ATTACHMENT 6

COASTAL PROCESS EFFECTS OF REDUCED INTAKE FLOWS AT AGUA HEDIONDA LAGOON

Coastal Processes Effects of Reduced Intake Flows at Agua Hedionda Lagoon

Submitted by:
Scott A. Jenkins, Ph. D. and Joseph Wasyl
Dr. Scott A. Jenkins Consulting
14765 Kalapana Street, Poway, CA 92064

Submitted to:

Tenera Environmental
141 Suburban Rd., Suite A2
San Luis Obispo, CA 93401

and

Poseidon Resources, Suite 840
501 West Broadway
San Diego, CA 92101

13 December 2006

Abstract:

This study evaluates the coastal processes effects associated with reduced flow rate operations of a stand alone desalination plant co-located at Encina Generating Station. The generating station presently consumes lagoon water at an average rate of about 530 mgd. If this consumption rate were reduced to 304 mgd to maintain end-of-pipe salinity below 40 ppt, we find that the capture rates of littoral sediment would be reduced by 42.5%, thereby reducing the environmental impacts associated with maintenance dredging. Reduced flow rate operations will not increase the magnitude of cyclical variations in habitat or residence time that presently occur throughout each maintenance dredge cycle, but will increase the length of time over which those variations occur. Low flow rate operations will result in reductions of 8% to 10% in the fluxes of dissolved nutrients and oxygen into the lagoon through the ocean inlet, but this effect is relatively minor in comparison to the 17.4% decline in nutrient and D.O. flux

that occurs in the latter stages of each dredge cycle. On balance, low flow operations do not appear to create any significant adverse impacts on either the lagoon environment or the local beaches; and it could be argued that the reduction in capture rates of littoral sediment is a project benefit.

1.0) Introduction:

The present day Agua Hedionda Lagoon is not a natural geomorphic structure, rather it is a construct of modern dredging. Its west tidal basin (Figure 1) is unnaturally deep (-20 to – 32 ft NGVD) and the utilization of lagoon water for once-through cooling by the Encina Generating Station renders Agua Hedionda's hydraulics distinctly different from any other natural tidal lagoon. Power plant cooling water uptake (Q_{plant}) acts as a kind of "negative river." Whereas natural lagoons have a river or stream adding water to the lagoon, causing a net outflow at the ocean inlet, the power plant infall removes water from Agua Hedionda Lagoon, resulting in a net inflow of water (Q_{plant}) through the ocean inlet. This net inflow has several consequences for particulate transport into and out of the lagoon: 1) it draws nutritive particulate and suspended sediment from the surf zone into the lagoon, the latter forming bars and shoals (Figure 2) that subsequently restrict the tidal circulation, and 2) the net inflow of water diminishes or at times cancels the ebb flow velocities out of the inlet, thereby providing insufficient transport energy to flush sediments (essentially uphill) out of the deep west basin of the lagoon. Therefore, the plant demand for lagoon water strongly controls the rate at which Agua Hedionda traps sediment and other solid particulate.

This is a technical note on the potential coastal processes effects arising from reduced once-through flow rates at the Encina Generating Station, Carlsbad, CA. Specifically, we evaluate long-term, stand-alone operation of a proposed desalination plant at this site using the minimum once-through flow rate available with the existing hydraulic infrastructure that will allow the production of 50 mgd of potable water by reverse osmosis (R.O.) without exceeding 40 ppt salinity at end-of-pipe. When taken in combination with worst-case mixing conditions in the receiving water, this minimum flow rate configuration is referred to in the certified project EIR as the "unheated

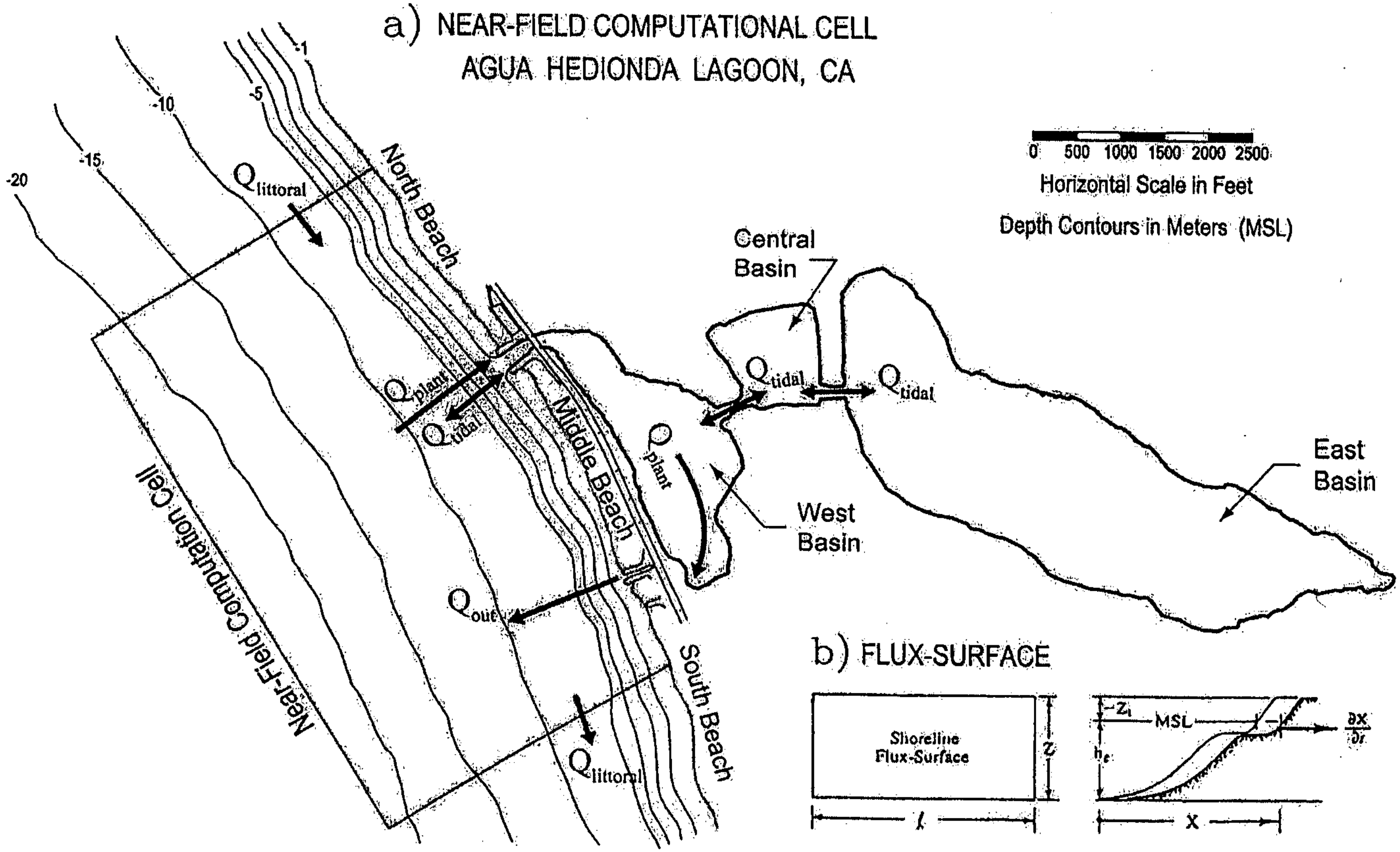

Figure 1. Near-field computational cell for calculating sediment transport at Agua Hedionda Lagoon, CA; a) Lagoon Plan View. b) Beach Cross-section.

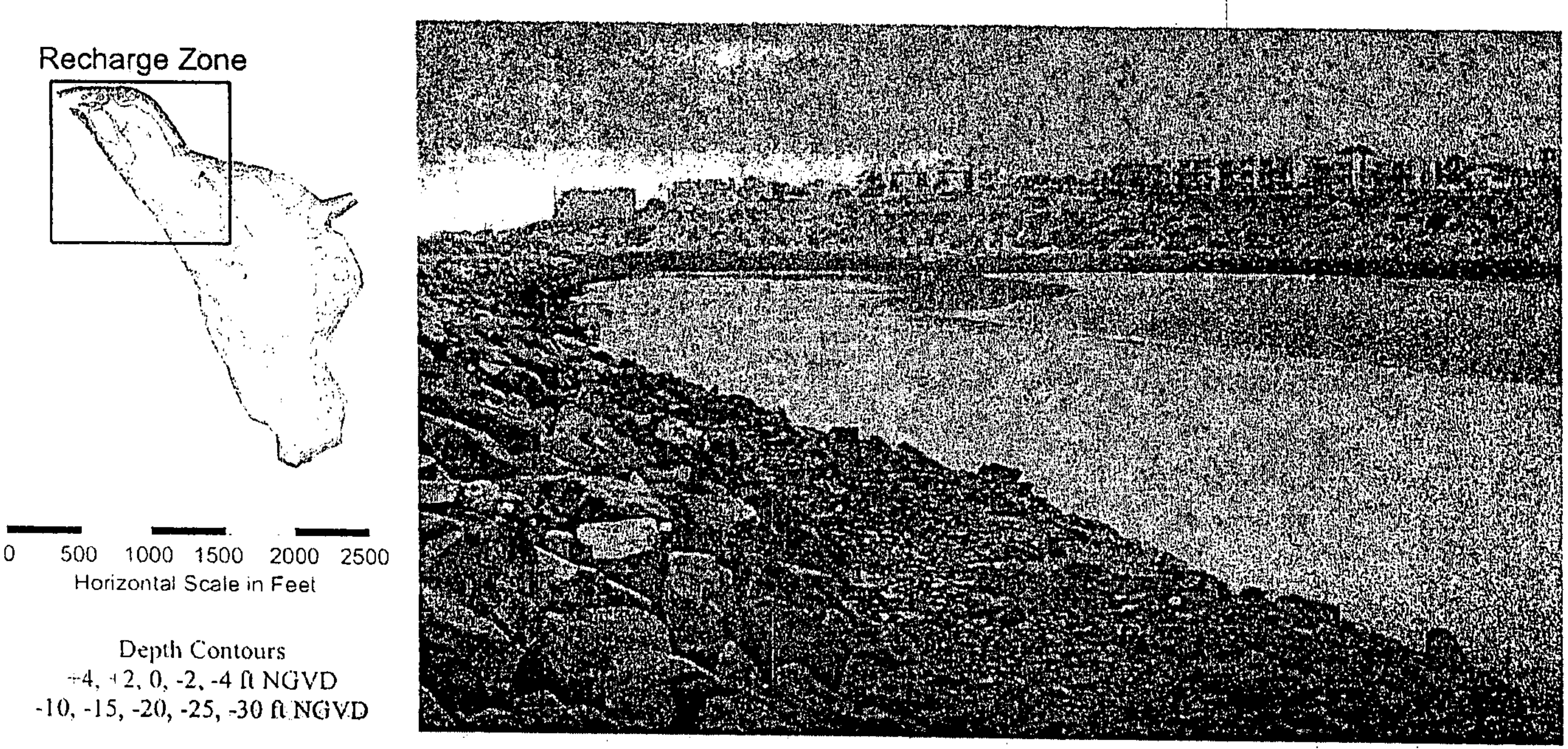

Figure 2. West Basin of Agua Hedionda Lagoon showing inlet (flood) bar formation at low tide. Insert shows the recharge area of the lagoon where this bar forms and the preponderance of maintenance dredging is performed.

historical extreme" and involves a once through flow rate of 304 mgd at the intake structure located at the southern end of the west basin of Agua Hedionda Lagoon. Table 1 below gives various operational combinations of existing circulation and service water pumps that can provide this minimum flow rate within 5%.

