COST-BENEFIT ANALYSIS
SAN DIEGO REGION BACTERIA TOTAL MAXIMUM DAILY LOADS

Version 0.9
for public comment

July 2017

CBA Steering Committee

County of San Diego · County of Orange, California · The San Diego River Park Foundation · The City of San Diego, State of California · California Water Boards · San Diego County Taxpayers Association

CBA Producers

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ACRONYMS

AC	Aliso Creek	O&M	Operations and Maintenance
ADHD	Attention Deficit Hyperactivity Disorder	OMB	Office of Management and Budget
AIS	Any Infectious Systems	PLSD	Private lateral Sewage Discharge
BMP	Best Management Practice	P4	Potential Public Private Partnership Program
CBA	Cost Benefit Analysis	QMRA	Quantitative Microbial Risk Assessment
CC	Chollas Creek	REC criteria	Recreational Water Quality Criteria
CEQA	California Environmental Quality Act	RIS	Residential Indicator Score
CIP	Capital Improvement Projects	SANDAG	San Diego Association of Governments
CIPP	Cured-in-Place Pipe Liners	SANGIS	San Diego Geographic Information Source
CLRP	Comprehensive Load Reduction Plans	SC	Steering Committee
CPH	Cost per Household	SCCWRP	Southern California Coastal Water Research Project
CPI	Consumer Price Index	SDG	San Dieguito
CWA	Clean Water Act	SDR	San Diego River
DEH	San Diego County Department of Environmental Health	SFH	Single Family Home
E. coli	Escherichia coli	SHS	Surfer Health Study
ENT	Enterococcus	SJ	San Juan
FCA	Financial Capability Assessment	SLR	San Luis Rey
FCS	Financial Capability Score	SSF	Submerged Surface Flow
FIB	Fecal Indicator Bacteria	SSO	Sanitary Sewer Overflow
GI	Green Infrastructure	SWRCB	State Water Resources Control Board
GS	Green Streets	TC	Tecolote Creek
LCS	Laguna Coastal Streams	TMDL	Total Maximum Daily Load
LID	Low-Impact Development	TSS	Total Suspended Solids
LP	Los Peñasquitos	USCB	United States Census Bureau
LR	Load Reduction	USDA	United States Department of Agriculture
MHI	Median Household Income	USEPA	United States Environmental Protection Agency
MNS	Modeled Nonstructural Strategies	USGS	United States Geological Survey
MS4	Municipal Separate Storm Sewer System	WTP	Willingness-to-Pay
MUTA	Multiuse Treatment Area	WQO	Water Quality Objective
NEEAR	National Epidemiological and Environmental Assessment of Recreational Water	WQS	Water Quality Standard
NMNS	Non-Modeled Nonstructural Strategies	WY	Water Year
NoV	Norovirus		

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EXECUTIVE SUMMARY

The coastal water resources of San Diego and Orange Counties are important to the attractiveness and economic vitality of the region. It is well documented that pollution originating in the urban environment can affect the health of people who recreate along the coast. Water borne pathogens can cause illness, requiring people to miss work and spend money for medical care. Water quality at San Diego and Orange County beaches is generally very good during summer months when beach attendance is at its peak. However, health concerns can influence beach attendance, particularly during winter months and following rain events when levels of fecal indicator bacteria commonly increase as a result of storm-generated runoff. Public health agencies regularly issue health advisories warning against water contact in the 72-hours period following any rain event greater than 2.0 inches.

To address the impacts of elevated bacteria levels in recreational waters, in February 2010 the San Diego Regional Water Quality Control Board (San Diego Water Board) adopted a Total Maximum Daily Load (TMDL) regulation for 20 beach and creek segments in San Diego and southern Orange Counties. The Bacteria TMDL sets a numeric limit on how much fecal indicator bacteria is allowed in the 20 water bodies regulated by the TMDL and allocates clean-up responsibility among a variety of local government agencies. Responsibilities focus on managing stormwater flows to achieve the required bacteria reductions. The Bacteria TMDL established a timeline to achieve compliance during dry weather conditions by 2021. The longer compliance timeline for wet weather (by 2031) reflects the higher cost and increased complexity of mitigating pollution impacts following rain events, which generate high volumes of runoff with increased bacteria loading. Estimated costs to comply with the Bacteria TMDL's wet weather requirements are in the billions of dollars.

COST-BENEFIT ANALYSIS PURPOSE AND USES

In 2015, the San Diego Water Board initiated a project as part of the Triennial Review of its Water Quality Control Plan (Basin Plan) to determine whether and to what extent data supports amending water quality objectives established for water contact recreation as well as the implementation provisions of applicable TMDLs. As part of this project, the San Diego Water Board committed to "seek a third-party cost-benefit analysis regarding compliance with regulations of the San Diego Water Board, with a specific focus on the infeasibility of meeting wet weather TMDL water quality objectives for bacteria indicators." The purpose of this CBA, then, is to provide unbiased and credible information to decision makers and stakeholders who will consider potential revisions to the Bacteria TMDL as part of the San Diego Water Board-initiated Triennial Review project. In October 2016, the County of San Diego, City of San Diego, County of Orange and San Diego Water Board entered into a Memorandum of Understanding to define roles and timelines for completing the CBA.

The CBA evaluates a range of scenarios that vary implementation methods for achieving the Bacteria TMDL's wet weather numeric targets. The focus on wet weather conditions is responsive to the Regional Board's Triennial Review project description and acknowledges the fact that it is considerably more difficult and expensive to reduce bacteria loading during and following rain events when large volumes of stormwater runoff mobilize bacteria from the urban environment and are transported to creeks and the ocean. The CBA has been designed to help Copermittees and regulators use its results to inform new and appropriate compliance strategies, TMDL water quality targets and implementation schedules. However, cost-benefit information is not intended as the sole consideration for these important policy and management decisions, nor does the CBA attempt to present recommendations for change to the Bacteria TMDL. Decision makers are expected to synthesize additional information, beyond costs and benefits, and to consider stakeholder input in their policy decisions.

SUMMARY OF THE ANALYSIS

The CBA follows federal guidance from the U.S. Environmental Protection Agency *Guidelines for Preparing Economic Analyses* and Office of Management and Budget Circular A-4, which together provide best-practices for regulatory economic analysis. The CBA assesses health, recreation and environmental benefits under various scenarios compared to a business-as-usual baseline condition (Figure ES-1) and encompasses the eight San Diego County and five Orange County watersheds addressed by the Bacteria TMDL. Benefits and costs are calculated only for wet weather conditions during a 65-year time period. The CBA also compares each scenario's costs and benefits to determine the benefits per dollar and the net benefits for each scenario. The analysis addresses the following categories of benefit:

BEST MANAGEMENT PRACTICES (BMPS) include any structure, program or action undertaken with the intent of reducing bacteria loads to surface waters.

- **Avoided Illnesses** — the value to individuals of avoiding infectious illness including gastrointestinal illness. Benefits include reducing medical expenditures, regaining lost work days and alleviating discomfort. The CBA makes use of a unique data set to conduct this analysis; namely, a first-of-its-kind Surfer Health Study that quantifies the existing risk of illness among San Diego County surfers entering the ocean within the 72-hour period following a rain event (available at sccwrp.org/shs).
- **Additional Beach Trips** — the value of regaining trips to the beach due to reduced beach closure days and water quality advisories for a broad group of recreation activities. The CBA uses local data on beach usage and thorough beach attendance modeling to project the increased beach usage estimated to result from improved water quality following rain events.
- **Co-Benefits** — the additional benefits, such as carbon sequestration, air quality, wildfire risk and other pollutant removal from water, resulting from BMPs implemented to reduce bacteria loads.

Categories of cost included in this analysis are:

- **Programmatic costs** — costs to establish and maintain bacteria-reduction activities, such as public educational programs, marketing campaigns and street sweeping.
- **Capital costs** — one-time costs to install structural practices that remove bacteria such as infiltration and detention basins, cured in place sewer pipes for sewage collection and engineered wetlands.
- **Operation and maintenance costs** — costs associated with operating and maintaining the capital practices.

The CBA analyzes more than a dozen scenarios related to possible changes in implementation plans for the Bacteria TMDL. Each scenario alters an aspect of TMDL implementation. While each scenario is analyzed independently as a distinct variation to the Bacteria TMDL, the scenarios are grouped into four types based on the potential policy-decisions that could affect their implementation:

- **Focus on stormwater implementation (stormwater)**: Achieve compliance through implementation of stormwater BMPs and programs designed to reduce bacteria loading that may originate from a variety of sources (stormwater and other human sources) but is carried by runoff. Potential adjustments to regulatory endpoints were evaluated.
- **Change schedule of compliance (scheduling)**: Extend the Bacteria TMDL wet weather compliance deadline beyond 2031 or provide flexibility for interim-milestones to allow for better coordination of BMP implementation with capital improvement projects to reduce project costs.
- **Target human waste sources of bacteria (human sources)**: Emphasize reduction of human sources of bacteria which scientists agree have a high likelihood of causing illness by repairing leaking sewer pipes, failing septic systems and reducing the number of transient encampments near waterways by providing housing in addition to other support services.
- **Reduce bacteria through stream restoration (stream)**: Implement stream enhancement and wetland restoration projects to reduce bacteria loading.

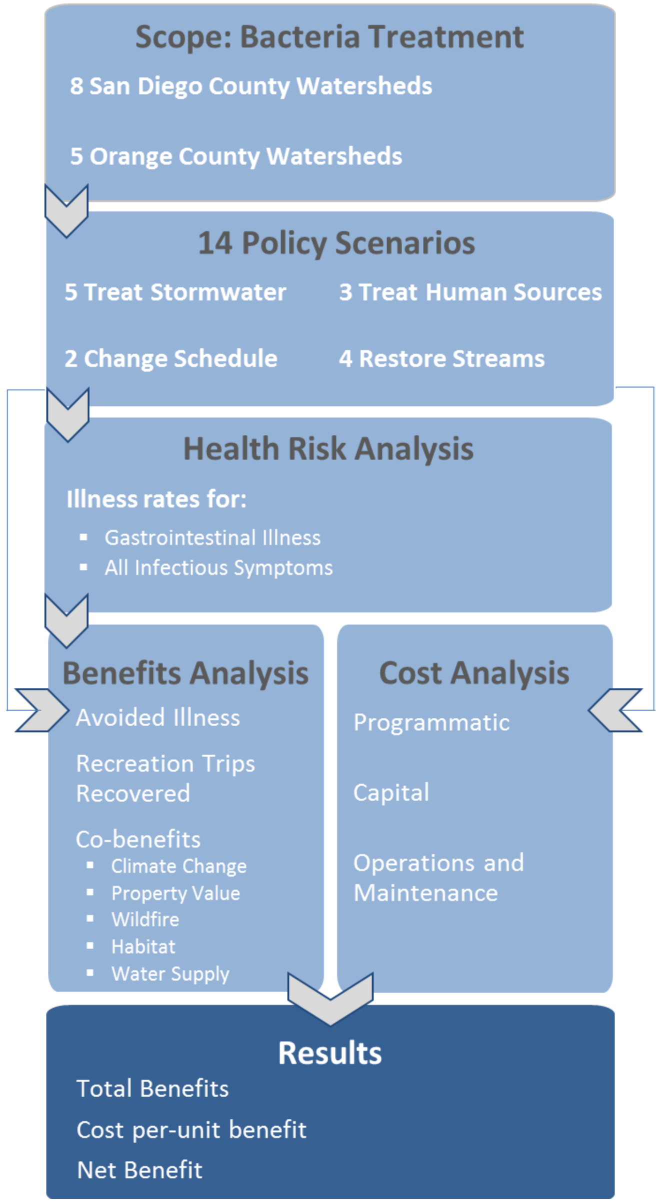


Figure ES-1: The CBA follows a specific process to determine the costs and benefits for multiple scenarios in defined geographic areas. Fourteen policy scenarios grouped into four types define the parameters to be analyzed. Analysis outputs are costs and benefits which are compared in several ways to produce results and findings.

In addition to the CBA, a screening-level Financial Capability Assessment examines the financial burden on rate payers for integrated clean water services including stormwater compliance and wastewater treatment.

CBA DEVELOPMENT PROCESS

A Steering Committee representing diverse stakeholders including regulators, stormwater permittees, a wastewater agency and nongovernmental organizations guided the project throughout the process. The public was consulted during key stages and on the final document, and the analyses were performed by several consulting firms with specialized expertise in economics, stormwater, wastewater, public health and stream restoration. A Technical Advisory Committee with leading experts provided feedback and guidance on both the work plan and draft report. The individuals comprising each of these groups are listed in the *Acknowledgements* section.

SCENARIO DEVELOPMENT

Scenarios were defined by the Steering Committee with guidance from consultants regarding possible evaluations within the limitations of a cost-benefit analysis, the data available and the project timeline. Scenarios were not included or excluded based on the likelihood of meeting regulatory requirements, political acceptability or feasibility of adoption. The purpose of analyzing multiple scenarios was to understand how bacteria loads, the frequency of illness, public health benefits, recreation benefits and other co-benefits might change under different scenarios. Inclusion of scenarios within the analysis does not indicate endorsement by the Steering Committee, or by others, for adoption of any scenario.

FINDINGS

Targeting human waste sources of bacteria is the most cost-effective strategy to improve public health and increase recreational opportunities following rain events. Cost-effectiveness results are provided as the total number of benefit units (i.e., avoided illnesses (Figure ES-2) or additional beach trips (Figure ES-3) in the 65-year analysis period per million dollars of investment. The Human Sources: High scenario, which focuses on treating the highest-risk sources of human pathogens (i.e., sewer and septic leakage, transient encampments), is many times more cost effective than the 2010 TMDL scenario that focuses on treating bacteria transported by runoff within the stormwater conveyance system. This finding is true for both avoiding illness and regaining beach trips. The CBA Technical Advisory Committee (TAC) found this result to be intuitive because human waste contains pathogens such as Norovirus that are more likely to cause illness in swimmers and surfers compared to more general sources of fecal bacteria that could originate from any warm-blooded animal. Scenarios involving the extension of the compliance schedule were also shown to be relatively more cost effective compared to the Stream Restoration and other Stormwater scenarios because they reduce annual costs and achieve the same bacteria load reductions over a longer period of time. Stream Restoration scenarios are less cost effective due to the limited availability of public land to reduce bacteria loads, the high cost of restoration projects, and fact that such projects have not been shown to be particularly effective at reducing bacteria loading.

Findings of the cost-benefit analysis do not make recommendations for adopting a particular scenario and the CBA does not discuss potential implications of adopting scenarios, other than numeric costs and benefits.

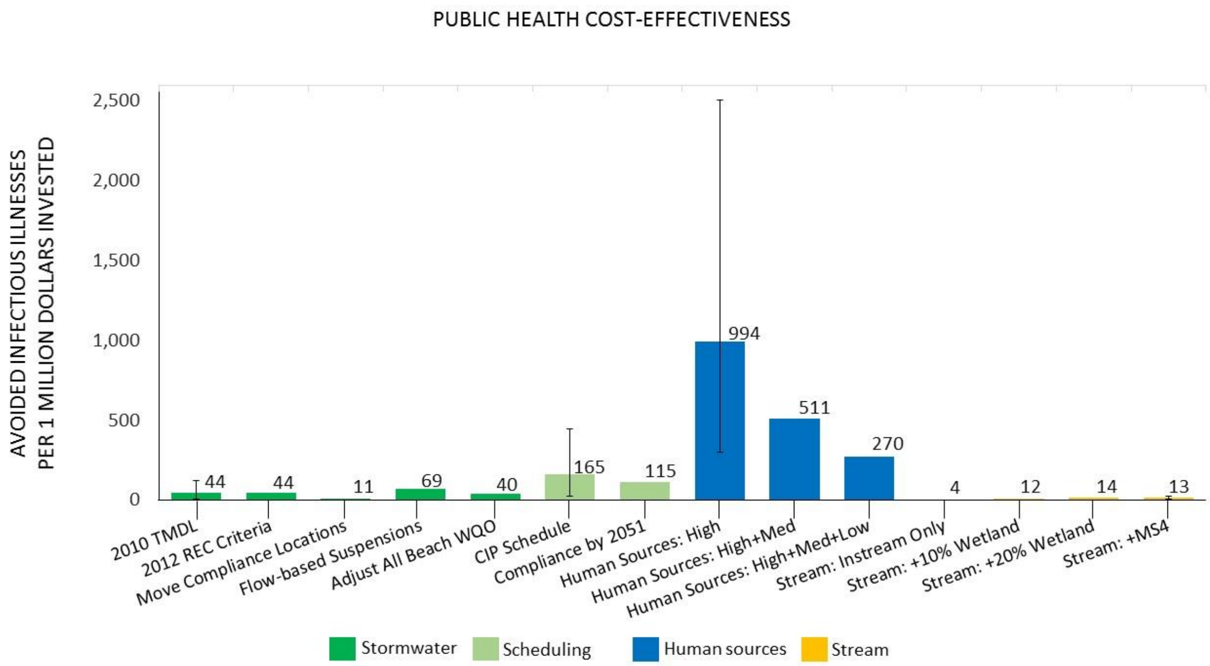


Figure ES-2: A chart showing number of illnesses avoided throughout the 65-year analysis period per million dollars invested. Human Sources scenarios (blue bars) provide many times greater cost-effectiveness compared to other scenarios. Whiskers indicate the ranges of uncertainty calculated using appropriate methods for each scenario; creating statistical high and low bracket values based on the important drivers of uncertainty in each scenario's benefits and costs.

