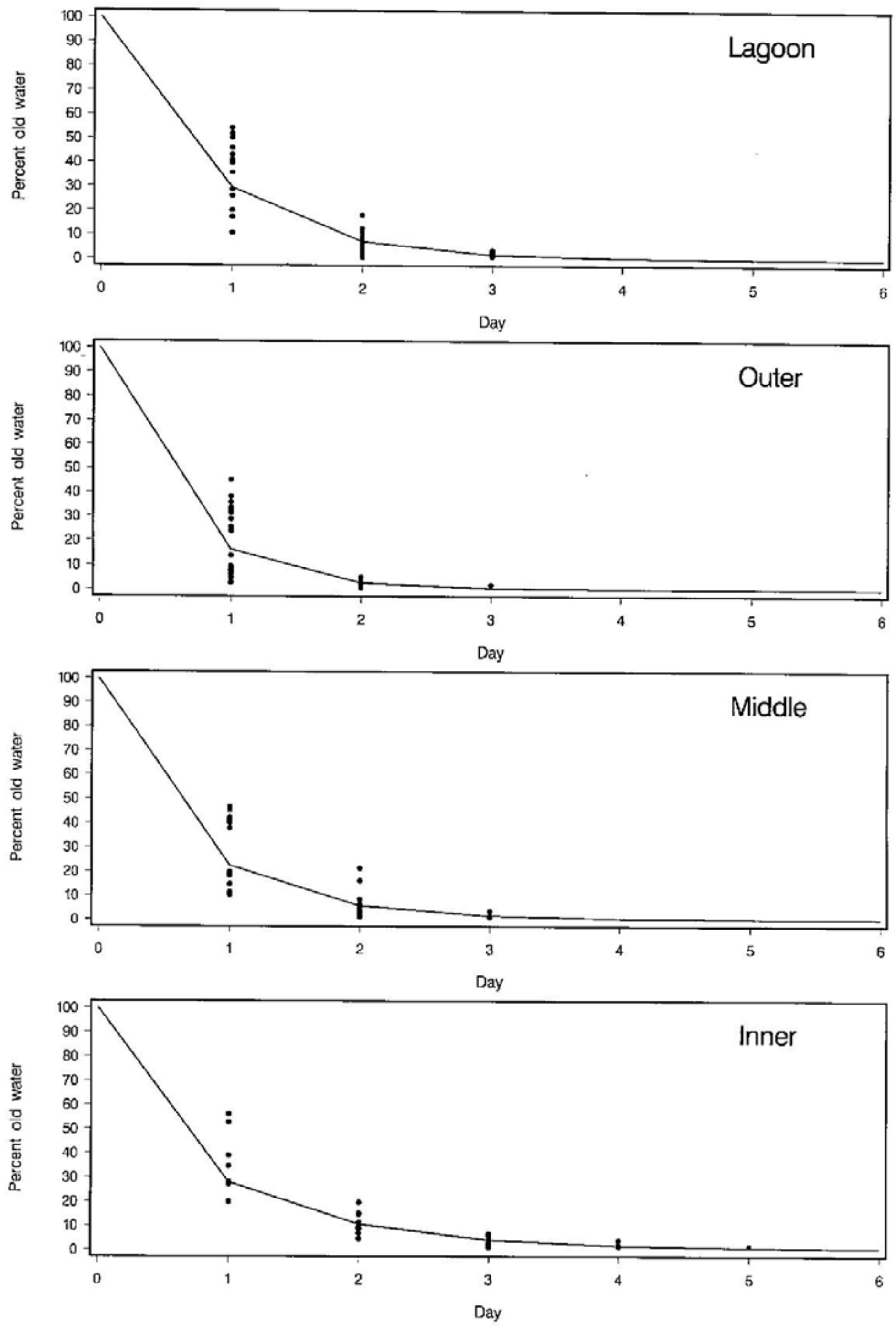

Figure 4-2. Percentage of old water in the lagoon vs. day, with solid line showing best-fit curve.

The best-fit curve is given by the equation:

$$y(x) = A\, e^{-Bx} \qquad (5)$$

where *A* and *B* are equation parameters, and *x* is the number of tidal cycles or days.

Tables 4-1 and 4-2 give the curve-fitting parameters from equation (5), that is *A* and *B*, for the percentage of old water in the lagoon and lagoon basins per tidal cycle and per day, respectively.

Table 4-3 gives the residence time of water in Agua Hedionda Lagoon. This table provides the mean, standard deviation, and range for both tidal cycles and days for the lagoon (total) and for the three basins, Outer, Middle, and Inner. Water remains in the lagoon (total) for a mean period of about 5.0 tidal cycles or 2.6 days. In the Inner Basin, water remains for a mean period of 6.27 tidal cycles or 3.2 days.

The lagoon inflow and outflow through the inlet during the period 1 June 05 through 7 July 05 is shown in Figures 4-3 and Figure 4-4 per tidal cycle and day, respectively. These figures are based on the water level and velocity measurements carried out in this study (Chapter 3).

The ratio between the inflowing water and the water taken in by the power plant cooling system is plotted in Figures 4-5 and 4-6 per tidal cycle and day, respectively. The solid lines in these two figures represent the mean ratio over the measurement time period. On average, the power plant cooling system takes in 51% of the inflowing water per tidal cycle and 46% per day.

Table 4-1. Curve-fitting parameters for "old water" percentage per tidal cycle.

Location	A	B
Lagoon	79.6766	−0.75256
Outer Basin	80.2683	−1.09736
Middle Basin	90.1073	−0.88907
Inner Basin	81.4989	−0.55056

Table 4-2. Curve-fitting parameters for "old water" percentage per day.

Location	A	B
Lagoon	122.360	−1.42331
Outer Basin	100.384	−1.82958
Middle Basin	87.945	−1.36858
Inner Basin	73.958	−0.97584

Table 4-3. Residence time of water in Agua Hedionda Lagoon.

Location	Tidal Cycles			Days		
	Mean	Std[a]	Range	Mean	Std[a]	Range
Lagoon	5.0	1.2	2 - 6	2.6	1.0	1 - 4
Outer Basin	3.6	0.5	2 - 4	1.9	0.5	1 - 3
Middle Basin	4.47	0.8	2 - 5	2.3	0.6	1 - 3
Inner Basin	6.27	1.8	2 - 9	3.2	1.0	1 - 5

[a] Std = Standard Deviation

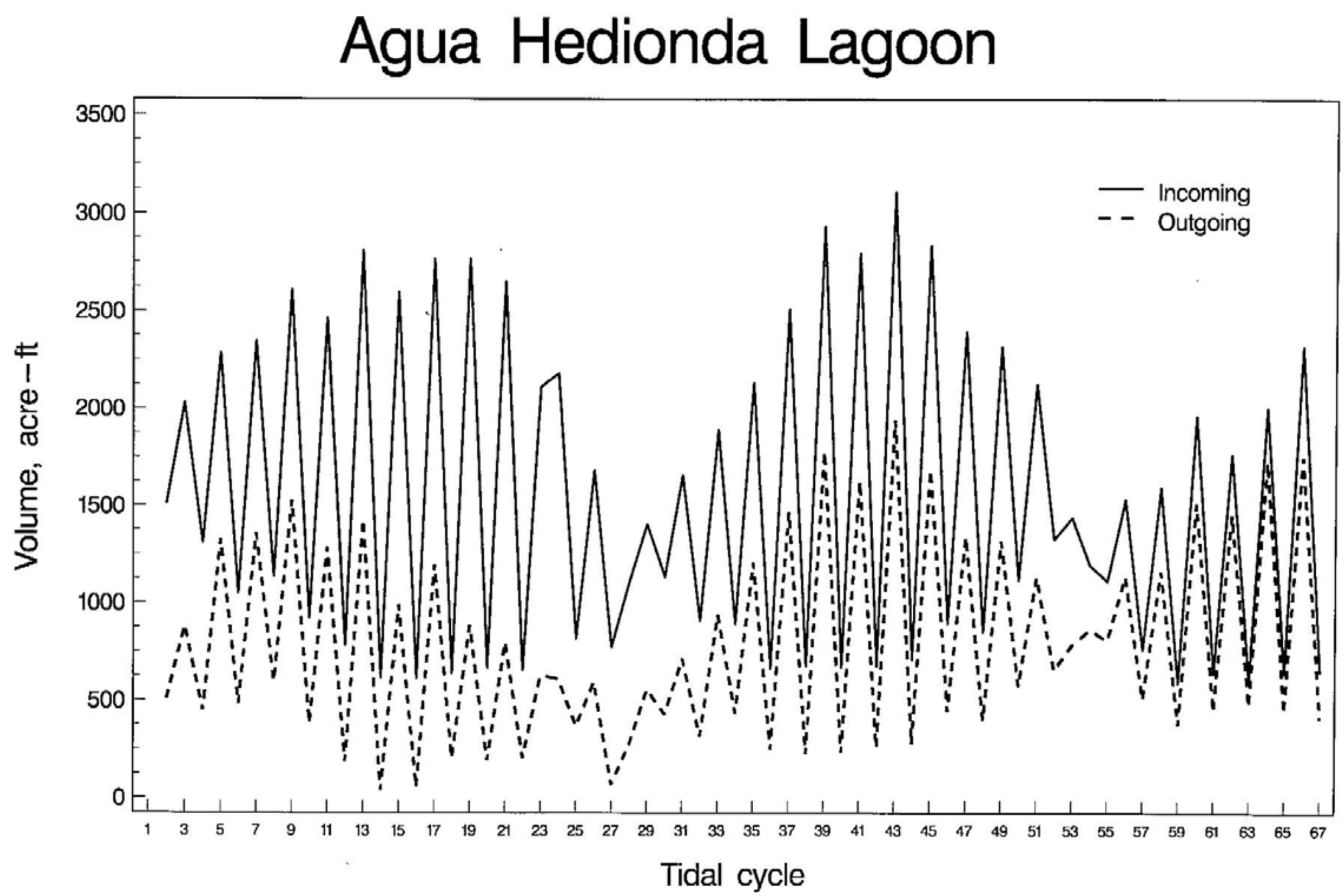

Figure 4-3. Lagoon inflow and outflow through the inlet per tidal cycle during 1 June 05 through 7 July 05.

