Shelter Island Yacht Basin Tidal Flushing Modeling and Engineering Feasibility Study

Final Report

Prepared For:

Port of San Diego
3165 Pacific Highway
San Diego, California

February 2013

WESTON SOLUTIONS

Shelter Island Yacht Basin Tidal Flushing Modeling and Engineering Feasibility Study

Prepared For:

Port of San Diego
3165 Pacific Highway
San Diego, California

Prepared By:

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February 2013

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ACRONYMS AND ABBREVIATIONS

ACH	America's Cup Harbor
Basin Plan	*Water Quality Control Plan for the San Diego Basin – Region 9*
BMP	best management practice
CWA	Clean Water Act
CMA	Coastal Monitoring Associates, LLC
Implementation Plan	SIYB Dissolved Copper TMDL Implementation Plan
Investigative Order	Investigative Order No. R9-2011-0036
MAR	marine habitat
OAL	Office of Administrative Law
Port	San Diego Unified Port District
RCB	reinforced concrete box
RCP	reinforced concrete pipe
Regional Board	San Diego Regional Water Quality Control Board
SIYB	Shelter Island Yacht Basin
SDB	San Diego Bay
TMDL	Total Maximum Daily Load
Weston	Weston Solutions, Inc.
WILD	wildlife habitat
WQO	water quality objectives

UNITS OF MEASURE

µg/L	microgram per liter
%	percent

1.0 INTRODUCTION

1.1 TMDL Summary & Background

In 1996, the Shelter Island Yacht Basin (SIYB) was placed on the Clean Water Act (CWA) Section 303(d) list of impaired waters due to elevated levels of dissolved copper in the water column. The CWA requires that the Regional Board implement a TMDL for 303(d)-listed waters of SIYB since the existing water quality did not meet numeric water quality standards for dissolved copper or narrative water quality objectives (WQOs) for toxicity and pesticides. As a result, the Regional Board developed a TMDL for SIYB, with the purpose of achieving applicable WQOs as well as the restoration of marine habitat (MAR) and wildlife habitat (WILD) beneficial uses within the basin. The San Diego Regional Water Quality Control Board (Regional Board) incorporated the dissolved copper TMDL into the *Water Quality Control Plan for the San Diego Basin – Region 9* (Basin Plan)(Regional Board, 2005) through Resolution No. R9-2005-0019. The Office of Administrative Law (OAL) reviewed and approved the dissolved copper TMDL on December 2, 2005.

1.2 TMDL Implementation Plan

Named Parties (i.e., Dischargers) prepared a TMDL Implementation Plan (Implementation Plan) that describes the collective approach to achieving reductions in copper loading into SIYB in order to preserve and restore beneficial uses. The Implementation Plan takes a solutions-oriented approach of establishing and implementing Best Management Practices (BMPs) that directly and indirectly facilitate reductions in copper loading into the basin to meet the SIYB TMDL interim and final dissolved copper loading compliance thresholds. The Implementation Plan was prepared in response to Resolution No. R9-2005-0019 (Weston, 2011).

This Implementation Plan incorporates an adaptive management model of planning, implementation, and assessment. The first step in the planning phase is to develop a BMP implementation strategy by which the Named Parties will work independently and collectively to reduce copper loading into SIYB. It is recognized that the current primary source of dissolved copper to the water column originates from copper-based antifouling paints. A potential strategy to reduce dissolve copper in the water column is to increase tidal flushing (i.e., reduce the average time that water remains in SIYB) resulting in the more rapid removal of dissolve copper and thus lower concentrations of dissolved copper in the water column.

1.3 Study Purpose

The purpose of this Tidal Flushing Modeling and Engineering Feasibility Study (Study) is to utilize a predictive model to simulate the processes that regulate copper concentrations in SIYB under current and modified conditions. The modified conditions evaluated for this Study include the potential strategies of constructing a submersed connection (pipe or culvert) between SIYB and the San Diego Bay (SDB) or a connection between SIYB and the America's Cup Harbor (ACH). In support of the modeling effort the cost and construction feasibility of each potential strategy was evaluated. The results of this Study may be used by planners to facilitate future decisions regarding the best implementation strategies to achieve TMDL interim and final dissolved copper loading compliance thresholds.

2.0 ENGINEERING FEASIBILITY ASSESSMENT

The feasibility, considering the engineering and construction involved, of providing a submersed connection (culvert or pipe) between SIYB and SDB or between SIYB and ACH was evaluated. This included an evaluation of existing underground utilities and providing rough order of magnitude cost estimates. Potential conflicts with existing underground utilities were evaluated. Depending on size, location, and type of utility, conflicts may impact the constructability of the proposed scenarios (e.g., a large gravity sewer line in the path of a culvert or pipe may cause the project to not be constructible).

In order to assess the engineering feasibility of the modeling enhanced flushing scenarios, conceptual drawings of the potential improvements (connections) were prepared. Research of the existing underground utilities was conducted at the City of San Development Services Department and included a review of Shelter Island Drive sewer as-built drawings, which also show other existing utilities. The topographic elevations for the conceptual drawings were estimated by City of San Diego SanGIS 2-foot contour data, and elevations data obtained from as-built drawings of the Shelter Island Drive. Street centerline and right-of-way as well as property lines were estimated by combining SanGIS data, information from as-built drawings, and aerial photographs.

Profiles of the proposed culverts (or pipes) were prepared in order to compare the locations of the proposed connections to those of the existing utilities. No direct conflict with underground utilities for any of the scenarios is indicated on these profiles. Various utilities are located beneath Shelter Island Drive that would require additional attention during construction activities to ensure that they remain protected-in-place (e.g., hand excavation around them, shoring, etc. or employing horizontal construction). Additionally, dewatering would be required for the entire project excavation and may include constructing temporary coffer dams in SYIB and SDB or ACH.

The preparation of the conceptual drawings was based on limited data in order to identify potential obvious and major conflicts and issues. If one or more of these scenarios is proposed for potential implementation, additional assessment shall be conducted early in the project planning phase in order to refine the design and further assess the feasibility and cost of the scenario.

2.1 Shelter Island Yacht Basin to San Diego Bay Connection

Connecting SIYB to SDB would require about 750 feet of underground culvert or pipe. Figure 2-1 shows SYIB connected to SDB utilizing a reinforced concrete box (RCB) culvert (12 feet wide by 8 feet height). Table 2-1 provides the rough cost estimate associate with constructing the RCB culvert. Unit prices in the cost estimate are based on the City of San Diego Development Services Department *Unit Price List* (San Diego, 2009), if applicable. In cases where items are not listed in this reference, reasonable assumptions regarding costs were made. Figure 2-2 shows SYIB connected to SDB utilizing a 54-inch diameter reinforce concrete pipe (RCP), and Table 2-2 provides the rough cost estimate associate with constructing the RCP.

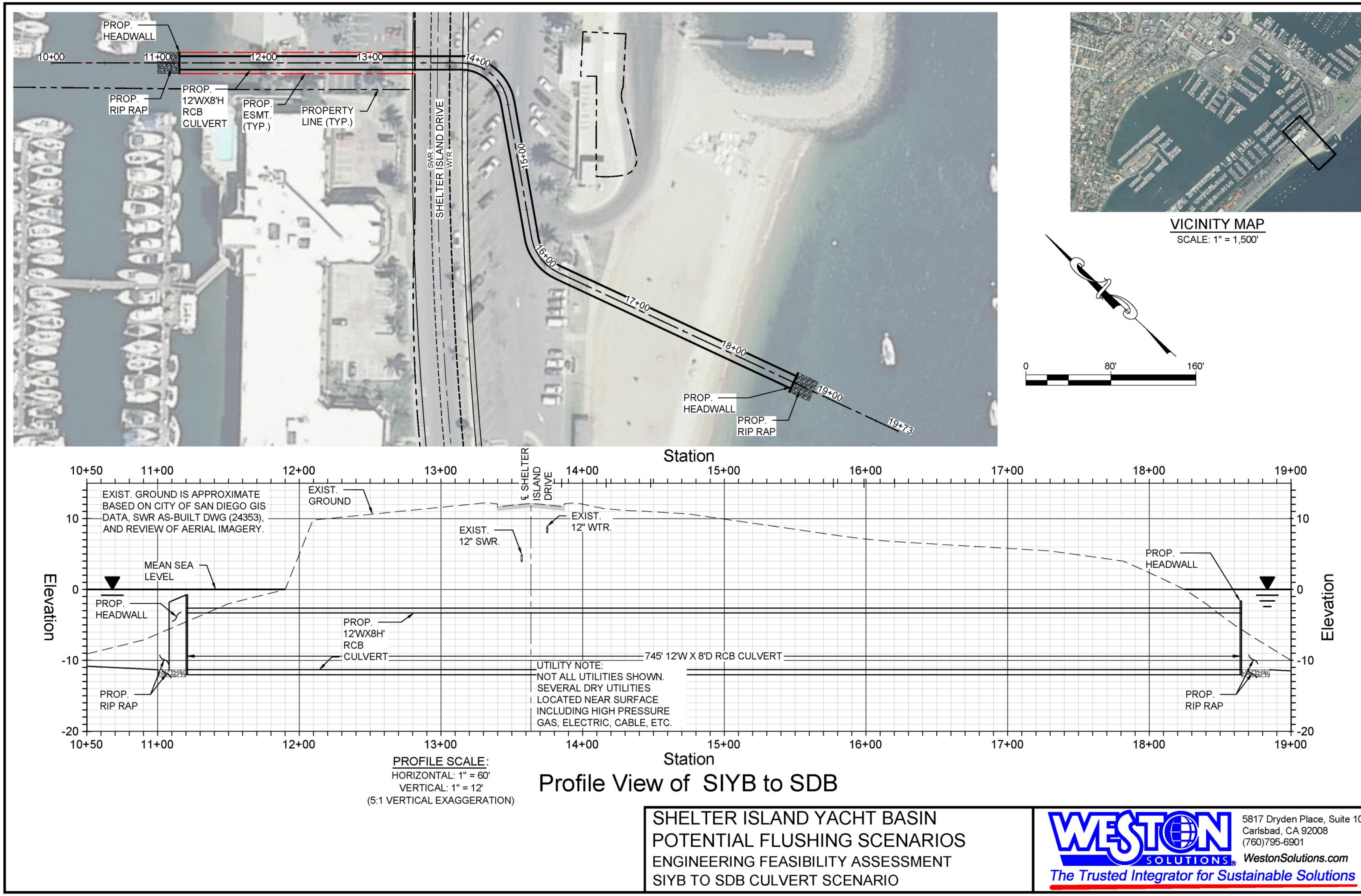

Figure 2-1. Shelter Island Yacht Basin to San Diego Bay Box Culvert Connection Conceptual Plan Drawing

Table 2-1. Cost Estimate for SIYB to SDB Culvert Connection Scenario

ITEM	QUANTITY	UNIT	UNIT PRICE	COST
Demo Existing Asphalt Parking Lot	4,900	SF	$3.50	$17,150
Demo Existing Roadway Asphalt Concrete	658	SF	$4.00	$2,632
Demo Existing Roadway Sidewalk	140	SF	$2.50	$350
Demo Existing Roadway Curb & Gutter	56	LF	$8.00	$448
Grading (Excavate, Stockpile, Backfill)	7,073	CY	$25.00	$176,825
Storm Darin Pipe - 12' X 8' RCB (Caltrans D-80)	745	LF	$988.00	$736,060
Storm Drain Structure - Headwall	2	EA	$7,000.00	$14,000
Construct Type A Cleanout (Per D-9)	3	EA	$6,368.00	$19,104
Rip Rap	46	CY	$125.00	$5,750
Dredge Area of Storm Drain Pipe & Rip Rap	400	CY	$45.00	$18,000
Repair Asphalt Concrete Parking Lot	4,900	LF	$6.00	$29,400
Repair Asphalt Concrete Roadway	658	SF	$9.00	$5,922
Repair Curb & Gutter in Roadway	56	LF	$30.00	$1,680
Repair Sidewalk in Roadway	140	SF	$16.00	$2,240
Trench Shoring	620	LF	$32.00	$19,840
Construct Cofferdam	2	LS	$15,000.00	$30,000
Traffic Control	1	LS	$8,000.00	$8,000
Protect-in-place existing utilities	1	LS	$5,000.00	$5,000
Concrete Washout	1	EA	$825.00	$825
Construction Fence	1,200	LF	$4.00	$4,800
Gravel Bag	1,200	EA	$1.82	$2,184
			Construction Subtotal	**$1,100,210**
			Environmental Permitting	$60,000
			Engineering Design - 20% of construction subtotal	$220,042
			Mobilization - 10% of construction subtotal	$110,021
			Construction Bond - 5% of construction subtotal	$55,011
			Contingency - 20% of construction subtotal	$220,042
			Construction Total	**$1,765,326**

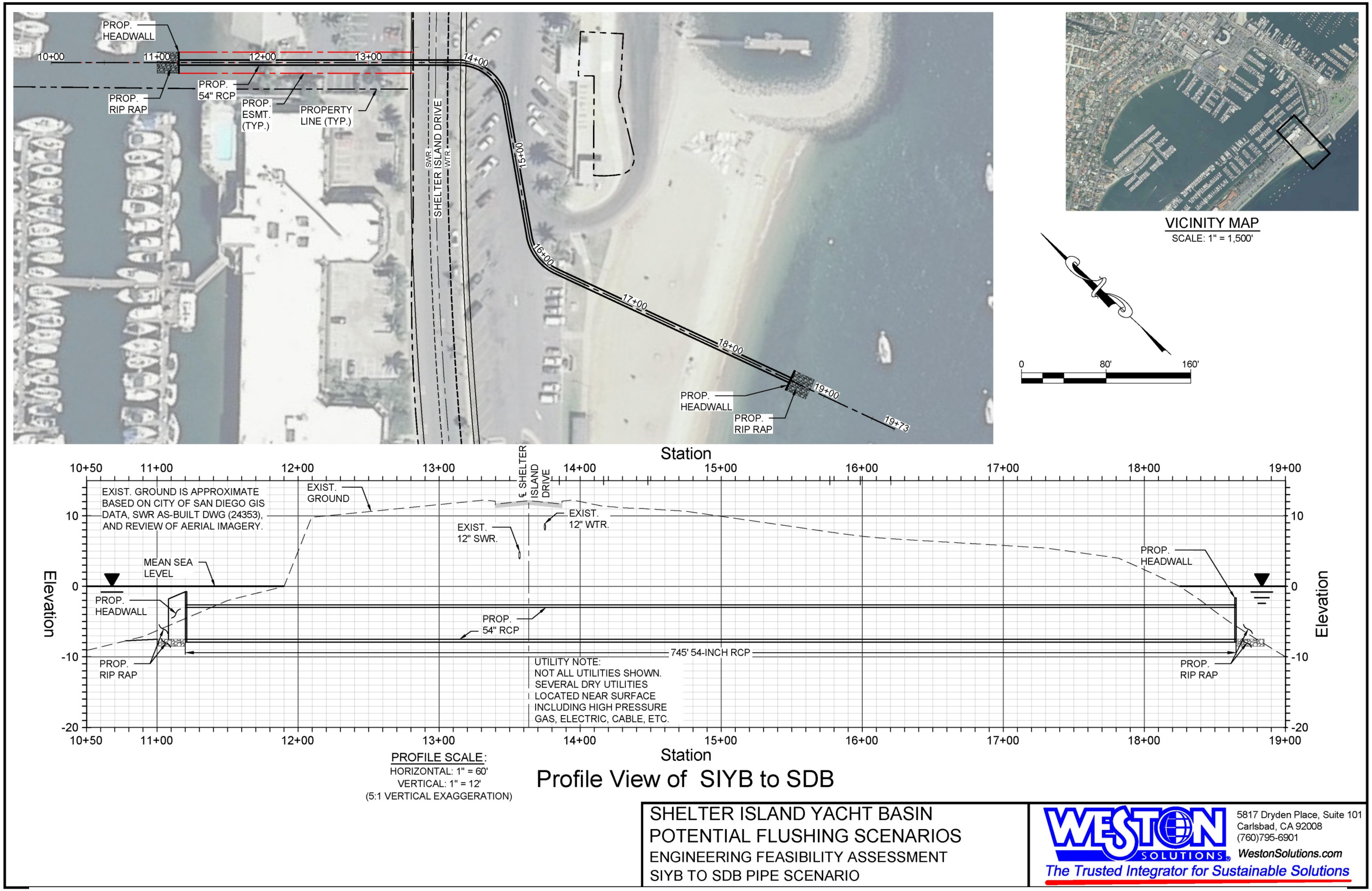

Figure 2-2. Shelter Island Yacht Basin to San Diego Bay Pipe Connection Conceptual Plan Drawing