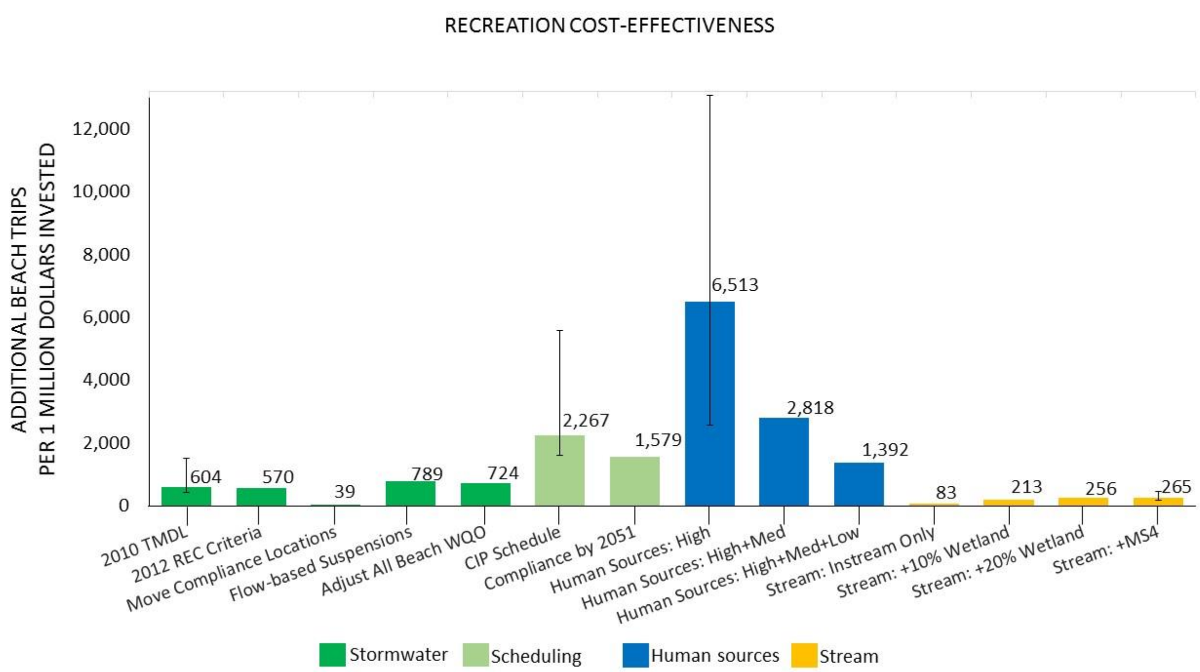


Figure ES-3: A chart showing number of additional beach trips throughout the 65-year analysis period per million dollars invested. Human Sources scenarios (blue bars) provide many times greater cost-effectiveness compared to Stormwater scenarios (green bars). Whiskers indicate the ranges of uncertainty calculated using appropriate methods for each scenario; creating statistical high and low bracket values based on the important drivers of uncertainty in each scenario's benefits and costs.

Net benefits are discounted costs subtracted from discounted benefits for the analysis period (2017-2081).

Net benefits are negative for all scenarios. A Human Sources scenario, Human Sources: High+Med+Low, has the lowest net benefits because of the high cost of treating large amounts of sewer/septic infrastructure without substantially larger benefits value. Several of the Stormwater scenarios have relatively higher net benefits because they have lower load reduction targets - leading to low benefits and low costs. The Scheduling scenarios have relatively higher net benefits because they have cost synergies resulting in substantially lower costs while providing only somewhat lower benefits than the 2010 TMDL scenario. The *Benefits Analysis* section contains detailed information about which benefits are quantified in this analysis and the net benefits from each scenario. Co-benefits, such as property values, riparian habitat and carbon sequestration, are greater than the associated human health and recreation benefits. Consequently, some scenarios do not provide efficient approaches to reducing bacteria and addressing recreational uses but may be appropriate for other purposes.

Programmatic and O&M costs dominate cost categories, while co-benefits dominate benefit categories. Programmatic costs are significant for Stormwater scenario types because education, marketing, street sweeping and other non-structural BMPs are sufficient to reduce bacteria loads to necessary levels in many watersheds. Operations and maintenance (O&M) activities comprise the largest costs for Human Sources scenarios and stream scenario types where structural practices provide necessary load reduction. Co-benefits such as property value, riparian habitat and treatment of other water pollutants provide more than half of the total benefits. The *Cost Analysis* and *Benefits Analysis* sections contain detailed results as well as the methods used to make these findings.

Quantitative uncertainty analysis and sensitivity testing shows that major cost-effectiveness and net benefit findings are high confidence. The CBA includes a substantial effort to provide a broad and quantitative sense of the uncertainty within the CBA results. This uncertainty calculation provides a "best estimate" that is analyzed in the CBA, then introduces high and low "bracket values" that are passed through the remainder of the analyses steps to show uncertainty in CBA results focused on units of benefit and cost effectiveness. Sensitivity testing involves adjusting assumptions to check for changes in numeric results. For example, benefits under the most ambitious human sources scenario represent avoidance of all wet weather infectious illness and lost trips, yet benefits are still well below costs for most scenarios. A variety of other sensitivity tests are described throughout this document and the CBA provides recommendations for additional research to further refine numeric results. The *Cost Analysis*, *Benefits Analysis* and *Water Quality Input Data* sections contain findings for uncertainty and sensitivity analyses.

FINANCIAL CAPABILITY ASSESSMENT

In addition to the CBA, a screening-level Financial Capability Assessment examines the financial burden on rate payers for integrated clean water services, including both stormwater compliance and wastewater treatment. The Financial Capability Assessment and CBA are completely separate analyses. The Financial Capability Assessment does not consider alternative scenarios and results cannot be compared with the CBA.

Screening Financial Capability Assessment results indicate a high financial burden for residential water services. According to USEPA guidance, a high financial burden exists when annual water costs exceed 2% of median household income. In this analysis, results exceed 4%, more than double the threshold level. Current services produce a "high burden" of $2,660/year on residents, while the Bacteria TMDL adds a smaller $391/year additional cost (Table ES-1). Further, the trash amendment, which requires BMPs to reduce trash entering TMDL watersheds, adds $18.50/year in additional costs. USEPA requires a full FCA to be completed as evidence for justifying a schedule extension as analyzed in the Compliance by 2051 and

CIP Schedule scenarios. Detailed FCA results are available in the *Screening Financial Capability Assessment: Results & Discussion* section.

Table ES-1: Results of the Financial Capability Assessment

	MEDIAN HOUSEHOLD INCOME	COST PER HOUSEHOLD	RESIDENTIAL INDICATOR SCORE	LEVEL OF BURDEN
Current Services				
Stormwater and Wastewater	$66,100	$2,660	4.02%	High
Additional Services				
Bacteria TMDL	$66,100	$391	0.590%	N/A
Trash Amendment	$66,100	$18.5	0.030%	N/A
Current + Additional Services	**$66,100**	**$3,070**	**4.63%**	**High**

LIMITATIONS AND NEXT STEPS FOR RESEARCH

The CBA employs the most current practices in economic modeling and valuation. However, like any cost-benefit analysis of this type, there are limitations to the analysis and thus the information that results provide to decision makers. For example, while the CBA benefit analysis produces a valuation of all quantifiable benefits and co-benefits, there are co-benefits that could not be quantified. CBAs are separate from economic impact analysis and intentionally do not analyze the effects of scenarios on job creation, economic conditions or wages. Dry weather flows were not quantitatively analyzed in this analysis because, during dry weather, current conditions rarely exceed receiving-water concentration limits for bacteria. Benefits could arise from reducing pollutants beyond bacteria during dry weather. The choice to focus on wet weather benefits and costs was made early in the project with the Steering Committee and stated in the CBA Work Plan that was reviewed by the public. Efforts such as providing housing to transient populations may achieve social goals that are not quantified in the CBA. Ultimately, peoples' values and preferences will greatly affect the decisions regarding the ways to make surface waters safe to swim.

While the CBA is based on the best available science; substantial data gaps remain. Sensitivity analyses show that despite important data gaps, current findings are high confidence; however further research could reduce uncertainty in numeric results. Additional research should focus on

- Monitoring pathogen loading from human sources such as sewer leakage and transient encampments- While the Surfer Health Study and follow-up monitoring projects have found markers of human waste to be ubiquitous in two San Diego County watersheds, it is not clear from which sources the human waste originates. Possible sources include the sanitary sewer system, failing septic systems, transient encampments, and illicit dumping from mobile sources such as recreational vehicles.
- Validating bacteria and pathogen dilution factors between fresh water and marine recreation sites- While the Surfer Health Study quantified dilution factors for two San Diego County watersheds, different beach configurations could exhibit different dilution dynamics that could limit the applicability of recent studies to these areas.
- Comparisons of the relative effectiveness of BMPs on multiple types of bacteria and pathogens- For example, very little data are available on the ability of traditional stormwater BMPs to reduce pathogens such as Norovirus.

1. SYNTHESIS OF FINDINGS

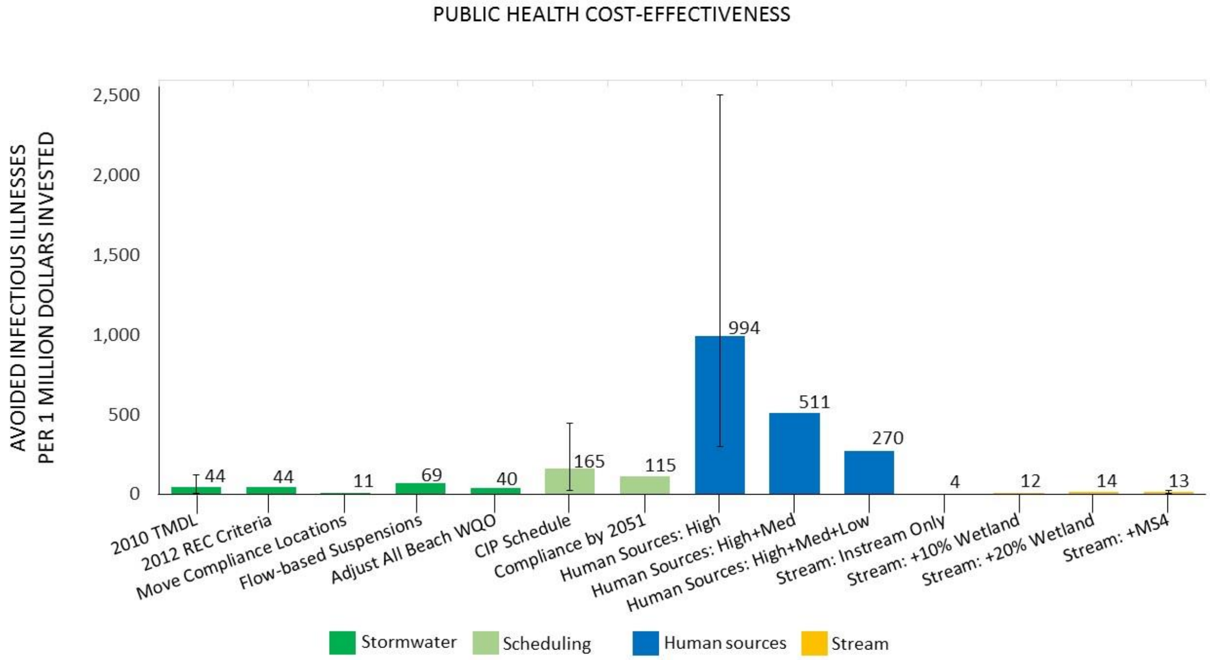
The multiple analyses in this study combine to provide several important findings and numeric results for decisionmakers to consider as they evaluate revisions to the Bacteria TMDL. While the *Benefits, Cost Analysis, Water Quality Input Data, Screening Financial Capability Assessment* and *Peer Review* sections convey nuances and discussion, key results are summarized here for easy reference. These findings do not attempt to recommend any particular scenario and avoid value judgements about underlying results. They may be used as a rationale for selecting or rejecting a particular scenario and are likely to be integrated with information from other sources by decisionmakers.

CBA FINDINGS

The CBA findings focus on cost-effectiveness of scenarios, net benefits, costs and benefits. Cost-effectiveness evaluates the scenarios that provide the greatest benefit at the lowest cost. Net benefit, cost and benefit findings help to compare the benefits received from implementing each scenario, compared to the cost for that scenario. The *Introduction and Approach Overview* section provides descriptions of each scenario.

COST-EFFECTIVENESS FINDINGS

Targeting human waste sources of bacteria is the most cost-effective strategy to improve public health and increase recreational opportunities following rain events. Cost-effectiveness results are provided as the total number of benefit units (i.e., avoided illnesses (Figure SF-1) or additional beach trips (Figure SF-2) in the 65-year analysis period per million dollars of investment. The Human Sources: High scenario, which focuses on treating the highest-risk sources of human pathogens (i.e., sewer and septic leakage, transient encampments), is many times more cost effective than the 2010 TMDL scenario that focuses on treating bacteria transported by runoff within the stormwater conveyance system. This finding is true for both avoiding illness and regaining beach trips. The CBA Technical Advisory Committee (TAC) found this result to be intuitive because human waste contains pathogens such as Norovirus that are more likely to cause illness in swimmers and surfers compared to more general sources of fecal bacteria that could originate from any warm-blooded animal. Scenarios involving the extension of the compliance schedule were also shown to be relatively more cost effective compared to the Stream Restoration and other Stormwater scenarios because they reduce annual costs and achieve the same bacteria load reductions over a longer period of time. Stream Restoration scenarios are less cost effective due to the limited availability of public land to reduce bacteria loads, the high cost of restoration projects, and fact that such projects have not been shown to be particular effective at reducing bacteria loading. The *Benefits Analysis* and *Cost Analysis* sections provide more information on these findings, including the methods and assumptions.



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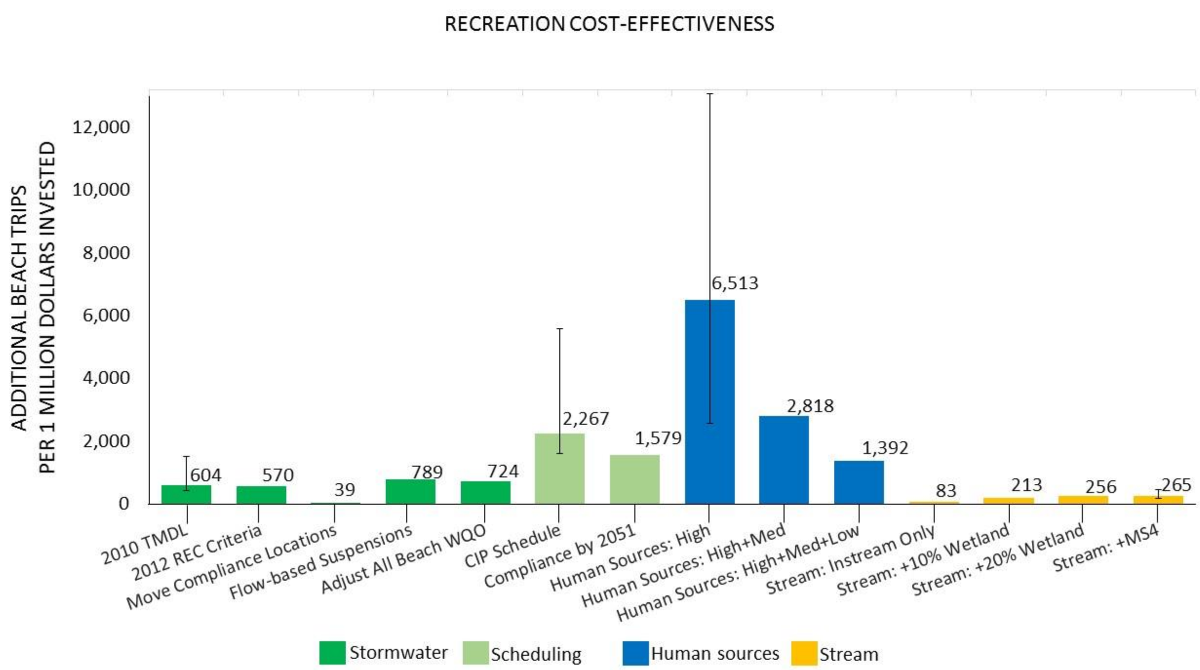

Figure SF-2: A chart showing number of additional beach trips throughout the 65-year analysis period per million dollars invested. Human Sources scenarios (blue bars) provide many times greater cost-effectiveness compared to Stormwater scenarios (green bars). Whiskers indicate the ranges of uncertainty calculated using appropriate methods for each scenario; creating statistical high and low bracket values based on the important drivers of uncertainty in each scenario's benefits and costs.