The existing cascade of circulation and service water pumps available at Encina Generating Station can provide a maximum once-through flow rate of 808 mgd, but has averaged about 530 over the long term (Jenkins and Wasyl, 2001). During peak user demand months for power (summer), plant flow rates are typically between 635 and 670 mgd (Elwany, et al, 2005). Thus the flow rates passing through the Encina facility during stand-alone desalination operations would be about 43% less than the present average when power generation is occurring, and 62% less than the peak flow rate capability. In this technical note, we utilize data from the existing literature to deduce probable impacts that this flow rate reduction would have on sand and nutrient flux into Agua Hedionda Lagoon and implications for the neighboring beaches and nearshore morphology.

2.0) Reduced Flow Effects on Sediment Flux

The most profound and far-reaching consequence of long-term operation of the Encina facility at reduced flow rate will be on the flux of sand into the lagoon through the ocean inlet. The sand influx controls the tidal exchange in the lagoon by regulating the depth of an inlet sill associated with inlet bars that form in the West Basin of the lagoon (see Figure 2). These sand bars restrict the effective tidal range in the lagoon and ultimately threaten closure of the inlet, thereby requiring periodic maintenance dredging to mitigate that threat. The bars are formed by sands that are suspended in the surfzone and entrained by the inflowing stream of water through the inlet. During peak demand months for power, typically 46% of the daily inflow volume is due the power plant flow rate, causing the daily outflow through the inlet to be 48% less than the inflow (Elwany, et al, 2005). As a result, the transport of sand into the lagoon through the ocean inlet has a strong inflow bias (flood dominance) that scales in direct proportion to the power plant flow rate. In the review of lagoon sedimentation that follows, we will show a correlation between sand influx rates and plant flow rates, indicating that reduction of plant flow rates will reduce the influx rate of sand into the lagoon. While this is an apparent benefit

Table 1. COMBINATIONS OF PUMPS OF TOTAL CAPACITY WITHIN 5 % OF 304 MGD

Operational Condition 1 – 304.7 MGD			
Unit 1 (Both Pumps)		=	68.3 MGD
		Subtotal =	104.3 MGD (Desal Intake)
Unit 2 (2 S Pump)		=	36.0 MGD
Unit 3 (Both Pumps)		=	63.9 MGD
		Subtotal =	200.4 MGD (Dilution)
Unit 4 (4 W Pump)		=	136.5 MGD
	Total	=	304.7 MGD (0.2 % above 304 MGD)
Operational Condition 2 – 306.3 MGD			
Unit 4 (Both Pumps)		=	270.4 MGD
Unit 1 (1 S Pump)		=	35.9 MGD
	Total	=	306.3 MGD (1 % above 304 MGD)
Operational Condition 3 – 306.4 MGD			
Unit 4 (Both Pumps)		=	270.4 MGD
Unit 2 (2 S Pump)		=	36.0 MGD
	Total	=	306.4 MGD (1 % above 304 MGD)
Operational Condition 4 – 315.4 MGD			
Unit 4 (4 E Pump)		=	133.9 MGD
Unit 5 (5 W Pump)		=	157.0 MGD
Unit 2 (2 N Pump)		=	24.5 MGD
	Total	=	315.4 MGD (3.8 % above 304 MGD)
Operational Condition 5 – 315.4 MGD			
Unit 5 (Both Pumps)		=	315.4 MGD
	Total	=	315.4 MGD (3.8 % above 304 MGD)
Operational Condition 6 – 302.1 MGD			
Unit 1 (Both Pumps)		=	68.3 MGD
	Total =		104.3 MGD (Desal Intake)
Unit 2 (2 S Pump)		=	36.0 MGD
Unit 3 (Both Pumps)		=	63.9 MGD
	Total =		197.8 MGD (Dilution)
Unit 4 (4 E Pump)		=	133.9 MGD
	Total	=	302.1 MGD (0.6 % below 304 MGD)

of stand alone operations of a desalination plant, it raises a number of cost trade-off and regulatory issues that would ultimately need to be decided.

2.1) Lagoon Sedimentation History: Prior to the 1950's, Agua Hedionda was a slough comprised of shallow marsh channels filled with anaerobic hyper-saline water and flushed only briefly during winter months when high tides and rain runoff from Agua Hedionda Creek would broach the barrier berm across the lagoon inlet. A Southern

Pacific Railroad survey of the track across Agua Hedionda in 1889 (Figure 3) shows no extensive open water areas where the present day lagoon is situated. Instead, only winding marsh channels and marsh vegetation is apparent. Also apparent in this survey map is the closed state of the inlet on the south side of the marsh plain, and a narrow barrier beach with cobble ridge system across the entire extent of Middle Beach and portions of North Beach and South Beach. (ref. Figure 1 for beach nomenclature). Thus these were historically narrow beaches that did not retain large volumes of sand given the presence of the surveyed cobble ridges.

Over a period of 247 days beginning June 1953, a total of 4,279,000 cubic yards of mostly beach grade sediment was dredged from the Agua Hedionda Lagoon system. Referring to Figure 1, the total dredge volume was 1,025,000 cubic yards from the outer or western basin, and 3,254,000 cubic yards from the middle and east basins, see Ellis (1954). This dredged material was deposited primarily on Middle Beach with residual amounts on North and South Beach, forming a large deltaic shoreline form which had the effect of widening the beach by an additional 500 ft. In order to allow the intake and discharge flows to cross this man-made delta, the intake and discharge channels were armored with rubble mound jetty structures approximately 700-750 ft. in length as measured from the center line of the Pacific Coast Highway (Jenkins and Wasyl, 2001).

The dredge delta caused wave energy to converge on this section of shoreline inducing erosion progressively over time until the original beach width at Agua Hedionda was re-established by 1956 (Jenkins and Wasyl, 2001). As the delta eroded, the un-engineered rock structures were exposed to large breaking wave forces and the intake and discharge jetties were reduced by this storm damage to their present nominal lengths circa 1960 to 1963. Meanwhile, the 4.3 million cubic yards of sand that had made up the dredged delta formation was transported southward by the net littoral drift that predominates throughout the Oceanside Littoral Cell as shown in Figure 4. In the Oceanside Littoral Cell, the prevailing wave direction is from the northwest due to the combined effects of coastline orientation, island sheltering and the most prevalent storm track which is associated with extra tropical cyclones and cold fronts from the Gulf of

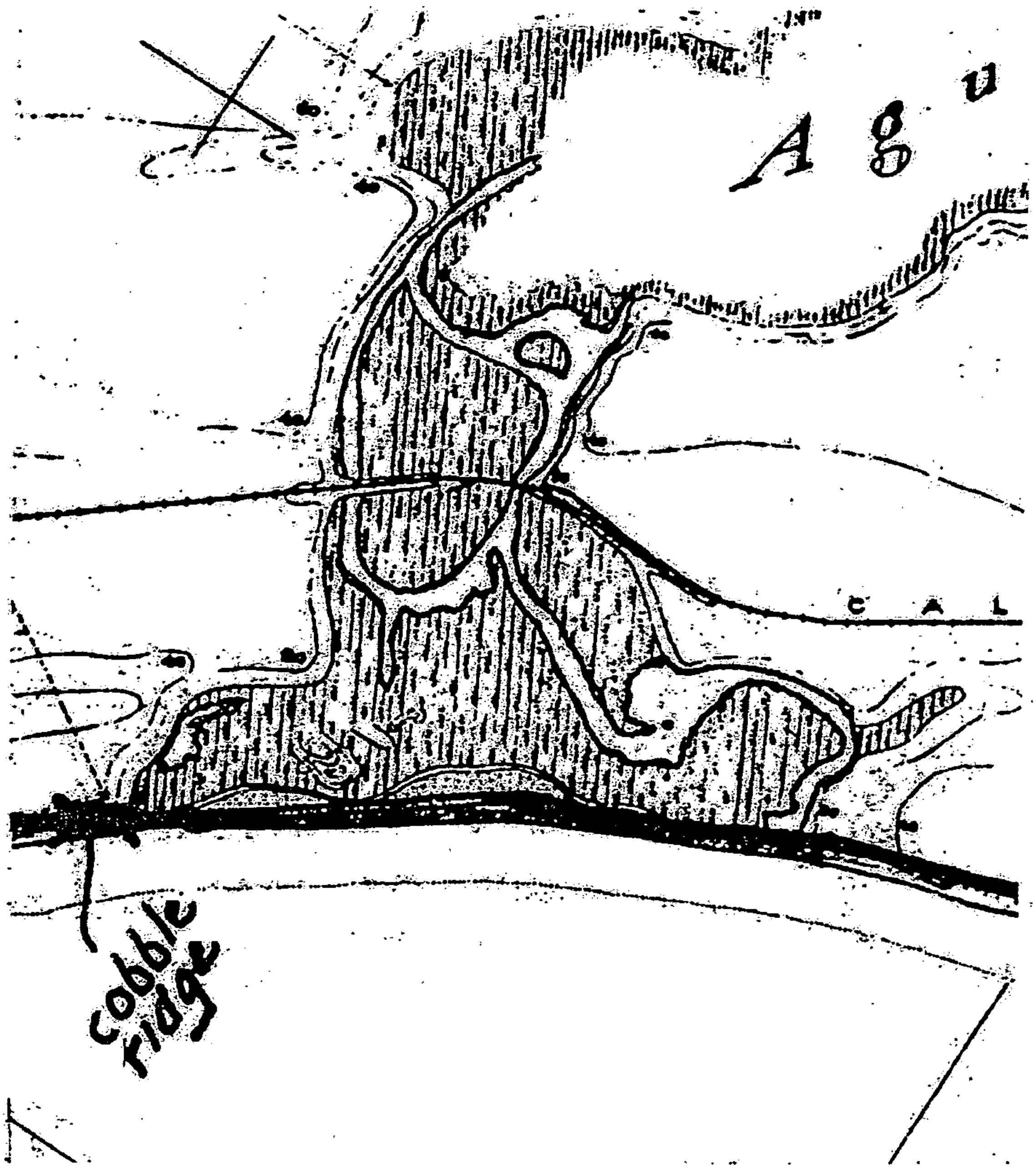

Figure 3 Railroad Survey of Agua Hedionda Lagoon, 1884.