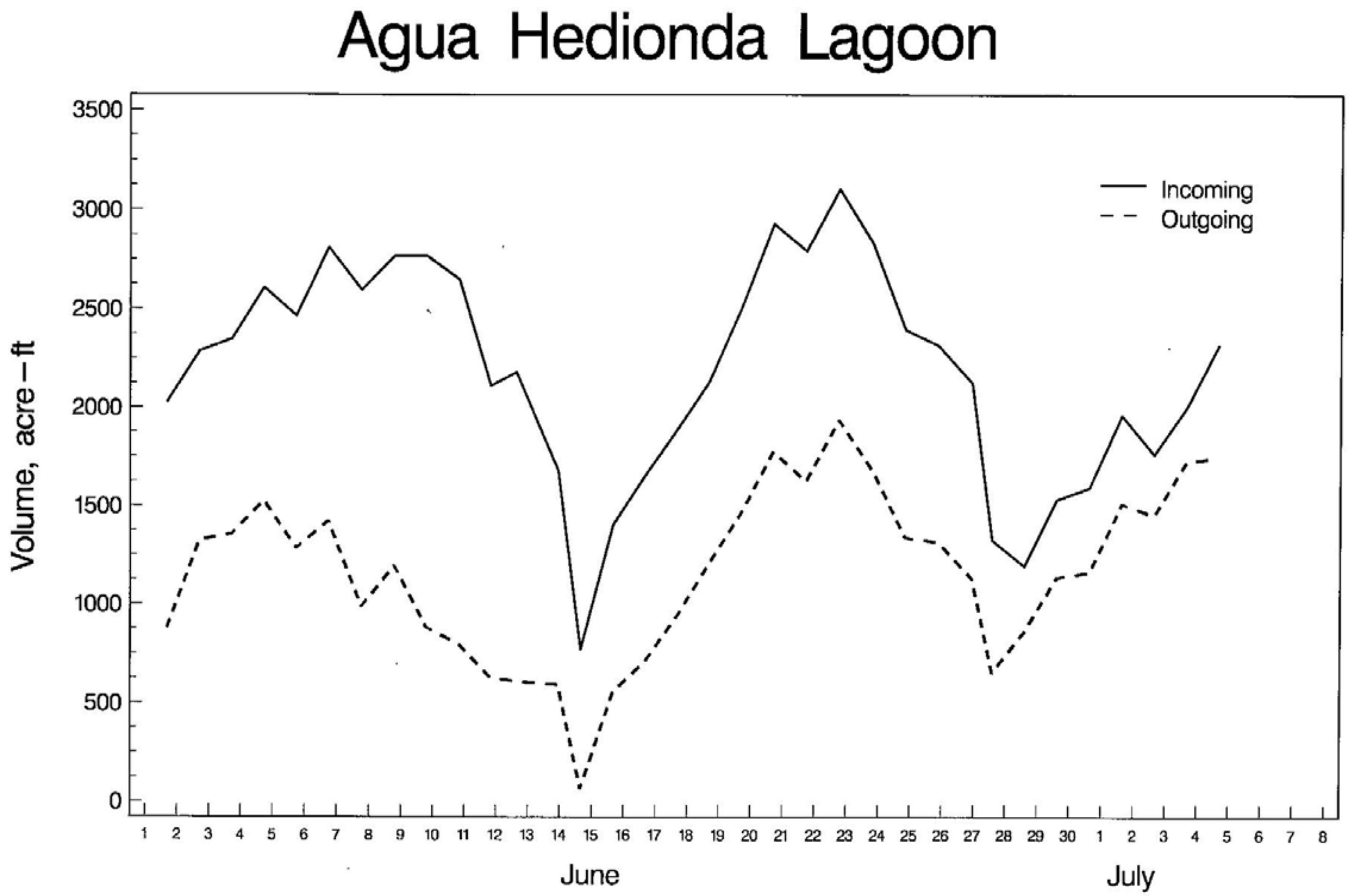

Figure 4-4. Lagoon inflow and outflow through the inlet per day during 1 June 05 through 7 July 05.

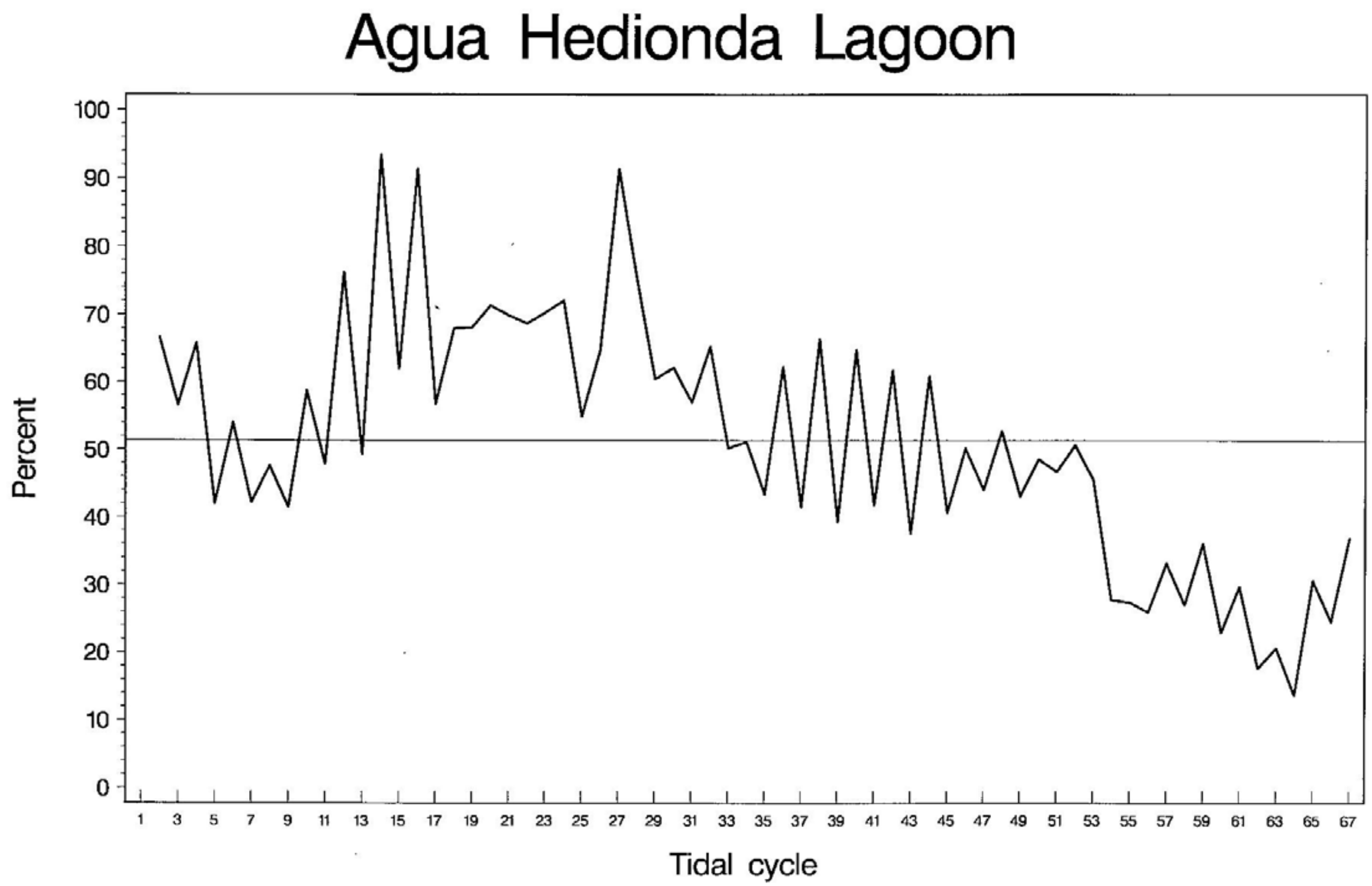

Figure 4-5. **Ratio between inflowing water and water taken in by power plant cooling system by tidal cycle. The solid line represents the mean ratio over the measurement time period.**

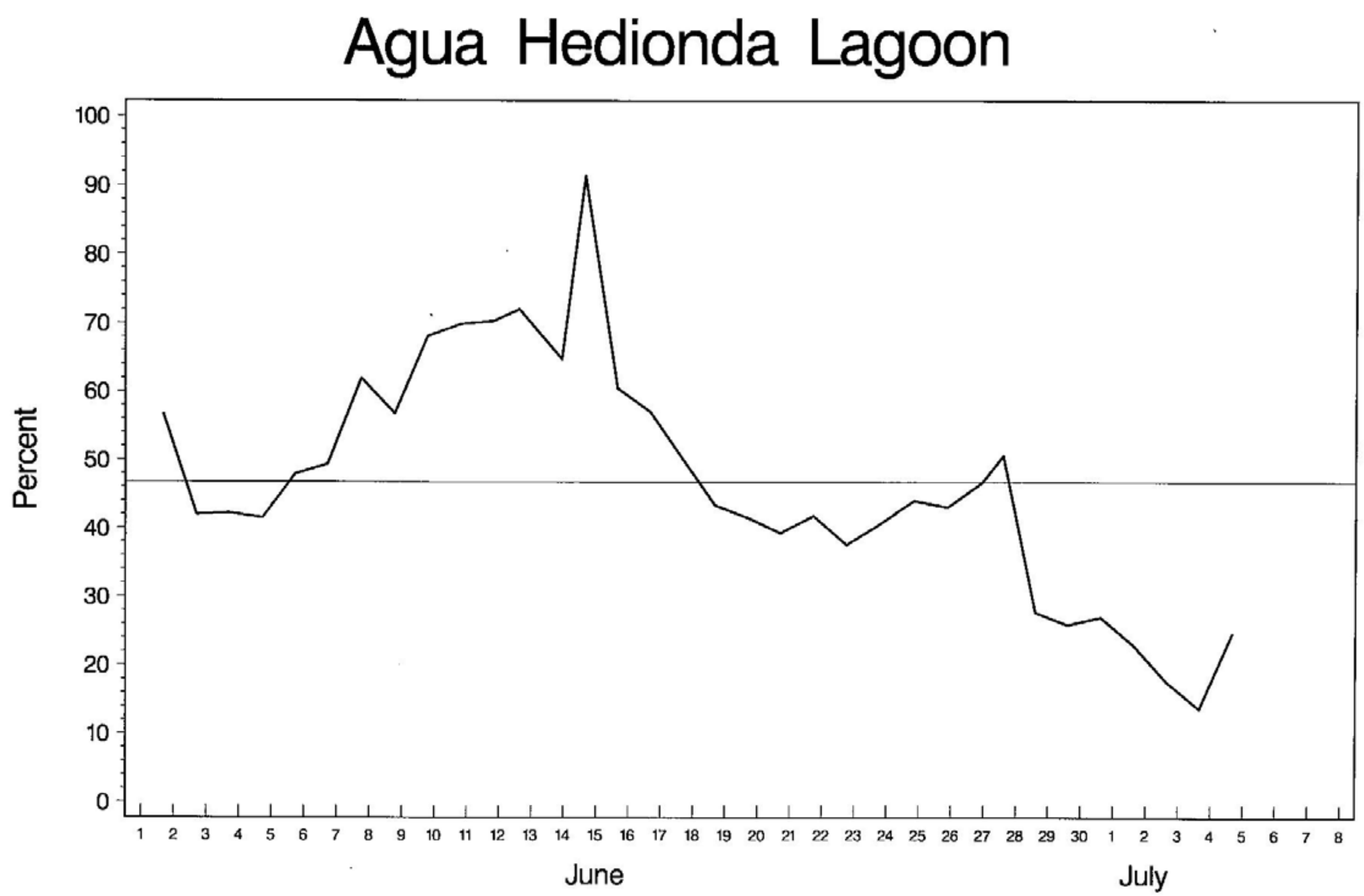

Figure 4-6. Ratio between inflowing water and water taken in by power plant cooling system by day. The solid line represents the mean ratio over the measurement time period.

5.0 SUMMARY AND CONCLUSIONS

In this study, we have provided a description of the Agua Hedionda Lagoon and the general lagoon hydrodynamics. Agua Hedionda Lagoon differs from other southern California lagoons in the respect that the volume of inflowing water is vastly larger than the volume of outflowing water. The operation of the cooling system at the Encina Power Station alters these hydrodynamics. The power generating units take about 625-670 mgd of water from the lagoon to the power plant condenser system for cooling purposes. This process reduces the volume of the outflow water from the lagoon by about 40-50%. The heated water is discharged directly to the ocean through the discharge channel (Figure1-2).