NET BENEFIT FINDINGS

Net benefit is the difference between total benefits and total costs of a scenario for the entire 65-year analysis period, using a 3% discount rate. The values include all watersheds; all benefits (recreation, public health and co-benefits); and all costs (i.e., programmatic, capital, O&M costs) (Figure SF-3).

Net benefits are discounted costs subtracted from discounted benefits for the analysis period (2017-2081).

Net benefits are negative for all scenarios. A Human Sources scenario, Human Sources: High+Med+Low, has the lowest net benefits because of the high cost of treating large amounts of sewer/septic infrastructure without substantially larger benefits value. Several of the Stormwater scenarios have relatively higher net benefits because they have lower load reduction targets - leading to low benefits and low costs. The Scheduling scenarios have relatively higher net benefits because they have cost synergies resulting in substantially lower costs while providing only somewhat lower benefits than the 2010 TMDL scenario. The *Benefits Analysis* section contains detailed information about which benefits are quantified in this analysis and the net benefits from each scenario. Co-benefits dominate benefit categories. Co-benefits such as property values, riparian habitat and carbon sequestration are greater than the associated human health and recreation benefits. Consequently, some scenarios do not provide efficient approaches to reducing bacteria and addressing recreational uses but may be appropriate for other purposes. Additional information on cost results is found in the *Cost Analysis: Results and Discussion* section and additional information on benefits results is found in the *Total Quantified Benefits* section.

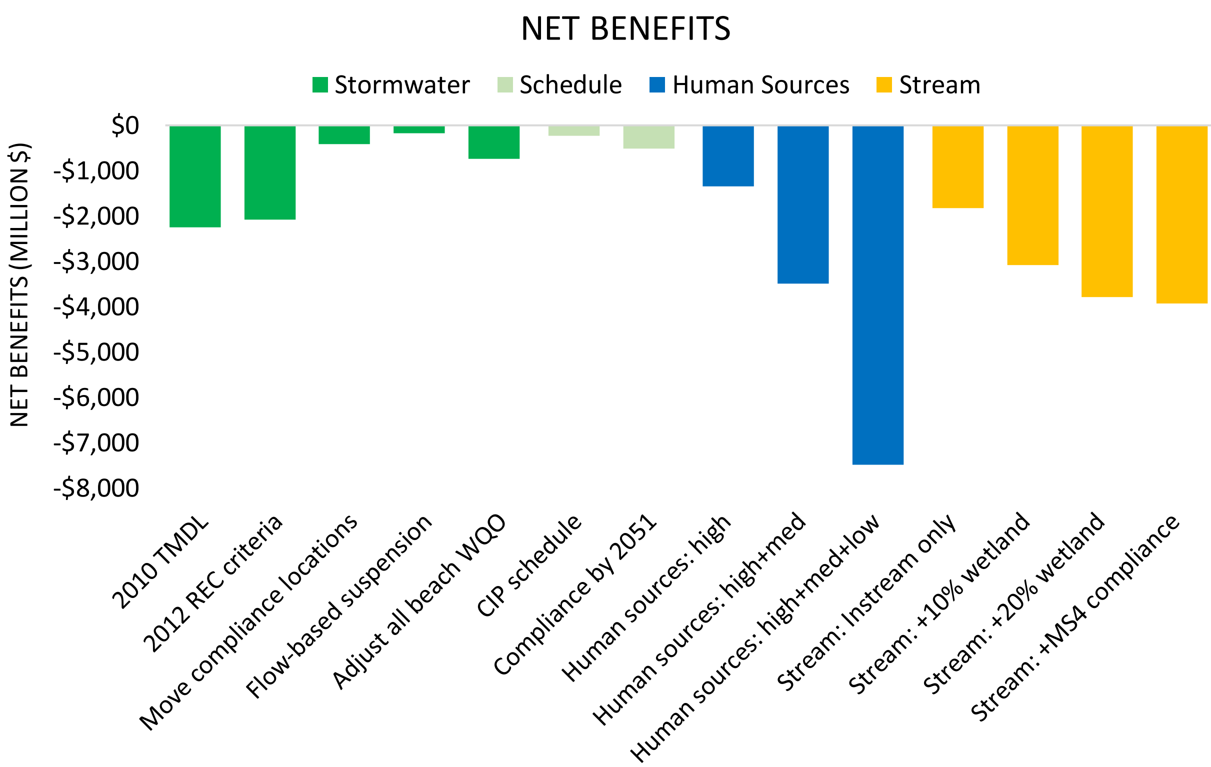

Figure SF-3: A chart displaying net benefits (total benefits minus total costs) with color coding for scenario types. Net benefits are lowest for the Human Sources: High+Med+Low scenario and highest for the Flow-based Suspensions scenario.

Scenarios should not be excluded from consideration by decision makers solely on the basis of negative net benefits. History records examples of policies that were implemented even when quantifiable costs were larger than quantifiable benefits including a well-known national debate on the allowable level of arsenic in drinking water during the late 1990s. There are other examples of environmental laws, such as the Clean Air Act, that were passed with negative net benefits prior to adoption, and were later determined to have positive net benefits after implementation. Non-quantified benefits, such as the co-benefits of enhanced drinking water supply from infiltrated stormwater could also close the gap between benefits and costs. Future generations may identify and value additional benefits beyond those considered in the CBA. Possible implications of CBA results extend beyond monetary impacts to include other considerations.

COST FINDINGS

Stormwater scenarios that allow for more dilution are the least expensive scenarios, with human sources having the highest costs (Figure SF-4). Specifically, the Flow-based Suspensions scenario is least expensive followed by Move Compliance Locations. These results occur because both Flow-based Suspensions and Move Compliance Locations scenarios reduce the required load reduction compared to the 2010 TMDL scenario. Further cost findings include

- **Scheduling scenarios that extend compliance deadlines are also among the least expensive scenarios.** The CIP schedule scenario, which includes the same load reduction as the TMDL schedules but provides 30 additional years to meet the load reduction requirement, expends lower costs each year and discounts costs over a longer timeframe.
- **Stream scenarios have high capital and O&M costs compared to other scenarios.** Since the stream scenarios implement only physical BMPs, they have capital and O&M costs. For stream scenarios, 59% of the total cost is incurred by the compliance deadline. Further, annually, capital costs comprise 80% of annual costs for stream scenarios, while O&M costs are 20%. In other scenarios, O&M costs average 59% of annual costs. Since human sources are not broken down by cost category, they are presented by total cost.
- **Watersheds with relatively low load reduction requirements use mostly programmatic BMPs.** In the stormwater and schedule scenarios, costs are mostly programmatic because those approaches will achieve the relatively lower load reductions. The lowest load reductions are 10.5%, which can be achieved by education, marketing, street sweeping and similar program-based BMPs. Additional information on cost results is found in the *Cost Analysis: Results & Discussion* section.

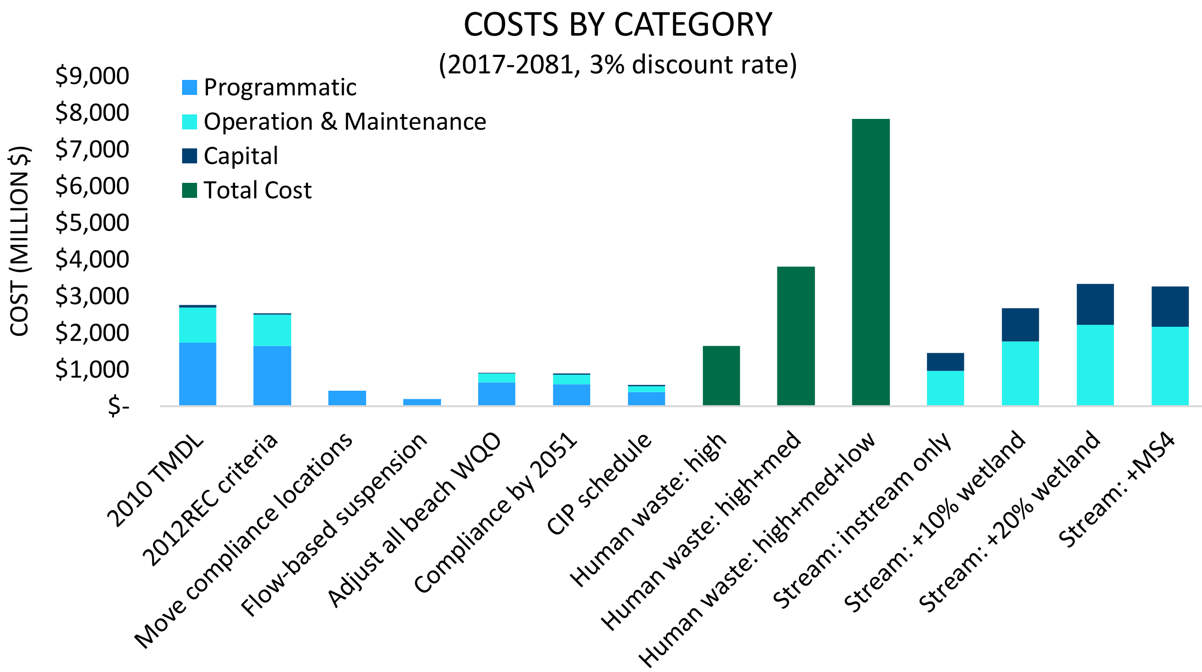

Figure SF-4: Stormwater and schedule scenarios that allow for more dilution or extend compliance deadlines are the least expensive scenarios, with human sources having the highest costs.

Costs are lowest in San Marcos watershed and highest in San Diego River watershed (see Table SF-1). Primary cost drivers for watersheds include watershed size, land use, the load reduction required and physiographic characteristics such as slope.

Table SF-1: CBA watersheds ranked by lowest to highest total cost

COUNTY	WATERSHED	COST RANK
San Diego County	San Marcos	1
Orange County	San Joaquin Hills	2
Orange County	San Clemente	3
Orange County	Dana Point	4
San Diego County	San Dieguito	5
San Diego County	Scripps	6
San Diego County	Tecolote	7
Orange County	Aliso	8
Orange County	San Juan	9
San Diego County	San Luis Rey	10
San Diego County	Chollas	11
San Diego County	Los Peñasquitos	12
San Diego County	San Diego River	13

BENEFIT FINDINGS

Overall, co-benefits are more than twice as valuable as the other benefit categories (Table SF-2). Benefit values for each benefit category include all scenarios over the 65-year timeframe. Additional information about co-benefits is available in the *Total Quantified Benefits* section.

Table SF-2: Total value of each benefit category across all scenarios (2017-2081)

BENEFIT CATEGORY	BENEFIT VALUE (MILLION $)
Recreation	$613
Public Health	$714
Co-benefit	$1,560

Co-benefits are substantially larger than the other benefit categories for all scenario types except for the human sources scenarios. For the human sources scenarios, there are no co-benefits calculated (Figure SF-5). However, the human sources scenario contributes 77% of the total recreation benefits ($475 million) and 65% of the total public health benefits ($467 million), as shown in Table SF-3.

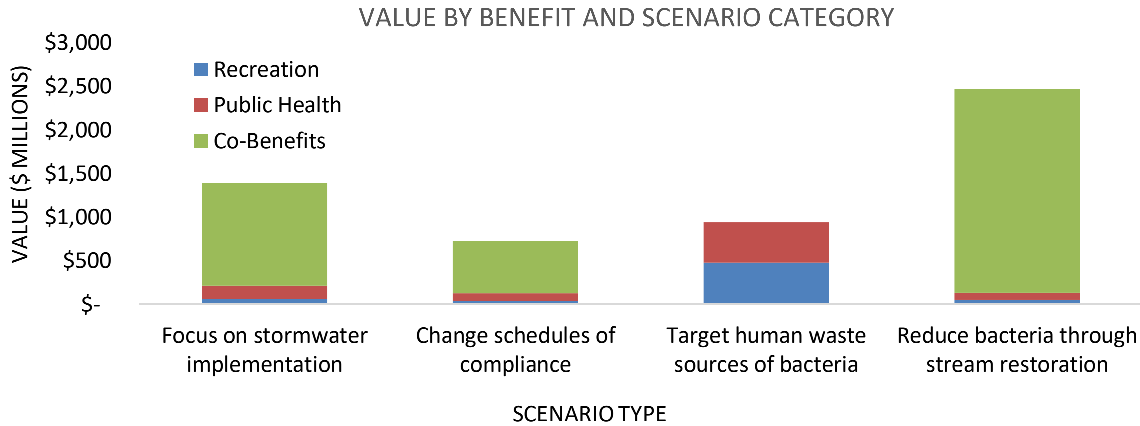

Figure SF-5: A chart comparing benefit categories for each scenario type shows that co-benefits are substantially more valuable than recreation and health benefit categories except for the Human Sources scenario type.

Table SF-3. Net benefit results by scenario type over 65-year analysis period

NET BENEFIT RESULTS (MILLION $)

FOCUS ON STORMWATER IMPLEMENTATION

		2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO
Benefit Analyses	Recreation	$23.7	$20.6	$0.20	$2.20	$9.40
	Public Health	$66.8	$60.9	$1.00	$5.80	$19.10
	Co-benefits	$412	$376	$2.30	$22.0	$153
	Benefits	$502	$457	$3.50	$30.0	$181
Cost Analyses	Programmatic	$1,730	$1,640	$416	$199	$645
	Capital	$56.6	$49.4	--	--	$12.9
	Operation & Maintenance	$961	$848	--	--	$255
	Costs	$2,750	$2,540	$416	$199	$914
	Net benefits	**($2,250)**	**($2,080)**	**($412)**	**($169)**	**($732)**

CHANGE SCHEDULE OF COMPLIANCE

		CIP SCHEDULE	COMPLIANCE BY 2051
Benefit Analyses	Recreation	$15.5	$17.9
	Public Health	$43.5	$50.3
	Co-benefits	$277	$320
	Benefits	$336	$389
Cost Analyses	Programmatic	$396	$592
	Capital	$25.1	$43.7
	Operation & Maintenance	$149	$266
	Costs	$570	$901
	Net benefits	**($234)**	**($512)**

NET BENEFIT RESULTS (MILLION $)

TARGET HUMAN WASTE SOURCES OF BACTERIA

		HUMAN SOURCES: HIGH	HUMAN SOURCES: HIGH+MED	HUMAN SOURCES: HIGH+MED+LOW
Benefit Analyses	Recreation	$154	$155	$166
	Public Health	$134	$160	$174
	Co-benefits	$0.00	$0.00	$0.00
	Benefits	$288	$315	$340
Cost Analyses	Programmatic	--	--	--
	Capital	--	--	--
	Operation & Maintenance	--	--	--
	Costs	$1,640	$3,800	$7,830
	Net benefits	($1,350)	($3,490)	($7,490)

REDUCE BACTERIA THROUGH STREAM RESTORATION

		STREAM: INSTREAM ONLY	STREAM: +10% WETLAND	STREAM: +20% WETLAND	STREAM: +MS4
Benefit Analyses	Recreation	$2.40	$11.5	$17.3	$17.4
	Public Health	$2.20	$22.0	$33.1	$28.3
	Co-benefits	$213	$643	$856	$616
	Benefits	$217	$677	$906	$662
Cost Analyses	Programmatic	$0.00	$0.00	$0.00	$0.00
	Capital	$354	$652	$814	$794
	Operation & Maintenance	$1,690	$3,110	$3,890	$3,790
	Costs	$2,040	$3,770	$4,700	$4,590
	Net benefits	($1,830)	($3,090)	($3,790)	($3,930)

The majority of total co-benefits come from property value, riparian habitat and Nitrogen and Phosphorous reductions. Stream scenarios provide substantial riparian habitat co-benefits while stormwater scenarios provide large property value co-benefits. No co-benefits are possible to quantify for Human Sources scenarios (Figure SF-6). Additional co-benefit information is in the *Summary of Co-Benefits* section.