Table 2-2. Cost Estimate for SIYB to SDB Pipe Connection Scenario

ITEM	QUANTITY	UNIT	UNIT PRICE	COST
Demo Existing Asphalt Parking Lot	2,800	SF	$3.50	$9,800
Demo Existing Roadway Asphalt Concrete	376	SF	$4.00	$1,504
Demo Existing Roadway Sidewalk	80	SF	$2.50	$200
Demo Existing Roadway Curb & Gutter	32	LF	$8.00	$256
Grading (Excavate, Stockpile, Backfill)	3,307	CY	$32.20	$106,485
Storm Darin Pipe - 54" RCP	745	LF	$273.00	$203,385
Storm Drain Structure - Headwall	2	EA	$7,000.00	$14,000
Construct Type A Cleanout (Per D-9)	3	EA	$6,368.00	$19,104
Rip Rap	46	CY	$125.00	$5,750
Dredge Area of Storm Drain Pipe & Rip Rap	400	CY	$45.00	$18,000
Repair Asphalt Concrete Parking Lot	2,800	LF	$6.00	$16,800
Repair Asphalt Concrete Roadway	376	SF	$9.00	$3,384
Repair Curb & Gutter in Roadway	32	LF	$30.00	$960
Repair Sidewalk in Roadway	80	SF	$16.00	$1,280
Trench Shoring	620	LF	$32.00	$19,840
Construct Cofferdam	2	LS	$15,000.00	$30,000
Traffic Control	1	LS	$8,000.00	$8,000
Protect-in-place existing utilities	1	LS	$5,000.00	$5,000
Concrete Washout	1	EA	$825.00	$825
Construction Fence	1,200	LF	$4.00	$4,800
Gravel Bag	1,200	EA	$1.82	$2,184
			Construction Subtotal	**$471,557**
			Environmental Permitting	$60,000
			Engineering Design - 20% of construction subtotal	$94,311
			Mobilization - 10% of construction subtotal	$47,156
			Construction Bond - 5% of construction subtotal	$23,578
			Contingency - 20% of construction subtotal	$94,311
			Construction Total	**$790,914**

The cost associated with constructing a single 54-inch RCP is much less than the cost associated with constructing a 12 feet wide by 8 feet in height RCB culvert. The 54-inch pipe has a much smaller cross section area (about 16 square feet) compared to the RCB (96 square feet), and therefore will provide less enhanced flushing (exactly how much less is determined by modeling). In order to get the same approximate cross sectional area, and similar flushing, 5 pipes could be constructed in parallel in with an alignment and profile shown in Figure 2-2. Although not modeled, there may be advantages to constructing multiple pipes rather than a large RCB culvert (e.g., shorter construction schedule and easier to perform horizontal boring and placement). Table 2-3 shows the cost associated with constructing 5 pipes to connect SIYB to SDB.

Table 2-3. Cost Estimate for SIYB to SDB 5-Pipe Connection Scenario				
ITEM	**QUANTITY**	**UNIT**	**UNIT PRICE**	**COST**
Demo Existing Asphalt Parking Lot	11,375	SF	$3.50	$39,813
Demo Existing Roadway Asphalt Concrete	1,528	SF	$4.00	$6,110
Demo Existing Roadway Sidewalk	350	SF	$2.50	$875
Demo Existing Roadway Curb & Gutter	70	LF	$8.00	$560
Grading (Excavate, Stockpile, Backfill)	13,434	CY	$25.00	$335,850
Storm Darin Pipe - 54" RCP	3,725	LF	$273.00	$1,016,925
Storm Drain Structure - Headwall	4	EA	$7,000.00	$28,000
Construct Type A Cleanout (Per D-9)	15	EA	$6,368.00	$95,520
Rip Rap	90	CY	$125.00	$11,250
Dredge Area of Storm Drain Pipe & Rip Rap	400	CY	$45.00	$18,000
Repair Asphalt Concrete Parking Lot	11,375	LF	$6.00	$68,250
Repair Asphalt Concrete Roadway	1,528	SF	$9.00	$13,748
Repair Curb & Gutter in Roadway	70	LF	$30.00	$2,100
Repair Sidewalk in Roadway	350	SF	$16.00	$5,600
Trench Shoring	620	LF	$32.00	$19,840
Construct Cofferdam	2	LS	$15,000.00	$30,000
Traffic Control	1	LS	$8,000.00	$8,000
Protect-in-place existing utilities	1	LS	$5,000.00	$5,000
Concrete Washout	1	EA	$825.00	$825
Construction Fence	1,200	LF	$4.00	$4,800
Gravel Bag	1,200	EA	$1.82	$2,184
Construction Subtotal				**$1,713,249**
Environmental Permitting				$60,000
Engineering Design - 20% of construction subtotal				$342,650
Mobilization - 10% of construction subtotal				$171,325
Construction Bond - 5% of construction subtotal				$85,662
Contingency - 20% of construction subtotal				$342,650
Construction Total				**$2,715,536**

2.2 Shelter Island Yacht Basin to America's Cup Harbor Connection

Connecting SIYB to ACH would require about 340 feet of underground box culvert or pipe. Figure 2-3 shows SYIB connected to ACH utilizing a RCB culvert (12 feet wide by 8 feet height). Table 2-4 provides the rough cost estimate associate with constructing the RCB culvert. Similarly, Figure 2-4 shows SYIB connected to ACH utilizing a 54-inch diameter RCP, and Table 2-5 provides the rough cost estimate associate with constructing the RCP.

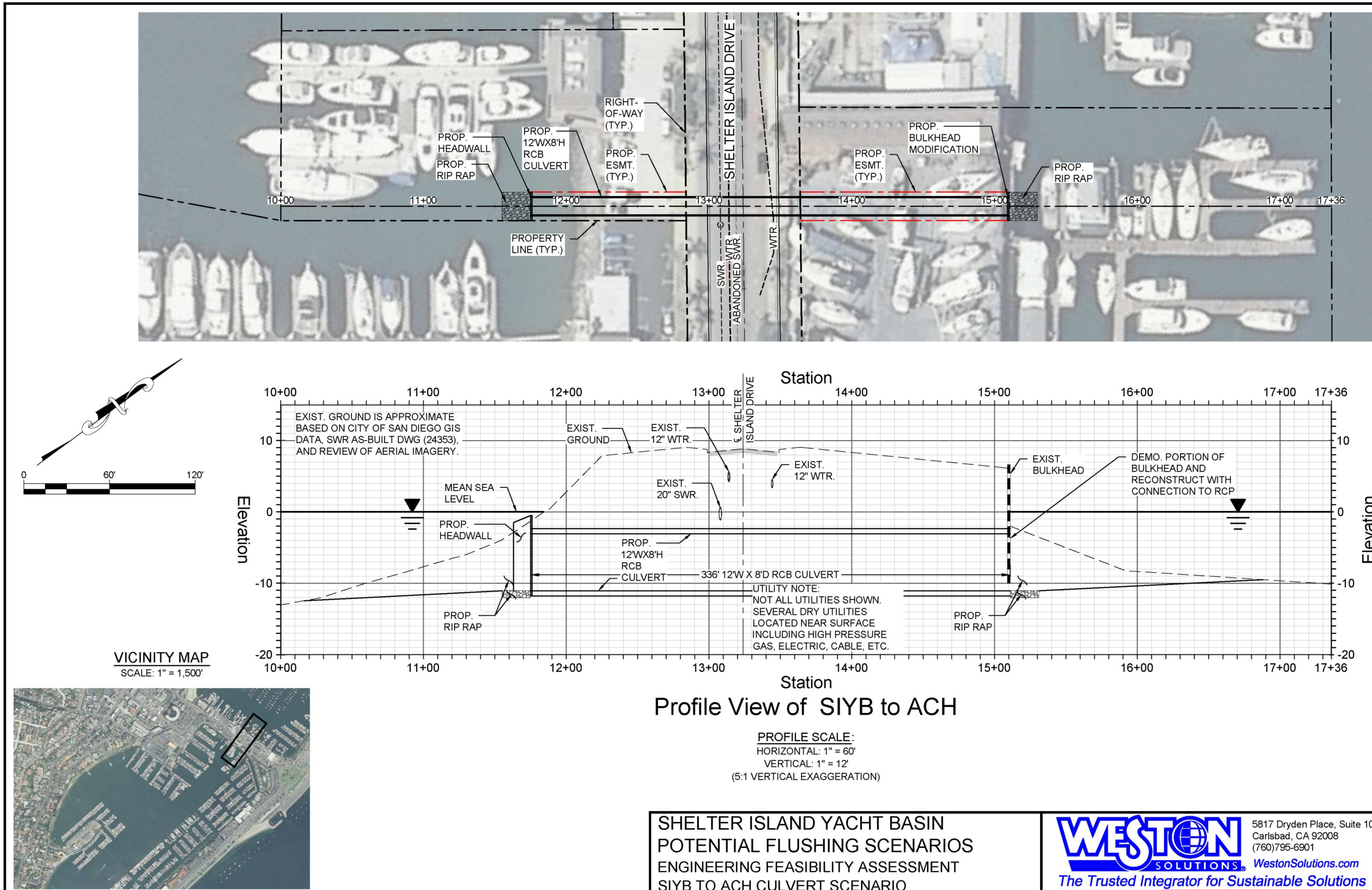

Figure 2-3. Shelter Island Yacht Basin to America's Cup Harbor Box Culvert Connection Conceptual Plan Drawing

Table 2-4. Cost Estimate for SIYB to ACH Culvert Connection Scenario				
ITEM	**QUANTITY**	**UNIT**	**UNIT PRICE**	**COST**
Demo Existing Asphalt Parking Lot	2,800	SF	$3.50	$9,800
Demo Existing Roadway Asphalt Concrete	658	SF	$4.00	$2,632
Demo Existing Roadway Sidewalk	140	SF	$2.50	$350
Demo Existing Roadway Curb & Gutter	28	LF	$8.00	$224
Grading (Excavate, Stockpile, Backfill)	2,562	CY	$25.00	$64,050
Storm Darin Pipe - 12' X 8' RCB (Caltrans D-80)	336	LF	$988.00	$331,968
Storm Drain Structure - Headwall	1	EA	$10,500.00	$10,500
Connection / Reconstruct Bulkhead	280	SF	$50.00	$14,000
Construct Type A Cleanout (Per D-9)	1	EA	$6,368.00	$6,368
Rip Rap	46	CY	$125.00	$5,750
Dredge Area of Storm Drain Pipe & Rip Rap	200	CY	$45.00	$9,000
Repair Asphalt Concrete Parking Lot	2,800	LF	$6.00	$16,800
Repair Asphalt Concrete Roadway	658	SF	$9.00	$5,922
Repair Curb & Gutter in Roadway	28	LF	$30.00	$840
Repair Sidewalk in Roadway	140	SF	$16.00	$2,240
Trench Shoring	260	LF	$32.00	$8,320
Construct Cofferdam	2	LS	$15,000.00	$30,000
Traffic Control	1	LS	$8,000.00	$8,000
Protect-in-place existing utilities	1	LS	$5,000.00	$5,000
Concrete Washout	1	EA	$825.00	$825
Construction Fence	600	LF	$4.00	$2,400
Gravel Bag	1,200	EA	$1.82	$2,184
Construction Subtotal				**$537,173**
Environmental Permitting				$60,000
Engineering Design - 20% of construction subtotal				$161,152
Mobilization - 10% of construction subtotal				$53,717
Construction Bond - 5% of construction subtotal				$26,859
Contingency - 20% of construction subtotal				$107,435
Construction Total				**$946,336**

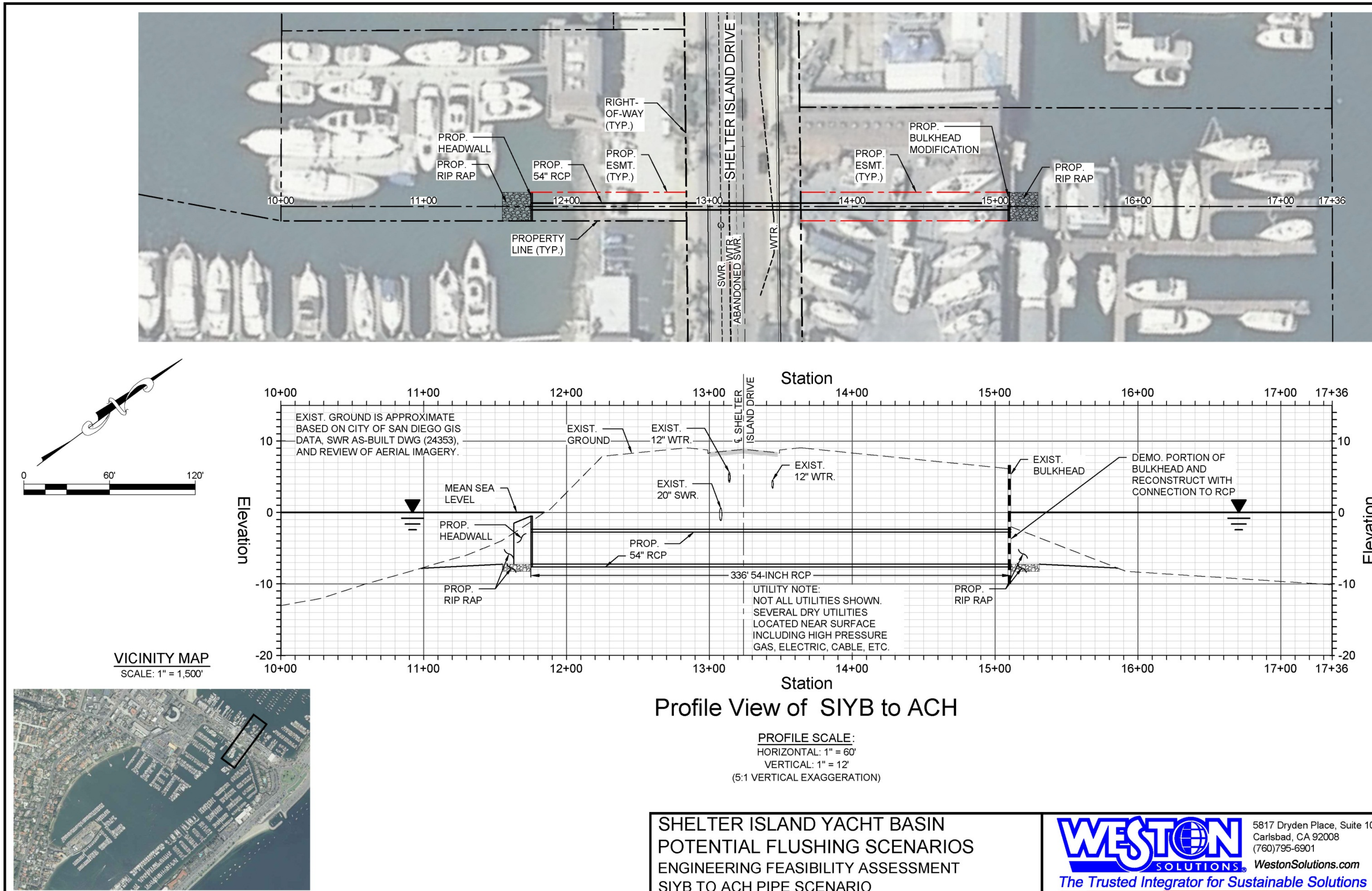

Figure 2-4. Shelter Island Yacht Basin to America's Cup Harbor Pipe Connection Conceptual Plan Drawing