5.1 LAGOON DESCRIPTION

Data from a bathymetry survey conducted in 2005 were used in this study (Figure 2-1). Surface area and water volume in the lagoon were computed from this survey. The results are shown in Figure 2-5. The surface area of the lagoon was about 360 acres at 6 ft NGVD and 225 acres at MLLW. At MLLW, the volume of the lagoon was about 1750 acre-ft. The majority of the area and water volume come from the large Inner Basin.

5.2 FIELD MEASUREMENTS

Data were collected during a one-month survey at four stations (Figure 3-1) in the lagoon from 1 June 2005 to 7 July 2005. The four stations are S0, S2A, S2B, and S3. Water level measurements were taken at all four stations, and water velocity measurements were taken at two of the stations, S0 and S2B. Water levels generally followed the tides (Figures 3-3 to 3-5). Water velocity was predominately in an east-west direction, with a small component in a north-south direction (Appendix B). Tidal conditions during three time periods were identified for neap, spring and mean tides (Figures 3-3, 3-4, and 3-5). Figures overlaying flow velocity over water level measurements are shown in Figures 3-6, 3-7, and 3-8. Water level and velocity measurements were used to estimate tidal prism, determine the volume of inflow and outflow water, and estimate the residence time of water in the lagoon.

Water elevation, velocity, salinity, and temperature measurements were taken. These data were used to describe lagoon dynamics and compute water exchange between the lagoon and ocean. The tidal prism of the lagoon during the time period of the measurements is shown in Figure 3-9. It varied from approximately 1000 acre-ft during neap tide to 2125 acre-ft during spring tide to 1700 acre-ft during mean tide.

Salinity measurements were made primarily to find out whether there was a difference between the salinity of the water coming into the lagoon and the outgoing water. It was found that the difference was so small that the approach used by Largier (1996) in San Francisco Bay and Jay (2001) at Morro Bay to estimate the residence time of water in the lagoon was not appropriate.

5.3 RESIDENCE TIME

A mathematical model designed to compute the residence time of water in the lagoon and its three basins is described in Chapter 4. Based on this model, we determined the amount of "old water" in the lagoon during a tidal cycle. In the lagoon (total) after 5.0 tidal cycles or 2.6 days, the "old water" is essentially flushed out of the lagoon. In the Inner Basin, 6.27 tidal cycles, or 3.2 days, are required to flush out the "old water." Due to water intake by the cooling system of the EPS, the outgoing flow through the inlet is less than the incoming flow through the inlet . Figures 4-3 and 4-4 show the lagoon inflow and outflow during the period of 1 June through 7 July 2005, per tidal cycle and per day, respectively. The mean reduction of the outflow water from the lagoon with respect to incoming water was about 51% per tidal cycle and 48% per day during the time period of the measurements.

6.0 REFERENCES

Bhogal, V., and S. Costa, 1989. Modeling Flood Tidal Deposits in Tidal Inlets. In *Oceans '89: An International Conference Addressing Methods for Understanding the Global Ocean*, Seattle, Washington, September 18-21, 1989, IEEE Publication Number 89CH2780-5, p. 90-95.

Bradshaw, J., B. Browning, K. Smith, J. Speth, and E. Fullerton, 1976. The Natural Resources of Agua Hedionda Lagoon. Coastal Wetlands Series #16. Prepared for U.S. Fish and Wildlife Service, June 1976. 110 pp. + 9 appendices.

Coastal Environments, 1998. Bibliography of Pertinent Research on Existing Conditions and Monitoring Studies in the Vicinity of Agua Hedionda Lagoon. Prepared for the California Coastal Commission, City of Carlsbad, and San Diego Gas and Electric Company, 2 January 1988, CE Ref. No. P98-1. 2 pp. + 3 appendices.

EA Engineering, Science, and Technology, 1997. Final Encina Power Plant Supplemental 316(a) Assessment Report, Volume 2 of 2, Appendices. Prepared for San Diego Gas & Electric Co., July 1997. 2 appendices.

Ellis, J., 1954. Dredging Final Report, October 29, 1954, Agua Hedionda Slough Encina Generating Station. San Diego Gas & Electric Co., Carlsbad, CA, 43 pp.

Elwany, M. H. S., A-L. Lindquist, R. Flick, W. O'Reilly, J. Reitzel, and W. Boyd, 1999. Study of Sediment Transport Conditions in the Vicinity of Agua Hedionda Lagoon, Volume 1: Technical Report. SIO Reference No. 00-07, Scripps Institution of Oceanography, Center for Coastal Studies, La Jolla, CA, 8 January 1999. 10 chapters + 3 appendices.

Jay, D., 2001. The Morro Bay Power Plant and Circulation Processes in Morro Bay. Prepared for Duke Energy North American, Oakland, CA, 15 March 2001. 106 pp.

Jenkins, S., and D. Skelly,1988. An Evaluation of the Coastal Database Pertaining to Seawater Diversion at Encina Power Plant, Carlsbad, CA. Prepared for San Diego Gas & Electric Co., July 1988. 56 pp.

Jenkins, S., D. Skelly, and J. Wasyl, 1989. Dispersion and Momentum Flux Study of the Cooling Water Outfall at Agua Hedionda. Scripps Institution of Oceanography, Center for Coastal Studies, La Jolla, CA. Prepared for San Diego Gas & Electric Co., September 1989. 36 pp. + 3 appendices.

Jenkins, S., and J. Wasyl, 2001. Agua Hedionda Lagoon North Jetty Restoration Project: Sand Influx Study. Submitted to Cabrillo Power LLC, Carlsbad, CA on 14 September 2001. 178 pp. + 8 appendices.

Largier, J. L., 1996. Hydrodynamic Exchange Between San Francisco Bay and the Ocean: The Role of Ocean Circulation and Stratification. In *San Francisco Bay, The Ecosystem: Further Investigations.* Proceedings of the 75th Annual Meeting, Pacific Division, American Association for the Advancement of Science, held in San Francisco, CA, June 19-24, 1994, pp. 69-104.

Reid, J., and A. Mantyla, 1976a. The Effect of the Geostrophic Flow Upon Coastal Sea Elevations in the Northern North Pacific Ocean. *Jour. Geophysical Research,* v.81, n.18, 3100-3110.

Zetler, B., and R. Flick, 1985. Predicted Extreme High Tides for California, 1983–2000. *Jour. Waterway, Port, Coastal, and Ocean Engineering*, ASCE, v. 111 (4), 758–765.

APPENDIX A

WATER LEVEL MEASUREMENTS AT OUTER, MIDDLE, AND INNER BASINS

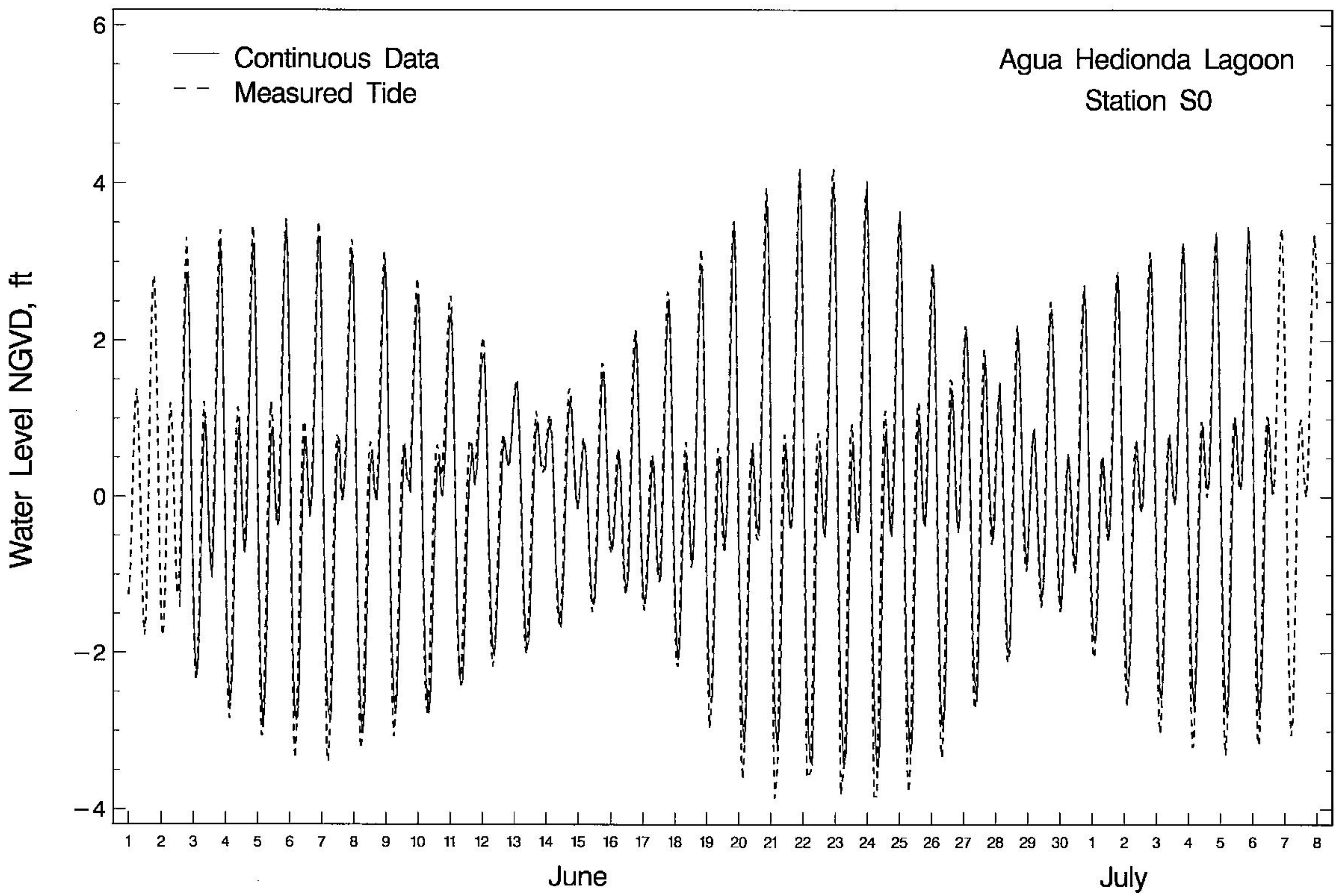

Figure A-1. Comparison between water level measurements at Station S0 and ocean tide.