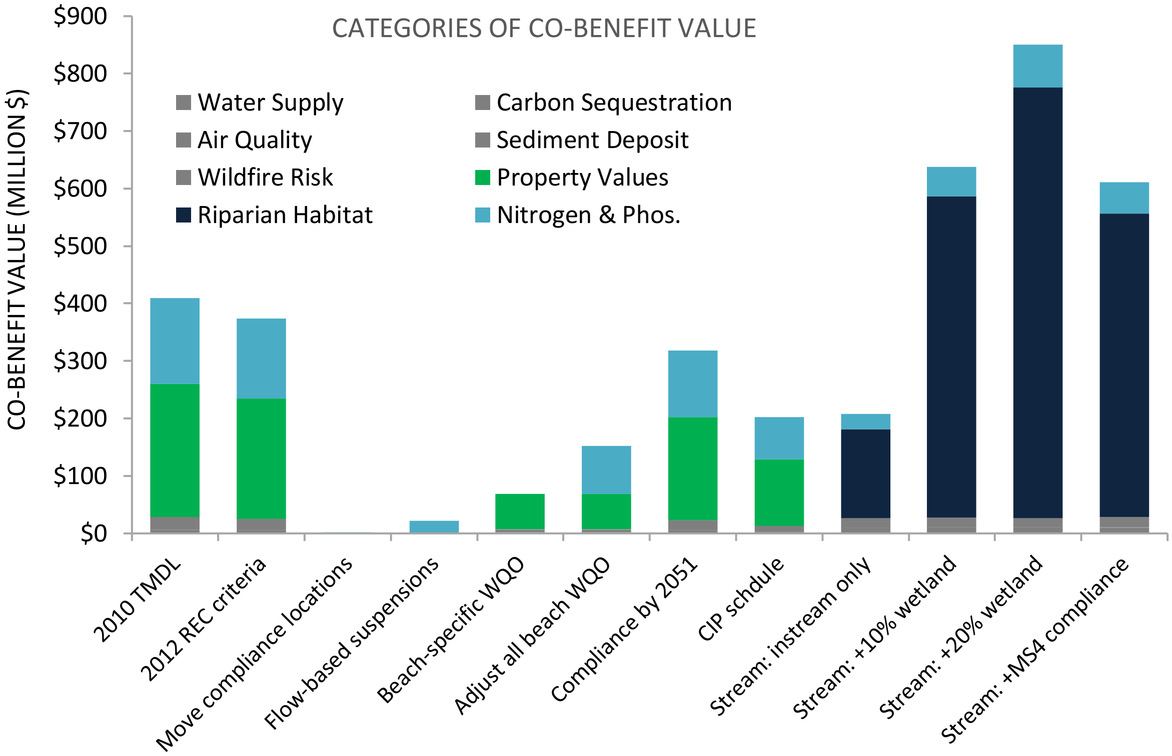

Figure SF-6: A chart comparing the categories of co-benefits and their contributions to each scenario. The majority of total co-benefits come from property value, riparian habitat and Nitrogen and Phosphorous reductions. Stream scenarios provide substantial riparian habitat co-benefits while most stormwater scenarios provide large property value co-benefits.

UNCERTAINTY AND SENSITIVITY

Quantitative uncertainty analysis shows that major cost-effectiveness and net benefit findings are high confidence. The CBA includes a substantial effort to provide a broad and quantitative sense of the uncertainty within the CBA results. This uncertainty calculation provides a "best estimate" that is analyzed in the CBA, then introduces high and low "bracket values" that are passed through the remainder of the analyses steps to show error bars in CBA results focused on units of benefit and cost effectiveness. The CBA provides recommendations for additional research to further refine numeric results.

Sensitivity testing shows that numeric results would change with different assumptions but these adjustments are unlikely to adjust major cost-effectiveness and net benefit findings. Sensitivity testing of assumptions in the human sources analysis would change the ratio of pathogen sources but would not significantly change the relative risk analysis and benefits values in terms of their orders of magnitude. Sensitivity testing of illness valuations would change net benefit results but would not change the negative net benefit finding. Sensitivity tests that assume much greater avoidance of baseline illness substantially close the net benefit gap, but would not change the negative net benefit finding. For example, benefits under the most ambitious human sources scenario represent avoidance of all wet weather infectious illness and lost trips, yet are still not of the magnitude of costs for most scenarios. A variety of other sensitivity tests are described throughout the document.

SCREENING FINANCIAL CAPABILITY ASSESSMENT FINDINGS

Screening FCA results indicate a high financial burden for residential water services. According to USEPA guidance, a high financial burden when annual water costs exceed 2% of median household income. In this analysis, results exceed 4%, more than double the threshold level. Current services produce a "high burden" of $2660/year on residents, while the Bacteria TMDL adds a smaller $391/year additional cost (Table SF-4). Further, the trash amendment, which requires BMPs to reduce trash entering TMDL watersheds, adds $18.50/year in additional costs. USEPA requires a full FCA to be completed as evidence for justifying a schedule extension as analyzed in the Compliance by 2051 and CIP Schedule scenarios.

Table SF-4. Screening FCA results indicating the level of burden for water services.

	ADJUSTED MHI	CPH	RIS	LEVEL OF BURDEN
Current Services				
Wastewater	$66,100	$1,970	2.98%	
Stormwater	$66,100	$658	1.04%	
Combined	$66,100	$2,660	4.02%	High
Additional Services				
Bacteria TMDL	$66,100	$391	0.59%	
Trash	$66,100	$18.5	0.03%	
Combined	$66,100	$410	4.63%	High
Current + Additional Services	**$66,100**	**$3,070**	**4.63%**	**High**

SCENARIO LOAD REDUCTIONS COMPARED TO GOALS

Many scenarios achieve current TMDL load reduction targets but others achieve different targets based on adjusted regulatory endpoints. Human Sources scenarios are not comparable because they are calculated from a different baseline. Load reductions are calculated for each scenario and compared to the TMDL load reduction target in each watershed. All Stormwater and Scheduling scenarios achieve compliance under the scenario assumptions but some scenarios do not need to achieve the current TMDL load reduction target. For example, the Move Compliance Locations scenario relocates sampling points to areas of greatest recreation and exposure, which allows for greater dilution. Stream scenarios, which are defined by their load reduction compared to the TMDL load reduction target, achieve compliance in only the Stream: +MS4 scenario, as expected. Human Sources scenarios reduce loads by 92-100% of existing loads from sewers and transient encampments and other human sources, but this is a different baseline load and cannot be compared to scenarios that focus on Stormwater and Stream treatment. Figure SF-7 shows load reductions in the San Diego River watershed. Results are similar across all watersheds.

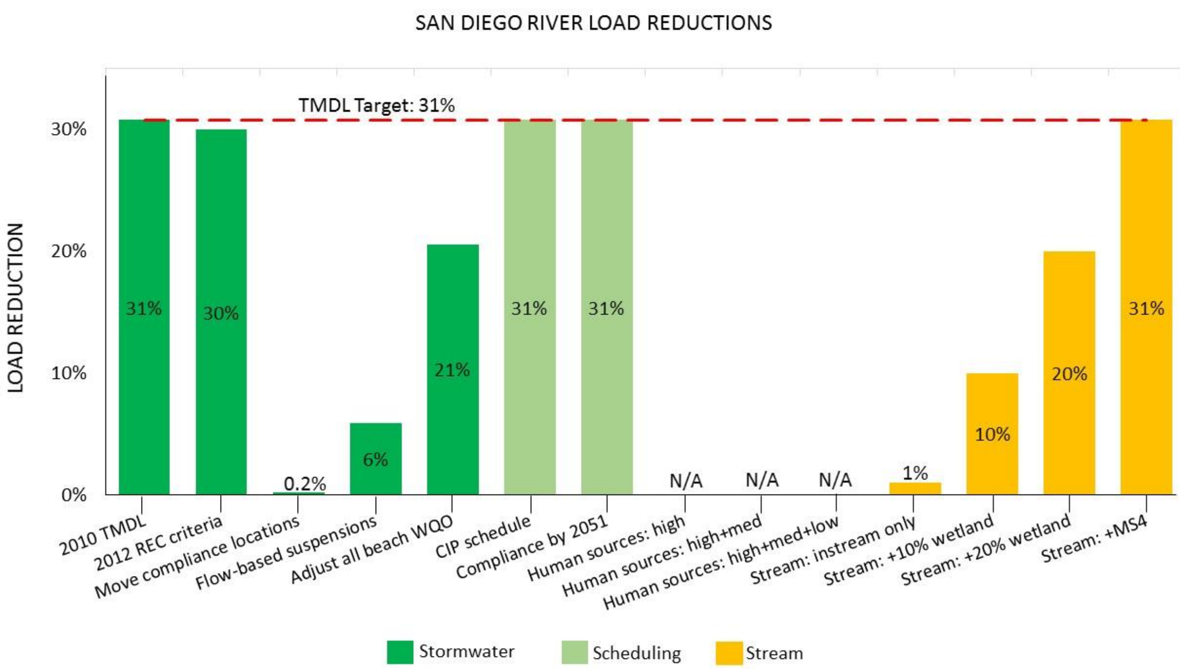

Figure SF-7: A figure showing planned load reductions for each scenario compared to the TMDL load reduction target (red line) for the San Diego River watershed. Stormwater scenarios that move sampling locations or suspend requirements during certain times do not need to meet the current target to achieve compliance. Human Sources scenario load reductions are calculated on a different loading baseline and are not comparable to other scenarios. Stream scenarios achieve goals under the MS4 compliance scenario only.

2. INTRODUCTION AND APPROACH OVERVIEW

San Diego's coastline and water resources are important to its attractiveness and economic vitality. However, water-borne illnesses affect beach visitation and impact the regional economy through lost work days and additional health care expenses. In 2010, state and federal agencies established the Bacteria TMDL to limit the fecal indicator bacteria entering the region's coastal ecosystems. As part of the Triennial Review of the Regional Board's Basin Plan, a Steering Committee guided development of a cost-benefit analysis (CBA) to evaluate the benefits and costs of various implementation decisions.

Guided by a Steering Committee, and with technical direction from a Technical Advisory Committee, the CBA follows federal guidance for conducting economic analysis. It applies available science and leading economic theory to assess scenarios, each altering how bacteria are controlled. There are four types of scenarios, including those that treat stormwater, change schedules of implementation, treat human sources of bacteria and restore streams to filter and eliminate bacteria that would otherwise flow to coastal water bodies. Scenarios are evaluated by their effect on human health, recreation trips and co-benefits, which are additional measures of environmental and social benefit. Results convey the cost-effectiveness, net benefits and total costs of each scenario, which comprise important information for decision makers as they consider changes to the way the Bacteria TMDL is implemented.

PROCESS PARTICIPANTS

The CBA was guided by a Steering Committee comprised of Bacteria TMDL permittees, utilities, regulators and local stakeholders. Over the duration of the project, Steering Committee members convened regularly to define project objectives and review consultants' progress towards meeting these objectives. Completion of these analyses required the work of several different consultants with varying areas of expertise. Primary and sub-consultants were contracted to complete the project. A Technical Advisory Committee (TAC), comprised of experts from relevant disciplines, reviewed the consultants' work to ensure the technical appropriateness of methodologies implemented. Consultants then modified the CBA analysis, as appropriate, based on feedback received from the TAC. Following incorporation of comments from the TAC, the public was given an opportunity to review and comment on the CBA document. Consultants then modified the CBA, as appropriate, based on public feedback. Members of the Steering Committee, TAC, consulting team and facilitators are listed in the *Acknowledgements* section.

FEDERAL GUIDANCE ON CBA

These analyses follow federal guidance for economic analysis to assess costs and benefits, augmented by relevant economic theory, literature and research precedents, particularly from peer-reviewed sources. The primary guidance for this work is the U.S. Environmental Protection Agency's *Guidelines for Preparing Economic Analyses*[1]. These USEPA guidelines follow general guidance to all federal agencies for economic analysis in a regulatory context. The Office of Management and Budget provides guidance to federal agencies on development of regulatory economic analyses via Circular A-4.[2] Circular A-4 recognizes that proposed regulations require economic analysis to understand tradeoffs. As initial overall guidance, it states,

[1] U.S. Environmental Protection Agency. 2010. Guidelines for Preparing Economic Analyses. December. http://yosemite.USEPA.gov/ee/USEPA/eed.nsf/pages/guidelines.html.

[2] Office of Management and Budget. 2003. Circular A-4. http://www.whitehouse.gov/omb/circulars_a004_a-4.

> *"Cost-benefit analysis is a primary tool used for regulatory analysis. Where all benefits and costs can be quantified and expressed in monetary units, cost-benefit analysis provides decision makers with a clear indication of the most efficient alternative, that is, the alternative that generates the largest net benefits to society (ignoring distributional effects). This is useful information for decision makers and the public to receive, even when economic efficiency is not the only or the overriding public policy objective."*[3]

This overall guidance indicates that all benefits and costs should be considered, and it recognizes that a balanced trade-off analysis would use dollars as the most appropriate metric.

> *"When important benefits and costs cannot be expressed in monetary units, BCA is less useful, and it can even be misleading, because the calculation of net benefits in such cases does not provide a full evaluation of all relevant benefits and costs."*[4]

Circular A-4 recognizes that CBA can lead to incorrect decisions if it does not include a complete valuation of all benefits and costs. OMB emphasizes that all benefits and costs of importance should be considered:

> *"A good regulatory analysis should include [...] an evaluation of the benefits and costs— quantitative and qualitative—of the proposed action and the main alternatives identified by the analysis. [...] If you are not able to quantify the effects, you should present any relevant quantitative information along with a description of the unquantified effects, such as ecological gains, improvements in quality of life, and aesthetic beauty."*[5]

Circular A-4 goes on to provide guidance on how to measure and compare benefits and costs. The USEPA echoes and references Circular A-4 guidance and these fundamental principles of CBA in its own *Guidelines for Preparing Economic Analyses.*[6] USEPA states in its *Guidelines:*

> *"Estimating benefits in monetary terms allows the comparison of different types of benefits in the same units, and it allows the calculation of net benefits – the sum of all monetized benefits minus the sum of all monetized costs – so that proposed policy changes can be compared to each other and to the baseline scenario."*

USEPA's *Guidelines* provide extensive detail on appropriate techniques for conducting cost-benefit analysis. This study follows those guidelines to the fullest extent feasible.

APPROACH TO CBA

The CBA follows a defined analytical approach within the framework of Figure 1. In general, the analysis approach involves

- **Defining the scope: bacteria treatment -** The CBA assesses costs and benefits from implementing wet weather BMPs in San Diego County and Orange County watersheds that have required load reductions under the Bacteria TMDL.
- **Developing scenarios for analysis -** Scenarios define the conditions that are assessed in the CBA. Each scenario alters aspects of implementation strategies to achieve Bacteria TMDL goals. Scenarios are organized into four types, including Stormwater scenarios that focus on traditional implementation strategies and Scheduling scenarios that extend compliance deadlines and coordinate BMP implementation with capital infrastructure projects. Further, Human Sources scenarios focus on efforts to reduce leaking sewer pipes, repair septic systems and assist transient populations that contribute additional bacteria loads beyond those from conventional stormwater.

[3] OMB Circular A-4.
[4] OMB Circular A-4.
[5] OMB Circular A-4.
[6] U.S. Environmental Protection Agency. 2010. Guidelines for Preparing Economic Analyses. December. http://yosemite.USEPA.gov/ee/USEPA/eed.nsf/pages/guidelines.html.

Finally, Stream Restoration scenarios focus on stream restoration and engineered wetland implementation to improve ecosystem services that results in sequestration and/or destruction of fecal indicator bacteria and pathogens.

- **Conducting an analysis on health risk to understand illness rates under different water quality conditions -** Using area-specific data, the CBA estimates illness rates from pathogens covered under the Bacteria TMDL. Assumptions regarding dilution rates, loads from contributing sources, natural attenuation and peoples' beach attendance, inform rates of illness.
- **Analyzing benefit and costs from each scenario's efforts -** Once the health risk analysis determines illness rates, the CBA quantifies the costs of reducing illnesses and obtaining more beach trips. Further, it determines the value of avoided illnesses and regained recreation days. Since the strategies to address public health and recreation have ancillary benefits, the CBA quantifies those co-benefits too.
- **Presenting results in terms of cost-effectiveness, total costs, total benefits and net benefits -** Results provide insight into changes to Bacteria TMDL implementation strategies that could maximize benefits for their cost. Cost-effectiveness, which calculates illnesses avoided and beach trips regained per million dollars, inform decisions about thoughtful use of public funding. Further, net benefits help inform actions that provide greatest positive effects compared to other approaches.