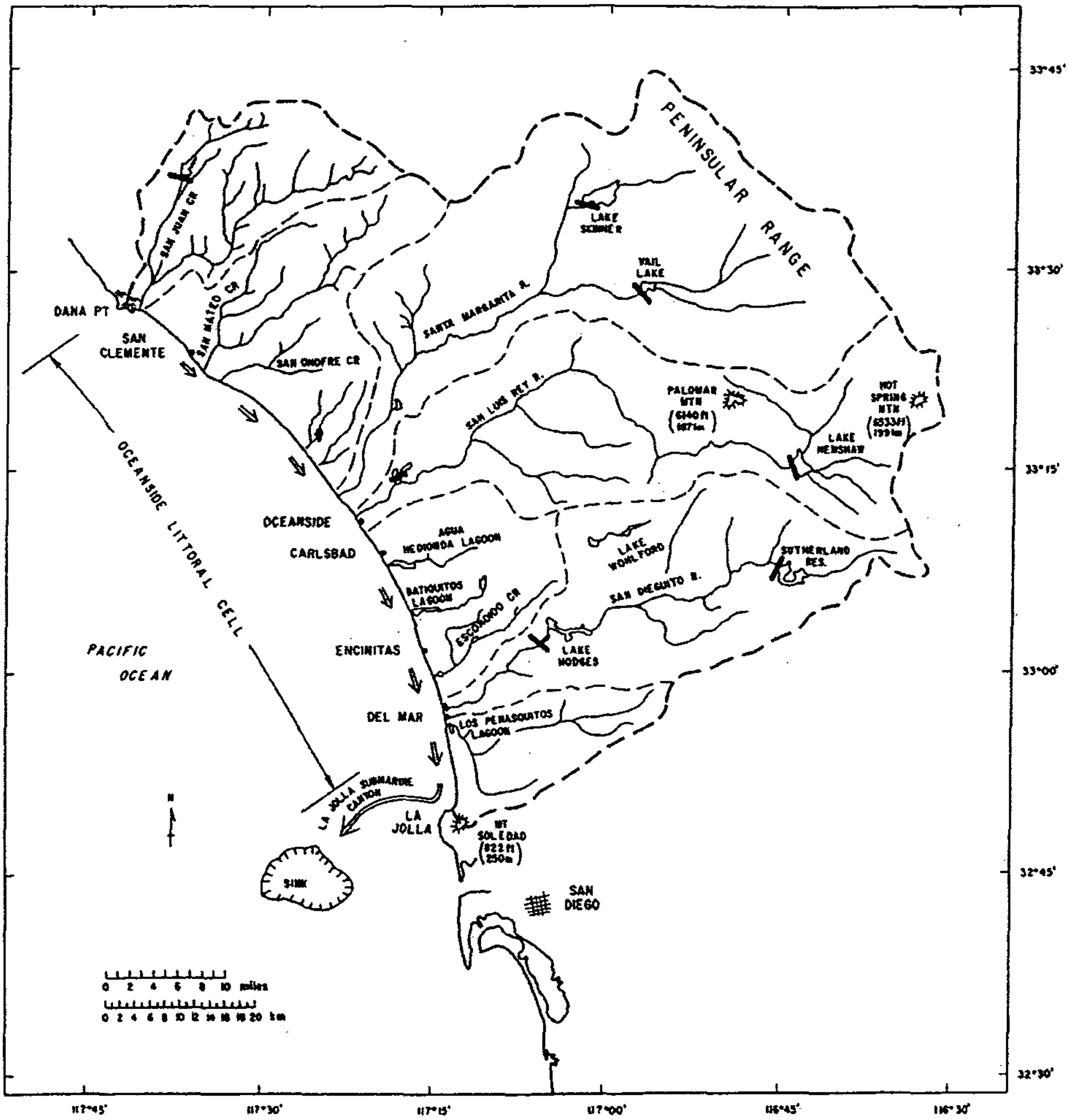

Figure 4. Oceanside Littoral Cell [Inman and Brush, 1973].

Alaska. Consequently, the long-term average littoral drift is from north to south as shown in Figure 4. This southward directed littoral drift is intercepted by submarine canyons (the La Jolla and Scripps Submarine Canyons) at the extreme southern (down-drift) end of the littoral cell where it is lost in turbidity currents that flow down the shelf rise, making the Oceanside Littoral Cell is a constant loss system. The only way the beaches can remain stable in this constant loss system is by continual replacement of these sand losses. When the inflowing stream of water into Agua Hedionda entrains sand from the littoral drift and deposits it in the west basin, the beaches down-drift of the lagoon suffer a loss of sand supply unless maintenance dredging returns those sands to the beaches. Since the inflow rates increase with the rate of consumption of cooling water, it is logical to look for a relationship between dredge quantities and cooling water consumption. To quantify this relationship we examine the historic dredge and flow rate data.

Table 2 gives a listing of the complete dredging history at Agua Hedionda Lagoon. The dredging events listed as "maintenance" in Table 2 occurred within the recharge zone of the west basin (Figure 2) and give estimates of sediment influx rates when the volumes for these events are factored against the time intervals between them. Annual sand influx rates calculated in this way are compared against the annual consumption of cooling water in Figure 5. Annual consumption of cooling water is plotted against the left hand axis in Figure 5 (black) in units of millions of gallons of seawater; while the annual sand influx volume is plotted against the right hand axis (red) in units of thousands of cubic yards. The individual data appear for each year as black diamonds for flow rate and red crosses for sand influx rates. Over-laid on these data are linear best fits to each. There is a clear trend showing that the consumption of cooling water by the power plant has increased over time (in response to expansion of generating capacity and increased user demand for power); and that the sand influx rates have followed that increase. From the best fit lines derived from the 48 year period of record in Figure 5, annual consumption of cooling water by the power plant has increased nearly 5 fold (growing on average by 3.3 billion gallons per year), while the annual influx of sand has doubled (increasing by 2 thousand cubic yards per year). Although the

Table 2. Dredging and Disposal History at Agua Hedionda Lagoon (from Jenkins and Wasyl, 2001)

Dredging And Disposal History							
Year	**Dredging**				**Disposal**	**Comments**	
	Date		**Volume (yds³)**	**Basin Dredged**	**Volume (yds³)**	**Location Placed 1**	
	Start	Finish					
1954	Feb-54	Oct-54	4,279,319	Outer, Middle, & Inner	4,279,319	N, M, S	Initial construction dredging
1955	Aug-55	Sep-55	90,000	Outer	90,000	S	Maintenance
1957	Sep-57	Dec-57	183,000	Outer	183,000	S	Maintenance
1959-60	Oct-59	Mar-60	370,000	Outer	370,000	S	Maintenance
1961	Jan-61	Apr-61	227,000	Outer	227,000	S	Maintenance
1962-63	Sep-62	Mar-63	307,000	Outer	307,000	S	Maintenance
1964-65	Sep-64	Feb-65	222,000	Outer	222,000	S	Maintenance
1966-67	Nov-66	Apr-67	159,108	Outer	159,108	S	Maintenance
1968-69	Jan-68	Mar-69	96,740	Outer	96,740	S	Maintenance
1972	Jan-72	Feb-72	259,000	Outer	259,000	S	Maintenance
1974	Oct-74	Dec-74	341,110	Outer	341,110	M	Maintenance
1976	Oct-76	Dec-76	360,981	Outer	360,981	M	Maintenance
1979	Feb-79	Apr-79	397,555	Outer	397,555	M	Maintenance
1981	Feb-81	Apr-81	292,380	Outer	292,380	M	Maintenance
1983	Feb-83	Mar-83	278,506	Outer	278,506	M	Maintenance
1985	Oct-85	Dec-85	403,793	Outer	403,793	M	Maintenance
1988	Feb-88	Apr-88	333,930	Outer	103,000	N	Maintenance
					137,860	M	Maintenance
					93,070	S	Maintenance
1990-91	Dec-90	Apr-91	458,793	Outer	24,749	N	Maintenance
					262,852	M	Maintenance
					171,192	S	Maintenance
1992	Feb-92	Apr-92	125,976	Outer	125,976	M	Maintenance
1993	Feb-93	Apr-93	115,395	Outer	115,395	M	Maintenance
1993-94	Dec-93	Apr-94	158,996	Outer	74,825	N	Maintenance
					37,761	M	Maintenance
					46,410	S	
1995-96	Sep-95	Apr-96	443,130	Outer	106,416	N	Maintenance
					294,312	M	
					42,402	S	
1997	Sep-97	Nov-97	197,342	Outer	197,342	M	Maintenance

Table 1. Continued

Dredging And Disposal History							
Year	Dredging				Disposal	Comments	
	Date		Volume(yds³)	Basin Dredged	Volume (yd³)	Location Placed 1	
	Start	Finish					
1998	Dec-97	Feb-98	60,962	Middle	60,962	M	Modification dredging
	Feb-98	Feb-99	498,736	Inner	370,297	M	Modification dredging
					128,439	S	
1999	Feb-99	May-99	202,530	Outer	202,530	N	Maintenance
2000-01	Nov-00	Apr-01	429,084	Outer	142,000	N	Maintenance
					202,084	M	
					85,000	S	
2002	Sept02	Dec 02	190,600		190,600	M	Maintenance
Total			11,482,966		11,482,966		

N = North Beach
M = Middle
S = South Beach

coefficient of determination (R-squared) is 0.68 for the cooling water relation and 0.60 for the sand influx relation, the scatter in the data about the best fit lines is due to several transient external factors. The cooling water relationship is effected by weather events and variations in climate patterns, especially the occurrence of warm humid El Niño (ENSO) events that result in protracted heat waves, increasing user demand for power to cool homes and work places. The sand influx relationship is similarly impacted since these same ENSO events also correlate with intensification of wave climate, accelerated beach erosion and transport; and consequently more suspended sediment in the neighborhood of the lagoon inlet to be entrained by the net inflowing stream. However, the sand influx rates are further impacted by beach nourishment activities up-drift of the

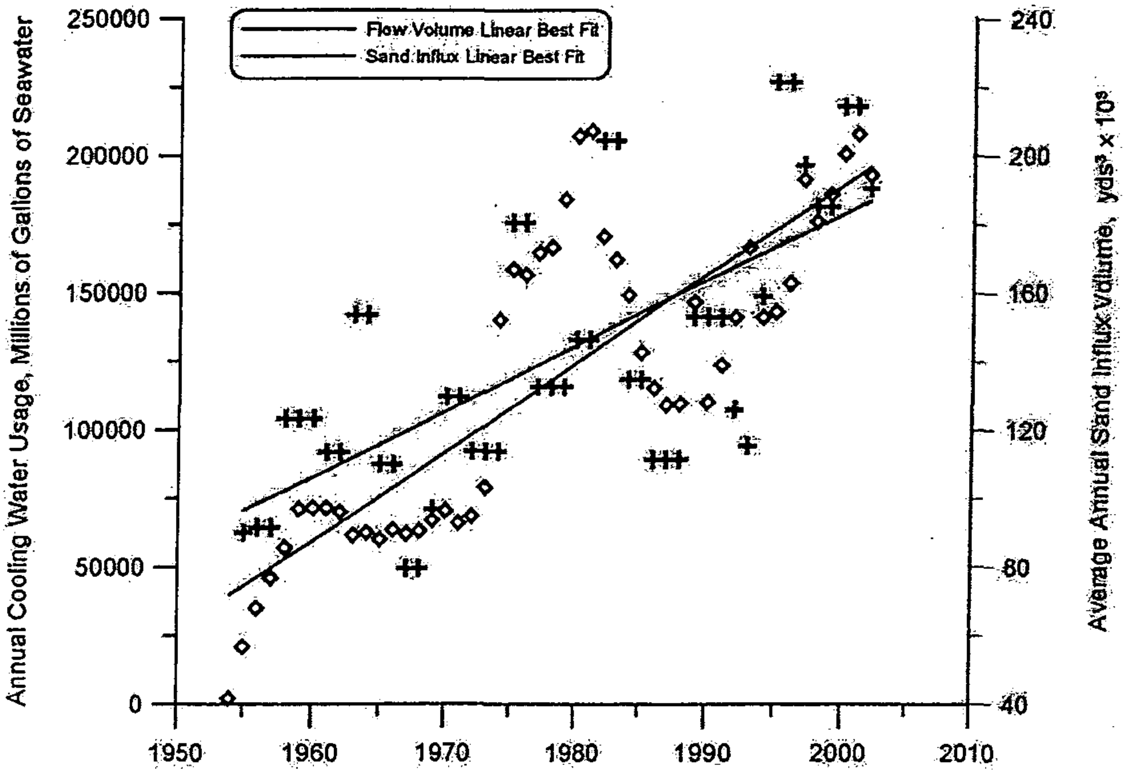

Figure 5. Time history of annual Encina cooling water usage and average annual sand influx from dredged volume for the years 1954-2002, [data from Jenkins and Wasyl, 1998 and 2003].

lagoon. Beach nourishment activities up-drift of Agua Hedionda are seen to have roughly doubled the daily influx rates to 400-600 cubic yards per day, as occurred following beach building projects in 1963, 1973, 1982, 1994 and 2001. Because of the transient impacts of beach restoration on sand influx rates, the coefficient of determination for the sand influx relation in Figure 5 is less than that for the cooling water flow rate relation. For a more detailed account of the effects of regional beach nourishment projects on sand influx rates at Agua Hedionda, see Appendix A.