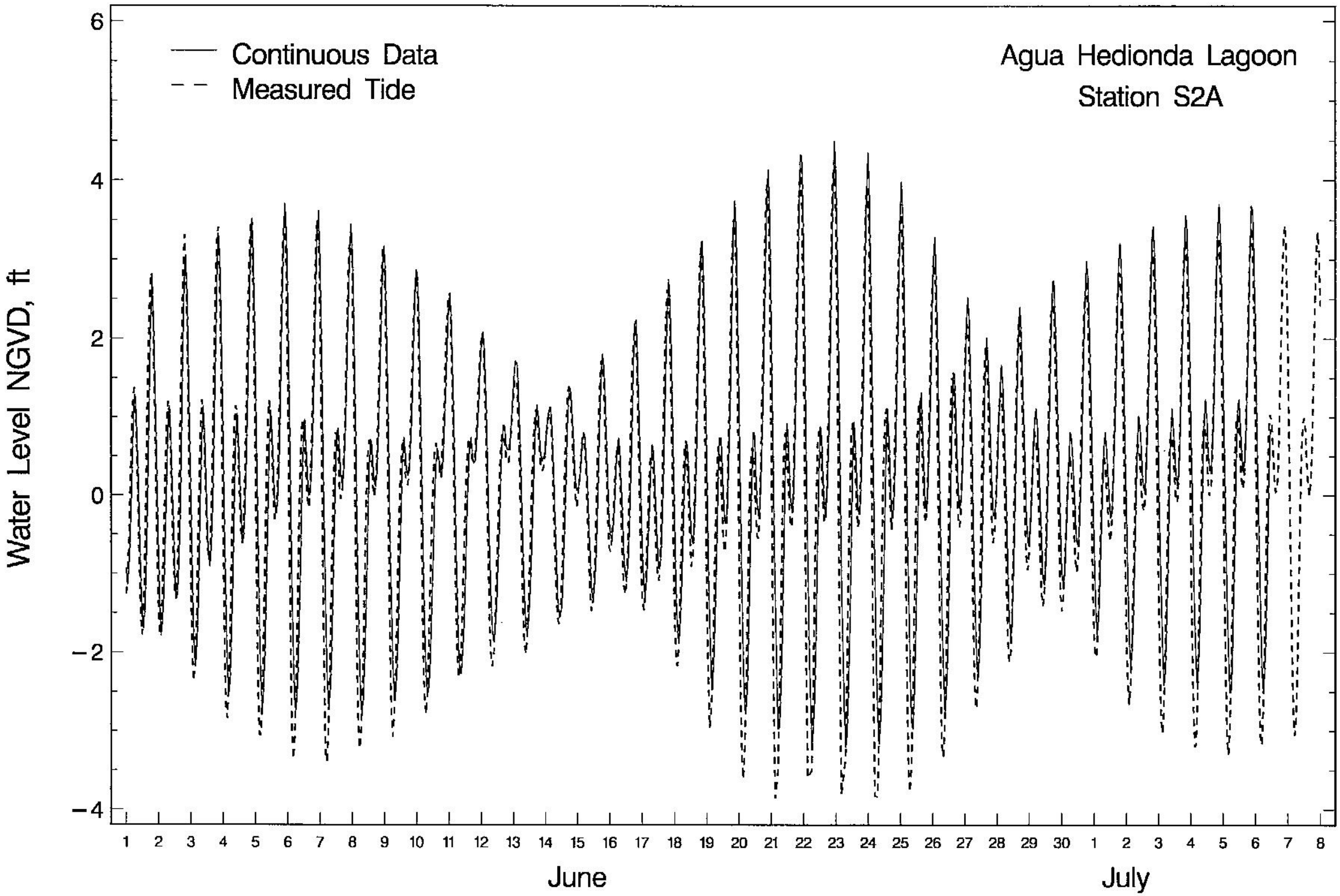

Figure A-2. Comparison between water level measurements at Station S2A and ocean tide.

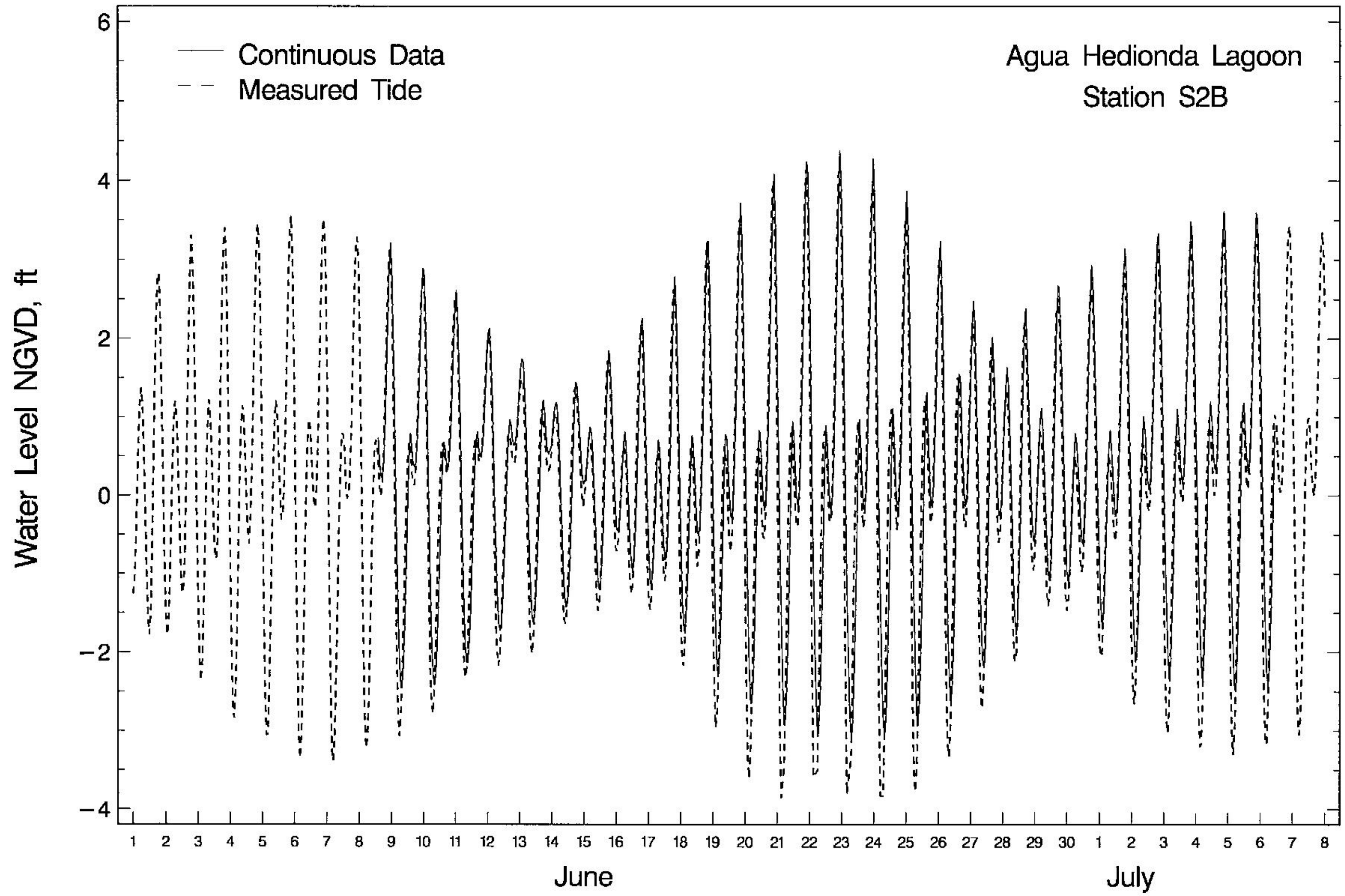

Figure A-3. Comparison between water level measurements at Station S2B and ocean tide.

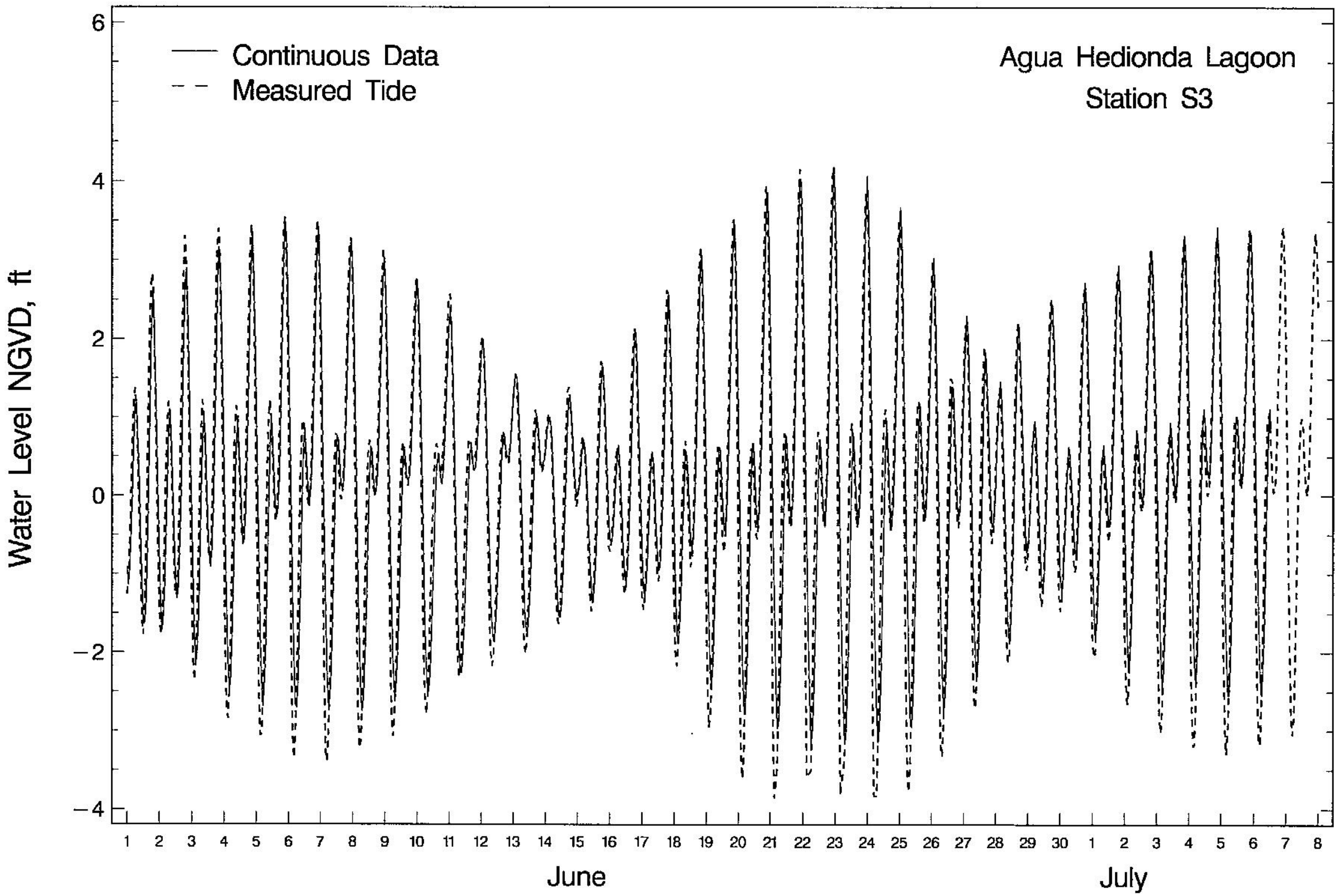

Figure A-4. Comparison between water level measurements at Station S3 and ocean tide.