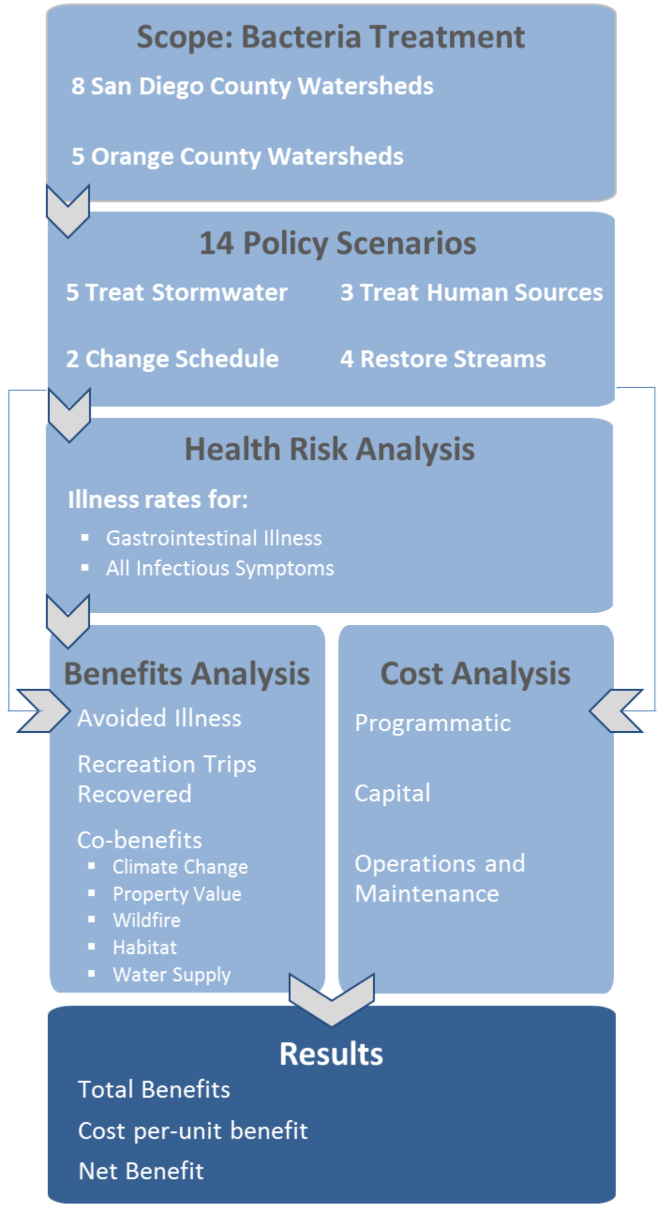

Figure 1: This effort analyzes more than a dozen scenarios to compare their cost effectiveness and net benefit across more than a dozen San Diego and Orange County watersheds.

The CBA uses the best economic approaches and scientific data to conduct analyses and determine results. Scenarios use a standard, defined time period and discount rate. Also, uncertainty analyses run for each scenario provide best, high- and low-bracket values showing ranges of potential outcomes, with best values equaling the original calculations. Sensitivity analyses show the effect of major assumptions on numeric results, informing an understanding of the likelihood for results or findings to change with future research.

ANALYSIS PRINCIPLES FOR THIS CBA

Certain key economic principles underlie the approach in this study. These principles, while not exhaustive, support an effort to compare all scenarios on common terms and with a comprehensive perspective. Analysis principles include marginal benefits, supply and demand, and geographic and temporal scale. These principles help guide how to identify and analyze the data representing benefits for each scenario, and how to consider the full set of benefits that can accrue over time.

Marginal and Incremental Effects

Measuring benefits and costs to society requires identifying and measuring the incremental changes in valuable goods and services provided by a scenario with respect to a baseline representation of the world without that scenario. The comparison of each scenario to the baseline and other scenarios extends into the future to capture all important effects of the investments and actions of a scenario. It also allows identification of differences among scenarios for measurement and valuation. If certain goods and services are consistent across all scenarios, it is not necessary to measure their value as that value is not attributed to any of the scenarios. This approach also supports capture of all costs and benefits under a scenario, but not those that would have occurred regardless. For example, if certain upgrades to water treatment are underway and will occur regardless of scenario, those costs and benefits should be considered part of the baseline, and not attributed to any other scenario.

As a whole, this analysis is concerned with improvements in water quality on the margin. It does not assess the total value of current water quality conditions. That is, given current water quality conditions and opportunities for improvements, it assesses marginal costs and marginal benefits. Throughout this study, costs and benefits are assessed forward-looking, evaluating the additional costs of options moving forward, and the additional benefits that those options would provide.

Focus on Wet Weather Benefits

The focus is on wet weather events when relevant recreation opportunities decrease in quality and quantity in terms of water quality, as opposed to dry weather improvements that would improve all conditions beyond those currently experienced. This distinction is relevant because of elasticity of demand, or responsiveness of demand to changes in supply. In general, due to diminishing returns, an increase in recreation opportunities in terms of quality or quantity would not produce a proportional response in participation. For example, if a surfer has one beach to choose from and suddenly has two beaches to choose from, it is unlikely he or she would double total surfing trips. It is also difficult to predict how much more surfers would participate if current dry weather conditions were dramatically improved. It should be noted, however, that BMPs for wet weather water quality improvements such as LID, stream restoration, and human input reduction, are also effective in dry weather conditions.

Supply and Demand

Supply is measured through changes in water quality and other effects of actions and investments on the future state of the world. Scenario analyses rely on information produced by the Bacteria TMDL, historical data and modeling results to determine supply. The objective is to quantify and value changes in the supply of final goods and services of worth to people, such as reduced illness risk. Demand for these goods and services determine their value to society. Data and information requirements for determining supply and demand include:

- The number of people using the good or service
- The overall abundance of the good or service (e.g., scarce = demand exceeds supply, willingness-to-pay is greater than zero.)

- The cost of coping with the absence of a good or service (how expensive is medical treatment if an illness occurs?)
- The importance of the final use or activity (e.g., is beach or ocean recreation important?)

Collectively, the supply of goods and services from investments is often relatively straightforward (although not necessarily simple) to quantify, but valuation requires consideration and measurement of demand and scarcity as well.

Geographic and Temporal Scale

The geographic focus of this analysis is the area of basins associated with Bacteria TMDL watersheds. According to federal guidelines, the appropriate geographic scale is that area sufficient to capture all relevant benefits and costs, and of immediate jurisdictional interest for potential beneficiaries. All analyses in this section found the occurrence of benefits limited to the basins included in the Bacteria TMDL, although some of the beneficiaries likely travel from outside the basins.

The appropriate timeframe for analysis captures all substantial benefits and costs of scenario investments and actions. It is important to include all appropriate costs for corresponding benefits including any capital replacement and operation and maintenance costs over time necessary to maintain the flow of benefits. And it is important that any comparisons between scenarios use similar timeframes. In general, the analyses focus on 65 years for each scenario.

Discounting for Time

Discounting is a necessary step in cost-benefit analysis to equalize the weighting of effects that occur in different years. OMB's *Circular A-4* recommends discount rates of 3% and 7%, generally based on market factors of growth in the economy and return on capital investments. A single consistent discount rate of 3% is used in this CBA.

Many prominent economists in environmental and natural resource economics advocate for a discount rate that declines over time when evaluating long-term effects. The benefits section does include a sensitivity analysis to check the effects of using a declining discount rate. By including a declining discount rate to compare to 3%, sensitivity to long-term effects can be considered across scenarios, particularly given that some scenarios do not reach full effect for several decades.

BMP Performance and Design

While the CBA makes some extrapolations and refinements, in general the analyses and scenarios do not involve new modeling to identify effective BMPs. For example, some infiltration-based low impact development BMPs have been shown to be effective on removing indicator bacteria, but assumptions must be made on their effectiveness at removing pathogens. Future technology advances might improve the overall effectiveness of stormwater BMPs. However, these considerations are not reflected in this CBA. Instead, the CBA relies on existing water quality data and BMP information and coordination with engineering and water quality experts for application, extension, and refinement of those data. This is particularly relevant for quantitatively defining scenarios and developing necessary inputs.

SCENARIO DEVELOPMENT

The CBA reveals how the costs and benefits of compliance change under different scenarios based on alternative strategies to achieve Bacteria TMDL goals, such as modifying compliance requirements or using different methods to achieve compliance. Scenarios analyzed were defined by the Steering Committee with guidance from consultants on what could be analyzed within limitations of a CBA, the data available, and the project timeline. Scenarios were not included or excluded based on the likelihood of meeting regulatory requirements, political acceptability, feasibility of adoption, or other factors which could prevent adoption. While all Steering Committee members contributed to the development of included scenarios, they do not all support implementing each scenario to achieve Bacteria TMDL goals. A range of scenarios was included to represent the wide variety of possible regulatory and implementation approaches to complying with the TMDL.

A qualitative description and numeric goal was developed for each scenario selected. The qualitative description was agreed upon by the Steering Committee during the scenario development process. The numeric goal (i.e., WQO or water quality endpoint) for each scenario was developed in consultation with the steering committee to allow for quantitative evaluation through modeling and/or other methods. Each scenario is described in detail in the *Analysis Structure: Scenario Types and Scenarios* section below.

ANALYSIS STRUCTURE: SCENARIO TYPES AND SCENARIOS

The CBA is structured around a set of scenario types which are informed by policy decisions. The primary scenario types are

- Focus on stormwater implementation (Stormwater);
- Change schedule of compliance (Scheduling);
- Target human sources of bacteria (Human Sources); and
- Reduce bacteria through stream restoration (Stream).

Each scenario type has potentially significant ramifications related to the way water quality objectives are achieved and the costs to achieve them. In addition to the scenarios, additional economic analyses beyond the technical boundary of cost-benefit analyses, such as financial capability assessment, were included. The CBA structure is presented in Figure 2, including scenario types as green boxes and scenarios as dark blue boxes.

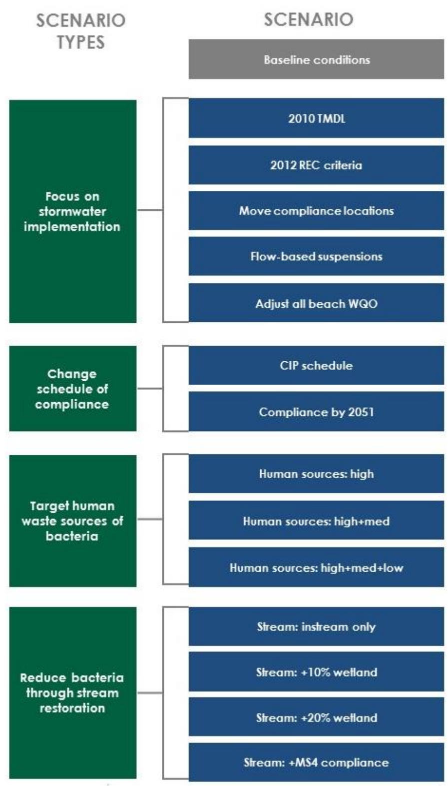

Figure 2. The scenario types, scenarios and anticipated results that form the structure of this economic analysis. Green boxes indicate scenario types, blue boxes indicate individual scenarios which are grouped by scenario type. The CBA methodology is applied to each individual scenario.

BASELINE FOR CALCULATING SCENARIO RESULTS

Economic analysis requires a well-defined baseline for identification and measurement of the marginal or incremental effects of new policies and actions.[7] Analyzing changes resulting from scenarios, such as improvements in water quality and costs of compliance and noncompliance, requires information on baseline conditions. Therefore, both costs and benefits are the differences between the current (baseline) costs and benefits and those associated with WQIP implementation.

Baseline Conditions

Baseline conditions extrapolate from 2014-2015 conditions through the 65-year analysis period, including anticipated climate change effects on regional storm timing, frequency, and severity as well as temperature. Such changes will influence the timing and frequency of wet weather events with bacteria/pathogen levels above background, and the demand for activities at beaches that can result in exposure risk. Numerous studies exist to consider the regional effects of climate change, including the San Diego Foundation's 2050 Study[8].

While establishment of an understanding of current conditions to support scenario analysis will entail quantification of certain benefits and costs, this scenario does not include a definition of some specific set of actions and outcomes that were historically necessary to arrive at the current set of water quality conditions. This analysis describes current conditions and the baseline in detail, but does not fully value all benefits and costs that have arisen through regional water quality improvement investments to-date.

SCENARIO TYPE: FOCUS ON STORMWATER IMPLEMENTATION

Bacteria regulatory endpoints are described in the Bacteria TMDL and each permittee's approach for achieving these endpoints is established in its respective WQIP(s). The WQIPs focus on activities and projects to manage bacteria loading and runoff from urbanized areas and other sources conveyed by the MS4 system. The WQIPs target stormwater bacteria reductions and dry weather runoff to achieve TMDL compliance. These regulatory endpoints can be adjusted in several ways based on interpretation of the water quality requirements necessary to achieve recreational beneficial uses, as represented by the associated scenarios. Each scenario is described in terms of how it compares to the 2010 TMDL scenario. For each scenario, except the baseline scenario, compliance is achieved through implementation of BMPs identified in the WQIPs. BMPs generally represent all nonstructural and structural load reduction strategies considered. Baseline conditions are based on existing BMPs and programs. The estimated costs and benefits of stormwater BMPs implementation informed the CBA analysis results. Based on these results and in combination with discussions regarding how to incorporate the Surfer Health Study and proposed updated to statewide bacteria water quality objectives, the CBA provides useful information that can be used to determine appropriate adjustments to the compliance endpoints.

Scenario: 2010 TMDL

Summary: Determine the costs and benefits of meeting the 2010 Bacteria TMDL through WQIP strategies.
Fecal Coliform Water Quality Objective: 400 (colonies/100ml) as a not-to-exceed value[9]
This scenario estimated the costs and benefits of complying with the current San Diego Basin Plan water quality objectives for bacteria. Bacteria levels have historically exceeded the current fecal coliform water

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[7] See Chapter 5 for full discussion of baseline considerations in U.S. Environmental Protection Agency. 2014. Guidelines for Preparing Economic Analyses. May. http://yosemite.USEPA.gov/ee/USEPA/eed.nsf/pages/guidelines.html.

[8] San Diego Foundation. 2009. San Diego's Changing Climate: A Regional Wakeup Call.

[9] Note that WQOs in the CBA are fecal coliform-based or equivalent, though some criteria are based on *Enterococcus*- or *E. coli*. Units are often expressed as most-probable number (MPN) or colony-forming units (CFU) to allow for comparisons among criteria.

quality objectives, especially during wet weather conditions. TMDLs represent the maximum amount of bacteria that waterbodies can receive and still attain water quality objectives. To provide reasonable assurance that water quality objectives identified in the 2010 Bacteria TMDL are achieved, WQIPs were developed to identify the MS4s' numeric water quality goals, schedules for achieving these goals, and proposed water quality improvement strategies. Examples of WQIP compliance strategies include structural and nonstructural BMPs, including various BMP types that are designed to treat or remove bacteria and programs that are designed to reduce bacteria loading through various mechanisms and outreach efforts. BMPs identified in the WQIPs generally focus reducing stormwater loading and dry weather runoff, rather than focusing on source control efforts that may be more effective in some cases.

Scenario: 2012 REC Criteria

Summary: Determine the costs and benefits of meeting the USEPA 2012 Recreational Water Quality Criteria.

Fecal Coliform Water Quality Objective: 565 (colonies/100ml) as a not-to-exceed value

USEPA's 2012 recreational water quality criteria recommendations are intended to protect people recreating at beaches and creeks from exposure to water that contains organisms that indicate the presence of fecal contamination (*Enterococcus* and *E. coli*).[10]

REC criteria apply to uses of water for recreational activities involving body contact, where ingestion of water is reasonably possible, such as swimming or other water sports. USEPA's 2012 criteria recommend an acceptable health risk based on meeting an additional gastrointestinal illness rate of 32 or 36 per 1,000 primary contact recreators. California is currently considering adopting USEPA's recommendations at the 32 additional illness rate. The REC criteria include requirements for *E. coli* and *Enterococcus*, but not fecal coliform. A geometric mean of 100 (colonies/100ml) and a statistical threshold value (STV) of 320 (colonies/100ml) is specified for *E. coli* and a geometric mean of 30 and a STV of 110 is specified for *Enterococcus*. To facilitate comparison to the fecal coliform-based water quality objectives in other scenarios, USEPA's *E. coli*-based criteria were used as a surrogate for fecal coliform. A fecal coliform-based endpoint of 565 (colonies/100ml) at the 32 additional illness rate was derived from the dataset that was used to develop USEPA's 2012 REC criteria (i.e., the National Epidemiological and Environmental Assessment of Recreational Water [NEEAR] data). Note that an *E. coli* STV criterion of 320 (colonies/100ml) is the 90th percentile of NEEAR *E. coli* data at the additional illness rate of 32. 565 (colonies/100ml) is the 97th percentile of the NEEAR *E. coli* data. Use of the 97th percentile value was recommended as an equivalent not-to-exceed value under a typical sampling regime. As quantified by the SHS, the region currently experiences less than half of the allowable illness rates in the 2012 REC criteria, even during wet weather.