2.2) Effects of Reduced Flow Operations on Sedimentation: From the flow rate and influx rate relations in Figure 5, we conclude that, on average, the lagoon presently traps 184,724 yds^3 of sand per year in response to an average daily once-through plant flow rate of 528.69 mgd. Probability analysis of inlet closure in Jenkins and Wasyl (1997,

2001) finds that the accumulated risk of inlet closure grows at 11% per year for sand influx rates of this magnitude, making inlet closure more probable than not within 4.5 years if no maintenance dredging is performed. In view of this risk, the historic dredge record in Table 2 shows that the longest interval between dredge events has been 3 years, and the predominant dredge interval has been 2 years. With in-house dredge assets home ported inside the lagoon, mobilization costs have been held to a minimum and marginal dredge costs have been running about $2.70 per cubic yard (Dyson, 2006). Thus, the costs of maintaining an open inlet (and hence, a healthy lagoon) under the present power generation operating scenario is about $499,000 per year.

If the flow rate is reduced to 304 mgd under the scenario of a stand-alone desalination plant, then the linear best fits in Figure 5 indicate that the average sand influx rates into the lagoon would be reduced to 106,218 yds^3 per year. This represents a 42.5% reduction in sand influx rates into the lagoon relative to the present power generation operating scenario. The reduction in sand influx rates reduces the accumulation of closure risk to only 6.3% per year, extending the safe interval for no dredge maintenance to 7.9 years before inlet closure would become more likely than not. Assuming the present marginal dredge cost of $2.70 per cubic yard, the annual cost of maintaining an open inlet under the reduced flow scenario would be $287,000 per year. Not factored into these cost comparisons are the costs of obtaining dredge permits and providing the pre- and post-dredging surveys and documentation necessary to obtain those permits. Dredge permits must be obtained from the City of Carlsbad, the California Coastal Commission, and the US Army Corps of Engineers on a year-to-year basis, as no blanket permits are currently issued.

Although the reduced flow rate scenario will reduce the rate of sand influx into the lagoon, it is clear that some degree of maintenance dredging must be continued for the indefinite future by whatever enterprise continues to use the lagoon for source water. While inlet closure becomes more probable than not after 7.9 years under the low flow rate scenario, it is a virtual certainty within 15 years in the absence of any form of maintenance dredging. Closure would be the consequence of about 840,000 cubic yards of sand being trapped in the west basin of the lagoon (Jenkins and Wasyl,1997, 2001), representing a permanent loss to the beaches down-drift of the lagoon. The magnitude of this loss (representing about 50% of the sand yield from the Bataquitos Lagoon Restoration) is quite significant to the down-drift beaches in Leucadia and Encinitas where chronic beach erosion has been the focus of public concern for many years. In addition to the beach impacts, inlet closure at Agua Hedionda would cause a precipitous drop in dissolved oxygen in lagoon waters (possibly even anaerobic) and a progressive transformation to hyper-saline conditions that would devastate the existing food web and related aqua culture. In time, the interior portions of the lagoon would in-fill with up-land sediments and be transformed back into the ephemeral system of marsh channels depicted in Figure 3. Hence, continued maintenance dredging of the west basin of the lagoon is vital for the continued health of the lagoon, as well as for the stability of the down-drift beaches and shoreline. The decisive question in the context of the reduced flow rate scenario is how frequently dredging should be performed.

If the presently practiced bi-annual/tri-annual dredge cycle is continued under the reduced flow rate scenario, the dredge volume will be on average 42.5 % smaller. This is a significant benefit to local beach stability (since less sand will be scavenged by the inflow from the local beach volume for any given 2 or 3 year period). However a bi-annual/tri-annual dredge cycle under reduced flow rate operations will raise the costs of maintaining an open inlet because mobilization/demobilization costs per cubic yard of dredged material will increase, and these are a major component of the total marginal dredge costs. A reasonable alternative is to base dredge scheduling on an equivalent dredge volume (~ 300 to 400 thousand cubic yards) as practiced under the existing bi-annual/tri-annual cycle, since these quantities when held and released from the lagoon appear to have an acceptable degree of impact on local beaches under present dredge permit conditions. Given these parameters, the dredge interval under the reduced flow rate scenario could be extended to once every 4 to 5 years, where rounding to nearest year gives:

$$\frac{(2yr \quad to \quad 3yr)(184{,}724\, yds^3 / yr)}{106{,}218\, yds^3 / yr} \cong 4yr \quad to \quad 5yr \qquad (1)$$

By extending the dredge cycle for low flow operations, the west basin of the lagoon will exist in a partially shoaled condition for a longer period of time. In this condition, the inlet sill depth is reduced and the inlet flow stream must proceed through constricted equilibrium tidal channels around the inlet bar. The flood flow channel forms along the north-west bank of the west basin immediately east of the HWY 101 bridge, while the ebb channel forms along the opposite bank with the inlet bar bedform lying in between. Typical morphology for this shoaled condition is shown in Figure 6 (taken from the pre-dredge survey of the west basin on 12 October 2002, prior to the 2002 maintenance dredging event). The constricted channels and reduced sill depth prevent the lagoon from fully draining during lower-low tide levels and induce hydraulic losses to friction and turbulence. These effects are referred to as *tidal muting* and reduce the tidal range throughout the interior of the lagoon system. With reduced tidal range, there is typically a reduction in inter-tidal habitat and a shift in the mix of habitat types.

3.0) Effects of Low Flow and Inlet Sedimentation on Tidal Hydraulics

To quantify potential effects associated with protracted periods of operations with a partially shoaled inlet, we perform tidal hydraulic simulations using the west bathymetry from Figure 6. The TIDE_FEM tidal hydraulics model presented in Jenkins and Inman (1999) was gridded for a computational mesh of Agua Hedionda Lagoon as shown in Figure 7, using pre- and post dredging bathymetry from the 2002 dredge event from Jenkins and Wasyl (2003). The pre-dredging bathymetry featured the inlet bar in the west basin that was mapped during the October 2002 sounding shown in Figure 6. The post-dredging survey performed in April 2003 indicated uniform deep water throughout the west basin with depths ranging from -20 ft NGVD to – 30ft NGVD, similar to that found in Figure 2-2 of Elwany, et al (2005). The lagoon model was excited at the ocean inlet by the 4.5 year maximum spring tides derived from tidal harmonic constituents for the Scripps Pier tide gage (NOAA Station #941-0230). These tides provide an assessment of the maximum tidal range effects of the pre- and post-dredging bathymetry.

Figure 8 shows how the inlet bar formation in the pre-dredging bathymetry (green) reduces the tidal range in the east basin of the lagoon relative to the tidal response for the post-dredging bathymetry (red) when that bar formation has been removed. The primary effect of the inlet bar on tidal range is to limit the degree to which the lagoon can drain during low tide. In the pre-dredge condition the lower-low water level only drops to -2.7 ft NGVD, as compared to a LLW of -4.0 ft NGVD in the post-dredge condition

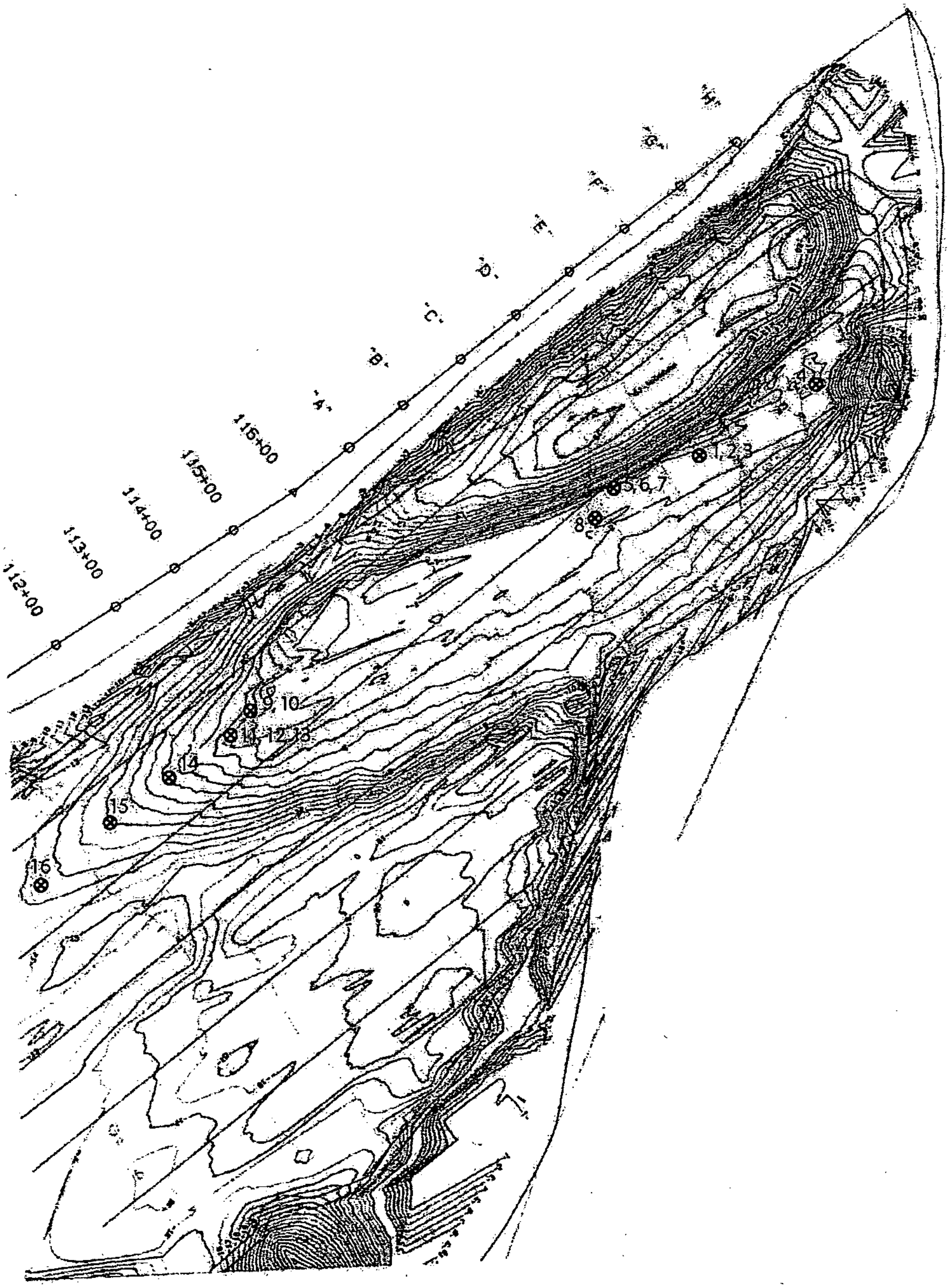

Figure 6. Location key for 12 October 2002 bottom sediment sampling.