Table 2-5. Cost Estimate for SIYB to ACH Pipe Connection Scenario

ITEM	QUANTITY	UNIT	UNIT PRICE	COST
Demo Existing Asphalt Parking Lot	1,600	SF	$3.50	$5,600
Demo Existing Roadway Asphalt Concrete	376	SF	$4.00	$1,504
Demo Existing Roadway Sidewalk	80	SF	$2.50	$200
Demo Existing Roadway Curb & Gutter	16	LF	$8.00	$128
Grading (Excavate, Stockpile, Backfill)	1,156	CY	$32.20	$37,223
Storm Darin Pipe - 54" RCP	336	LF	$273.00	$91,728
Storm Drain Structure - Headwall	1	EA	$7,000.00	$7,000
Connection / Reconstruct Bulkhead	128	SF	$50.00	$6,400
Construct Type A Cleanout (Per D-9)	1	EA	$6,368.00	$6,368
Rip Rap	46	CY	$125.00	$5,750
Dredge Area of Storm Drain Pipe & Rip Rap	200	CY	$45.00	$9,000
Repair Asphalt Concrete Parking Lot	1,600	LF	$6.00	$9,600
Repair Asphalt Concrete Roadway	376	SF	$9.00	$3,384
Repair Curb & Gutter in Roadway	16	LF	$30.00	$480
Repair Sidewalk in Roadway	80	SF	$16.00	$1,280
Trench Shoring	260	LF	$32.00	$8,320
Construct Cofferdam	2	LS	$15,000.00	$30,000
Traffic Control	1	LS	$8,000.00	$8,000
Protect-in-place existing utilities	1	LS	$5,000.00	$5,000
Concrete Washout	1	EA	$825.00	$825
Construction Fence	600	LF	$4.00	$2,400
Gravel Bag	1,200	EA	$1.82	$2,184
			Construction Subtotal	**$242,374**
			Environmental Permitting	$60,000
			Engineering Design - 20% of construction subtotal	$72,712
			Mobilization - 10% of construction subtotal	$24,237
			Construction Bond - 5% of construction subtotal	$12,119
			Contingency - 20% of construction subtotal	$48,475
			Construction Total	**$459,918**

The cost associated with constructing a single 54-inch RCP is much less than the cost associated with constructing a 12 feet wide by 8 feet in height RCB culvert. The 54-inch pipe has a much smaller cross section area (about 16 square feet) compared to the RCB (96 square feet), and therefore will provide less enhanced flushing (exactly how much less is determined by modeling). In order to get the same approximate cross sectional area, and similar flushing, 5 pipes could be constructed in parallel in with an alignment and profile shown in Figure 2-4. Although not modeled, there may be advantages to constructing multiple pipes rather than a large RCB culvert (e.g., shorter construction schedule and easier to perform horizontal boring and placement). Table 2-6 shows the cost associated with constructing 5 pipes to connect SIYB to SDB.

Table 2-6. Cost Estimate for SIYB to ACH 5-Pipe Connection Scenario

ITEM	QUANTITY	UNIT	UNIT PRICE	COST
Demo Existing Asphalt Parking Lot	6,500	SF	$3.50	$22,750
Demo Existing Roadway Asphalt Concrete	1,528	SF	$4.00	$6,110
Demo Existing Roadway Sidewalk	350	SF	$2.50	$875
Demo Existing Roadway Curb & Gutter	70	LF	$8.00	$560
Grading (Excavate, Stockpile, Backfill)	4,695	CY	$25.00	$117,375
Storm Darin Pipe - 54" RCP	1,680	LF	$273.00	$458,640
Storm Drain Structure - Headwall	2	EA	$7,000.00	$14,000
Connection / Reconstruct Bulkhead	520	SF	$50.00	$26,000
Construct Type A Cleanout (Per D-9)	5	EA	$6,368.00	$31,840
Rip Rap	90	CY	$125.00	$11,250
Dredge Area of Storm Drain Pipe & Rip Rap	200	CY	$45.00	$9,000
Repair Asphalt Concrete Parking Lot	6,500	LF	$6.00	$39,000
Repair Asphalt Concrete Roadway	1,528	SF	$9.00	$13,748
Repair Curb & Gutter in Roadway	70	LF	$30.00	$2,100
Repair Sidewalk in Roadway	350	SF	$16.00	$5,600
Trench Shoring	260	LF	$32.00	$8,320
Construct Cofferdam	2	LS	$15,000.00	$30,000
Traffic Control	1	LS	$8,000.00	$8,000
Protect-in-place existing utilities	1	LS	$5,000.00	$5,000
Concrete Washout	1	EA	$825.00	$825
Construction Fence	600	LF	$4.00	$2,400
Gravel Bag	1,200	EA	$1.82	$2,184
			Construction Subtotal	**$815,577**
			Environmental Permitting	$60,000
			Engineering Design - 20% of construction subtotal	$244,673
			Mobilization - 10% of construction subtotal	$81,558
			Construction Bond - 5% of construction subtotal	$40,779
			Contingency - 20% of construction subtotal	$163,115
			Construction Total	**$1,405,702**

3.0 TIDAL FLUSHING MODELING

Weston contracted Coastal Monitoring Associates, LLC (CMA) to perform Curvilinear Hydrodynamics in Three Dimensions (CH3D) modeling simulations of the existing condition and tidal flushing enhancement modification scenarios. The objective of the modeling was to evaluate the potential for enhanced flushing of SIYB through the placement of engineered culverts (or pipes) between the head of SIYB and SDB, and between the heads of SIYB and ACH. Flushing and associated total copper concentrations were modeled under five scenarios, including:

1. Baseline with no enhanced flushing.
2. Culvert connecting SIYB to SDB.
3. Culvert connecting SIYB to ACH.
4. Pipe[1] connecting SIYB to SDB.
5. Pipe[1] connecting SIYB to ACH.

Note 1: The modeling of the potential enhanced flushing scenarios as result of implementing pipe connections was conducted utilizing a 52-inch diameter pipe. The purposed of performing modeling for both a large geometry RCB culvert and a smaller geometry pipe was to provide data for comparison (large versus small connections). Available precast RCP sizes are limited to 3-inch increments that include 51-inch and 54-inch diameters, but not the modeled 52-inch diameter. The conceptual drawings for the pipe connections assumed 54-inch diameter pipes, which have a very similar, but slightly larger, geometry compared to 52-inch diameter pipes. The discrepancy between the different pipe sizes noted (2 inches) is considered insignificant and does not deduct from the overall modeling purpose or results.

Enhanced flushing configuration (connection to either SDB or ACH) model results were compared to the baseline condition with no enhanced flushing as well as to each other. The complete modeling report is provided in the Appendix A of this report and provides additional details on the modeling methods, approach, and simulation results.

4.0 RESULTS

The results showed that the CH3D Model provided a reasonable prediction of total copper concentrations in SIYB under baseline conditions (i.e., no enhanced flushing). In assessing the enhanced flushing scenarios, establishing a connection between SIYB and ACH was modeled to be much more effective in enhancing flushing and reducing copper concentrations than a connection between SIYB and SDB for both culvert and pipe scenarios. Installation of a submerged culvert between SIYB and ACH was modeled to provide the greatest benefit in terms of reducing total copper concentrations in SIYB, since it reduced concentrations by 17% on average throughout the basin and by 21% at the head (or enclosed end) of the basin. The single pipe connection between SIYB-ACH was modeled to reduce total copper concentrations by approximately 10% at the head and by approximately 9% basin-wide.

Based on the modeling study, it can be concluded that placement of a culvert connection between SIYB and ACH has the greatest potential to enhance flushing and reduce copper concentrations. Based on 2011 TMDL monitoring, the average dissolved copper concentration in SIYB was 8.3 µg/L; a 17% reduction in dissolved copper concentration would equate to an average concentration of roughly 6.9 µg/L. Based on the modeled results, enhancement of flushing alone would not result in compliance with the current water quality objective of 3.1 µg/L.

The engineering feasibility assessment, which included a review of the existing on-land infrastructure between SIYB and ACH, indicated that a standard 12 feet wide by 8 feet in height box culvert could be placed below the existing sewer and water lines that run parallel to Shelter Island Drive. Alternatively, multiple 54-inch diameter pipes could also be used to enhance flushing between the basins. The SIYB-ACH culvert connection was estimated to cost about $950,000, including permitting, design, and construction costs. Construction of pipe connections varied in cost from about $460,000 for a single 54-inch pipe to about $1,400,000 for five 54-inch pipes. Engineering feasibility and cost assessments were also performed for pipe and culvert connections between SIYB and SDB; however, the modeling shows lower efficacy of this connection in conjunction with the higher estimated costs indicates that the SIYB-ACH connection would be preferable.

5.0 REFERENCES

California Regional Water Quality Control Board, San Diego Region (Regional Board). 2005. *Total Maximum Daily Load for Dissolved Copper in Shelter Island Yacht Basin, San Diego Bay. Resolution No. R9-2005-0019. Basin Plan Amendment and Technical Report*. December 2005.

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APPENDIX A

Modeling Analysis of Enhanced Flushing of Shelter Island Yacht Basin, San Diego Bay, California

Final Report

Modeling Analysis of Enhanced Flushing of Shelter Island Yacht Basin, San Diego Bay, California

September 2012

Submitted to:

Port of San Diego.

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LIST OF ACRONYMS

ACH	America's Cup Harbor
CH3D	Curvilinear Hydrodynamics in Three Dimensions
RWQCB	Regional Water Quality Control Board
SDB	San Diego Bay
SD1D	One-Dimensional Steady State Box Model
SIYB	Shelter Island Yacht Basin
TMDL	Total Maximum Daily Load
WSL	Water Surface Elevation

UNITS

cm	centimeters
cm/s	centimeters per second
degrees	degrees
in	inches
kg	kilograms
km^2	square kilometers
ft	feet
ft^2	square feet
m	meters
ppb	parts per billion
ug/L	micrograms per liter
%	percent

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1 INTRODUCTION AND BACKGROUND

Shelter Island Yacht Basin (SIYB) is an enclosed recreational marina located in northern San Diego Bay (SDB) and connected to the Bay by a single entrance at the southern extent of Shelter Island. The basin contains a large number of recreational vessels (~2,300) that are typically painted with copper-based antifouling paints that are designed to leach into the environment to prevent marine fouling (Regional Water Quality Control Board [RWQCB, 2005]). The combination of the large number of vessels in the basin, and the limited hydrodynamic flushing has led to previously documented elevated concentrations of copper (Katz, 1998; VanderWeele, 1996; McPherson and Peters, 1995; Valkirs et al., 1994), placement on the State 303(d) List of Water Quality Limited Segments in 1996, and the subsequent development and initial implementation phases of a total maximum daily load (TMDL) for dissolved copper starting in 2005 (RWQCB, 2005).

The majority of the copper loading (~93%) is believed to come from passive leaching from antifouling coatings, and thus the TMDL has focused on reduction of this source (RWQCB, 2005). While the focus of the TMDL implementation phase has been on load reduction, the other primary factor driving elevated concentrations in the basin is the poor tidal flushing. To date, there has been no analysis of the potential to increase the flushing of SIYB and thus reduce the buildup of elevated copper concentrations. While Shelter Island was originally a sand-spit with open circulation between the island and the shore of SDB, subsequent modifications of SIYB and construction of the causeway connecting the island to the shoreline have significantly limited the flushing of the basin. Thus an alternative or supplemental management strategy for the TMDL could be to improve the flushing of SIYB by improving the connection of the basin with the main body of SDB or the adjacent America’s Cup Harbor (ACH).

In order to evaluate the potential to improve flushing of SIYB, an accurate predictive model is required that can capture the processes that regulate copper concentrations in the basin under current and modified conditions. Copper fate and transport in SDB has been extensively modeled in previous mass balance modeling studies by Chadwick et al. 2004 using a one-dimensional, steady-state box model (SD1D), and in full 3-D numerical modeling simulations using the Curvilinear Hydrodynamics in Three Dimensions (CH3D) model by Chadwick et al. 2008 and Wang et al. 2006. In these studies, extensive measurements were made throughout SDB, and models were calibrated and validated for use in simulating copper concentrations, mass balance among the loads, hydrodynamic advection and dispersion, partitioning and settling of particulate copper. Results from these studies showed that these models could accurately predict copper concentrations and these associated processes, and thus provide the best available tool for predicting future conditions in SDB, including those associated with changes in loading or other potential management strategies.

2 OBJECTIVE

The objective of this study was to evaluate the potential for enhanced flushing of SIYB through the placement of engineered culverts (or pipes) between the head of SIYB and SDB, and between the heads of SIYB and ACH. Flushing and associated total copper concentrations were modeled under five scenarios, including (1) baseline with no enhanced flushing, and enhanced flushing via (2) a culvert connecting SIYB to SDB, (3) a culvert connecting SIYB to ACH, (4) a pipe connecting SIYB to SDB, and (5) a pipe connecting SIYB to ACH. Enhanced flushing configurations were compared to the baseline condition with no enhanced flushing, as well as to each other, using the existing CH3D model that was modified to account for the connections and their effects on flows and copper concentrations in SIYB, ACH and SDB.

To achieve this, the specific technical objectives of this study included the following:

1) Simulate baseline total copper concentrations in SIYB with no added connectivity;
2) Simulate total copper concentrations in SIYB with an added culvert or pipe between SIYB and SDB, and between SIYB and ACH, respectively; and
3) Assess potential reductions in total copper concentrations under enhanced flushing scenarios as compared to baseline conditions.

3 METHODS AND APPROACH

3.1 FATE AND TRANSPORT MODELING

The numerical hydrodynamic fate and transport model applied for this study is the CH3D. This model is a boundary-fitted finite difference, Z-coordinate model developed at the U.S. Army Corps of Engineers Waterways Experiment Station (Johnson *et al*., 1991) to simulate physical processes in bays, rivers, lakes and estuaries (Wang and Martin, 1991; Wang, 1992; Wang and McCutcheon, 1993; Wang *et al*., 1997, 1998; Johnson *et al*., 1995). The model simulates hydrodynamic currents in four dimensions (x, y, z and time) and allows for the prediction of the fate and/or transport of metals, fecal coliforms and other contaminants in estuaries and coastal environments under the forcing of tides, wind and freshwater inflows (Sheng *et al*., 1990; Wang and Richter, 1999). The grid of the existing CH3D model for SDB covers an area of approximately 215 km^2, with about 7,000 grid elements, and a resolution of approximately 100 meters (Figure 3-1).