Scenario: Move Compliance Locations

Summary: Determine the costs and benefits to achieve compliance with the Bacteria TMDL in recreational areas, which are typically downcoast from a creek or outfall discharge point along a beach.

Fecal Coliform Water Quality Objective: 400 (colonies/100ml) as a not to exceed value

Final TMDL compliance is determined through sampling of bacteria concentrations at specific locations along streams and along the ocean coastline. This scenario maintains the same water quality objective in the 2010 TMDL scenario, but proposes moving the compliance location out of the creek, river mouth or in front of a storm drain outfall to the ocean downcoast to where recreation typically occurs (Figure 3). Therefore, the endpoint for this scenario is based on a more appropriate compliance location that is

[10] *Recreational Water Quality Criteria*. Tech. USEPA Office of Water 820-F-12-058, 26 Nov. 2012. Web. https://www.USEPA.gov/sites/production/files/2015-10/documents/rwqc2012.pdf.

representative of recreational exposure. As a result, samples collected at these locations will be more likely to represent actual health risk. For this scenario, the water quality objective and TMDL allowable loads were not changed, although bacteria concentrations at the new compliance location will likely be lower than at the current location due to dilution. The estimated load reduction required to meet the 2010 Bacteria TMDL will be lower considering dilution. Fewer BMPs will need to be implemented to meet the TMDL allowable loads; therefore, compliance costs will be lower. To account for dilution at the new compliance locations, a dilution factor of 22 was applied to all the TMDL waterbodies. Although dilution can vary among different ocean beaches and locations along a beach, a consistent dilution factor was applied to allow for comparison between scenarios and the watersheds. The dilution factor was derived using fecal coliform data from the Surfer Health Study and based on assumptions and methods which were used to derive dilution factors in the Surfer Health Study Quantitative Microbial Risk Assessment (QMRA). See Appendix B for more details on the derivation of the dilution factor.

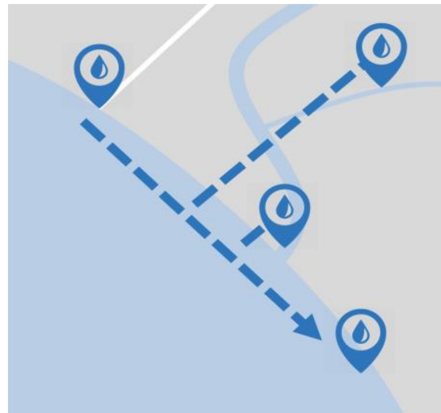


Figure 3. The Move Compliance scenario relocates sampling locations from storm drain outfalls, creeks and river mouths to downcoast recreation areas.

Scenario: Flow-based Suspensions

Summary: Determine the costs and benefits of suspending REC-1 compliance requirements under high flow conditions when it is unlikely people will be exposed to bacteria and pathogens within creeks and rivers due to hazardous conditions. This scenario is specific to recreational use within creeks and rivers, as beach use is not necessarily affected. Incorporation of a low flow suspension was also considered recognizing that many creeks and rivers (or segments) may be dry during certain periods or have very low water levels that would not support recreational uses. Currently, there is more regulatory precedent for incorporating a high flow suspension provision (as specified in the Los Angeles Basin Plan and the current draft statewide bacteria water quality objectives) and the wet-weather orientation of the CBA caused this scenarioto focus on evaluating the costs and benefits associated with excluding high flow periods in the analysis.

Fecal Coliform Water Quality Objective: 400 (colonies/100ml) as a not to exceed value

On days when rainfall is greater than or equal to 0.5 inch, as measured at the nearest local rain gauge, a high flow suspension applies to the storm day and 24 hours following the event. Compliance with REC-1 requirements are suspended during high-flow periods in this scenario due to hazardous conditions that are typically associated with large storms that generate increased flow volumes and velocities. The suspension was universally applied in this scenario rather than concrete-lined channels only (as specified in the Los Angeles Basin Plan, for example) to allow for comparison of the results across the watersheds. Bacteria loading may increase during large storm events; however, the risk of exposure is low because recreation will be minimal due to potentially dangerous flow conditions. As a result, bacteria loads associated with these high flow days do not need to be reduced. Fewer BMPs will need to be implemented to meet the TMDL allowable loads; therefore, compliance costs will be lower.

Scenario: Adjust All Beach WQO

Summary: Determine the costs and benefits to achieve compliance based on applying the beach-specific WQO endpoint derived from the SHS to all TMDL beaches.

Fecal Coliform Water Quality Objective: 2,215 (colonies/100ml) as a not to exceed value

The Surfer Health Study provided the best and most recent data available in the region to determine health risks at local beaches and results are assumed to be representative of bacteria water quality and health risks in the region. The fecal coliform endpoint of 2,215 (colonies/100ml) represents the 97th percentile of fecal coliform data at the additional illness rate of 32 from the Surfer Health Study. Note that the Surfer Health Study reported an *Enterococcus* concentration of 175 (colonies/100ml) and a fecal coliform concentration of 61 (colonies/100ml) associated with the additional illness rate of 32; therefore, the 97th percentile was calculated based on the fecal coliform geometric mean concentration of 61 (colonies/100ml) and the associated standard deviation. Use of the 97th percentile value was recommended as an equivalent not-to-exceed value for comparison to the endpoints in the other scenarios. In this scenario, the fecal coliform endpoint is applied to all beaches north of the City of Imperial Beach in the San Diego region.

SCENARIO TYPE: CHANGE SCHEDULE OF COMPLIANCE

Extended compliance timelines could reduce the annual cost burden for implementing BMPs. While dates for achieving compliance are established by the Bacteria TMDL and implementation of compliance strategies are described in the WQIP, this scenario type analyzes achievement of Bacteria TMDL compliance over an extended schedule compared to the current schedule. Differences are compared on the basis of costs, benefits and residential indicator scores.

Scenario: CIP Schedule

This scenario examines the costs and benefits of implementing structural BMPs in coordination with capital improvement projects (CIP) rather than as standalone projects. Implementation of BMPs at the same time as implementation of infrastructure projects according to the CIP Schedule will reduce construction costs. For example, implementation of permeable pavement to reduce stormwater runoff could be installed in coordination with pavement repair according to the CIP Schedule, which is usually 50 years or longer. As a result, pavement excavation and installation could be done for both projects simultaneously to eliminate the cost of multiple rounds of construction. Initial estimates for the timeframe necessary to glean a substantial savings are a 50-year extension of current compliance deadlines. This lengthened timeframe will also affect the distribution of costs and benefits over time and may adjust the net benefits calculated. This scenario reduces costs by 25% compared to the 2010 Bacteria TMDL schedule.

Scenario: Compliance by 2051

In this scenario, the deadline to achieve wet weather compliance as described in the Bacteria TMDL is extended to 2051. The extended compliance timeline alters the costs and benefits of wet weather TMDL compliance, with the timing or order of realizing costs and/or benefits altered under the extended timeframe. Additionally, discounting over the longer timeframe alters calculations of costs and/or benefits. As a result, the total calculation of costs or benefits may be different over the longer timeframe.

SCENARIO TYPE: TARGET HUMAN SOURCES OF BACTERIA

This scenario estimates the costs and benefits of addressing human sources of bacteria including leaking sewer lines, septic systems and transient encampments instead of traditional stormwater pollutant sources. Human waste has high concentrations of illness-causing pathogens and could originate in transient encampments, failing septic systems, leaking wastewater collection systems and sewer spills. The WQIP strategies focus on activities and projects to manage pollutant sources and flows from land runoff conveyed by the stormwater system, but in reality, other non-human, land-based sources are contributing bacteria loads and affecting receiving water compliance. In particular, water quality monitoring results from the Surfer Health Study and associated follow-on studies during rain events indicate the presence of human waste in discharges to the ocean in the San Diego River and Tourmaline Creek Watersheds.

Strategies to reduce bacteria and illness rates could prioritize human sources first, since stormwater projects proposed in the WQIPs may not be as effective at improving public health as other approaches. For example, the transient population is both a source of bacteria and exposed to bacteria in creeks. Costs to reduce loads from transient encampments could be substantially different than those in the Stormwater scenarios. However, efforts to reduce transient loads could present unique challenges, as they could require coordination among multiple agencies, civil society organizations and other stakeholders. In addition, leaking sewage and septic systems are sources of human pathogens that are prohibited from entering surface waters, but when they do, they represent a higher threat to public health than other sources of fecal indicator bacteria that are typically targeted by stormwater managers.

In this scenario, areas of land, sanitary sewer pipes and septic systems within the study area were prioritized according to the levels of potential risks of human-related bacteria input to the recreational waters. Proximity to receiving waters and soil characteristics are the main determinants of priority with older sewer lines and those close to or crossing storm drains having higher risks compared to other sewer lines; areas with more septic tanks having higher risks; and river sections with transient populations having higher risks than other sections. Prioritization enables identification and targeting of the sources most likely to contribute bacteria loads.

Additionally, costs of achieving a bacteria load reduction can be segmented into costs to mitigate only high priority sources, high and medium priority sources, or high, medium and low priority sources. Costs are determined based on the level of BMP implementation that would be needed to reduce the loading of human waste that was measured by SCCWRP's 2016 monitoring for the human genetic marker HF183 in the San Diego River Watershed. These BMPs include pipe repair, replacement of septic systems and rehousing the transient population. However, these scenarios were not designed to represent the actual load reduction requirement or cost of projects needed to comply with any current and/or future regulations including the Bacteria TMDL, Waste Discharge Requirements (WDRs), or any other regulatory requirements.

Scenario: Human Sources: High

High priority sanitary sewer pipes and septic systems are identified for each watershed. The load reduction and cost of rehousing all transients, pipe repair and septic system replacement for high priority sources is calculated to determine the costs and benefits of targeting only high priority sources of human bacteria.

Scenario: Human Sources: High+Med

In addition to high priority, medium priority sanitary sewer pipes and septic systems are identified for each watershed. The load reduction and cost of pipe repair and septic system replacement for high and medium priority sources is calculated to determine the costs and benefits of targeting both sources of human bacteria.

Scenario: Human Sources: High+Med+Low

In addition to high priority, medium and low priority sanitary sewer pipes and septic systems are identified for each watershed. The load reduction and cost of CIPP rehabilitation and septic system replacement for high, medium and low priority sources is calculated to determine the costs and benefits of targeting all three types of sources of human bacteria.

SCENARIO TYPE: REDUCE BACTERIA THROUGH STREAM RESTORATION

This scenario type evaluates the effect of restoring streams and engineering wetlands to improve ecosystem services and sequester or destroy fecal indicator bacteria and pathogens. Stream restoration offers an alternative approach beyond stormwater scenarios that emphasize the reduction of stormwater loads through structural and programmatic BMPs. Focusing on reducing bacteria loading in the rivers through stream restoration has the advantage of reducing bacteria loading high in the watershed and protecting additional local recreation resources beyond the coastline. Co-benefits of stream restoration such as improvements in benthic macro-invertebrate habitat, enhanced fish habitat, and removal of nutrients, sediment, metals and pesticides are substantial.

Scenario: Stream: Instream Only

In this scenario, the costs of in-stream restoration and continued maintenance efforts are compared to traditional BMP costs. The analyzed in-stream restoration strategies involve widening confined reaches of a stream channel to mimic historical and natural sizes, which slightly increases infiltration and retention time.

Scenario: Stream: +10% Wetland

In addition to in-stream restoration, wetlands are located along tributaries of the main stream channels in the larger watersheds and along both main stem and tributaries in the smaller watersheds. Modeled practices mimic natural processes where water is diverted from a channel and retained off-line for longer periods. The tributary approach modeled in this study involves creating a series of distributary channels that draw low flows off the main tributary and into depressions where percolation and evaporation can take place. This scenario targets a 10% bacteria load reduction via a combination of instream and off-line wetland restoration.

Scenario: Stream: +20% Wetland

Both in-stream restoration and wetlands contribute to load reductions in this scenario. Wetlands are located along tributaries of the main stream channels in the larger watersheds and along both main stem and tributaries in the smaller watersheds. Through the combined in-stream and wetland approach, a 20% bacteria reduction on a watershed scale is achieved.

Scenario: Stream: +MS4

This scenario uses in-stream restoration and wetland projects to achieve load-based effluent limits for the Bacteria TMDL expressed in Attachment E of San Diego's MS4 Stormwater Permit (Order No. R9-2013-0001). Feasible sites and achieved load reduction are based on the fecal coliform load reductions from Attachment E. In-stream approaches are used first to meet the reduction goals and then wetland approaches occupy the remaining sites, or up to the final load reductions specified in the permit.

ADDITIONAL ANALYSES

The CBA indicates how changing elements of the Bacteria TMDL, analyzed as scenarios, could change the costs and benefits resulting from TMDL compliance. In addition to the CBA, a screening financial capability assessment provides information about the financial burden of Bacteria TMDL compliance on the region's residents and indicates the likelihood for copermittees to obtain a compliance schedule extension from USEPA. Finally, the peer review: WQIP cost estimate, another included analysis, provides a more robust understanding of existing WQIP costs estimates.

Screening Financial Capability Assessment (FCA)

The costs required to achieve bacteria compliance through implementation of BMPs can create an additional economic burden on the residents in the local jurisdictions regulated by the Bacteria TMDL. This scenario calculates RIS to help determine the economic burden of compliance.

Peer review: WQIP cost estimates

Previous cost estimates like those incorporated in the WQIPs, used techniques developed in Los Angles and accepted by the Los Angeles Regional Water Quality Control Board. However, additional understanding of the estimates is helpful for implementation. This analysis provides a peer review that documents sensitive assumptions, compares methods used by each San Diego jurisdiction and checks for accounting issues.

3. WATER QUALITY INPUT DATA

The CBA requires information on the impacts to water quality from all scenarios to calculate benefits. The CBA also requires information on the costs of implementing BMPs within each scenario.

The Stormwater, Human Sources, and Stream Restoration scenarios employ different BMPs, achieve different water quality targets, cover different geographic areas and use distinctly different methods of analysis. BMPs range from detention basins and street sweeping for Stormwater scenarios, to retrofitting leaking sewer pipes in Human Sources scenarios to restoring wetlands in Stream Restoration scenarios. Water quality targets for Stormwater and Stream Restoration primarily focus on achieving the Bacteria TMDL in several ways while Human Sources scenarios analyze the effects of treating high, medium and low-risk infrastructure without setting a particular target for water quality. Each scenario type analyzes watersheds, defining them similarly, but with slightly different areas. Each scenario type also uses water quality models to predict the effects of BMPs included in the scenario. Each of these differences is summarized in this chapter.

The water quality input data from this chapter informs the *Benefits Analysis* chapter that includes analysis of human health, recreation and co-benefits components. The general costs of implementing the scenario are further analyzed in the *Cost Analysis* chapter to annualize and determine several sub-components of cost. The following appendices contain the detailed technical information provided by engineering experts

- Stormwater technical memo: Appendix A
- Human sources technical memo: Appendix B
- Stream restoration technical memo: Appendix C

STORMWATER AND SCHEDULING SCENARIOS

The stormwater implementation scenarios focus on achievement of FIB load reduction from targeted MS4 program enhancements and implementation of stormwater BMPs. Load reductions over time and under various weather conditions (within a "representative" rainfall year) are estimated from institutional and programmatic non-structural BMPs, such as street sweeping and downspout disconnection, to structural BMPs such as green infrastructure (GI), green streets (GS), and multiuse treatment area (MUTA) BMPs.

The key inputs to the benefit analysis are *Enterococcus* concentrations, which were used to calculate illness risk and recreation benefits for each scenario. The key inputs to the cost analysis are costs to implement BMPs to achieve the water quality objective endpoint for each scenario.