APPENDIX B

WATER VELOCITY MEASUREMENTS AT OUTER AND INNER BASINS

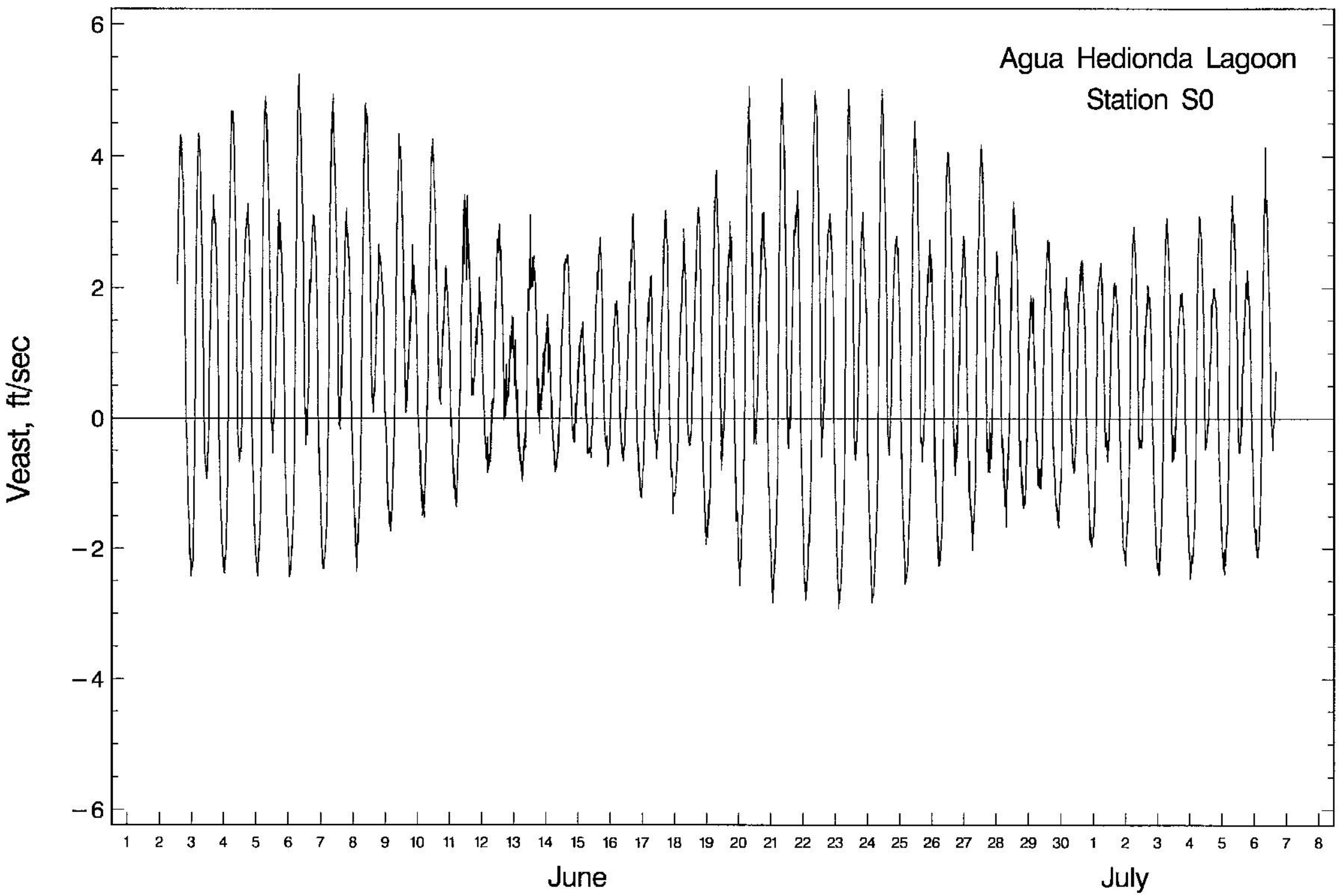

Figure B-1. East component of water velocity at Station S0.

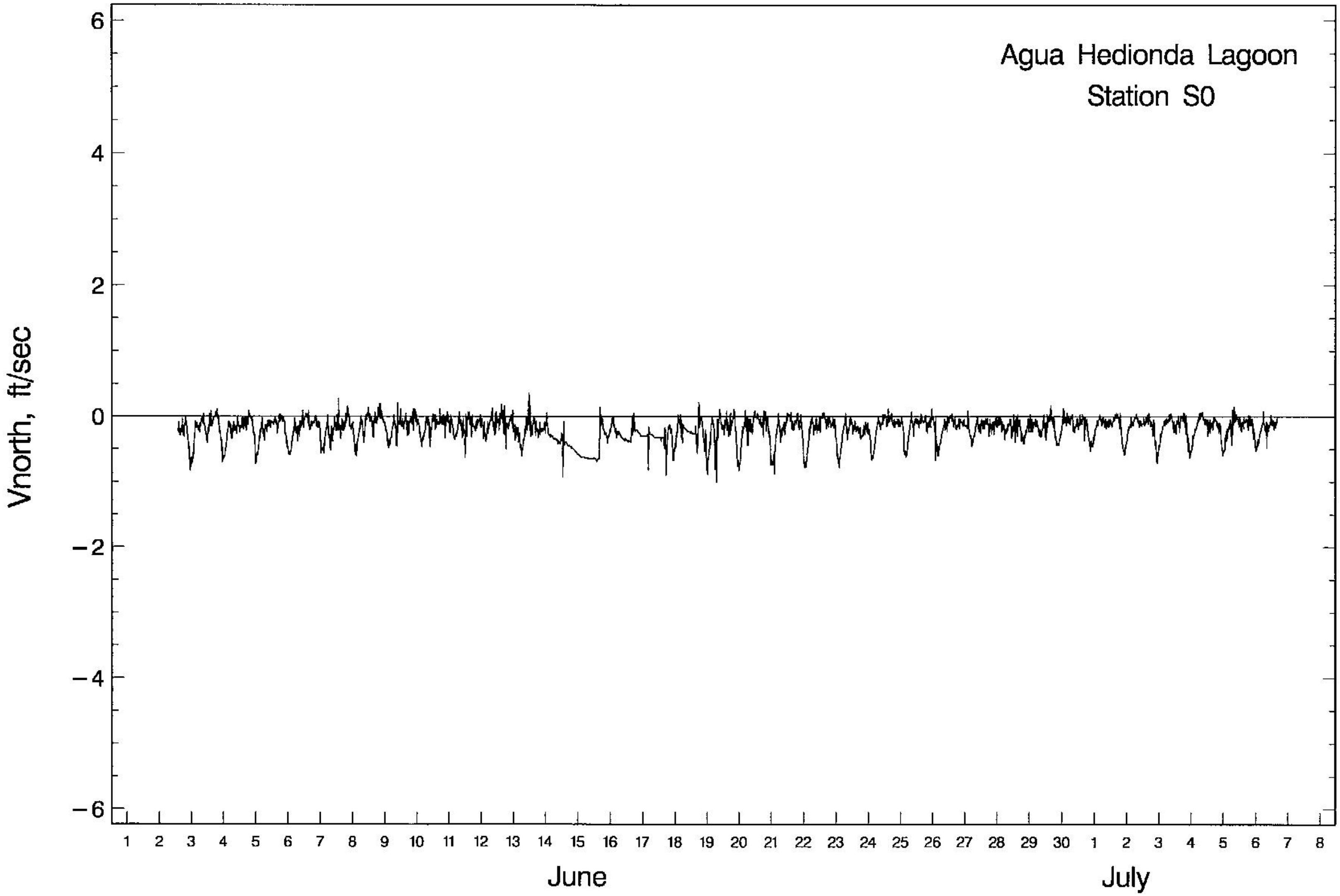

Figure B-2. North component of water velocity at Station S0.

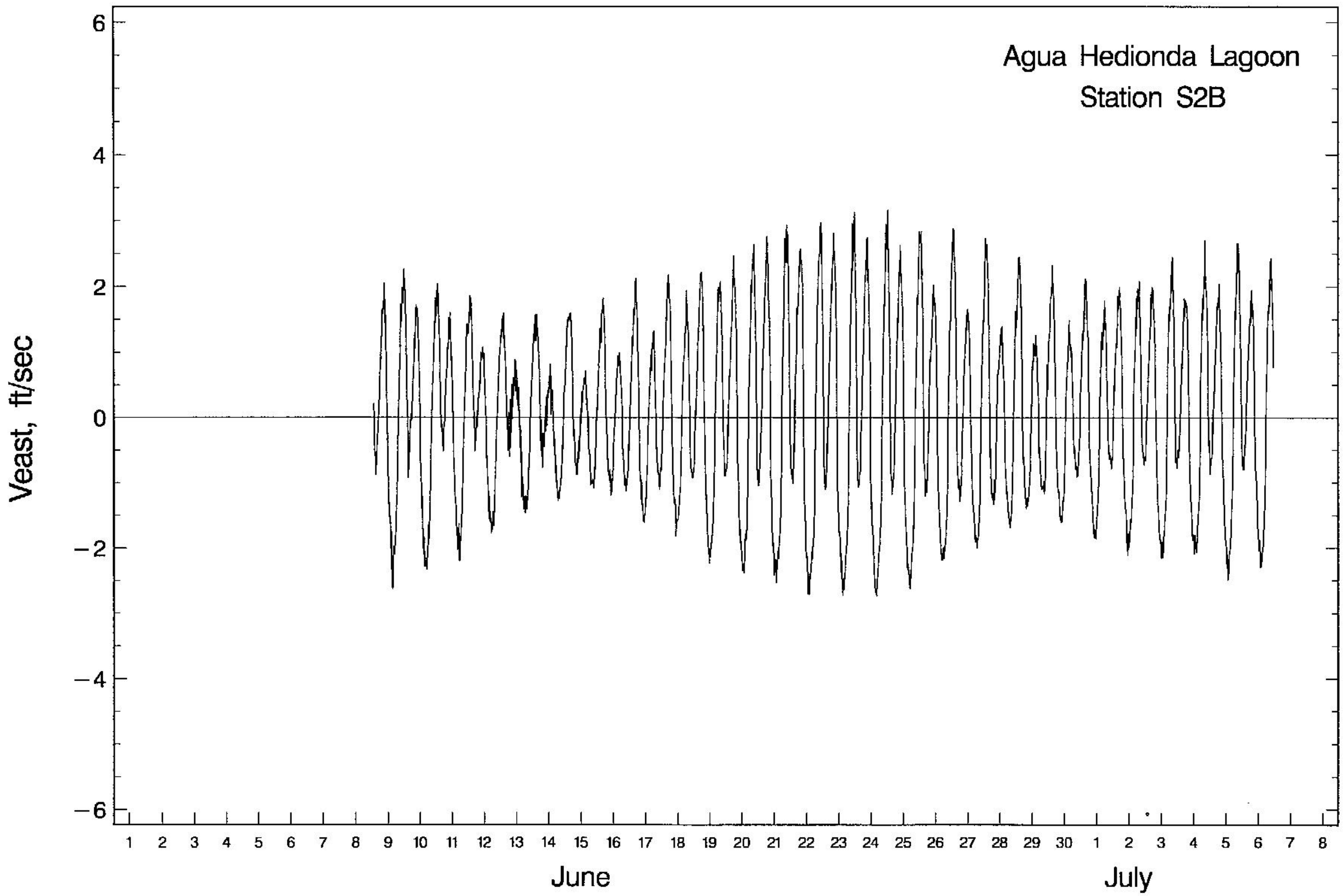

Figure B-3. East component of water velocity at Station S2B.