The CH3D model was implemented to simulate copper and other antifouling biocide concentrations from hull paint in San Diego Bay (Wang et al., 2006), and concentrations of copper and its species (Chadwick et al., 2008). In these two studies, mean annual copper loads from all the known sources, including Navy and non-Navy sources, were estimated (Chadwick et al., 2004; Johnson et al., 1998), and distributed over the model domain in accordance with their known source locations. The same copper model and copper load are used to support this study. In order to simulate culvert flows, the CH3D hydrodynamic model was implemented and a new modeling approach was developed to accommodate the addition of the culverts and their effects on hydrodynamics and copper fate and transport as described below.

3.2 MODEL SIMULATIONS

The CH3D model simulates advection processes due to water currents and tides in San Diego Bay. The effect of tides is driven by tidal harmonic constants, which were obtained by calibration, and are prescribed at the open ocean boundaries (Figure 3-1; Wang *et al.*, 1998). The sequence for the model simulation starts from quiescent initial conditions (zero water surface level for the entire Bay), with tidal forcing at the model's ocean boundaries starting with the simulation (t≥0). The water surface elevation and tidal currents at every grid cell is simulated at a time-step of 2 minutes, reaching simulated steady state hydrodynamic conditions within 4 days. From the end of the 4th day, steady-state copper loading from various sources are introduced into the model from the various loading source locations. Simulation of fate and transport of copper, which is driven by the hydrodynamics simulation in CH3D, continues for 320 days so that copper concentration and its fate and transport patterns in the Bay reach steady state.

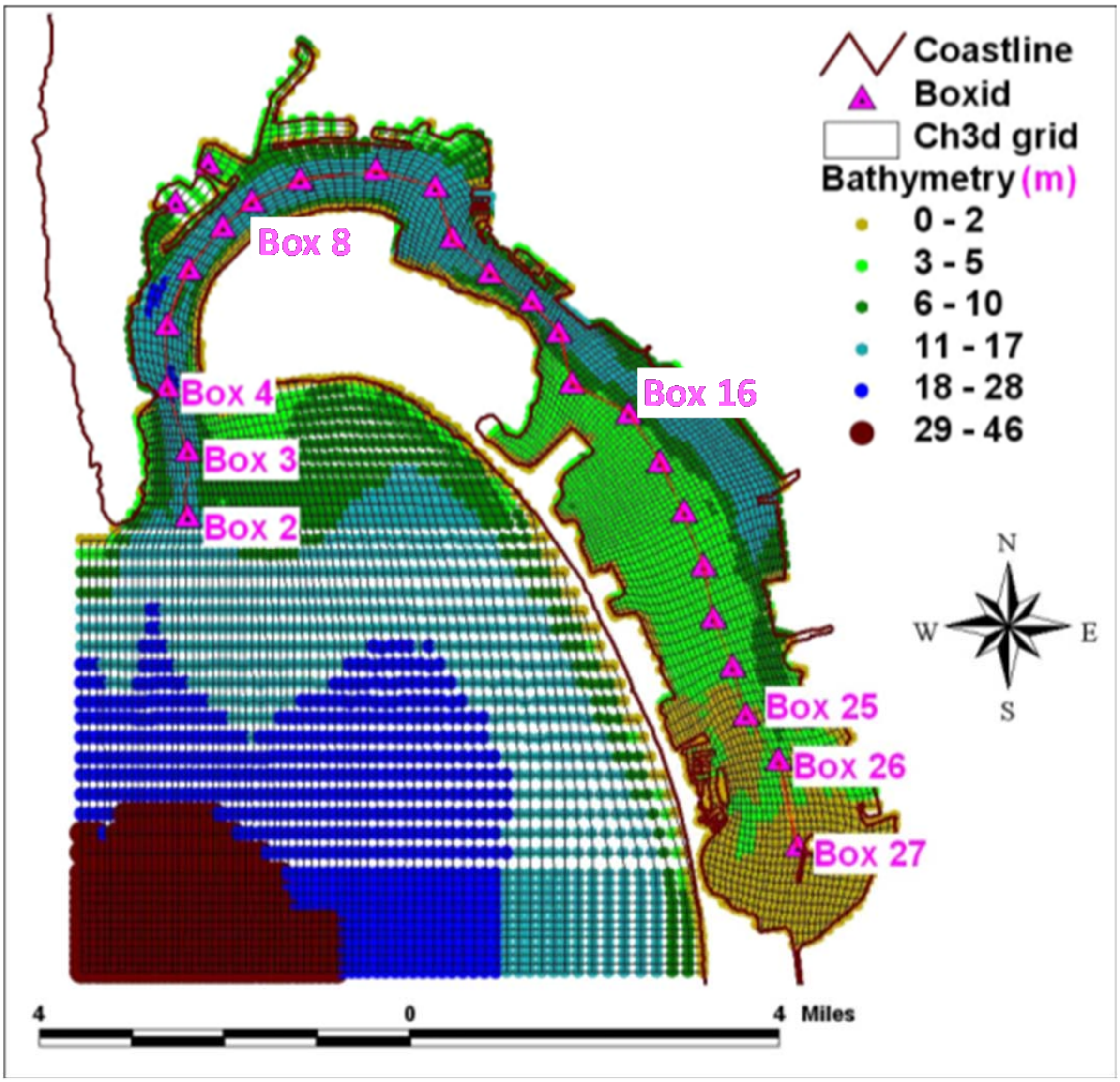

Figure 3-1. Grid for the Curvilinear Hydrodynamics in Three Dimensions (CH3D) model for San Diego Bay, California.

For the present study, the existing CH3D model configuration for SDB was modified to account for the addition of the connections between SIYB-SDB and SIYB-ACH, respectively. All the other assumptions and parameterization, including copper loads, of the existing CH3D model remained unchanged. Table 3-1 lists the major assumptions and the parameterization for the model.

Table 3-1. CH3D model assumptions/parameterization for copper loads and settling velocity.

Model Condition	**Assumption/Parameterization**
Copper Load	Total copper load to Shelter Island was estimated as 2,983 kg/year per Chadwick et al. 2004 and was initially distributed over the water column
Dissolved/Particulate Copper Partitioning	Partitioning coefficient based on field data from Chadwick et al. 2008 of 0.27 L/mg
Settling Velocity for Particulate Copper	Empirical net settling rate 4.3 cm/hr from SDB mouth (Box2) to south SDB (Box24), 2.1 cm/hr at the head of SDB (Box27), and linear decrease from Box24 to Box 26 (per Chadwick et al., 2008)
Model output	Water column averaged total copper concentrations in ug/L (ppb)

3.3 CULVERT CONFIGURATIONS AND SIMULATIONS

Figure 3-2 shows the modeling approach, which includes simulations of the culvert flows for culverts connecting between SIYB and SDB and between SIYB and ACH, respectively. The culverts were assumed to be a rectangular channel with a size of 12ft (width) by 8ft (depth, relative to mean sea level) in cross section. The addition of the culvert into the model grid severely restricts the model time-step to less than 20 seconds, compared to the normal time-step of 120-150 seconds for the original model. The small model time-step for the culvert model makes it impractical to perform the normal simulation period of 320 days, which is required for the model to reach steady state. Therefore, instead of simulating for 320 days to reach steady state, flow velocities through the culvert were simulated for two weeks, covering the full spring/neap tidal cycle. Flow velocity (speed and direction) was found to be a direct function of gradient of water surface elevation between the two waterbodies (e.g., SIYB and SDB, and SIYB and ACH). When the water surface elevation gradient was positive between SIYB and SDB (or ACH), flow was in the direction from SIYB to SDB (or ACH) and vice versa.

Simulated flow velocities through the culverts were functionally related to the water surface elevation gradients between the connecting water bodies.

Next we used the CH3D model to simulate copper concentrations with the culvert flows, previously simulated and quantified as a function of water elevation gradient, specified as fictitious river flows. During positive water surface elevation gradient between SIYB and SDB (or ACH), water flows out of SIYB and into SDB (or ACH) at the fictitious culvert (river) mouth locations. When the gradient is negative between SIYB and SDB (or ACH), water flows out of SDB channel (or ACH) and into SIYB at the fictitious culvert (river) mouth locations. This allowed for a relaxation of the time-step to the normal 120-150 seconds for the original model, and thus allowed the simulations to be run for the full 320 days required for steady state model output, which was then stored and analyzed to characterize the changes in flushing.

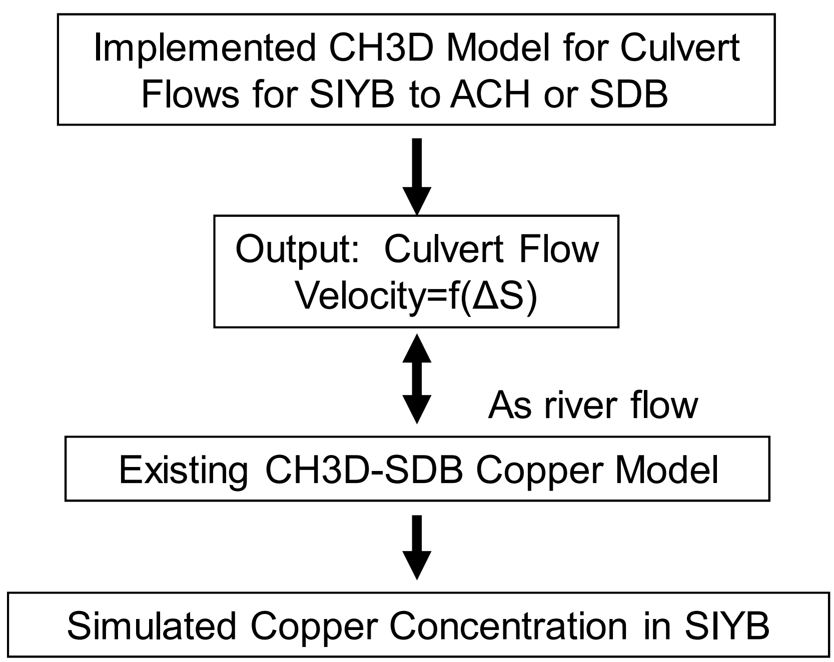

Figure 3-2. Modeling approach for the Shelter Island enhanced flushing analysis.

4 RESULTS AND DISCUSSION

4.1 GENERAL FLOW PATTERNS

In general currents in San Diego Bay are driven by tides from the Pacific Ocean, which are assigned as the tidal forcing at the model's ocean boundaries. Tides in San Diego Bay are predominantly driven by diurnal (K1) and semi-diurnal (M2) components. Simulated water surface elevations range from ±70 cm during the neap tides to ±100 cm during the spring tides relative to mean sea level (*Figure 4-1*). Tidal flows enter into the Bay through the mouth, where water is deep (~15-20 meters), and as the tidal flow propagates along the Bay's axis, water depth decreases to ~10 meters in mid-Bay and <5 meters in south Bay. The range of water surface elevation also grows slightly (~ 5 cm) from the mouth (Box 4) toward the head (Box 27) of the Bay, consistent with previously reported measurements and simulations (Wang *et al*., 1998).

There is a marked gradient in the magnitude of tidal currents within the Bay. Tidal currents are governed by multiple factors, including bathymetry, geometry (shape) of the Bay, bottom friction, etc. As a result, tidal current distributions differ from location to location in the Bay; but, in general, current directions are restricted and follow the geometry of the Bay. The speeds of the tidal current range from ~15-50 cm s^{-1} near the mouth, to over 65 cm s^{-1} in the channel bends and constrictions, and to less than 10 cm s^{-1} in the inner Bay (Figure 4-2).

In general the simulated current direction follows the shape of the Bay (Figure 4-3). Currents near the mouth are bi-directional, flowing north (~360°) and south (~180°) alternately, depending on the tidal stage. The direction of the current is dominated by the geometry of the Bay, and while simulated currents at box 4 and box 8 are going in or out of the Bay, the direction of the flow follows the direction of the axis of the Bay. While the direction in box 4 is North (or South), the corresponding direction in box 8 is rotated toward East and West. With the calibrated tidal harmonic constants assigned at the model's ocean boundaries, CH3D predicts both water surface elevations and tidal currents (both speed and direction) consistent with the results of Wang *et al*. (1998).

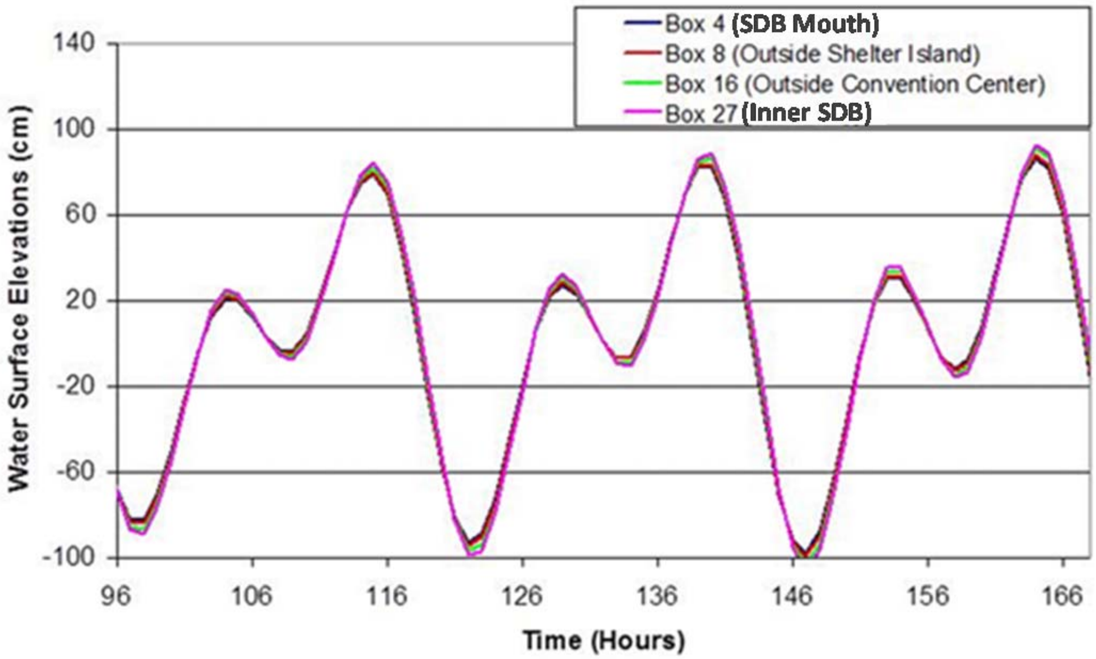

Figure 4-1. Simulated water surface elevations at several locations within San Diego Bay. The boxes are those designed in Figure 3-1.