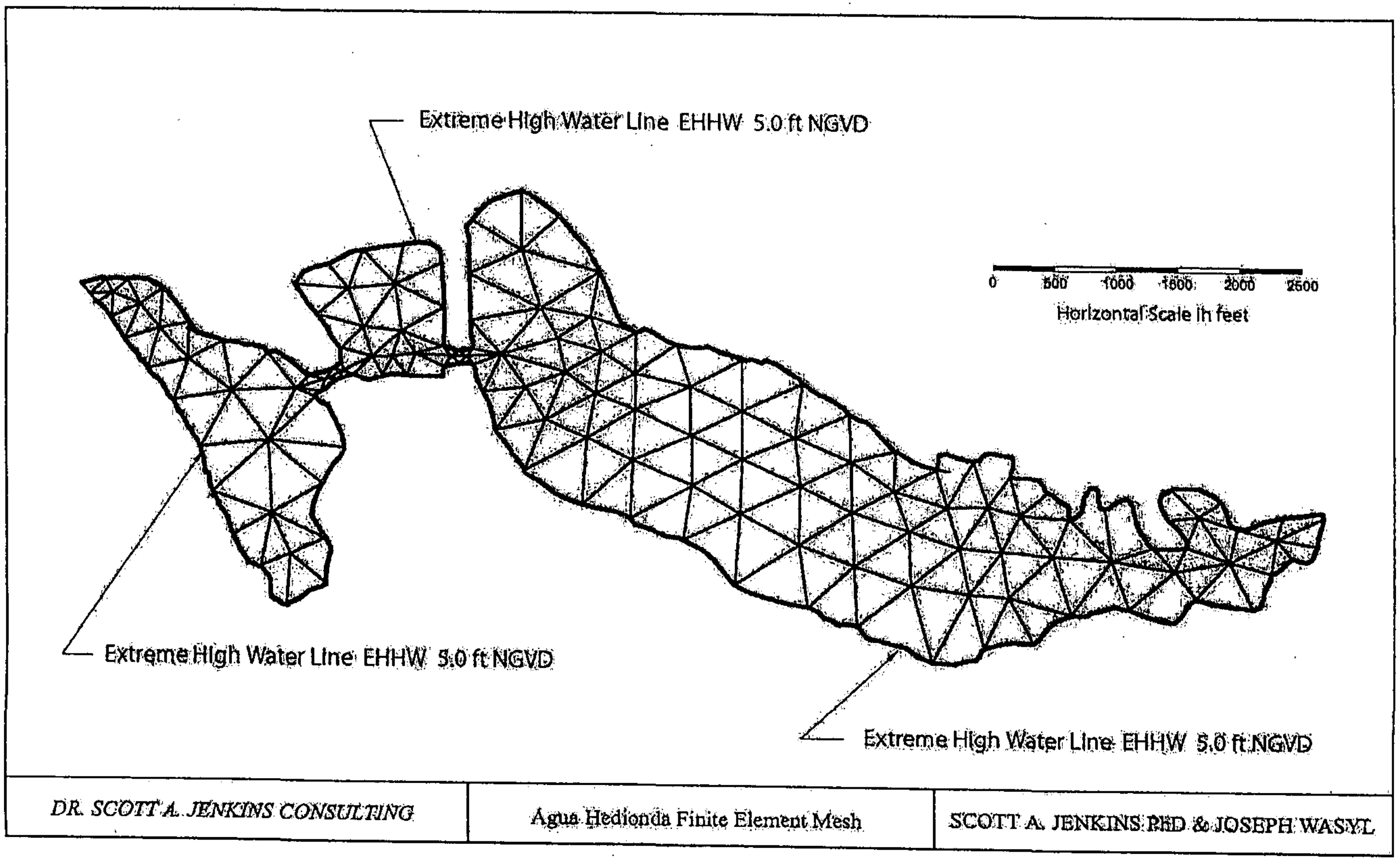

Figure 7. Computational mesh for TIDE_FEM tidal hydraulics model of Agua Hedionda Lagoon.

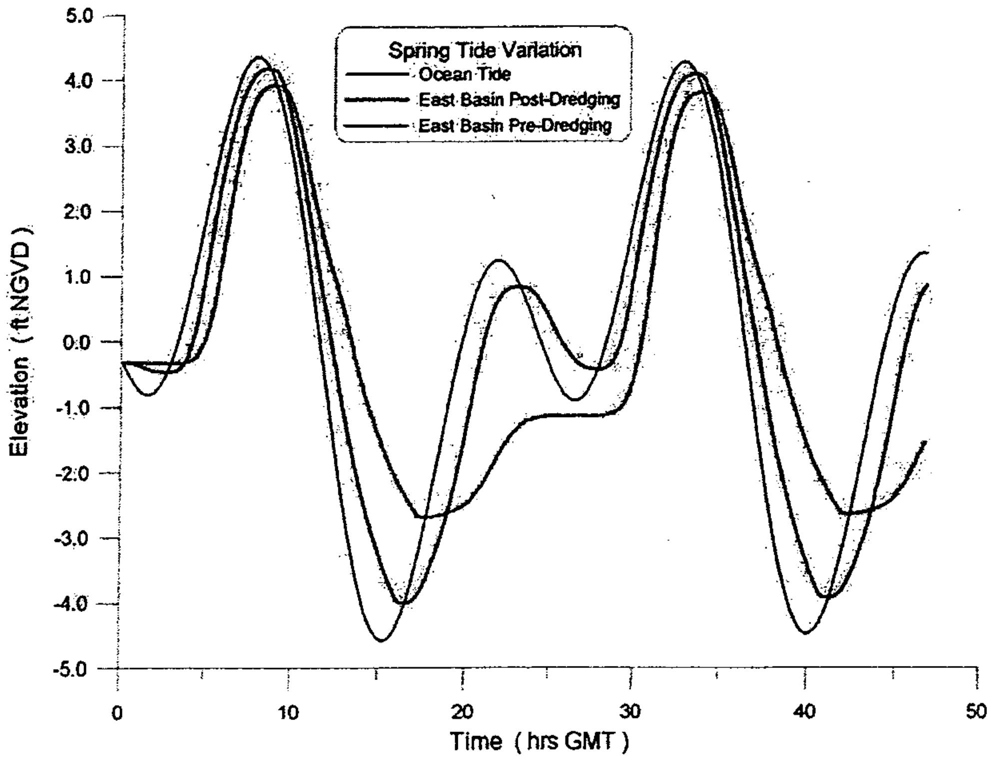

Figure 8. Effect of sedimentation on lagoon tidal range. Pre-dredging tide variation in East Basin (green); Post-dredging tides (red). Pre- and post- dredging tidal variations from TIDE_FEM simulation using ocean tides. Pre-dredging bathymetry from Jenkins & Wasyl 2003.

when the sill caused by the inlet bar is removed. The constricted inlet channels around the inlet bar also cause some muting of the higher-high water levels due to frictional losses and phase lags, with HHW for the pre-dredge condition reaching +3.9 ft NGVD as compared with +4.1 ft NGVD for HHW in the post-dredge condition. Altogether the inlet bar formation reduces the maximum diurnal tidal range by as much as 1.5 ft in the latter stages of west basin sedimentation prior to routine maintenance dredging.

To determine what effect the inlet bar exerts on lagoon habitat, we superimpose the diurnal tidal ranges obtained from hydraulic modeling on the area and volume rating functions of the lagoon derived from recent lagoon surveys by Elwany, et al (2005). Figure 9a shows that the maximum inter-tidal acreage of Agua Hedionda Lagoon is 107.9 acres due to spring tides acting on post-dredge bathymetry with no inlet bar formation. Sub-tidal acreage is 221.4 acres, giving a total lagoon habitat acreage of 329.3 acres post-maintenance dredging. Later, when shoaling develops in the west basin and a pronounced inlet bar forms, the tidal range is reduced throughout the lagoon and the maximum inter-tidal habitat is reduced by 32.9 acres to 75 acres, as indicated by the pre-dredging assessment in Figure 10a. Sub-tidal acreage is increased by 14.6 acres to 236 acres, because the reduced sill depth over the inlet bar restricts the ability of the lagoon to drain on a falling tide (Figure 8). Tidal muting of the higher-high water levels reduces the total lagoon habitat by 18.8 acres to 311 acres.

Consequently, a cyclical variation in the amount and proportions of lagoon habitat occurs throughout each dredge cycle, with the total lagoon habitat gradually declining by 5.7% following a post-dredging maximum, and reaching a minimum immediately before the mobilization of the next maintenance dredge event. This cyclical variation manifests itself most strongly in the inter-tidal habitat regime, where the habitat acreage declines by 30.5% following a post-dredging maximum. On the other hand, the sub-tidal habitat that supports the lagoon's fisheries varies inversely, with a post-dredging minimum followed by a gradual increase of as much as 6.5% prior to mobilization of the next maintenance dredge event. These variations are already built into the ecology of the present day lagoon and occur gradually enough over the existing bi-annual/tri-annual dredge cycle that significant impacts to that ecology have not been observed. What the reduced flow rate operations of a stand-alone desalination plant would do is extend the period of these variations by another 1 or 2 years (assuming the equivalent dredge volume policy of the previous section is adopted). The magnitude of the cyclical habitat variations would be the same, but those variations would evolve more slowly in time, thereby reducing the rate of cyclical decline of inter-tidal habitat and the rate of growth of sub-tidal habitat. This would give the lagoon ecology a longer response time to adapt to those cyclical changes, and presumably reduce the potential for any adverse consequences that have not yet been identified in the literature.