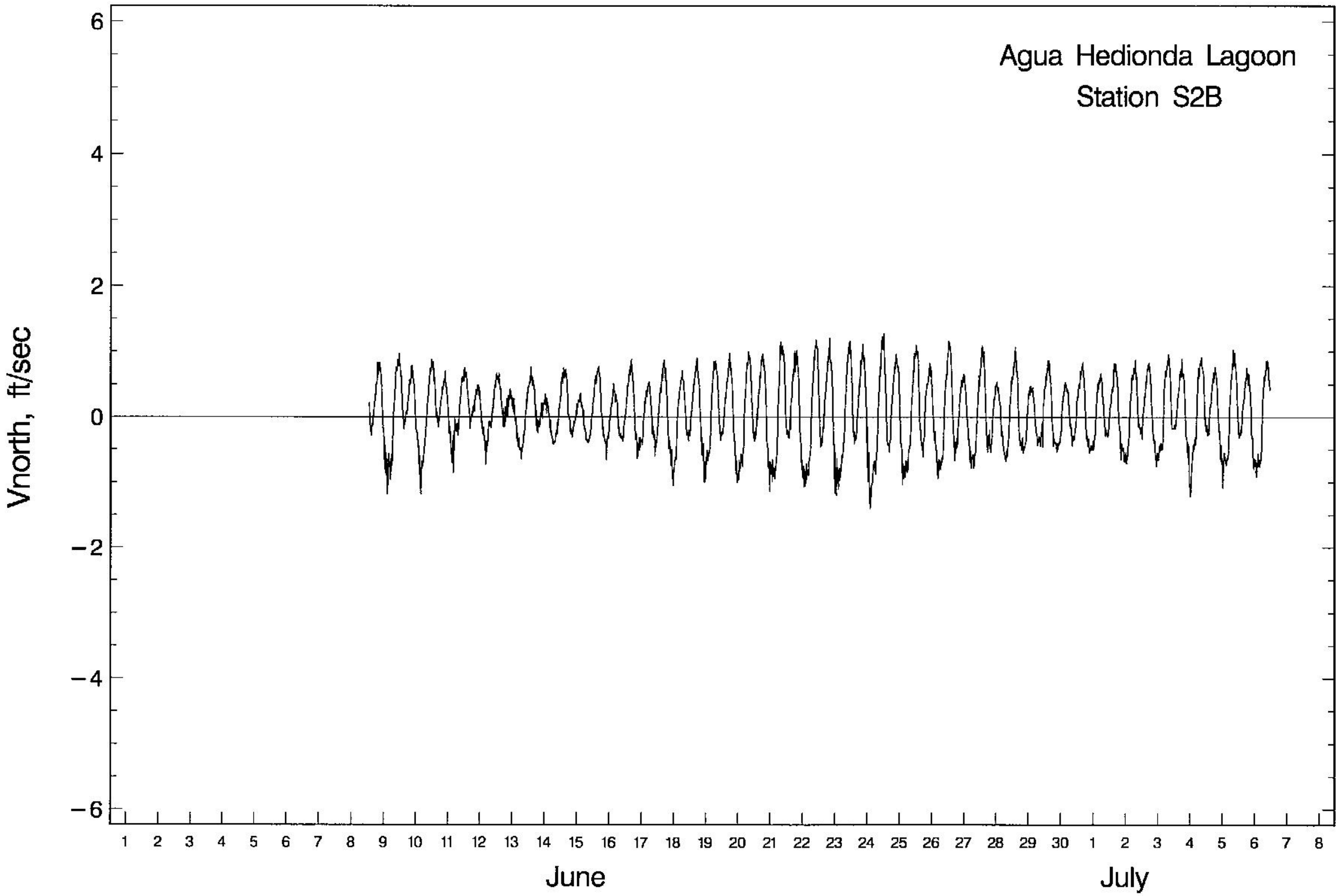

Figure B-4. North component of water velocity at Station S2B.

APPENDIX C

LAGOON TIDAL PRISM ALONG WITH CONTRIBUTIONS OF OUTER, INNER, AND MIDDLE BASINS TO THE TIDAL PRISM

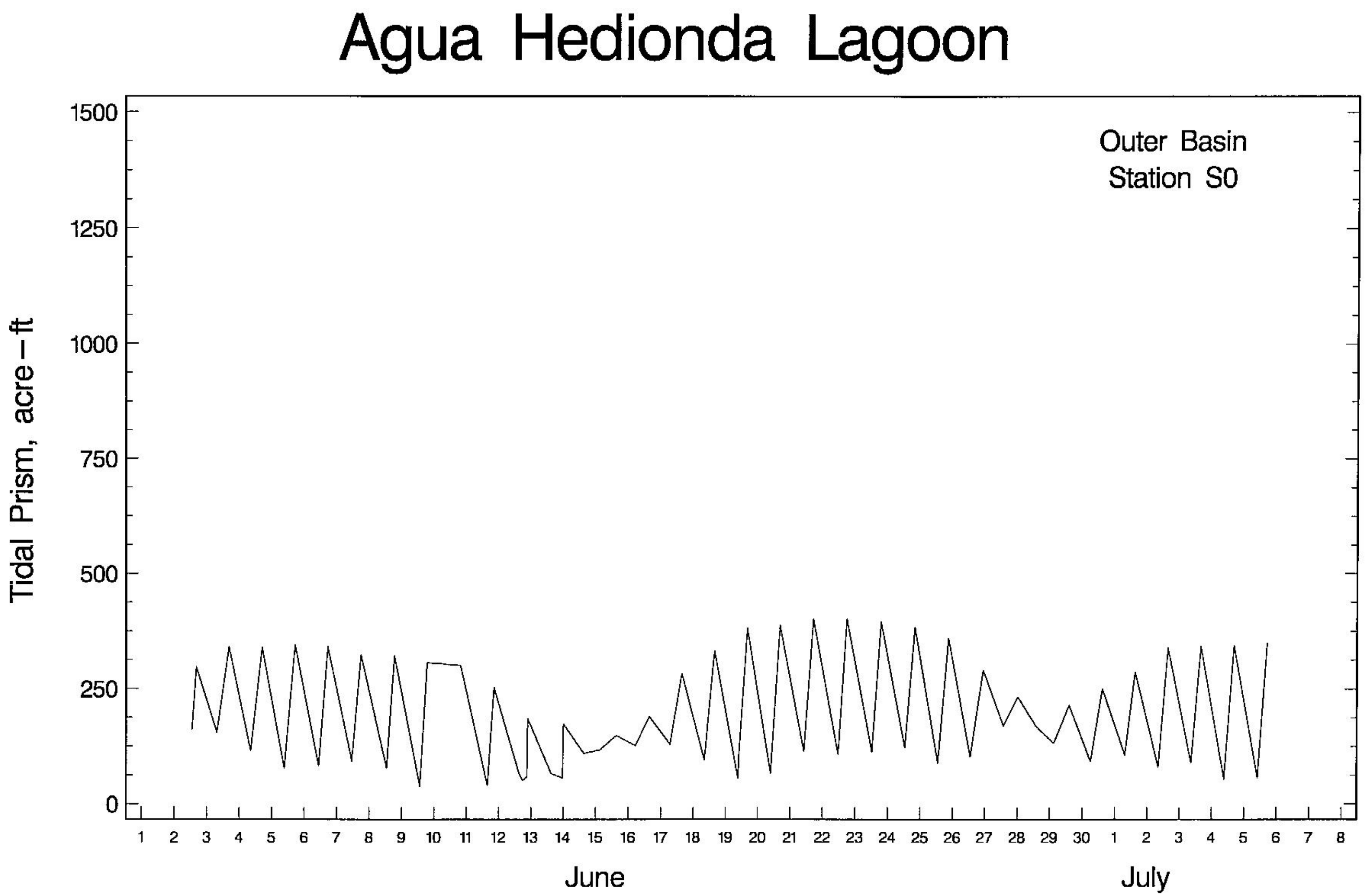

Figure C-1. Tidal prism of Outer Basin as computed from water level measurements at Station S0.

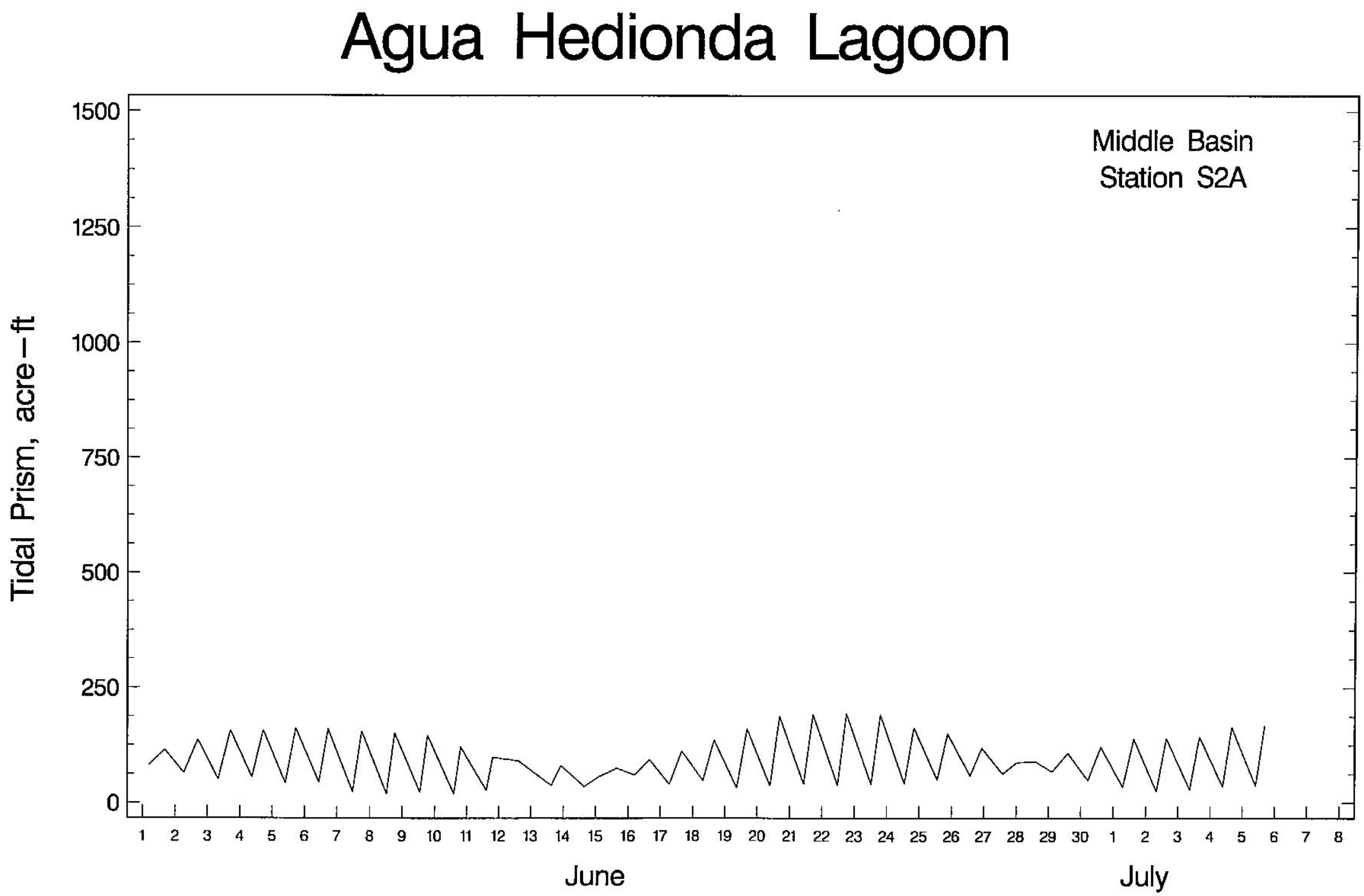

Figure C-2. Tidal prism of Middle Basin as computed from water level measurements at Station S2A.