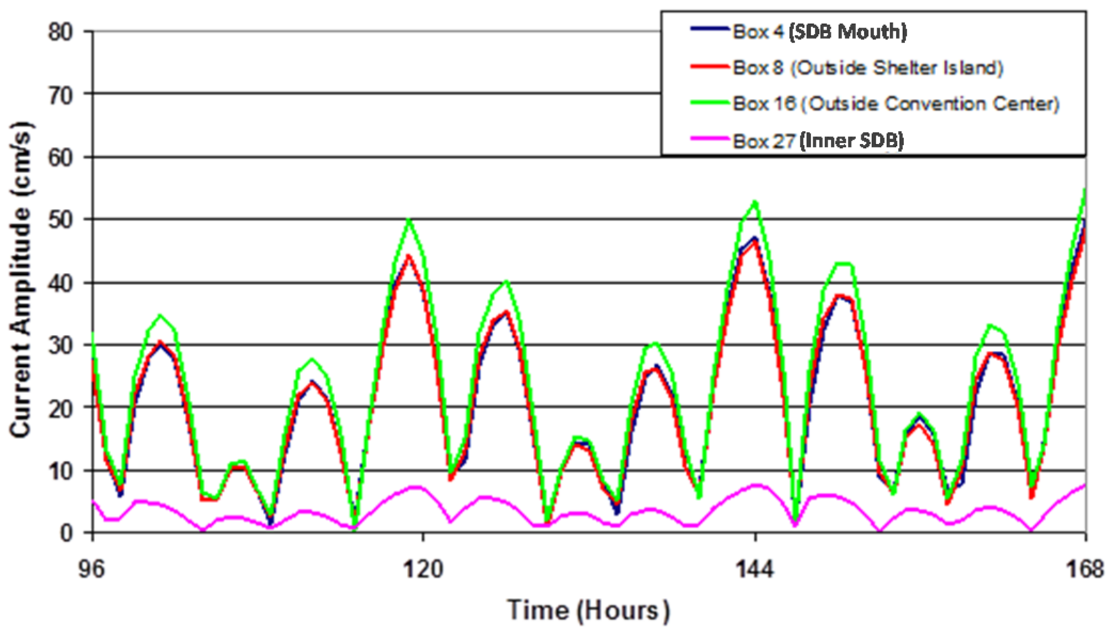

Figure 4-2. Simulated current amplitudes at four locations in San Diego Bay.

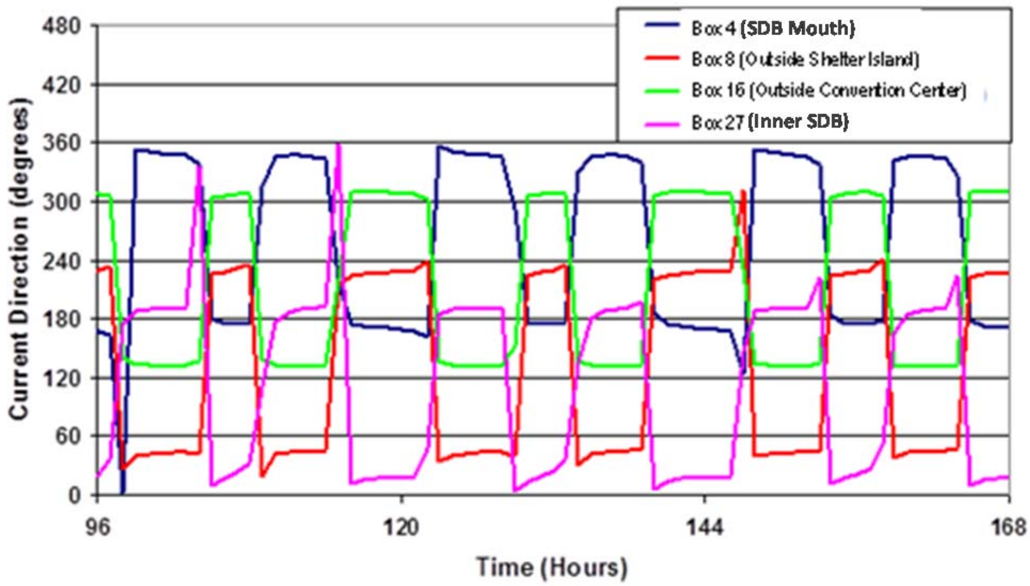

Figure 4-3. Simulated current direction at four locations in San Diego Bay. The angle is defined clockwise with 0° and 360° indicating North and 90° East.

4.2 CULVERT BETWEEN SIYB AND SDB

Figure 4-4 shows the modified CH3D model grid with the culvert added to connect SIYB and SDB channel. In order to accommodate the small size of the culvert (12ft x 8ft), the model grids near the culvert needed to be reduced and gradually increased to the sizes of the ambient grid cells. CH3D was run with the grid at a time step of 20 seconds, which is not efficient to run copper model, since it takes 320 days for the copper model to reach steady state. Instead, we ran the culvert model and quantified the flow through the culvert as a function of the difference of water surface elevations between SIYB and SDB.

CH3D was simulated for 20 days, covering the spring/neap tidal cycle (Figure 4-5). Flow through culvert is induced by difference in water surface elevations between SIYB and SDB. The relationship between flow velocity and water surface elevation difference is not linear, nor is it conservative with loss of momentum through bottom friction. Therefore, we hypothesized that culvert flow velocity is a fraction of the idealized conservative system, which dictates velocity is completely driven by difference of water surface elevations between the two water bodies such that

$$\vec{V}_{Ideal} = \mathrm{sgn}(\Delta S)\sqrt{2g|\Delta S|} \qquad (1)$$

where g is gravity acceleration constant, and vector V_{Ideal} is the idealized velocity (speed and direction) driven by the difference of water surface elevations between SIYB and SDB (ΔS), with direction determined by the sign of ΔS. Culvert flow velocity is positive, flowing from SIYB to SDB for $\Delta S > 0$, and flow velocity is negative, flowing from SDB to SIYB for $\Delta S < 0$.

Model results show that culvert flow velocity can be approximated by multiplying a constant of 0.42 and 0.36 to the idealized velocity (Eq.(1)) during the flooding and ebbing tides ($\Delta S > 0$, and < 0, respectively). Figure 4-5 and Figure 4-6 show time series of the simulated culvert flow velocity, which correlates with the difference of simulated water surface elevation, as expected. Simulated culvert velocity can also be regenerated by multiplying the 0.42 and 0.36 constants to the idealized velocity (Eq.(1)), as shown by line in yellow in Figure 4-5 and Figure 4-6.

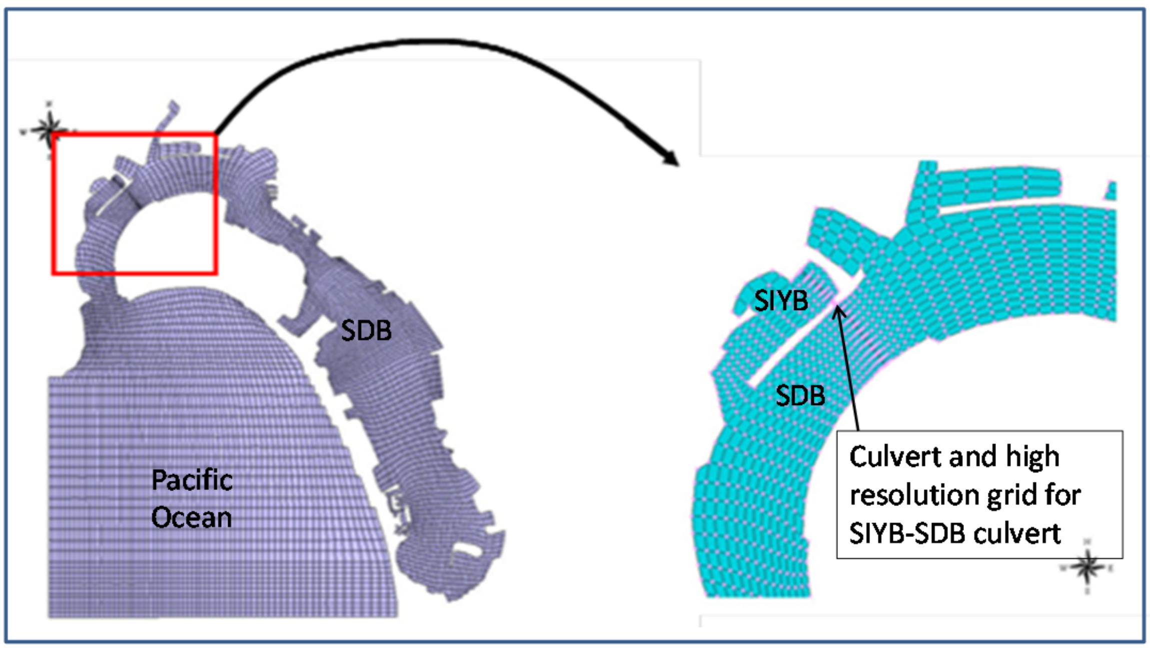

Figure 4-4. CH3D model grid with a culvert connecting SIYB and SDB.

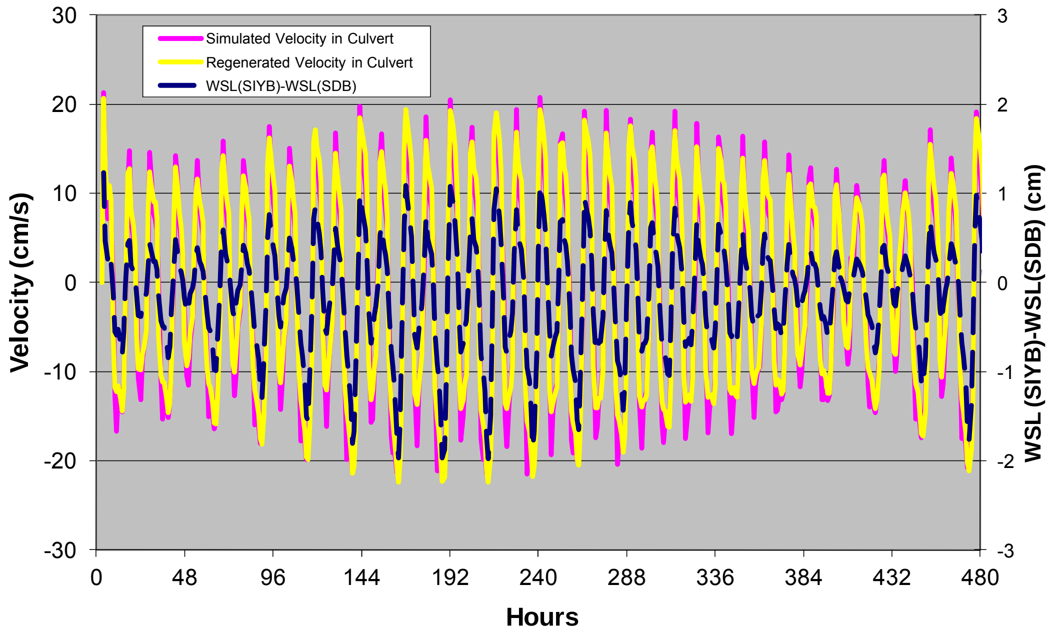

Figure 4-5. Simulated culvert flow velocity (pink) and difference of water surface elevations (WSLs) between SIYB and SDB (blue), reproduced culvert flow velocity by multiplying constants to the idealized velocity during flooding and ebbing tides.

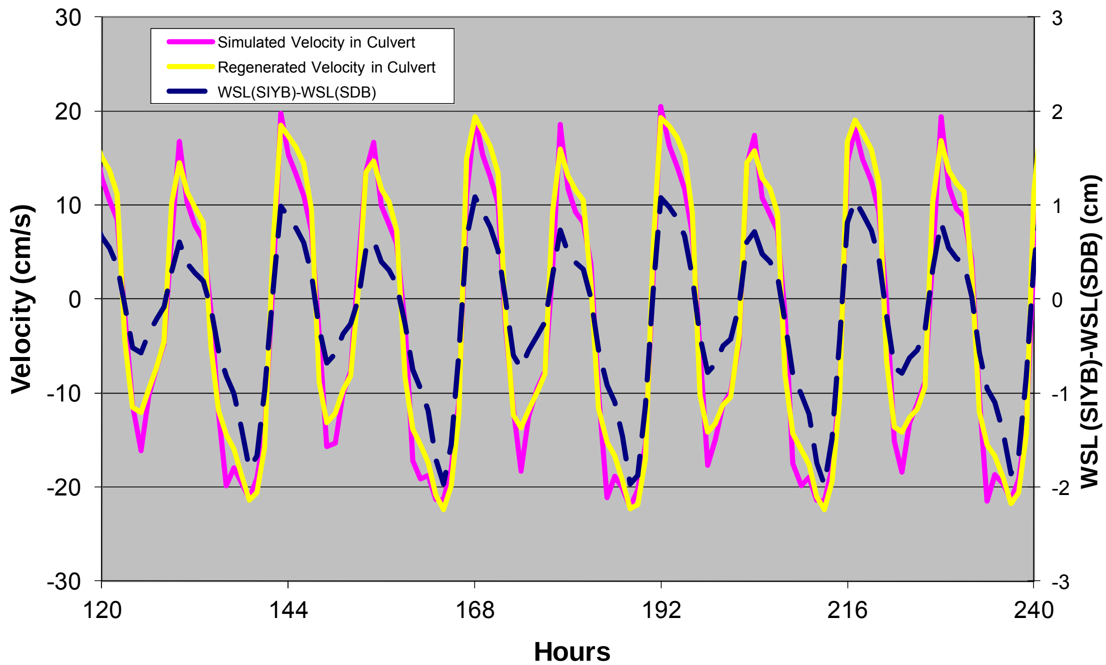

Figure 4-6. Close-up time series between 120-240 hours.

4.3 CULVERT BETWEEN SIYB AND ACH

Figure 4-7 shows the close-up look of the CH3D grid between SIYB and ACH. The culvert is of the same size (12ft x 8ft), for which re-gridding of the local regions near the culvert is required. The CH3D model runs with the grid at a time step of 20 seconds.

Following the SIYB-SDB analysis approach from the previous section, we reproduced the culvert flow velocities between SIYB and ACH by multiplying a constant of 0.6 to the idealized velocity which is generated by Eq.(1) with the difference of water surface elevations between SIYB and ACH (ΔS). The multiplicative constants for culverts between SIYB and SDB (case 1), and between SIYB and ACH (case 2) are summarized in Table 4-1.