The other important effect of the inlet bar formation and attendant dredge cycle is on the volume exchange that occurs between the ocean and the lagoon and the residence time of water in the lagoon. Figure 9b finds that the maximum diurnal tidal prism for the post-dredge bathymetry (no inlet bar) is 2,286 acre ft. This result obtained by hydraulic simulation for the 4.5 yr spring tide maximums agrees closely with the result of 2125

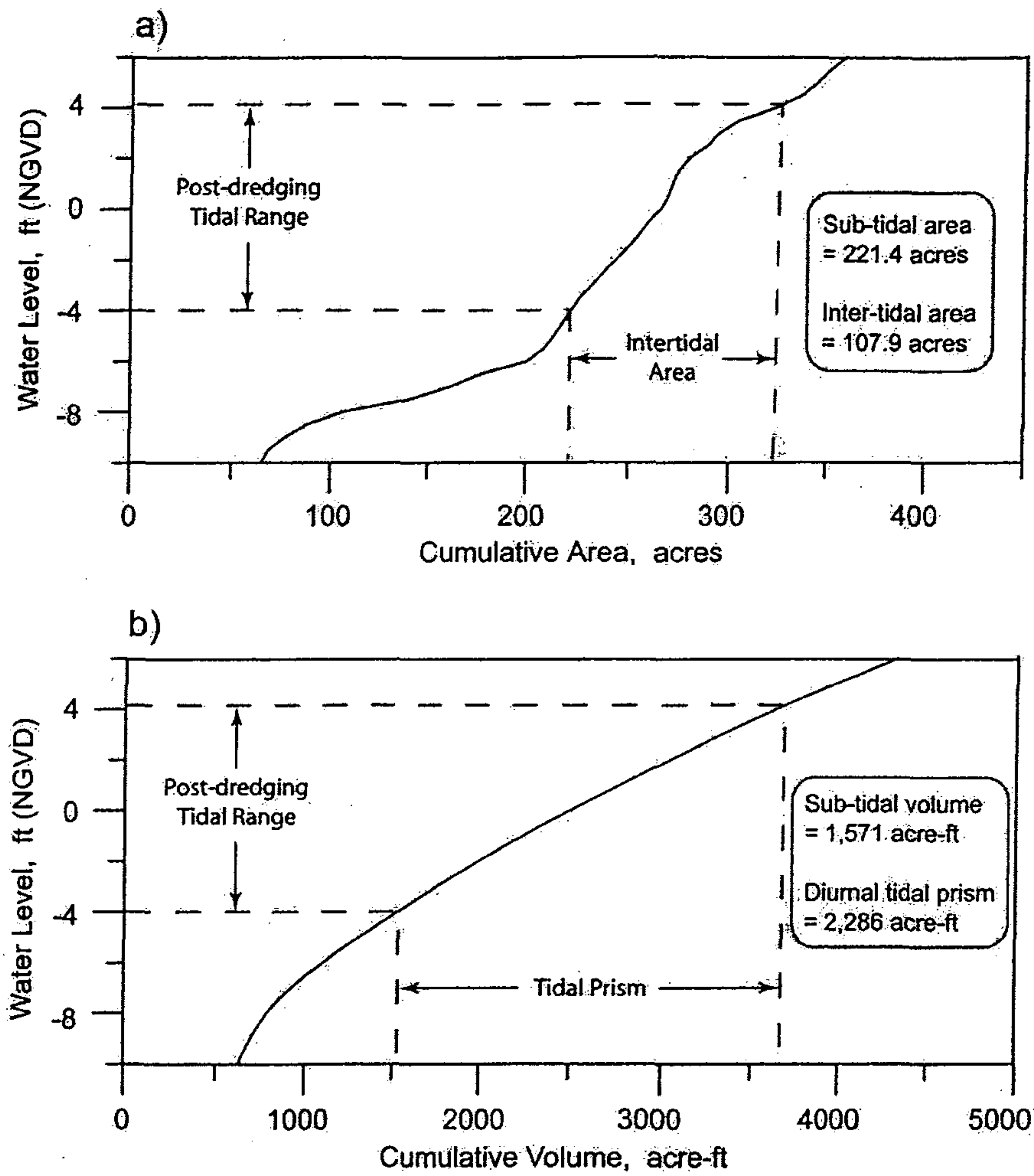

Figure 9. Post-dredging tidal hydraulics with West Basin inlet bar removed: a) Sub-tidal area and intertidal area during spring tide; b) Sub-tidal volume and diurnal tidal prism. Wetted area and volume function from Elwany et al., (2005).

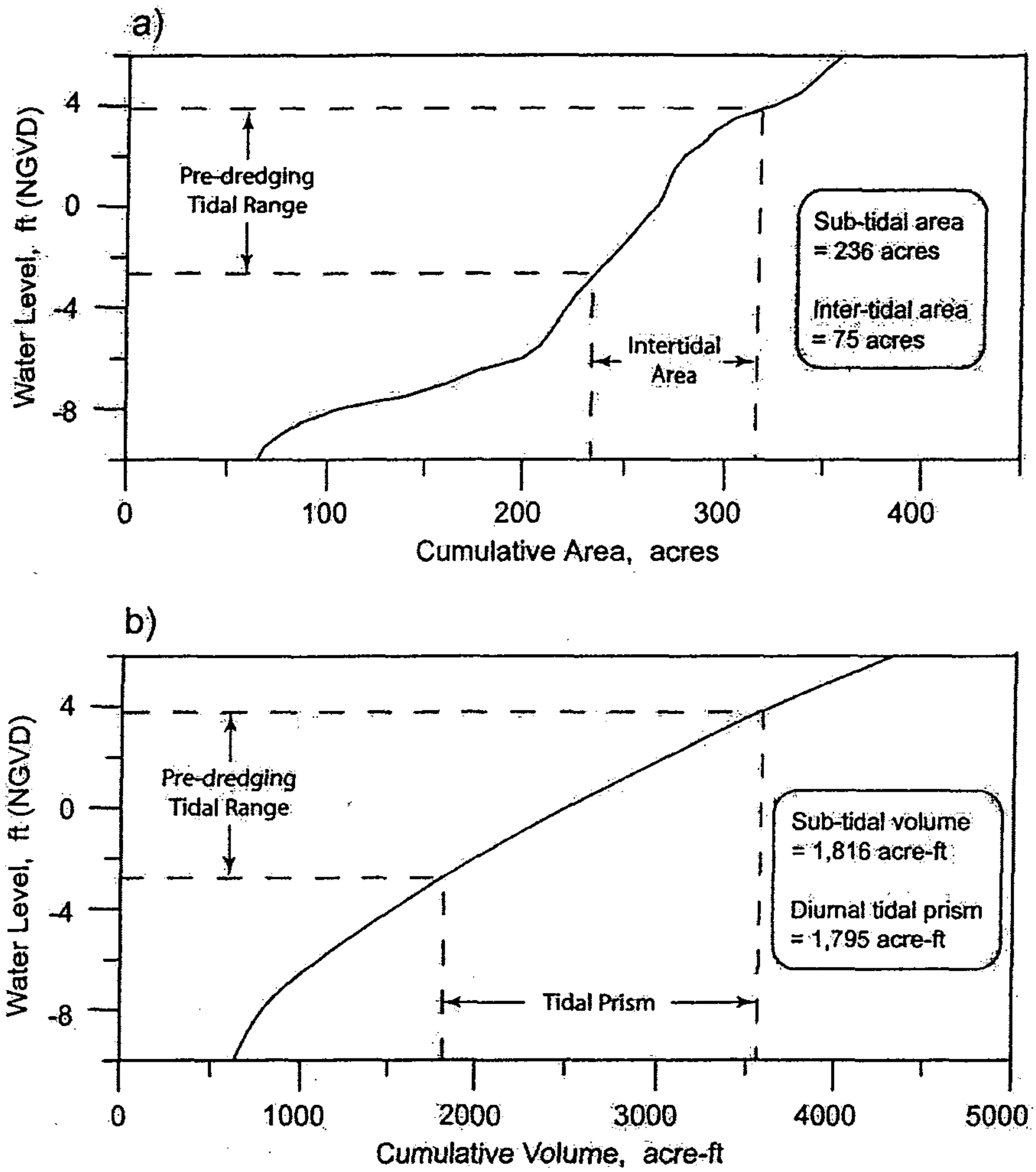

Figure 10. Pre-dredging tidal hydraulics with West Basin inlet bar per Figure 6: a) Sub-tidal area and intertidal area during spring tide; b) Sub-tidal volume and diurnal tidal prism. Wetted area and volume function from Elwany et al., (2005).

acre-ft obtained by water level measurements during spring tides in June 2005, as reported in Elwany (2005). This small discrepancy can be attributed to the larger tidal range of the ocean tides used in the hydraulic simulation in Figure 8. The hydraulic simulation in Figure 10b for the pre-dredge conditions (with well developed inlet bar) finds that the maximum diurnal tidal prism is reduced by 491 acre-ft to 1,795 acre-ft.

Thus, the west basin sedimentation diminishes the maximum diurnal prism of the lagoon by 21.5% over the course of a dredge cycle, and nearly 70% of this loss occurs in the east basin of the lagoon. Because the mass exchange between the east basin and the remainder of the lagoon is purely tidal in nature, the loss of tidal prism due to west basin sedimentation will impact the residence time of water in the highly productive east basin habitat zones. Figure 11 presents the water mass exchange rating functions of the east basin for pre- and post-dredging bathymetry. The hydraulic simulation (black) for the post-dredge bathymetry (with no inlet bar formation) gives a residence time of 3.7 days for water in the east basin. Here, residence time is taken as that point on the exchange rating curve when the percentage of old water declines to 2%. This compares with a mean value of 3.2 days reported in Elwany et al (2005) based on water level and velocity measurements over a one month period in June 2005. This is regarded as an insignificant difference that could easily be explained by differences between the 2003 bathymetry used in the hydraulic simulation versus the 2005 bathymetry that prevailed in the 2005 field measurements of Elwany et al (2005). With the reduction of tidal prism caused by the inlet bar formation, the residence time in the east basin is increased by 1 day to 4.7 days for pre-dredge bathymetry. Hence, the residence time in the largest basin of the lagoon experiences a cyclical increase of 27% of the course of the presently practiced bi-annual/tri-annual dredge cycle. This variation is not viewed to be significant as the residence time remains relatively short and oxygen deficiency or anoxic conditions have never been reported under present dredge practices. The effect of the of reduced flow operations of a stand alone desalination plant will not change the magnitude of this cyclical variation since mass exchange between the east and west basins is purely tidal. However, increasing the length of dredge cycle by 1 or 2 years under the reduced flow rate will increase the period of the residence time cycle by an equivalent duration.