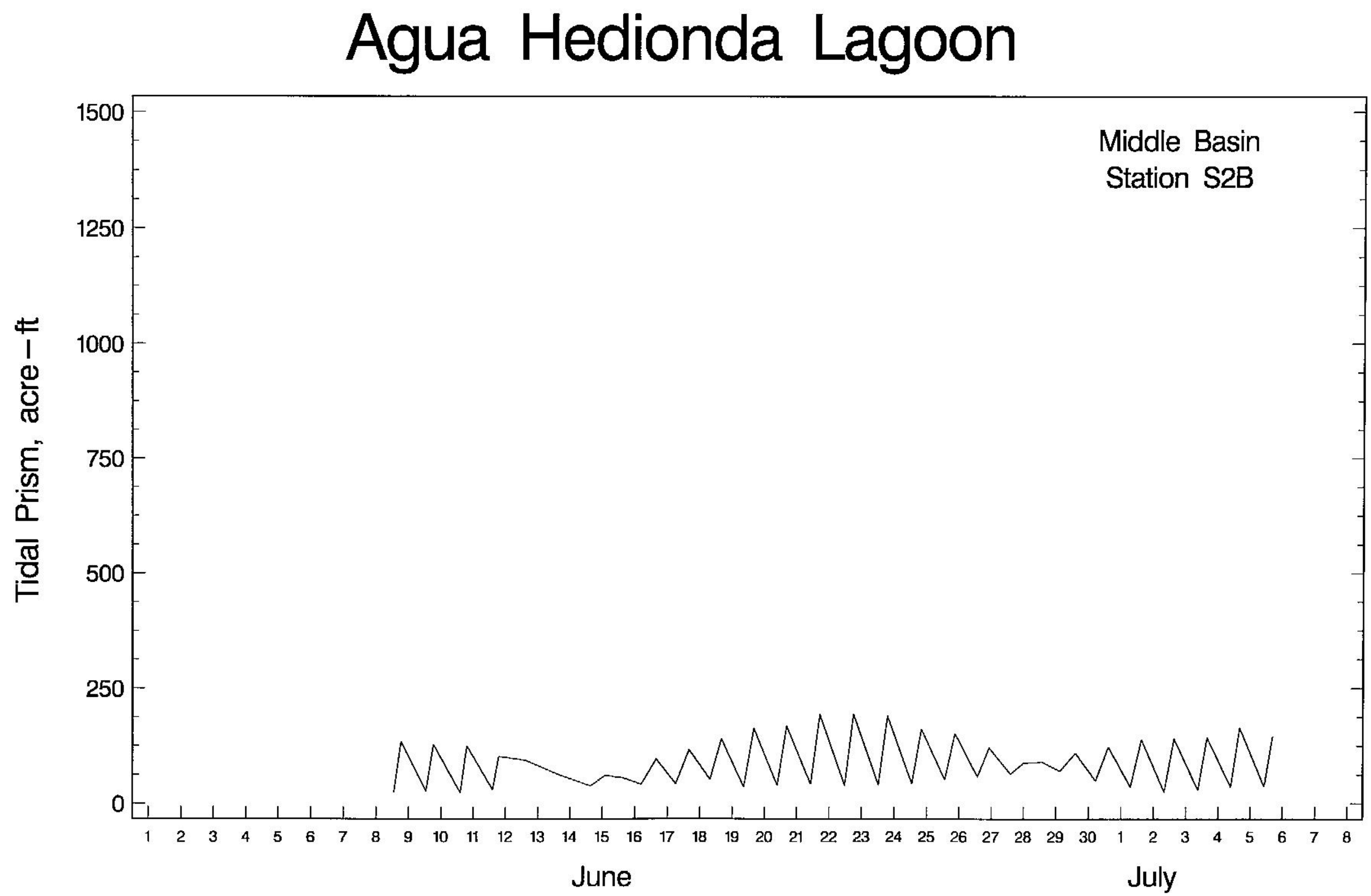

Figure C-3. Tidal prism of Middle Basin as computed from water level measurements at Station S2B.

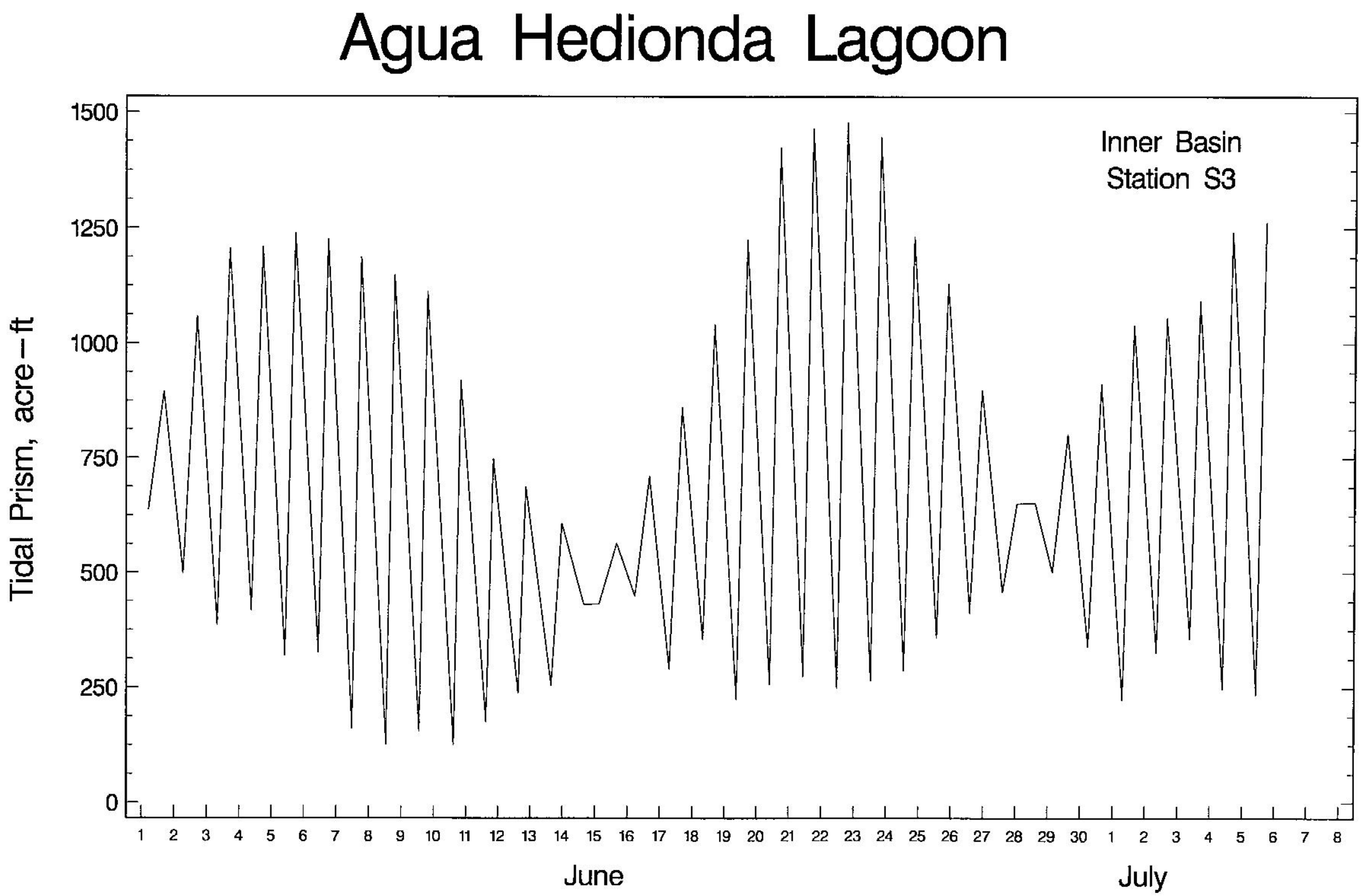

Figure C-4. Tidal prism of Inner Basin as computed from water level measurements at Station S3.

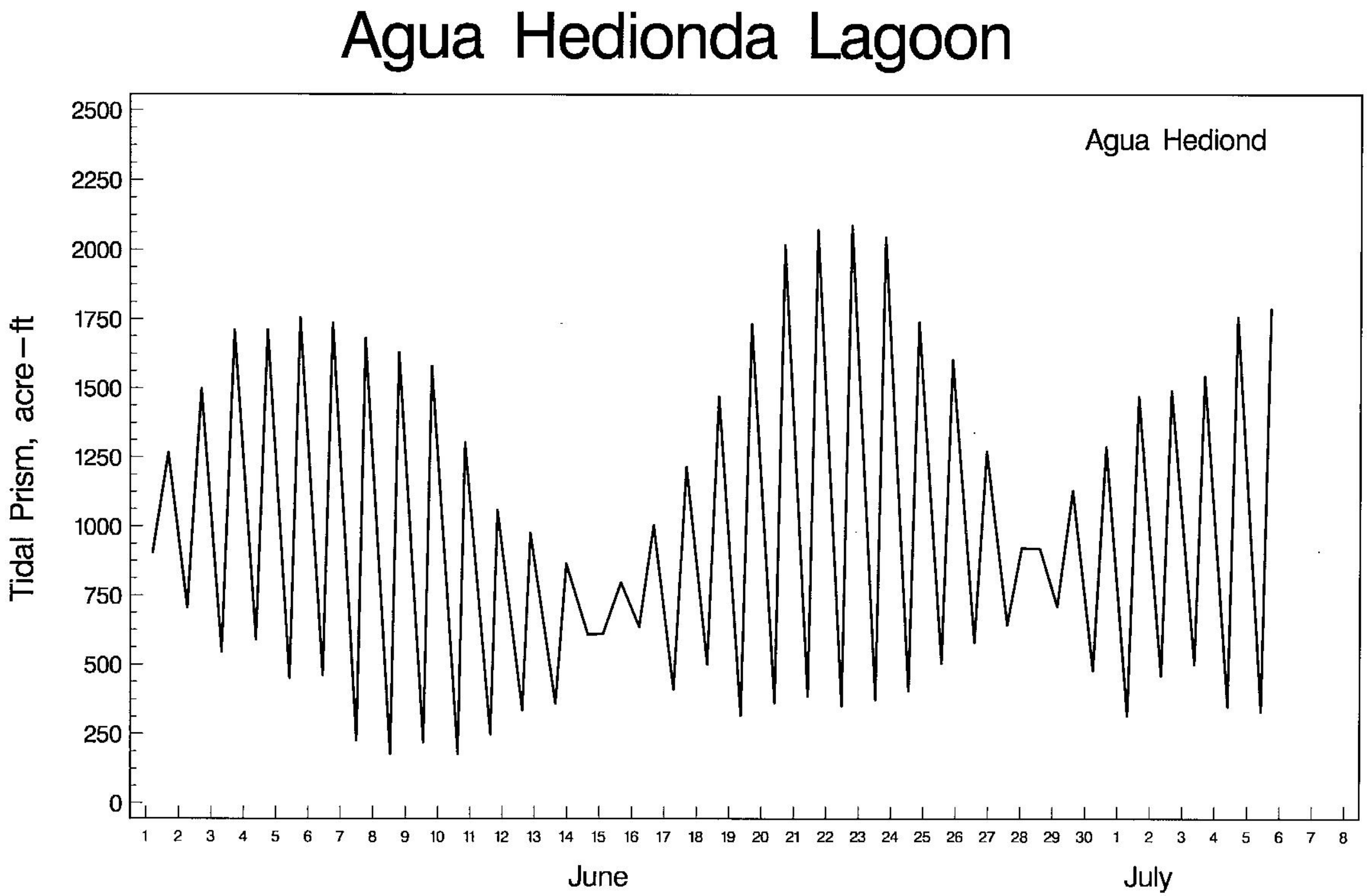

Figure C-5. Agua Hedionda Lagoon tidal prism.