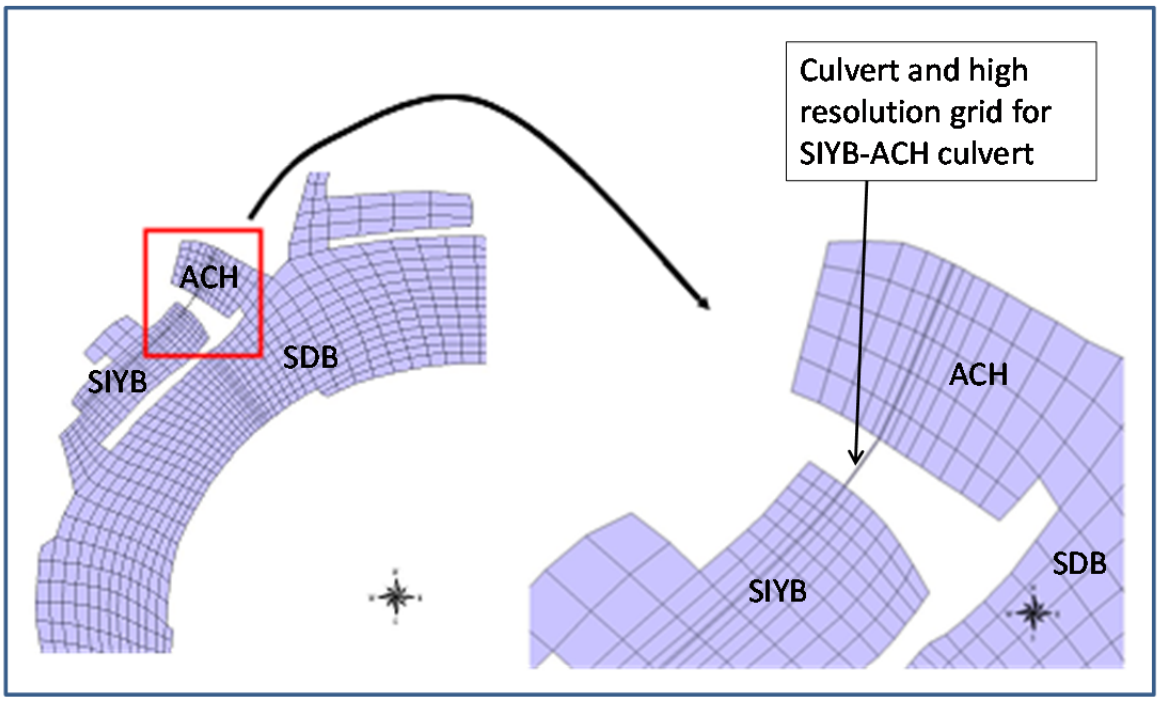

Figure 4-7. CH3D model grid with a culvert connecting SIYB and ACH.

Similar to the SIYB-SDB culvert analysis, culvert flow velocities can be reproduced from the difference of simulated water surface elevations between SIYB and ACH. A multiplicative constant of 0.6 was found to work well for the SIYB-ACH culvert flow. In general, these constants are functions of detailed circulation patterns, bathymetry, and nonlinear advection, which only can be adequately simulated by the model.

However, these two examples indicate that culvert flow velocities can be obtained from the difference of water surface elevations between the two water bodies, SIYB-SDB and SIYB-ACH, by way of an idealized velocity multiplied by a constant. In general, culvert flow velocities for SIYB-ACH are higher than those for SIYB-SDB. This is reflected in Figure 4-8 and Figure 4-9.

Table 4-1. Multiplicative constants for the regenerated culvert flow velocities from the idealized velocity (Eq.(1)).

Condition	SIYB-SDB	SIYB-ACH
ΔS > 0 (e.g., flooding tide)	0.36	0.6
ΔS < 0 (e.g., ebbing tide)	0.42	0.6

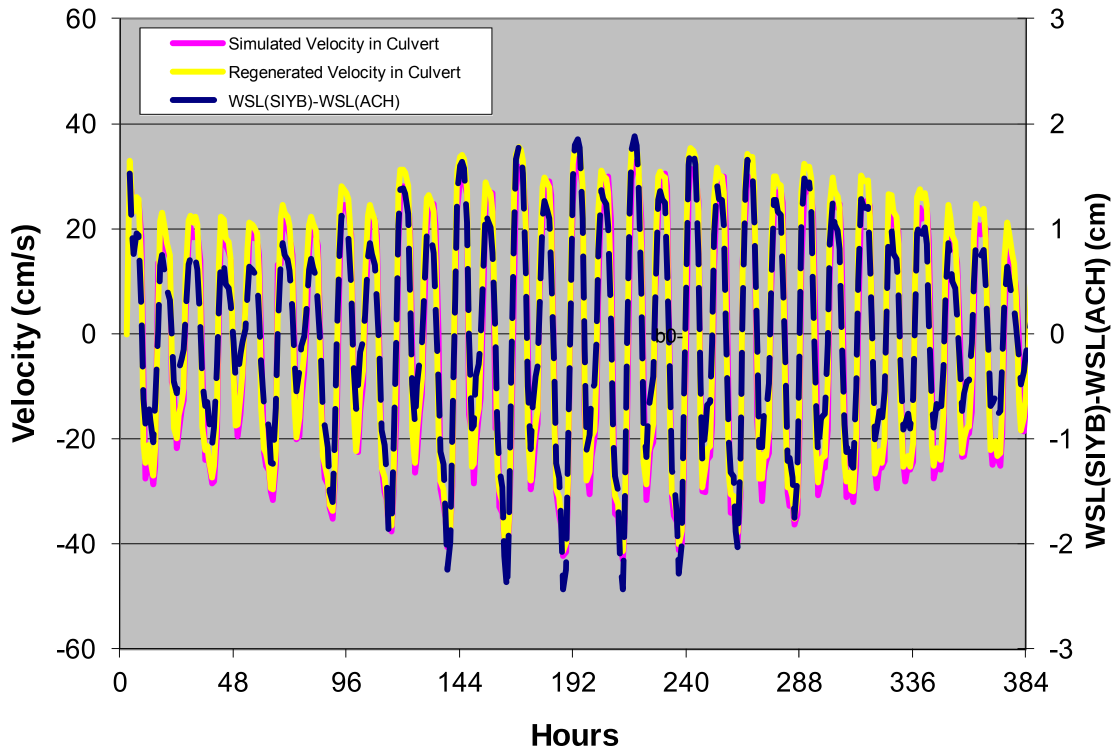

Figure 4-8. Simulated culvert flow velocity (pink) and difference of water surface elevations (WSLs) between SIYB and ACH (blue), reproduced culvert flow velocity by multiplying constants to the idealized velocity during flooding and ebbing tides.

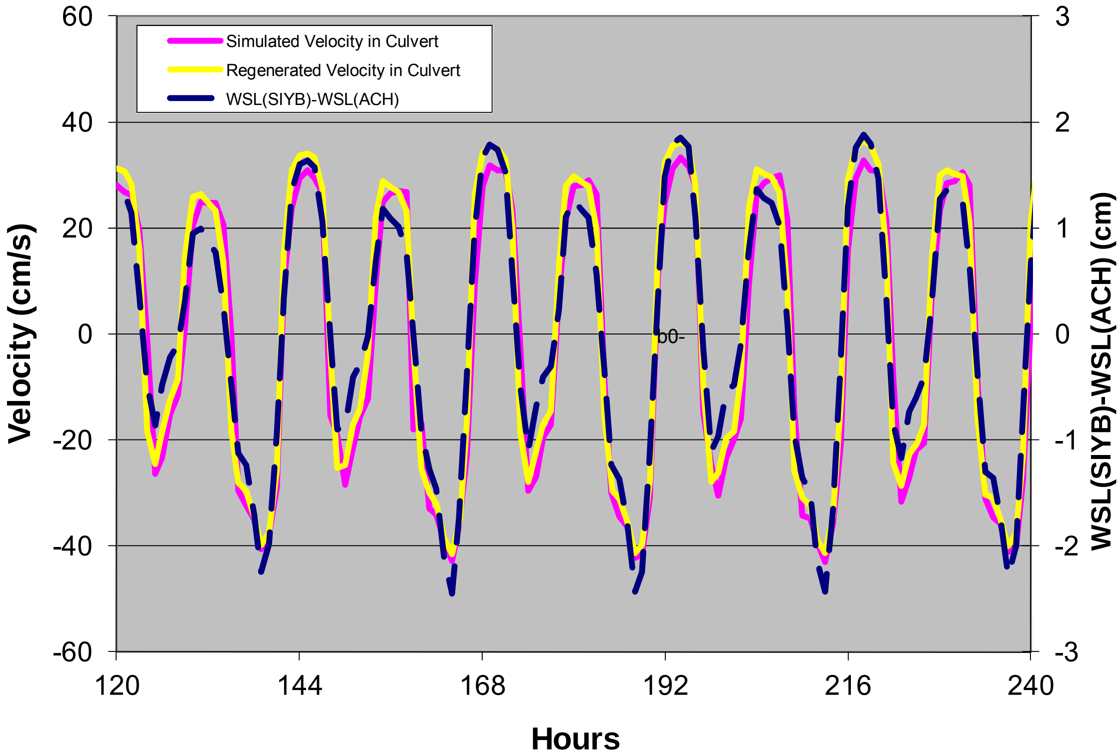

Figure 4-9. Close-up time series between 120-240 hours.

4.4 SUBMERGED PIPE FLOW SIMULATIONS

In addition to the open culvert flow scenarios, enhanced flushing was simulated for two scenarios – (1) placement of one 52"-diameter submerged pipe between SIYB and SDB, and (2) one 52"-diameter submerged pipe between SIYB and ACH. Flows through the submerged pipes are driven primarily by the differences of water surface elevations between the corresponding pairs of water bodies. The potential energy is compensated by the energy-dissipating processes, including pipe flow velocity, pipe friction and head losses due to pipe connectivity and/or pipe configuration. For this study, we assumed that pipe friction and head losses are minor and can be neglected. The potential energy from water surface elevation difference drives the pipe flow, which is a conservative assumption in that the pipe flows are optimally maximized. Therefore, the idealized flow, as depicted in Eq.(1), was used for the pipe flow scenario:

$$\vec{V}_{Ideal} = \mathrm{sgn}(\Delta S)\sqrt{2g|\Delta S|}$$

4.5 SIMULATED TOTAL COPPER CONCENTRATIONS IN SIYB WITH AND WITHOUT THE CULVERTS/SUBMERGED PIPES

Culvert flows implemented and simulated by the short-term CH3D hydrodynamic model runs were assigned as the riverine/withdrawal boundary conditions for the steady state copper modeling simulations. To accommodate the culvert flows between SIYB/SDB and SIYB/ACH, respectively, the regenerated culvert flow formulation (described above) was added to the model, which allowed culvert flows to be calculated at every time step as a function of difference of water surface elevation. The CH3D model was then used to simulate culvert flows as boundary condition at the culvert mouths in each water body. For example, when culvert flows were in the positive direction, flowing from SIYB to SDB (or SIYB to ACH), the culvert flow rates were treated as withdrawal from SIYB and as riverine input to SDB or ACH. When culvert flows were in negative direction, flowing from SDB or ACH to SIYB, the culvert flow rates were treated as withdrawal from SDB or ACH and as riverine input to SIYB. These input and withdrawal flows are a standard capability of the CH3D model that were customized to accommodate the specific conditions developed for the culvert flows.

The CH3D model was also configured to accommodate the additional river/withdrawal boundary conditions for copper concentrations. When water flows from SDB or ACH to SIYB, the culvert flows through the riverine mouths in SIYB carry concentrations from SDB or ACH into SIYB. The same flow conditions were treated as withdrawals for SDB or ACH and no additional adjustment was needed for boundary condition for copper. Conversely, when water flows from SIYB to SDB or ACH, the culvert flows through the riverine mouths in SDB or ACH carry the copper concentration of SIYB. The same flow conditions were treated as withdrawal for SIYB and no additional adjustment was needed for boundary condition for copper.

CH3D-simulated total copper concentrations in SIYB were compared for the five scenarios: (1) no culvert, (2) culvert between SIYB and SDB, (3) culvert between SIYB and ACH, (4) a submerged pipe with 52” diameter between SIYB and SDB, and (5) a submerged pipe with 52” diameter between SIYB and ACH.

Figure 4-10 shows three representative locations, including inner SDB, ACH, and SIYB, for model output. Figure 4-11 shows the time series of depth-averaged copper concentrations at the three locations. Simulation results indicate that total copper concentrations reach steady state relatively quickly at SIYB and ACH which are closer to the SDB mouth, and slower for the inner SDB. Figure 4-12 shows the time series of total copper concentrations at SIYB for the five scenarios: baseline scenario (no connection), culvert for SIYB-ACH and for SIYB-SDB, and pipe flow for SIYB-ACH and for SIYB-SDB, respectively. Reduction of total copper concentrations in SIYB is greatest for the SIYB-ACH culvert, followed by the SIYB-ACH submerged pipe scenario, and then the SIYB-SDB culvert and submerged pipe scenarios.

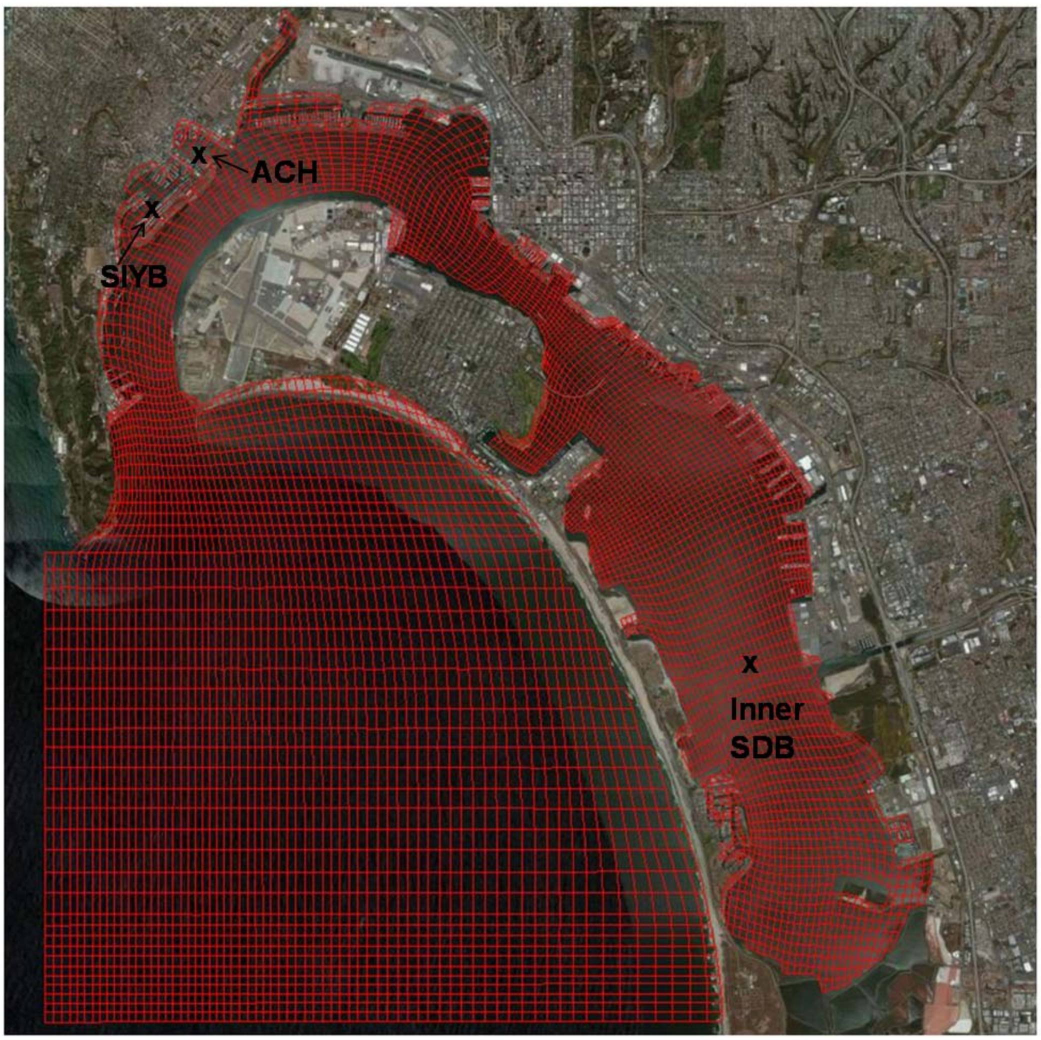

Figure 4-10. Representative locations of San Diego Bay model domain: Inner SDB, ACH and SIYB.