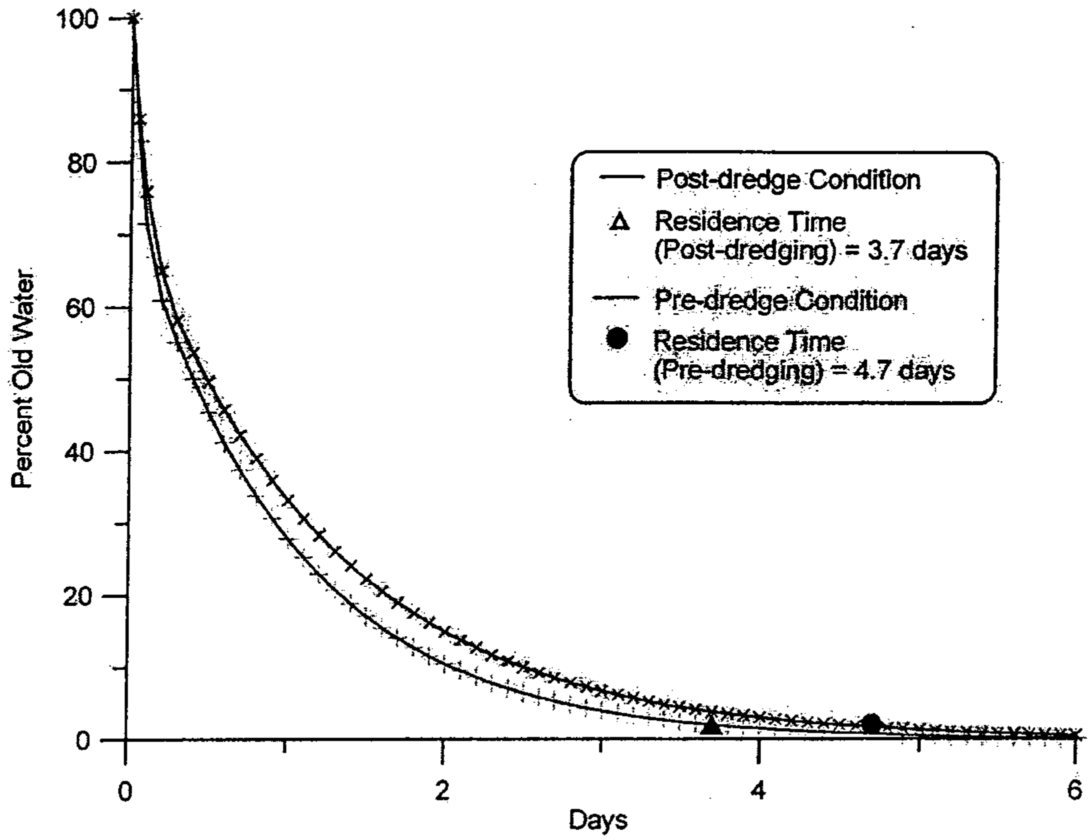

Figure 11. Water mass exchange rating function and residence time in the East Basin of Agua Hedionda Lagoon for pre-dredge (red) and post-dredge (black) bathymetry.

The effect of this longer cycle period, again, slows the rate at which biology must adapt to the cyclical increases residence time.

Reduced flow operations will affect the fluxes of nutrients and oxygen into the west basin. As commented in Section 2.2, fluxes of nutrients adsorbed to the surfaces of suspended sediment that enter the lagoon through the ocean inlet will be reduced by 42.5% under the low flow rate scenario. However, most of these sediments are sand sized and carry little if any nutrient load. The predominant nutrient load entering the lagoon through the ocean inlet is in the form of neutrally buoyant organisms and organic particles, colloids, and dissolved organic matter and oxygen. These constituents are fluxed with the inflow stream, and will be reduced by lower once-through flow rates through the plant, or by diminished tidal prism through the tidal muting effects of the inlet bar.

Elwany et al (2005) determined that on average, 46% of the daily inflow stream through the inlet was due to the power plant cooling water consumption based on water level and velocity measurements during the 5 week period between 1 June 2005 and 7 July 2005. Taking an average power plant flow rate during that period of 529 mgd and an average tidal prism of 1,700 acre ft, the flux balance obtained from this finding indicates that only 29% of the daily inflow volume would be due to the plant's circulation pumps under a low flow rate assumption of 304 mgd. This flow rate reduction would reduce the daily volume flux of new water and dissolved nutrients into the lagoon by 10.1%. However, the plants impact on dissolved nutrient influx becomes less during spring tides when a larger fraction of the inflow stream is due to pure tidal exchange (see Figure 1). The hydraulic model simulations for tidal exchange during spring tides with the post-dredge bathymetry (red line, Figure 8) indicate that only 36.4% of the daily inflow of new water is due to the power plant operating at its average annual flow rate of 529 mgd. If the plant flow rate is dropped to 304 mgd under the low flow rate scenario, then 22.7% of the daily inflow during spring tides (post-dredging) is due to the action of circulation pumps, and the nutrient flux will be reduced by 8% relative to present average pumping rates during power generation. When the west basin is in a pre-dredge configuration with a well developed inlet bar, the spring tide daily nutrient flux into the lagoon is reduced by 17.4% under present average flow rates of 529 mgd, and by 18.9% under the low flow scenario (304 mgd). Hence, inlet sedimentation and cyclical dredging causes a greater reduction on nutrient flux than would the reduction in plant flow rate under the low flow scenario of a stand alone desalination plant.

Summary and Conclusions:

Coastal processes and tidal hydraulic effects arising from reduced once-through flow rates at the Encina Generating Station, Carlsbad, CA are evaluated in the context of stand-alone operations of a co-located desalination plant. Stand alone desalination involves a once through flow rate of 304 mgd at the intake structure located at the southern end of the west basin of Agua Hedionda Lagoon. This flow rate would limit end-of-pipe salinity to no more than 40 ppt. The existing cascade of circulation and service water pumps available at Encina Generating Station can provide a maximum once-through flow rate of 808 mgd, but averages about 530 over the long term. Thus the flow rates passing through the Encina facility during stand-alone desalination operations would be about 43% less than the present average when power generation is occurring, and 62% less than the peak flow rate capability.

If the flow rate is reduced to 304 mgd under the scenario of a stand-alone desalination plant, then dredge records indicate that the average sand influx rates into the lagoon through the ocean inlet would be reduced to 106,218 yds^3 /yr from a present rate of 184,724 yds^3/yr. This represents a 42.5% reduction in sand influx rates into the lagoon relative to the present power generation operating scenario. The reduction in sand influx rates reduces the accumulation of inlet closure risk to only 6.3% per year, extending the safe interval for no dredge maintenance to 7.9 years before inlet closure would become more likely than not. Assuming the present marginal dredge cost of $2.70 per cubic yard, the annual cost of maintaining an open inlet under the reduced flow scenario would be $287,000 per year as compared to present maintenance costs of $499,000 per year. If dredge scheduling is based on an equivalent dredge volume (to minimize beach impacts) as practiced under the existing bi-annual/tri-annual cycle, the dredge interval under the reduced flow rate scenario could be extended to once every 4 to 5 years.

Under existing conditions with high flow rate power generation activity, a cyclical variation in the amount and proportions of lagoon habitat occurs throughout each dredge cycle, with the total lagoon habitat gradually declining by 5.7% following a post-dredging maximum, and reaching a minimum immediately before the mobilization of the next maintenance dredge event. This cyclical variation manifests itself most strongly in the inter-tidal habitat regime, where the habitat acreage declines by 30.5% following a post-dredging maximum. On the other hand, the sub-tidal habitat that supports the lagoon's fisheries varies inversely, with a post-dredging minimum followed by a gradual increase of as much as 6.5% prior to mobilization of the next maintenance dredge event. These variations are already built into the ecology of the present day lagoon and occur gradually enough over the existing bi-annual/tri-annual dredge cycle that significant impacts to that ecology have not been observed. What the reduced flow rate operations of a stand-alone desalination plant would do is extend the period of these variations by another 1 or 2 years (assuming the equivalent dredge volume policy as stated above). The magnitude of the cyclical habitat variations would be the same, but those variations would evolve more slowly in time, thereby reducing the rate of cyclical decline of inter-tidal habitat and the rate of growth of sub-tidal habitat. This would give the lagoon ecology a longer response time to adapt to those cyclical changes.

The dredge cycle under existing high flow rate operations also impacts the volume exchange that occurs between the ocean and the lagoon, causing a cyclical variation in the residence time of water in the lagoon. West basin sedimentation diminishes the maximum diurnal prism of the lagoon by 21.5% over the course of a dredge cycle, and nearly 70% of this loss occurs in the east basin of the lagoon. With the reduction of tidal prism caused by the inlet bar formation, the residence time in the east basin is increased by 1 day to 4.7 days. Hence, the residence time in the largest basin of the lagoon experiences a cyclical increase of 27% over the course of the presently practiced bi-annual/tri-annual dredge cycle. This variation is not viewed to be significant as the residence time remains relatively short and oxygen deficiency or anoxic conditions have never been reported under present dredge practices. The effect of the of reduced flow operations of a stand alone desalination plant will not change the magnitude of this cyclical variation since mass exchange between the east and west basins is purely tidal. However, increasing the length of dredge cycle by 1 or 2 years under the reduced flow rate scenario will increase the period of the residence time cycle by an equivalent duration. The effect of this longer cycle period, again, slows the rate at which biology must adapt to the cyclical increases residence time.

Reduced flow operations will affect the fluxes of nutrients and oxygen into the west basin. Flow rate reductions to 304 mgd would reduce the average daily volume flux of new water and dissolved nutrients into the lagoon by 10.1%, (assuming a mean tidal range). However, the plant's impact on dissolved nutrient influx becomes less during spring tides when a larger fraction of the inflow stream is due to pure tidal exchange. Under the low flow rate scenario, nutrient flux will be reduced by 8% relative to present average pumping rates during power generation. When the west basin is in a pre-dredge configuration with a well developed inlet bar, the spring tide daily nutrient flux into the lagoon is reduced by 17.4% under present average flow rates of 529 mgd, and by 18.9% under the low flow scenario (304 mgd). Hence, inlet sedimentation and cyclical dredging causes a greater reduction on nutrient flux than would the reduction in plant flow rate under the low flow scenario of a stand alone desalination plant.

In conclusion, the reduced flow rate operations of a stand alone desalination plant co-located at Encina Generating Station will reduce the capture rates of littoral sediment that presently occur under higher flow rates associated with power generation, thereby reducing the environmental impacts associated with maintenance dredging. Reduced flow rate operations will not increase the magnitude of cyclical variations in habitat or residence time that presently occur throughout each maintenance dredge cycle, but will increase the length of time over which those variations occur. Low flow rate operations will result in reductions of 8% to 10% in the fluxes dissolved nutrients and oxygen into the lagoon through the ocean inlet, but this effect is relatively minor in comparison to the 17.4% decline in nutrient flux that occurs in the latter stages of each dredge cycle. On balance, low flow operations do not appear to create any significant adverse impacts on either the lagoon environment or the local beaches; and it could be argued that the reduction in capture rates of littoral sediment is a project benefit.

Bibliography

Abbott, M. B., A. Damsgaard and G. S. Rodenhuis, 1973, ASystem 21, Jupiter,@ *Jour. Hydraulic Res.*, v. 11, n. 1.

Connor, J. J. and J. D. Wang, 1973, AFinite element modeling of two-dimensional hydrodynamic circulation,@ *MIT Tech. Rpt.*, #MITSG 74-4, p. 1-57.

Elwany, M. H. S., A. L. Lindquist, R. E. Flick, W. C. O'Reilly, J. Reitzel and W. A. Boyd, 1999, "Study of Sediment Transport Conditions in the Vicinity of Agua Hedionda Lagoon," submitted to California Coastal Commission, San Diego Gas & Electric, City of Carlsbad.

Elwany, M. H. S., R. E. Flick, M. White, and K. Goodell, 2005, "Agua Hedionda Lagoon Hydrodynamic Studies," prepared for Tenera Environmental, 39 pp. + appens.

Ellis, J.D., 1954, "Dredging Final Report, Agua Hedionda Slough Encina Generating Station," San Diego Gas and Electric Co., 44pp.

Gallagher, R. H., 1981, *Finite Elements in Fluids*, John Wiley & Sons, New York, 290 pp.

Inman, D. L., M. H. S. Elwany and S. A. Jenkins, 1993, "Shorerise and bar-berm profiles on ocean beaches," *Jour. Geophys. Res.*, v. 98, n. C10, p. 18,181-199.

Inman, D. L. & S. A. Jenkins, 1999, "Climate change and the episodicity of sediment flux of small California rivers," *Jour. Geology*, v. 107, p. 251–270.