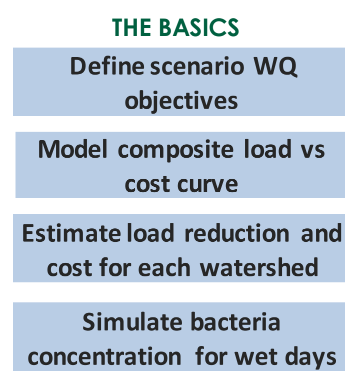


Figure 4 Overview of water quality inputs to the stormwater scenarios.

The analysis was based on a consistent approach to determine the percent load reduction required for each TMDL watershed under the six stormwater implementation scenarios (see Figure 4). Load reduction targets provide the basis for estimates of daily and annual bacteria concentrations for "wet weather" days for each watershed and scenario.

DATA SOURCES

The following data sources contain the primary information referenced in the stormwater inputs analysis

- Water Quality Improvement Plans (WQIPs) include detailed watershed modeling to support the identification of numeric goals, load reduction strategies, implementation schedules, and BMP cost estimates.
- The Surfer Health Study is a multi-year study that includes *Enterococcus* and fecal coliform concentrations data associated with specific health risk levels. Quantitative Microbial Risk Assessment (QMRA) of the Surfer Health Study includes dilution factors that inform the dilution factor for the Move Compliance Locations scenario.
- The National Epidemiological and Environmental Assessment of Recreational (NEEAR) Water dataset is from the studies that USEPA conducted for the 2012 Recreational Water Quality Criteria. The NEEAR dataset includes *Enterococcus* and *E. coli* data but no fecal coliform data. The NEEAR *E. coli* data are used as a surrogate for fecal coliform data to derive the fecal-coliform-based water quality objective for the 2012 REC Criteria scenarios.

METHODS

For the stormwater implementation scenarios, approaches used to derive the fecal coliform-based water quality objectives are summarized in Table 1. The load reduction target for each stormwater scenario, necessary BMPs and associated BMP cost are estimated via a general framework summarized in Figure 5. The main results of the analysis are wet day *Enterococcus* concentrations, cost and quantity of BMPs for each watershed and each scenario.

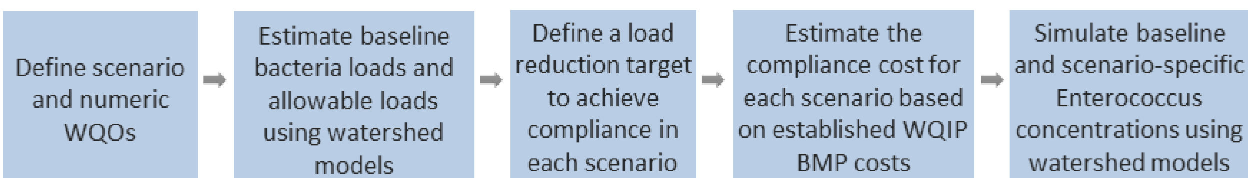


Figure 5. Overview of the methods for analyzing BMPs costs in the stormwater scenarios.

Table 1. Description of fecal coliform WQO of stormwater scenarios.

SCENARIO	DESCRIPTION	FC WQO (COLONIES/ 100 ML)	FECAL COLIFORM WQO IS BASED ON
2010 TMDL	WQIP costs associated with meeting the 2010 Bacteria TMDL	400	Current fecal coliform water quality objective in the San Diego Basin Plan; baseline cost for comparison to all other scenarios.
2012 REC Criteria	USEPA 2012 Recreational Water Quality Criteria	565	USEPA 2012 REC Criteria and NEEAR dataset; the WQO of 565 is the 97th percentile of NEEAR *E. coli* data as an equivalent non-to-exceed value based on a typical sampling regime. *E. coli* is used as a surrogate for fecal coliform because the NEEAR dataset does not contain fecal coliform measurements.
Move Compliance Locations	2010 TMDL; move wet-weather compliance locations down-coast based on winter recreational use	400	Current fecal coliform water quality objective in the San Diego Basin Plan with dilution factor of 22 applied to fecal coliform concentrations to estimate required load reduction.
Flow-based Suspensions	2010 Bacteria TMDL; suspend compliance with 2012 REC Criteria under high flow condition	400	Current fecal coliform water quality objective in the San Diego Basin Plan with high flow suspension for days ≥ 0.5” rainfall plus 24-hour antecedent period. The high flow suspension is applied to all fresh waterbodies, rather than certain concrete-lined channels (as specified in the Los Angeles Region Basin Plan) for CBA comparison purposes among the different watersheds and scenarios.
Adjust All-Beach WQO	Using Surfer Health Study data; site-specific load reduction goals for all beaches.	2,215	97th percentile of fecal coliform data at the illness rate of 32 in the Surfer Health Study. The 97th percentile was calculated based on the fecal coliform geometric mean concentration of 61 colonies/100 ml and the associated standard deviation. The 97th percentile is used as an equivalent not-to-exceed value for comparison to the endpoints in other scenarios.

For nearly all scenarios, the compliance location is defined as the watershed outlet above the tidal prism with no consideration of tidal mixing and dilution. The exception is the Move Compliance Locations scenario, which is based on achieving compliance at a point further downcoast based on recreation use patterns where dilution is expected. Also, the load reduction calculation considers natural sources of bacteria that may not cause human health risk through incorporation of an allowable exceedance frequency (AEF) based on previous reference studies in the region. This approach is consistent with the 2010 Bacteria TMDL and WQIPs.

Baseline and allowable loads for each scenario are based on WQIP models for watersheds when the models, load reduction, and BMP cost information are available (i.e., Los Peñasquitos, Scripps, Tecolote Creek, San Diego River, Chollas Creek). The models for developing the original 2010 Bacteria TMDLs are used to calculate the scenario results for the other TMDL watersheds (i.e., non-WQIP modeled watersheds) based on a WQIP representative rainfall year (WY2003). Required load reductions represent the difference between the baseline loads and allowable loads.

In addition to determining the required load reduction for each watershed and scenario, the analysis calculates the compliance cost based on BMP cost curves. For the WQIP-modeled watersheds, costs are estimated using the WQIP load reduction versus cost curve specific to each watershed. For non-WQIP watersheds, consistent load reduction versus cost information is not available. Therefore, costs are extrapolated using a composite cost curve based on the cost and load reduction information from the WQIP-modeled watersheds. The composite cost curve is adjusted to be consistent with the baseline load for each non-WQIP modeled watershed. This step normalizes the composite cost curve for each watershed.

These BMP cost curves include a range of BMP types that are implemented in order of cost effectiveness. Institutional and programmatic actions that are not able to be modeled and are nonstructural (NMNS) are the most cost effective BMPs and are implemented first. These BMPs can achieve up to 10.5% load reduction based on agreements in WQIP process. Street sweeping, catch basin cleaning and other traditional non-structural activities that could be modeled (MNS) are implemented next in the cost curve. Multi-use treatment areas (MUTA), which represent detention ponds and other traditional structural BMPs are the next most cost-effective approaches, followed by green infrastructure (GI) and green streets (GS) that are at the upper end of the curve. Figure 6 shows the composite BMP cost curve that was developed based on the WQIP results from the modeled watersheds. Cost for each scenario was determined by moving along the curve to achieve the required load reduction for each scenario.

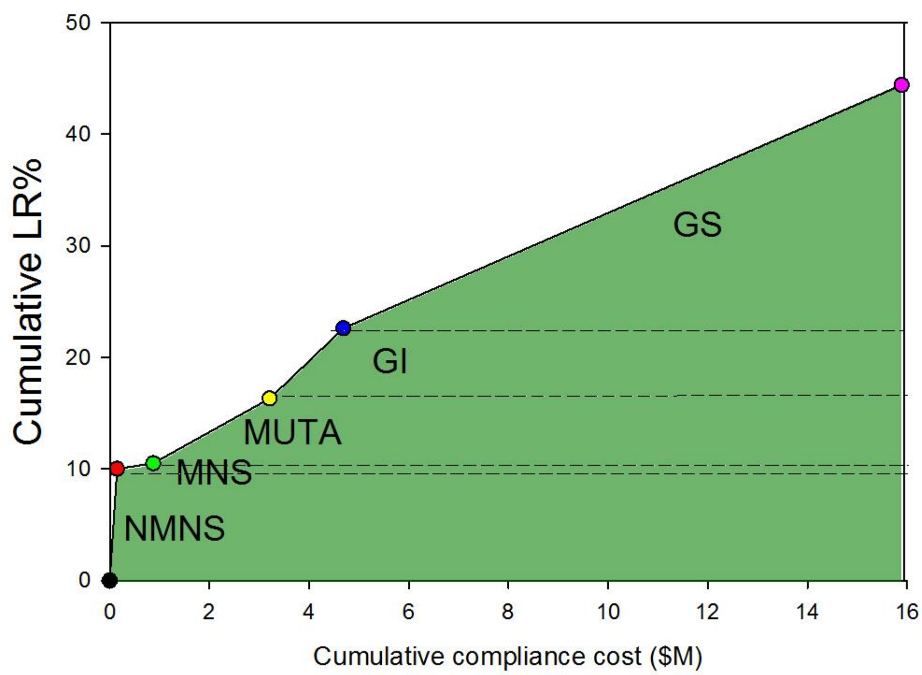


Figure 6: Overview of the methodology for analyzing BMPs costs in the stormwater scenarios.

Water Quality Model Usage and Calibration

For the illness reduction and recreation benefits, daily and annual baseline and scenario-specific *Enterococcus* concentrations were simulated for WY1990 through WY2015. *Enterococcus* concentrations at the outlet of each watershed, above the tidal prism, were simulated directly by the watershed models. For WQIP-modeled watersheds and Dieguito watershed, *Enterococcus* concentrations are based on updated watershed models developed to support the San Diego Bacteria TMDL Reopener effort. Results for the non-WQIP modeled watersheds except San Dieguito watershed were developed based on the original Bacteria TMDL models with necessary updates.

The models used were calibrated extensively to match hydrologic flow regimes, observed runoff concentrations and monitored stream loading data. The stormwater technical memo provides detailed information about the error statistics and uncertainty sources. Engineers providing the analysis believe that the models appropriately represent pollutant loading and transport.

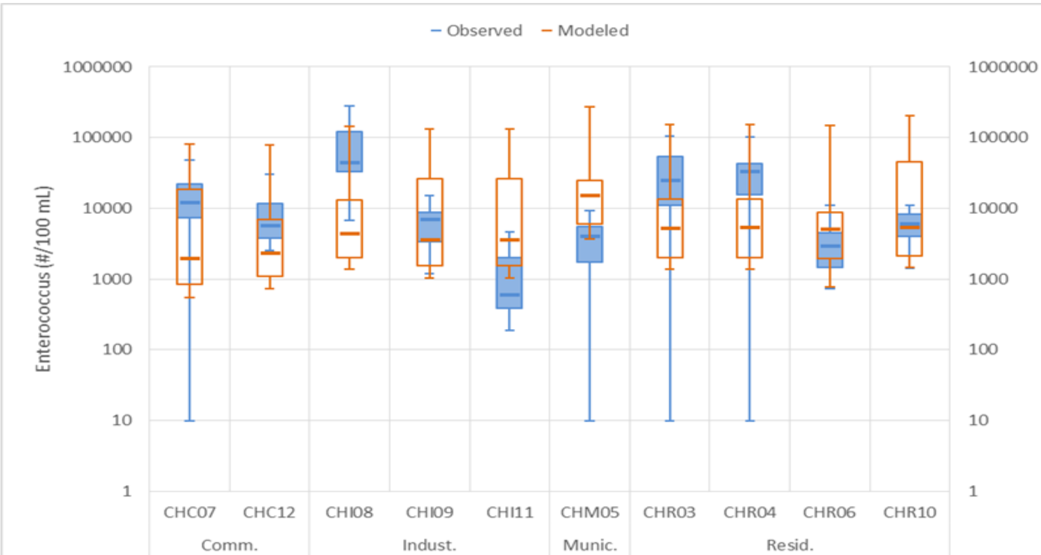


Figure 7. Example model output calibration comparing *Enterococcus* concentration of model outputs versus monitoring data for several land use types.

ASSUMPTIONS AND UNCERTAINTY

The stormwater scenarios assume that BMPs will reduce fecal coliform bacteria and *Enterococcus* equally. This is consistent with the 2010 Bacteria TMDL and WQIPs, which assume that removal rates represent bacteria in general and are not specific to a particular type.

To evaluate this assumption, a literature review was conducted. Of the studies identified, including review of the International Stormwater BMP database, only three evaluated the removal of *Enterococcus* and fecal coliform with the same BMPs at the same time (i.e., included "paired" data). The remaining studies compared *Enterococcus* and fecal coliform removal data from different BMPs located in different regions. All three of the paired BMP studies demonstrate that BMP performance between fecal coliform and *Enterococcus* is similar (GI data from Davies and Bavor 2000, and MUTA data from Krometis, L. H et al. 2009, City of San Diego 2016). Further, the BMP mechanisms that most effectively remove fecal colifom are the same for all bacteria indicators including *Enterococcus* and include desiccation due to wet and dry cycles, sorption to different media types, predation due to protozoa and other grazers within the microbial community, changes in flow regimes that improve settling, and UV inactivation due to sunlight exposure and daylighting of structural BMPs (UWRRC 2014, Hunt et al 2012, Hathaway 2010, Krometis, L. H et al 2009, Davies, C. M., and Bavor, H. J. 2000).

Literature sources further indicate that there may be differences in survival/die-off. However, there is minimal research from BMPs that can be used to accurately quantify a difference at this time. Due to the extremely limited availability of paired data, it is currently not feasible to evaluate the difference in BMP removal efficiencies for fecal coliform and *Enterococcus* and to develop an adjustment factor which can be applied to convert fecal coliform-based compliance costs to *Enterococcus*-based compliance costs.

Certain assumptions are also made to develop fecal coliform-based water quality objectives that define achievement of the regulatory endpoint for each scenario. As discussed in the *Water Quality Input Data Methods* section, WQIP BMP costs were available only for fecal coliform load reduction. Therefore, the water quality objectives for all of the stormwater scenarios are based on fecal coliform with translation as needed. For several scenarios, a 97^{th} percentile value was used as an equivalent, not-to-exceed value consistent with the current San Diego Basin Plan fecal coliform water quality objective. In addition, *E. coli* was used as a surrogate for fecal coliform to derive the fecal-coliform based water quality objective for the 2012 REC Criteria scenario because the NEEAR dataset does not contain fecal coliform data.

Uncertainty

The CBA also includes a substantial effort to provide a broad and quantitative sense of the uncertainty within the CBA results. The approach to this uncertainty calculation is to provide a "best" estimate of actual values, then provide high- and low-bracket values that can be passed through the remainder of the analyses to show error bars in CBA results focused on units of benefit and cost effectiveness.

For the stormwater inputs to the CBA, the best value is the water quality model output for *Enterococcus* concentration, averaged via a geometric mean. These averages are categorized by the type of day, including the day of precipitation (storm), the day after precipitation (storm+1) and so on up to the third day after precipitation (storm+3). High and low bracket values are calculated in two ways. The narrower bracket values are calculated as the statistical upper and lower 95% confidence interval for all days of a single type. The wider bracket values are calculated from the 5^{th} and 95^{th} percentile of the geometric mean value for all days of a single type (Table 2).

Table 2. High and low *Enterococcus* concentrations (#/100 ml.) to bracket uncertainty[11]

WATERSHED/ SCENARIO	WET DAY TYPE	UPPER 95% CONFIDENCE LEVEL	GEOMETRIC MEAN	LOWER 95% CONFIDENCE LEVEL	5TH PERCENTILE VALUE	95TH PERCENTILE VALUE
San Juan						
Baseline	Storm	2,330	2,660	3,020	195	12,160
	Storm+1	2,960	3,320	3,720	426	11,780
	Storm+2	1,060	1,220	1,400	131	5,280
	Storm+3	387	450	523	57.0	1,630
2010 TMDL scenario	Storm	2,310	2,630	3,000	193	12,000
	Storm+1	2,930	3,280	3,700	422	11,700
	Storm+2	1,050	1,210	1,390	130	5,200
	Storm+3	383	446	518	57.0	1,600
Scripps						
Baseline	Storm	27,900	30,700	33,800	5,350	111,000
	Storm+1	3,100	4,170	5,610	52.0	91,000
	Storm+2	205	272	361	50.0	48,000
	Storm+3	70.0	86.0	107	49.0	2,000
2010 TMDLscenario	Storm	24,950	27,500	30,300	4,790	99,800
	Storm+1	2,770	3,720	5,010	46.0	81,500
	Storm+2	184	244	324	44.0	43,200
	Storm+3	62.0	77.0	96.0	44.0	1,720
San Diego River						
Baseline	Storm	24,800	26,700	28,900	5,900	73,800
	Storm+1	15,120	16,900	18,800	2,780	61,700
	Storm+2	7,650	8,850	10,210	665	44,400
	Storm+3	3,770	4,520	5,410	284	34,000
2010 TMDL scenario	Storm	17,100	18,500	20,000	4,110	51,100
	Storm+1	10,500	11,700	13,100	1,920	42,700
	Storm+2	5,290	6,120	7,100	460	30,700
	Storm-3	2,610	3,130	3,750	197	23,600

RESULTS AND DISCUSSION

Intermediate results are highlighted by percent load reduction and compliance cost estimates for each scenario and watershed combination. The primary results that are passed along to the health risk and benefits analyses include simulated *Enterococcu*s concentration averages for each category of wet day for each TMDL watershed and scenario throughout the 25-year modeling period (1990 through 2015 water years). Other results include quantities of BMPs that are used to calculate Co-benefits.