Figure 4-13 shows total copper concentrations in ACH for the baseline, and the two culvert scenarios. Simulated total copper concentrations in ACH are comparable for the baseline case and the SIYB-SDB culvert scenario, whereas, the culvert between SIYB and ACH reduces total copper concentrations in ACH slightly, due to enhanced flushing. As shown in Figure 4-11 through Figure 4-13, total copper concentrations in SIYB, and ACH are strongly influenced by tidal actions. Significant diurnal and spring/neap tidal cycle effects are reflected in these results, with differences of total copper concentrations at different tidal stages reaching up to ~3.5ppb near the head and ~7 ppb near the mouth regions of SIYB.

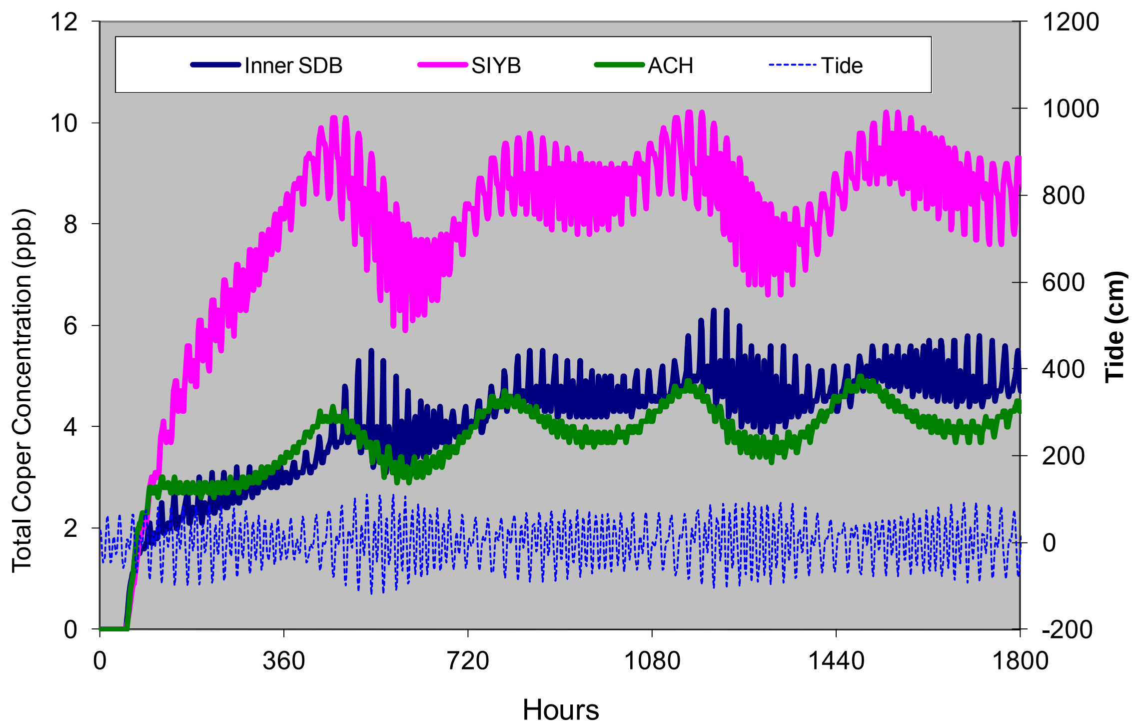

Figure 4-11. Simulated total copper concentration time series at three locations in SDB including a location in inner SDB, SIYB, and ACH. The tidal forcing is also shown relative to the scale on the right.

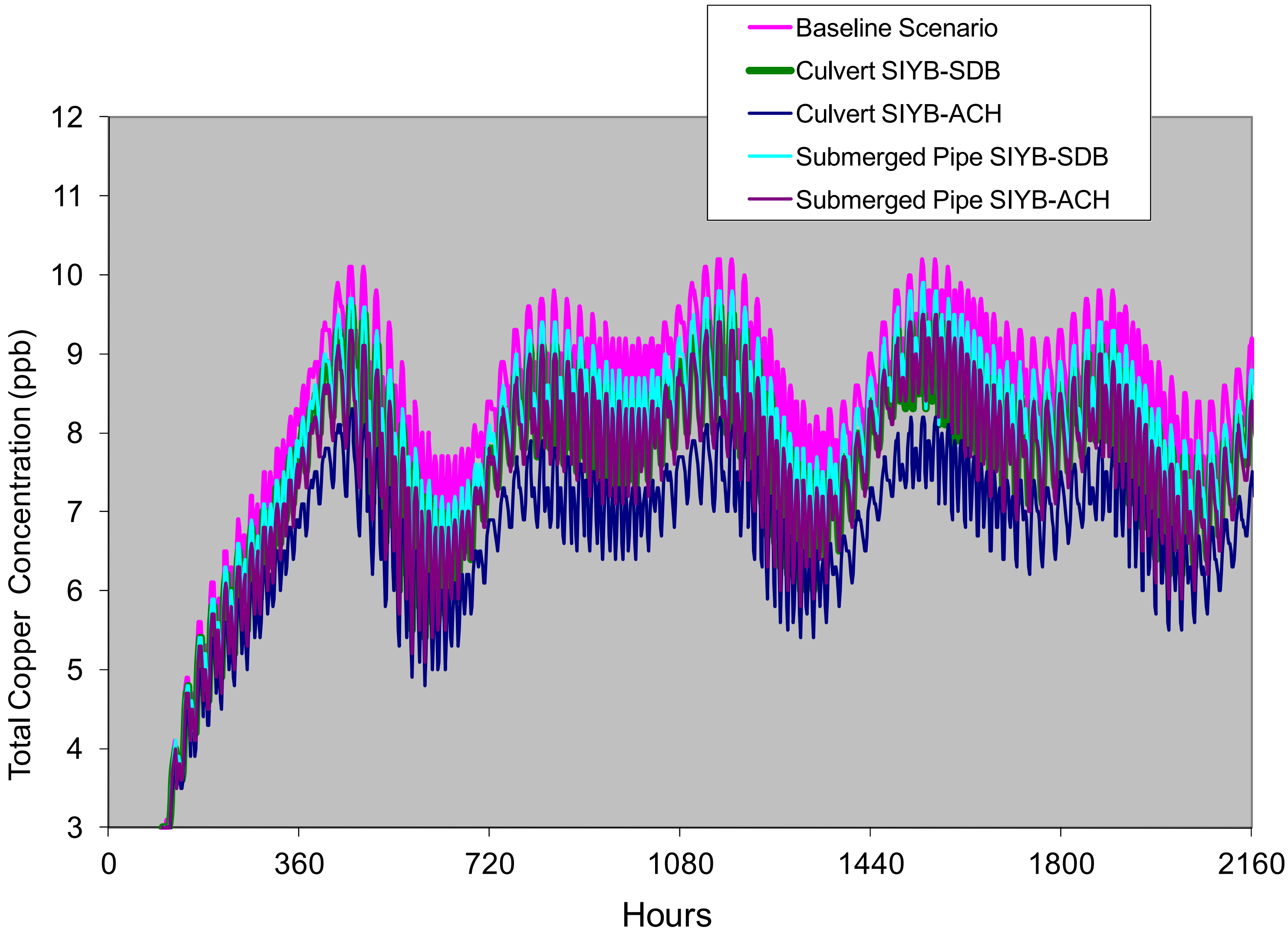

Figure 4-12. Total copper concentrations at SIYB for the five scenarios.

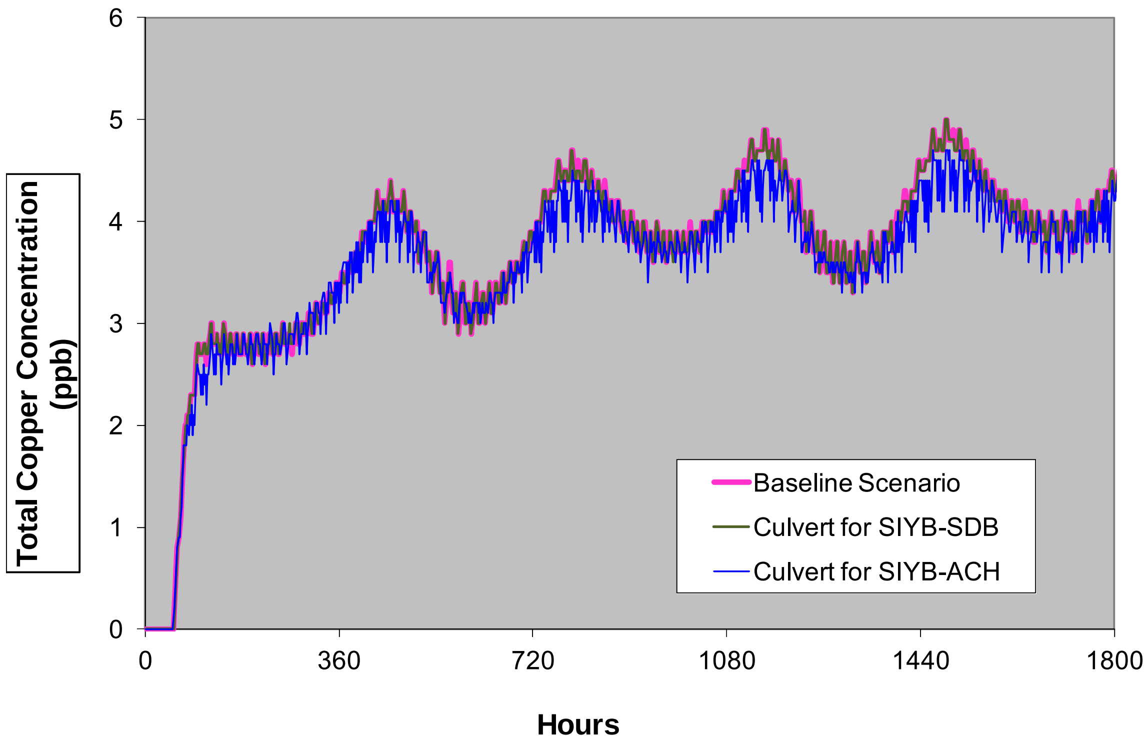

Figure 4-13.Copper concentrations in ACH for the base, SIYB-SDB and SIYB-ACH culvert scenarios.

In SIYB, concentrations tend to increase from the mouth toward the head of the basin. This is also primarily due to the flushing effect of the SDB water, which is strongest at the mouth. Simulated copper concentrations in ACH are at about half of those in SIYB. These concentration levels are obtained based on the best knowledge of copper loads, including those in ACH and the hydrodynamics of the Bay.

Figure 4-14 shows the three sub-divided regions of SIYB for model comparison and analysis: the inner, middle and mouth regions. Model results were averaged over a 15-day period to obtain mean values. Figure 4-15 shows simulated mean total copper concentrations for these three regions, and Figure 4-16 shows the corresponding percentage of reduction in copper concentrations compared to the baseline scenario. For the SIYB-ACH culvert scenario, simulated total copper concentrations were reduced by 21% in the head region, 15% in the middle region and 12% near the mouth of SIYB with an average reduction of 17% for the entire basin. For the SIYB-SDB culvert scenario, simulated total copper concentrations were reduced by 8% in the head region, 6% in the middle region and 5% near the mouth with an average reduction of 7% for the entire basin, approximately half of the reduction predicted for the SIYB-ACH culvert.

The reduction of copper concentration for the culvert scenarios depends on both the flow rate through the connecting culvert, and the relative copper concentrations in SDB and ACH compared to SIYB when inflow from these two water bodies takes place. Although copper concentrations are higher in ACH than SDB (~4 ppb vs. ~1.5 ppb), the flow rate for the SIYB/ACH culvert scenario is ~50% more than that for the SIYB/SDB culvert scenario. These higher flushing results in the greater reduction in total copper concentrations for the SIYB/ACH culvert scenario compared to the SIYB/SDB culvert scenario.

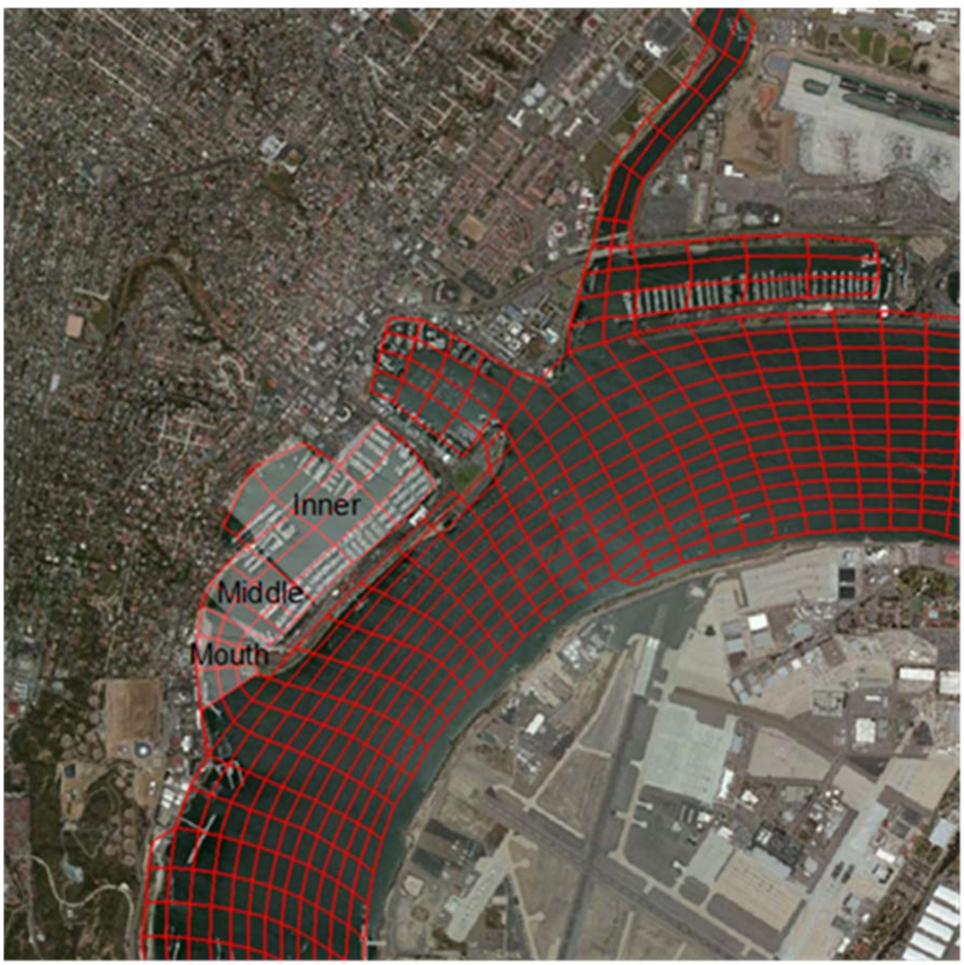

Figure 4-14. Sub-divided SIYB regions for model result analysis: Inner (Head), Middle and Mouth regions of SIYB.

It was also observed that reductions of copper in SIYB were similar between culvert and submerged pipe connection scenarios for the SIYB-SDB location. This indicates a higher exchange efficiency for the pipe, since the cross section of culvert is about 96 ft^2, whereas cross section area of the pipe is 14.8 ft^2, only 1/6 of the culvert. The flow velocity in the culvert was only half that of the pipe. The higher efficiency may be related to the assumption that the discharge from the pipe was fully mixed vertically, while the culvert flow was constrained to the surface layer (top ~2.5 m) of the water column by the channel geometry.