APPENDIX D

TEMPERATURE AND SALINITY MEASUREMENTS AT OUTER AND INNER BASINS

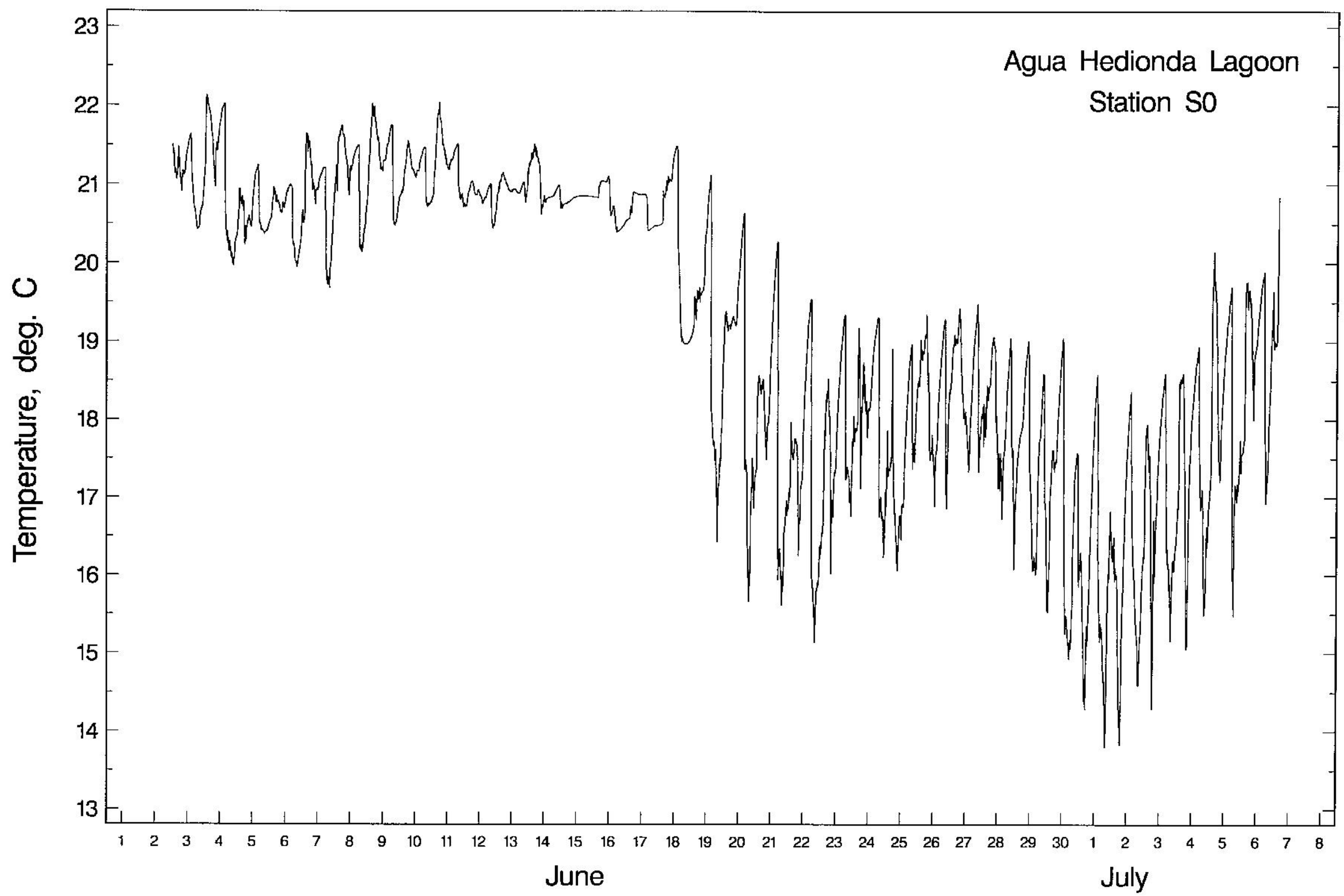

Figure D-1. Water temperature measurements at Station S0.

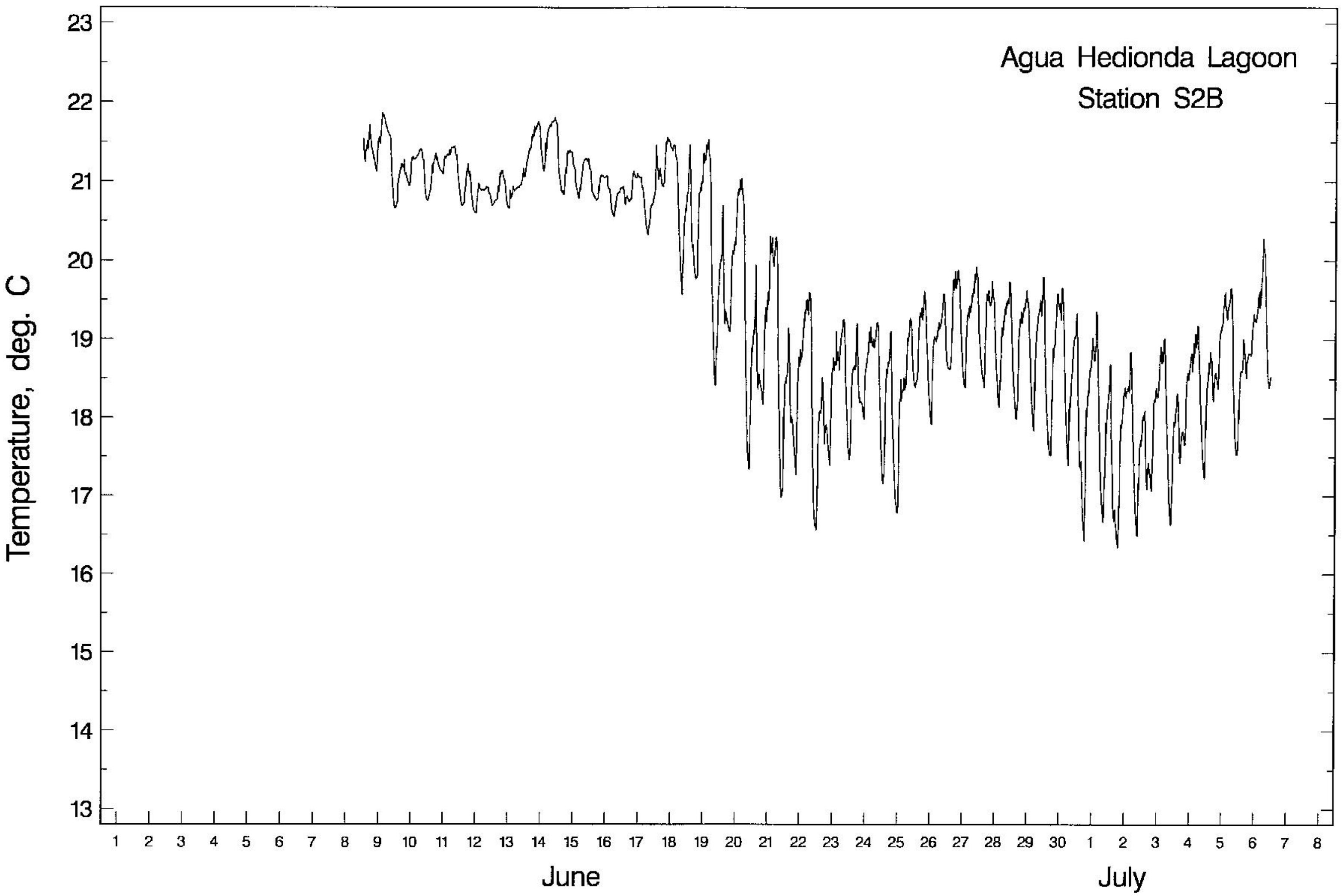

Figure D-2. Water temperature measurements at Station S2B.

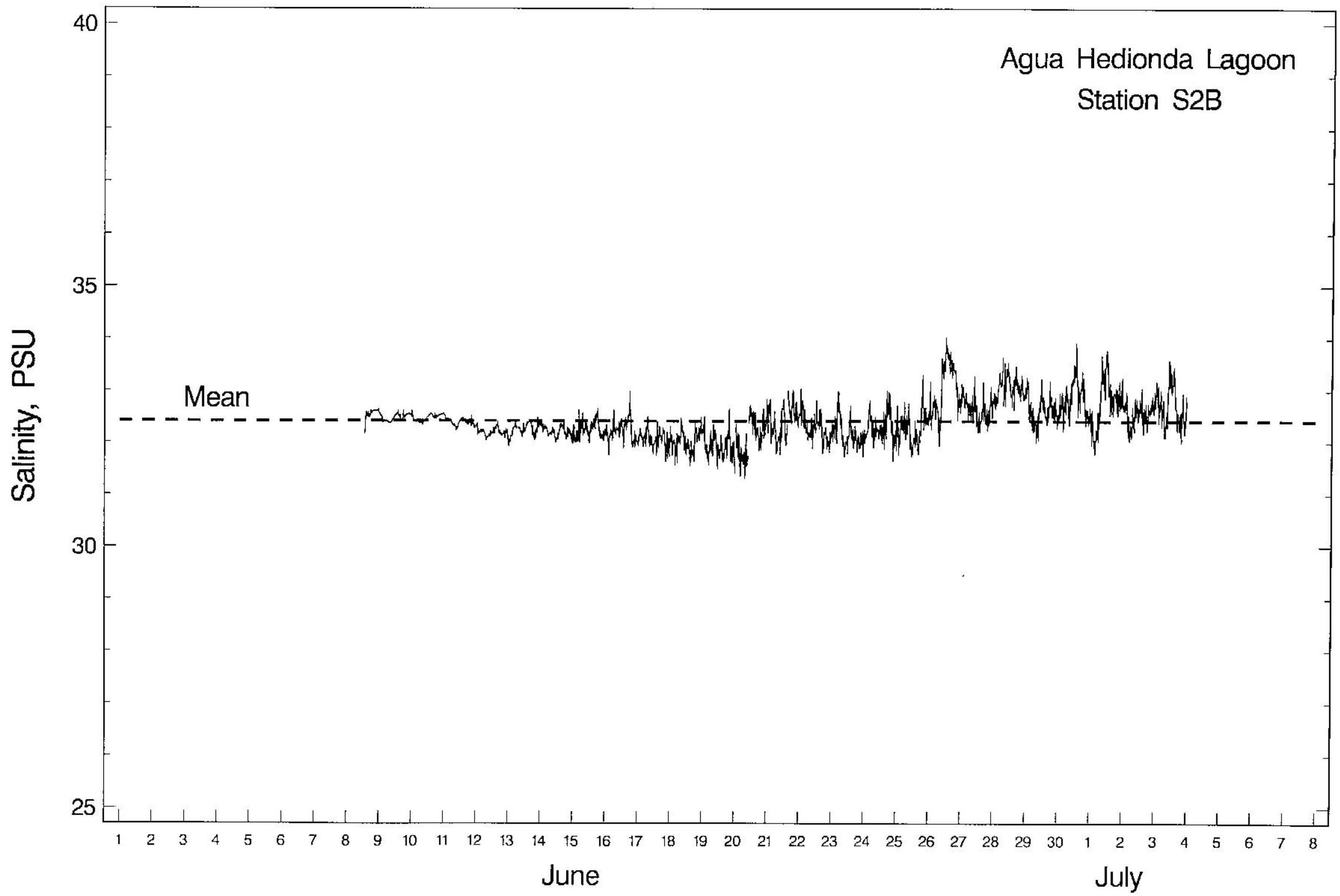

Figure D-3. Water salinity measurements at Station S2B.