Inman, D. L. & S. A. Jenkins, 2004, "Scour and burial of objects in shallow water," p. 1020–1026 in M. Schwartz, ed., *Encyclopedia of Coastal Science*, Kluwer Academic Publishers, Dordrecht, Netherlands.

Jenkins, S. A. and D. W. Skelly, 1988, "An Evaluation of the Coastal Data Base Pertaining to Seawater Diversion at Encina Power Plant Carlsbad, CA," submitted to San Diego Gas and Electric, Co., 56 pp.

Jenkins, S. A., D. W. Skelly, and J. Wasyl, 1989, "Dispersion and Momentum Flux Study of the Cooling Water Outfall at Agua Hedionda," submitted to San Diego Gas and Electric, Co., 36 pp. + appens.

Jenkins, S. A. and J. Wasyl, 1993, "Numerical Modeling of Tidal Hydraulics and Inlet Closures at Agua Hedionda Lagoon," submitted to San Diego Gas and Electric, Co., 91 pp.

Jenkins, S. A. and J. Wasyl, 1994, "Numerical Modeling of Tidal Hydraulics and Inlet Closures at Agua Hedionda Lagoon Part II: Risk Analysis," submitted to San Diego Gas and Electric, Co., 46 pp. + appens.

Jenkins, S. A. and J. Wasyl, 1995, "Optimization of Choke Point Channels at Agua Hedionda Lagoon using Stratford Turbulent Pressure Recovery," submitted to San Diego Gas and Electric, Co., 59 pp.

Jenkins, S. A. and J. Wasyl, 1997, "Analysis of inlet closure risks at Agua Hedionda Lagoon, CA and potential remedial measures, Part II," submitted to San Diego Gas and Electric, Co., 152 pp. + appens.

Jenkins, S. A. and J. Wasyl, 1998a, Analysis of Coastal Processes Effects Due to the San Dieguito Lagoon Restoration Project: Final Report, submitted to Southern California Edison Co., 333 pp.

Jenkins, S. A. and J. Wasyl, 1998b, Coastal Processes Analysis of Maintenance Dredging Requirements for Agua Hedionda Lagoon, submitted to San Diego Gas and Electric Co., 176 pp. + appens.

Jenkins, S. A. and D. L. Inman, 1999, A Sand transport mechanics for equilibrium in tidal inlets, *Shore and Beach*, vol. 67, no. 1, pp. 53-58.

Jenkins, S. A. and J. Wasyl, 2001, Agua Hedionda Lagoon North Jetty Resoration Project: Sand Influx Study, submitted to Cabrillo Power LLC., 178 pp. + appens.

Jenkins, S. A. and J. Wasyl, 2003, Sand Influx at Agua Hedionda Lagoon in the Aftermath of the San Diego Regional Beach Sand Project, submitted to Cabrillo Power LLC., 95 pp. + appens

Jenkins, S. A. and J. Wasyl, 2005, Hydrodynamic Modeling of Dispersion and Dilution of Concentrated Sea Water Produced by the Ocean Desalination Project at the Encina Power Plant, Carlsbad, CA. Part II: Saline Anomalies due to Theoretical Extreme Case Hydraulic Scenarios, submitted to Poseidon Resources, 97 pp.

Jenkins, S. A. and D. L. Inman, 2006, "Thermodynamic solutions for equilibrium beach profiles", *Jour. Geophys. Res.*, v.3, C02003, doi:10.1029, 21pp.

Leendertse, J. J., 1970, AA water quality model for well-mixed estuaries and coastal seas,@ vol. I, *Principles of Computation*, Memorandum RM-6230-RC, The Rand Corporation, Santa Monica, California, Feb.

Liebeck, R. H., 1976, "On the design of subsonic airfoils of high lift," paper no. 6463, McDonnell Douglas Tech. Report, 25 pp.

Liebeck, R.H., and Ormsbee, A.I., "Optimization of Airfoils for Maximum Lift," *AIAA*

Journal of Aircraft, v. 7, n. 5, Sept-Oct 1970.

McCormick, B., 1979, *Aerodynamics, Aeronautics and Flight Mechanics*, John Wiley & Sons, New York, 652 pp.

NOAA, 1998, AVerified/Historical Water Level Data@ http://www.opsd.nos.noaa.gov/data_res.html

Stratford, B.S., 1959, The Prediction of Separation of the Turbulent Boundary Layer, *Jour. Fluid Mech.*, v. 5.

Stratford, B.S., 1959, An Experimental Flow with Zero Skin Friction Throughout its Region of Pressure Rise, *Jour. Fluid Mech.*, v. 5.

Weiyan, T., 1992, *Shallow Water Hydrodynamics*, Water & Power Press, Hong Kong, 434 pp.

APPENDIX-A: Beach Nourishment Projects Near Agua Hedionda Lagoon

The lagoon prior to the late 1980's typically ingested 200-300 cubic yards per day unless major up-drift nourishment occurred along Oceanside and Carlsbad beaches. Table 3 gives a listing of all dredge disposal and beach nourishment activities occurring in the neighborhood of Agua Hedionda due to activities outside the lagoon's operation. Major beach building projects at Oceanside and Carlsbad were undertaken in 1963, 1973, 1982, 1994 and 2001. The most dramatic example of this updrift nourishment impact resulted from the massive beach nourishment projects in 1982 when 923,000 cubic yards of new sand was truck hauled from the San Luis Rey River and placed on Oceanside beaches. Coincidentally, the 1983-85 biannual maintenance dredging cycle of the west basin of Agua Hedionda yielded 447,464 cubic yards. This corresponded to an average daily influx rate of 613 cubic yards per day during that two year period. Such high daily influx rates had not been seen since 1960 when 841,200 cubic yards of beach nourishment was placed on Oceanside beaches following new construction dredging and enlargement of Oceanside Harbor facilities.

After the late 1980's there was only one minor new beach nourishment project in Oceanside, involving 40,000 cubic yards in 1994. However beginning in 1988, the City of Carlsbad imposed conditions requiring back-passing defined fractions of the Agua Hedionda dredge volume north of the inlet. In 1988, 103,000 cubic yards were back-passed from Agua Hedionda to North Beach (Figure 1), resulting in an influx of 458,793 cubic yards into Agua Hedionda Lagoon by 1990, for an influx rate of about 630 cubic yards per day. During 89 days of dredging operations between December 20, 1993 and April 26, 1994, there were 74,825 cubic yards placed immediately north (updrift) of the Agua Hedionda Lagoon and inlet jetty at the North Beach disposal site. The daily influx rate during this 89 day period rose to an average of 782 cubic yards per day. In 1996 there was 106,416 cubic yards of back-passing dredged sands from Agua Hedionda to North Beach and influx rates increased to 540 cubic yards per day in the year that followed. Although the volume of back-passing has been small relative to prior nourishment efforts in Oceanside, its effect on influx was large due to the close proximity of North Beach to the inlet of Agua Hedionda and the low retention of sand on this beach in the presence of rocky substrate immediately offshore, Elwany et al. (1999) .

Table 3: Dredge Disposal and Beach Nourishment Occurring Outside of Agua Hedionda Lagoon Operations

Year	Amt. Dredged (yd^3)	Material Source	Disposal Location	Comments
1942	500000	Del Mar Boat Basin	Increase grade around Boat Basin	Material was not placed on the beach
1944	200000	Entrance Channel	Upland	Material was not placed on the beach
1955	800,000	Harbor Construction	Oceanside Beach	Dredged Material
1960	41,000	Entrance Channel	Oceanside Beach	Dredged Material
1961	481,000	Channel	Oceanside Beach	Dredged Material
1963	3,800,000	Harbor	Oceanside Beach	1.4myd3 was new
1965	111,000	Entrance Channel	Oceanside Beach	Dredged Material
1966	684,000	Entrance Channel	2nd St.-Wisconsin St.	Dredged Material
1967	178,000	Entrance Channel	3rd St.-Tyson St.	Dredged Material
1968	434,000	Entrance Channel	River-Wilconsin St.	Dredged Material
1969	353,000	Entrance Channel	River-3rd	Dredged Material
1971	552,000	Entrance Channel	3rd-Wisconsin St.	Dredged Material
1973	434,000	Santa Margarita R.	Tyson-Wisconsin St.	New Material-Beach
1974	560,000	Entrance Channel	Tyson-Whitterby	Dredged Material
1976	550,000	Entrance Channel	Tyson-Whitterby	Dredged Material
1977	318,000	Entrance Channel	Tyson-Whitterby	Dredged Material
1981	403,000	Entrance Channel	6th St.-Buccaneer	Dredged Material
1981	403,000	Offshore Borrow Site	Oceanside Beach	Dredged Material
1982	923,000	San Luis Rey R.	Oceanside Beach	New Material-Beach
1983	475,000	Entrance Channel	Tyson Street	Dredged Material
1986	450,000	Entrance Channel	Tyson Street	Dredged Material
1988	220,000	Entrance Channel	Tyson Street	Dredged Material
1990	250,000	Entrance Channel	Tyson Street	Dredged Material
1992	106,700	Bypass System	Tyson Street	Dredged Material
1993	483,000	Modified Entrance	Tyson Street	Dredged Material
1994	40,000	Santa Margarita R.	Wisconsin St.	New Material-Beach
1994	161,000	Entrance Channel	Nearshore Wisconsin	Dredged Material
1994	150,000	Bataquitos Lagoon	Inlet South Side	New Material-Beach

Table 3: (continued)

Year	Amt. Dredged (yd^3)	Material Source	Disposal Location	Comments
1995	1,600,000	Bataquitos Lagoon	Ponto Beach	New Material-Beach
1996	162,000	Entrance Channel	Nearshore Wisconsin	Dredged Material
1997a	150,000	Entrance Channel	Nearshore Oceanside	
1997b	100,000	Entrance Channel	Wisconsin St.	Dredged Material
	17,316,700	**Total**		
	178,017	**Average (only including maintenance dredging)**		

Following the east basin dredge project, 202,530 cubic yards were back-passed to North Beach in April 1999. A dredge survey in July 2000 determined that 360,800 cubic yards had influxed into the lagoon, increasing the daily rate to an average of 846 cubic yards per day. Altogether the percentage of lagoon dredging that has been back-passed to North Beach averages 14.7% of the total dredge volume during the 1981-2000 model period. The remaining fraction of dredge volume that was not back-passed was divided between the Middle and South Beach disposal sites. This fraction was historically split in an 85% to 15% ratio between Middle and South Beach.

In 1994-95 a major beach building effort was conducted at Ponto Beach immediately to the south of Agua Hedionda, where 1,750,000 cubic yards of beach fill was placed using dredged material from the construction of the Bataquitos Lagoon Restoration. The most recent beach building project to impact Agua Hedionda was the San Diego Regional Beach Sand Project completed in September 2001. This project placed 1.83 million cubic yards of on beaches between Oceanside and Torrey Pines, of which 921,000 cubic yards were placed in the nearfield of Agua Hedionda. Within one year following completion of the 2001 maintenance dredging of the lagoon, it was necessary to dredge the lagoon again to remove an additional 196,000 cubic yards from the west basin of the lagoon, despite an extremely dry year with below normal wave climate. During this one year period, the average wave height was only 0.8 m, which in the absence of the San Diego Regional Beach Sand Project, should have produced a sand influx volume of only 103,500 cubic yards (Jenkins and Wasyl, 2003).