Overall, culvert and pipe flow rates were higher between SIYB and ACH than between SIYB and SDB. However, due to the elevated copper concentration in ACH, reduction through water exchange is more efficient between SIYB-SDB than SIYB-ACH. Combination of these factors results in reduction at the same level for these culvert or submerged pipe scenarios.

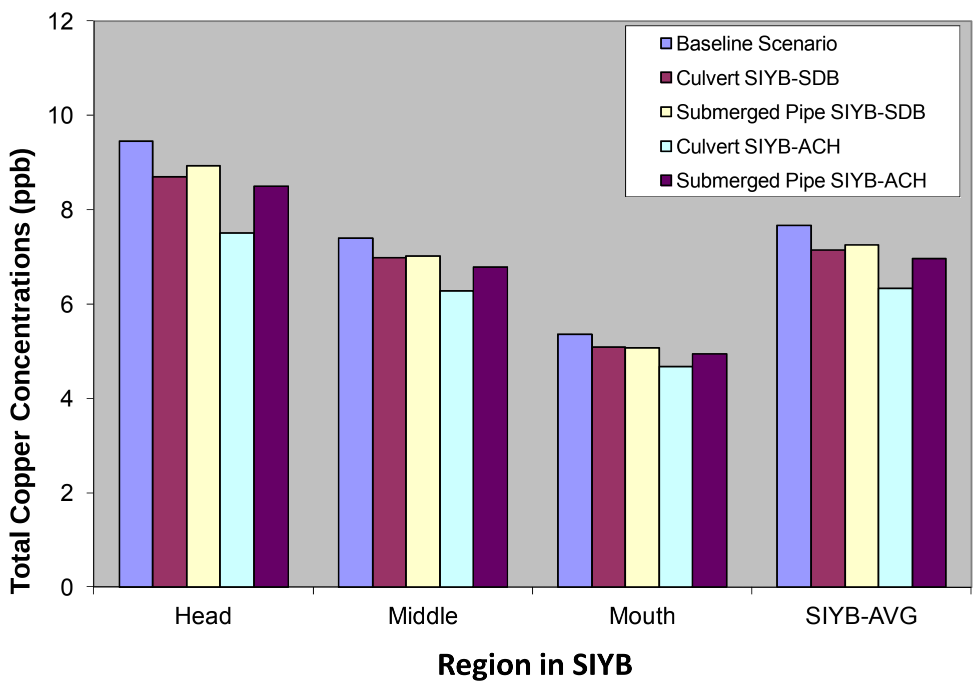

Figure 4-15. Total copper concentrations in inner, middle and mouth of SIYB for the baseline, culvert and pipe scenarios.

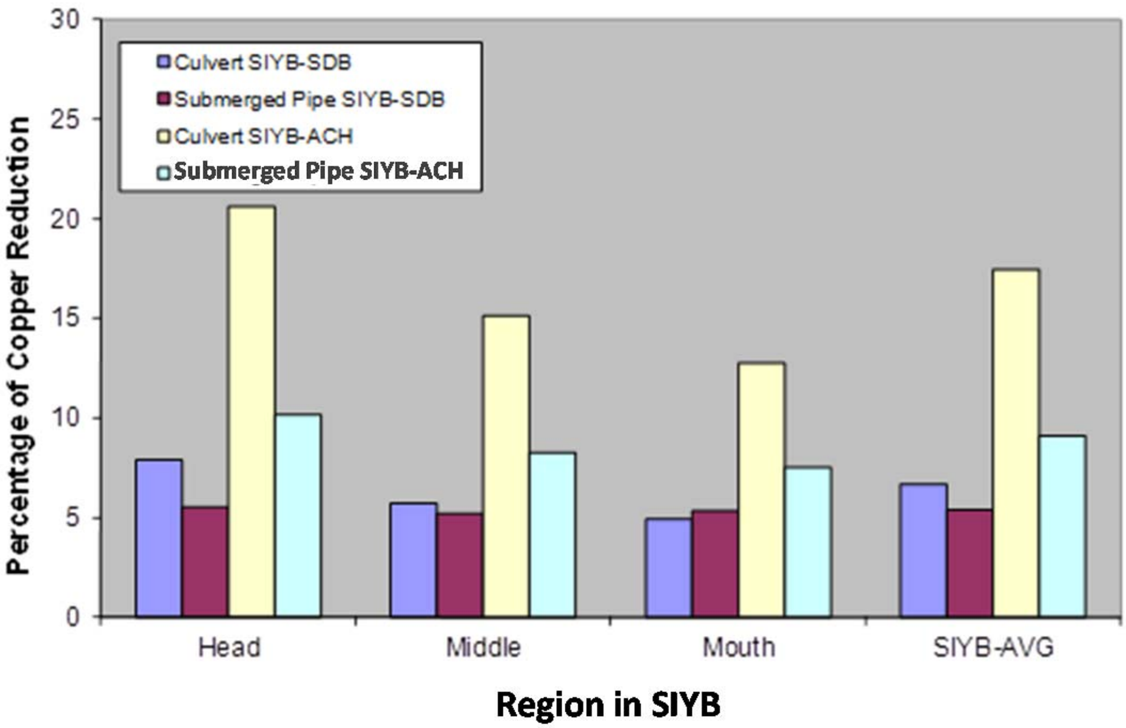

Figure 4-16. Percentage of copper reduction for SIYB for the two culvert/pipe scenarios.

Reduction of total copper concentrations were analyzed along the axis of SIYB in more detail. Model output of total copper concentration was laterally-averaged across the width of SIYB for 10 transect locations along the axis (Figure 4-17). The mean, minimum and maximum of simulated total copper concentrations at the 10 axis locations during a 15-day steady state period are shown in Table 4-2. Based on this analysis, copper reduction from the design scenarios were calculated and results shown in Figure 4-18. The culverts and pipes are located at north-eastern corner grid cell of SIYB, which corresponds with Station 1. A reduction of 25% was achieved at Station 1 for the SIYB-ACH culvert scenario, followed by 12% for SIYB-ACH submerged pipe, and 10% for SIYB-SDB culvert scenario. The SIYB-SDB submerged pipe scenario produced the lowest reduction (6.7%) at Station 1.

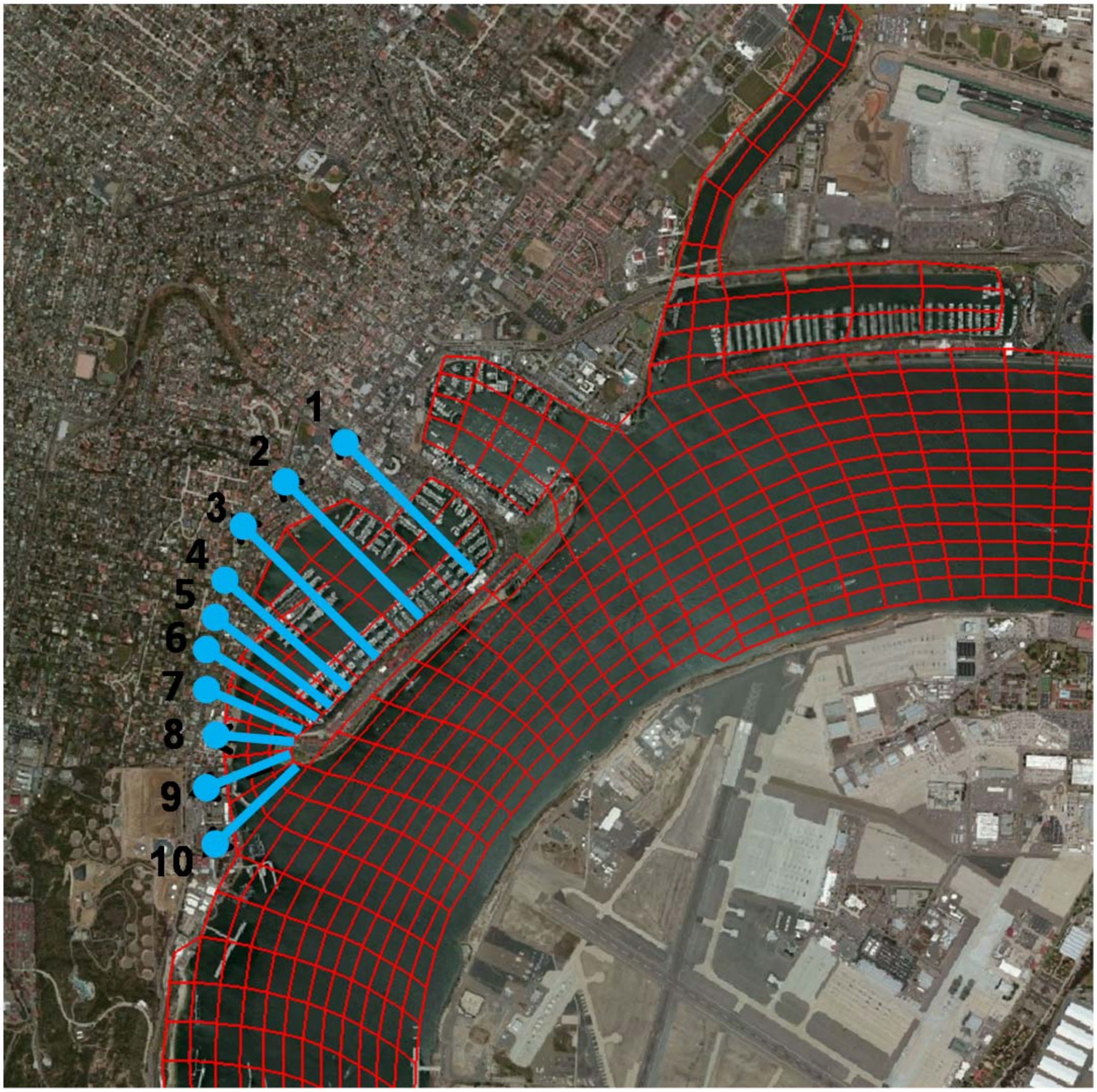

Figure 4-17. Ten transect locations along the axis of the SIYB model grid where total copper concentrations were spatially averaged laterally across the width of SIYB.

Table 4-2. Mean, minimum maximum of simulated total copper concentrations during 15-day period.

	Baseline			SIYB-SDB Culvert			SIYB-ACH Culvert			SIYB-SDB Pipe			SIYB-ACH Pipe		
SIYB Axis Box	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
1.0	10.3	8.8	12.2	9.2	7.9	11.0	7.6	5.1	9.5	9.6	8.1	11.9	9.0	7.7	10.8
2.0	9.5	7.6	11.8	8.8	6.9	10.9	7.6	6.1	9.2	9.0	7.0	11.4	8.6	6.7	10.6
3.0	8.9	5.7	11.2	8.3	5.3	10.6	7.4	4.8	9.3	8.4	5.1	10.9	8.1	5.0	10.4
4.0	7.9	3.3	11.3	7.5	3.1	10.7	6.6	2.9	9.5	7.5	2.9	10.9	7.3	2.9	10.5
5.0	7.4	2.9	10.9	7.0	2.7	10.4	6.3	2.5	9.3	7.0	2.5	10.6	6.8	2.5	10.2
6.0	6.8	2.2	9.7	6.5	2.1	9.4	5.9	1.9	8.5	6.5	1.9	9.4	6.3	1.9	9.1
7.0	6.3	1.7	9.1	6.0	1.7	8.8	5.5	1.6	8.0	6.0	1.6	8.8	5.8	1.5	8.6
8.0	5.5	1.3	8.0	5.3	1.2	7.6	4.8	1.2	7.0	5.2	1.2	7.6	5.1	1.2	7.5
9.0	4.2	0.6	7.2	4.0	0.6	7.0	3.7	0.6	6.4	4.0	0.6	6.9	3.9	0.5	6.8
10.0	2.9	0.4	7.1	2.8	0.4	6.7	2.6	0.4	6.2	2.8	0.4	7.1	2.7	0.4	6.9

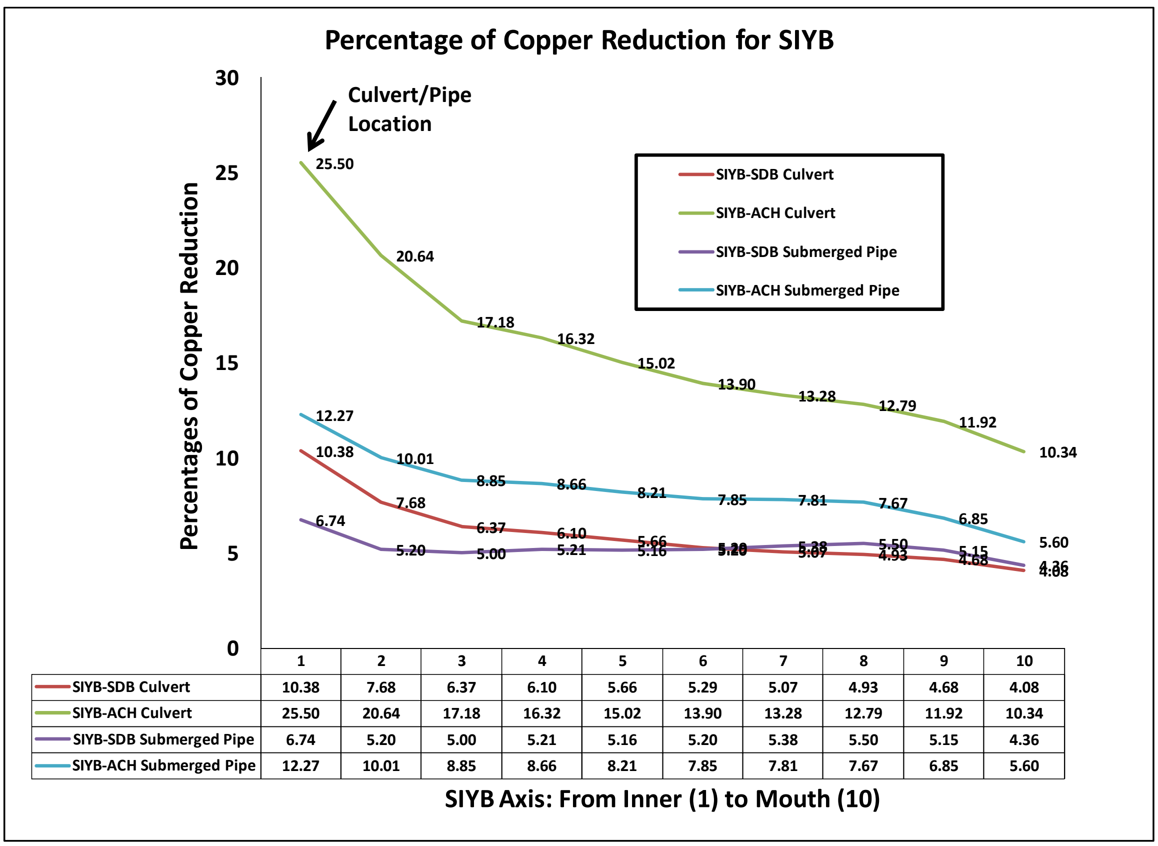

Figure 4-18. Percentages of reduction of width-averaged mean total copper concentrations along the axis of SIYB from the head (Station 1) toward the mouth (Station 10).

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