The percent load reduction target and compliance cost results associated with each watershed and scenario are presented in Table 3. For each watershed, the load reduction percentages vary substantially depending on the scenario. For example, the modeled load reduction percentages for Chollas Creek vary from 0.25% to 28.75% depending on the scenario. Costs also vary widely based on watershed size, land use and load reduction need.

[11] In general, this report presents data to three significant figures to provide a sense of the expected precision. However, many intermediate calculations use all available figures to avoid loss of accuracy. In certain cases, table totals may appear to sum incorrectly due to rounding error.

Table 3. Scenario-specific load reduction percentage (LR%) and costs (in millions) by watershed

	2010 TMDL		2012 REC CRITERIA		MOVE COMPLIANCE LOCATIONS		FLOW-BASED SUSPENSIONS		ADJUST ALL BEACH WQO	
	LR%	Cost ($M)	LR%	Cost ($M)	LR%	Cost ($M)	LR%	Cost ($M)	LR%	Cost ($M)
Laguna Coastal Streams	2.50%	$0.200	2.40%	$0.200	0.000%	$0.200	0.000%	$0.200	1.30%	$0.200
Aliso Creek	5.70%	$1.30	5.50%	$1.30	0.000%	$1.30	0.000%	$1.30	3.00%	$1.30
Dana Point	2.50%	$0.300	2.40%	$0.30	0.000%	$0.300	0.000%	$0.300	1.30%	$0.300
San Juan	17.6%	$9.10	14.3%	$6.30	0.000%	$0.400	0.100%	$0.400	0.000	$0.400
San Clemente	3.20%	$0.600	3.10%	$0.60	0.000%	$0.600	0.000%	$0.600	2.00%	$0.600
San Luis Rey	15.8%	$128	13.9%	$94.9	0.000%	$6.10	1.70%	$6.10	0.300%	$6.10
San Marcos	11.5%	$0.220	10.8%	$0.20	0.000%	$0.000	0.000%	$0.000	0.200%	$0.000
San Dieguito	13.0%	$24.0	11.6%	$16.6	0.000%	$1.80	1.20%	$1.80	0.300%	$1.80
Los Peñasquitos	17.8%	$255	17.0%	$241	0.400%	$8.50	2.90%	$8.50	8.50%	$8.50
Scripps	10.5%	$4.30	9.60%	$4.30	0.100%	$4.30	0.600%	$4.30	2.90%	$4.30
Tecolote Creek	18.0%	$31.0	17.2%	$29.5	0.200%	$1.90	1.00%	$1.90	8.90%	$1.90
San Diego River	30.8%	$414	30.0%	$396	0.200%	$10.7	5.90%	$10.7	20.6%	$234
Chollas Creek	28.8%	$140	28.0%	$131	0.300%	$3.70	4.30%	$3.70	19.3%	$60.5

Results also include the amount of BMPs implemented in each watershed so that co-benefits can be calculated. The most important results are for 1) acres of green infrastructure and green street BMPs (Table 4) and 2) ratios of co-pollutants that can reasonably be treated as bacteria treatment (Table 5).

Table 4. Area of BMPs with co-benefits by watershed

WATERSHED	SCENARIO	GREEN INFRASTRUCTURE AREA (ACRES)	GREEN STREETS AREA (ACRES)
Los Peñasquitos	2010 TMDL	16.2	0.000
	2012 Rec Criteria	11.8	0.000
Tecolote Creek	2010 TMDL	3.16	0.000
	2012 Rec Criteria	2.58	0.000
San Diego River	2010 TMDL	36.97	56.0
	2012 Rec Criteria	36.97	50.0
	Adjust All Beach WQO	33.01	0.000
Chollas Creek	2010 TMDL	24,900	27,500
	2012 Rec Criteria	2,760	3,720
	Adjust All Beach WQO	184	244

When stormwater BMPs are implemented they are able to treat additional pollutants that can be accounted through co-benefits in the CBA. Table 5 presents example ratios of the load reductions in relation to the treatment of fecal coliform. Other pollutants include sediment, copper (CU), lead (PB), total nitrogen (TN), total phosphorus (TP) and *Enterococcus* (ENT).

Table 5. Example Ratios of bacteria to other treated pollutants

WATERSHED	SEDIMENT TO FECAL COLIFORM RATIO	TOTAL CU TO FECAL COLIFORM RATIO	TOTAL PB TO FECAL COLIFORM RATIO	TOTAL ZN TO FECAL COLIFORM RATIO	TN TO FECAL COLIFORM RATIO	TP TO FECAL COLIFORM RATIO	ENT TO FECAL COLIFORM RATIO	TOTAL COLIFORM TO FECAL COLIFORM RATIO
Los Peñasquitos	0.960	1.13	0.940	1.23	0.850	0.780	1.04	0.970
Tecolote Creek	0.770	0.670	0.720	0.690	0.830	0.860	0.990	0.830
Scripps	1.09	1.00	1.01	0.970	1.05	1.19	0.980	0.950
Chollas Creek	0.680	0.780	0.710	0.800	0.820	0.870	1.01	0.880
San Diego River	0.750	0.680	0.670	0.760	0.850	0.820	0.860	0.940
Average of OC and SD WQIP watersheds	0.850	0.850	0.810	0.890	0.880	0.900	0.980	0.910

HUMAN SOURCES SCENARIOS

The Human Sources scenarios focus on achievement of illness rate reduction by targeting sources of human pathogens directly. These sources include leakage from sanitary sewer pipes (mains and laterals), malfunctioning septic systems and human waste from transient camps. The resulting inputs to the benefit analysis are the percentage reduction in human pathogen and bacteria loading to water bodies and cost of BMPs (Figure 8). This percentage reduction is employed in the health risk and benefits analysis to calculate the value of benefits.

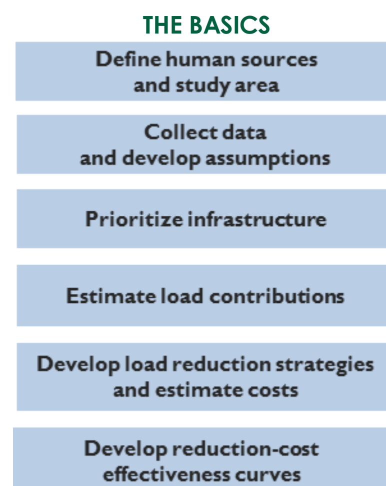


Figure 8. Overview of the human sources water quality inputs analysis

The analysis prioritizes infrastructure as high, medium and low risk or loading potential; estimates load contributions and expected load reductions; and produces load reduction cost effectiveness curves.

The BMPs considered for each human source were

- **Sanitary Sewers (mains and laterals)**: cured-in-place pipe (CIPP) liners that are composed of a plastic resin that is inserted and shaped within existing pipes and cured with heat to create a new pipe within a pipe
- **Septic**: replacement of failed septic systems with new tanks, piping and distribution fields.
- **Transient camps**: rehousing transient populations

DATA SOURCES

The data sources used in the analysis come from a broad array of regional sources including local governments and research institutions and federal sources including the U.S. Census Bureau and U.S. Department of Agriculture (Table 6). The critical data sources were spatial layout of sewer and septic systems, and soil types used to categorize infrastructure as high, medium or low risk. Cost estimates are conceptual, Class 5 estimates to be used for exploratory purposes only and are intended to be incremental.[12] Additional sources of data used to make effectiveness estimates are shown in the *Assumptions* section (below).

Table 6. Data sources for the human sources scenarios risk prioritization calculations

DATA LAYER	TYPE	SOURCE	NOTES
Population	Spatial	San Diego Association of Governments and San Diego Geographic Information Source (SANDAG) using data provided by the United States Census Bureau and Orange County Public Works using data provided by the United States Census Bureau	2010 United States Census Bureau census tracts for San Diego County
Soil Types	Spatial and PDF Report	SANDAG and United States Department of Agriculture and Orange County Public Works using data provided by the US Department of Agriculture	Soils layer based on USDA soil survey of the San Diego Area, published in 1973
Surface Waters, Streams, and Storm Drains	Spatial	United States Geological Survey, SANDAG, County of San Diego and Orange County Public Works	Surface water features from National Hydrography Dataset. Storm drain data provided by SANDAG, County of San Diego, and Orange County Public Works
Sanitary Sewer Infrastructure (mains and laterals)	Spatial	County of San Diego, City of San Diego, Padre Dam Municipal Water District, City of Escondido and Orange County Public Works provided data from local cities and water agencies including: City of Laguna Beach, City of San Clemente, City of San Juan Capistrano, El Toro Water District, Irvine Ranch Water District, Moulton Niguel Water District, Santa Margarita Water District, South Coast Water District, and Trabuco Canyon Water District	Available sanitary sewer pipe data including inspection records data collected by Hirsch and Co. from 1998-2005
Septic Systems	Spatial	County of San Diego, Department of Environmental Healths and Orange County Public Works	Provided by County of San Diego, Department of Public Works
SSO and PLSD Locations	Tabular	RWQCB	Category 1 SSOs from 2007 to 2016 and reported PLSDs from 2007
Unit Cost Estimates	Tabular	Brown and Caldwell Cost Estimating Group	Historic bid prices and historic project cost estimates

[12] Notably, cost estimates are not intended to represent the actual cost of projects needed to comply with any current or future regulations including the Bacteria TMDL, Waste Discharge Requirements (WDRs), or any other regulatory requirements. Costs are based on unit cost estimates applied to the amount of infrastructure data available at the time of this study. Actual strategies, projects and costs needed to comply with existing or future regulations may vary.

Spatial data of the infrastructure location was one of several data sets that allowed analysts to characterize risk of human-sourced FIBs reaching receiving waters. An example of this kind of data (Figure 9.) shows how sewer infrastructure is concentrated in the lower portions of the watersheds.

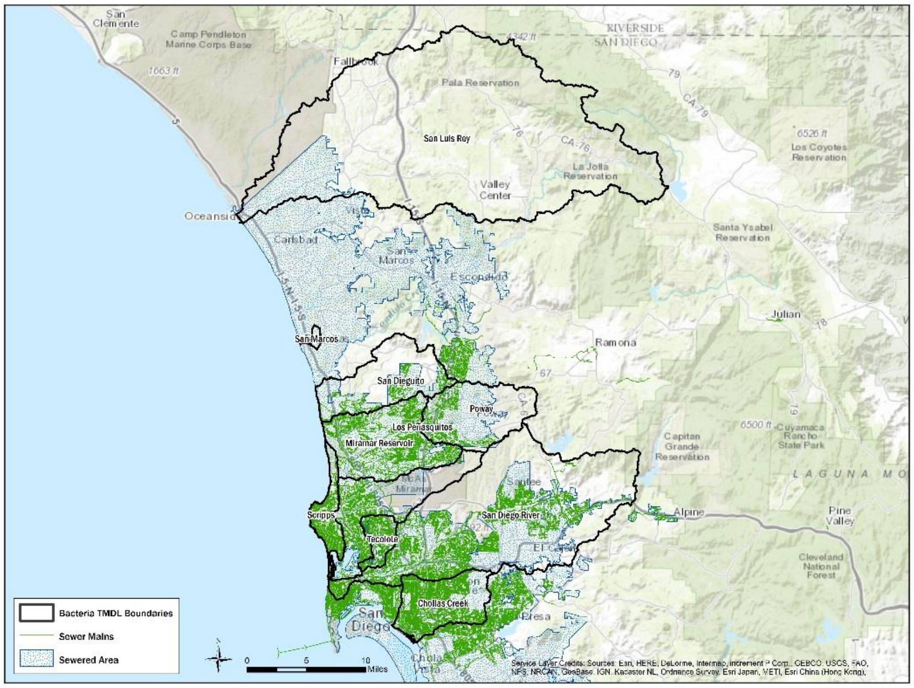


Figure 9. Map of sewer infrastructure location exemplifies the spatial data used to categorize high, medium and low risk human waste sources.

METHODS

The analysis focuses on prioritizing infrastructure by risk level and makes planning-level engineering estimates of the load reductions from BMPs. GIS data is used as input to a spreadsheet mass-balance model where individual inputs of load contribution are combined and calibrated to a downstream point based on measured data. The number of a human marker surrogate parameter called HF183 are used as the "mass" for the model. HF183 is an indicator of human fecal contamination and is commonly accepted to correlate with bacteria and viruses from human sources.

Prioritization

The prioritization approach uses spatial analysis to prioritize sanitary sewer pipes and septic systems over the watersheds. The spatial criteria are scored on a 1-3 scale and then aggregated via a weighted average (see Table 7). Note that different weighting factors are used for septic versus sewer infrastructure.

Table 7. Risk prioritization criteria for the human sources scenarios.

CRITERIA	SEPTIC WEIGHTING	SEWER WEIGHTING	CUTOFF VALUES	SCORE
Distance from Stream/Storm Drain	50%	35%	< 100 ft.	3
			100-500 ft.	2
			>500 ft.	1
Soil Types	50%	15%	High Permeability	3
			Moderate Permeability	2
			Low Permeability	1
Sanitary Sewer Pipe Diameter	NA	15%	0 – 15 inch	3
			16 – 24 inch	2
			>24 inch	1
Sanitary Sewer Pipe Age	NA	35%	>40 years	3
			21-40 years	2
			≤20 years	1

Once the weighted score for each segment of infrastructure is calculated, the segments are categorized for risk of loading potential according to the cutoff values (see Table 8).

Table 8. Cutoff points for prioritizing infrastructure for the human sources scenarios

WEIGHTED SCORE CUTOFF POINTS	PRIORITIZATION CATEGORY	DESCRIPTION
>2.5	High	Potential "hot spot." High priority for treatment and further investigation.
2.1-2.5	Medium	Medium priority for treatment and further investigation.
≤2	Low	Low priority for treatment and further investigation.

The resulting prioritized infrastructure tend to be higher risk near streams and at the base of watersheds as shown in Figure 10 (below).

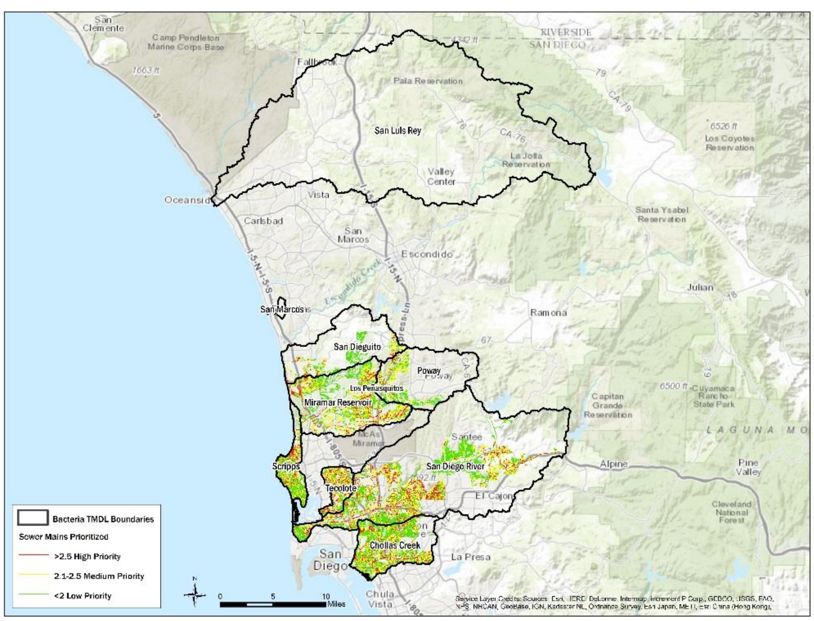


Figure 10. Map shows high, medium and low risk sewer systems in San Diego watersheds.

Load Contribution and Load Reduction Estimate

Load contributions were estimated using assumptions of leakage rates, septic failure rates, and counts of transient populations. Fate and transport factors were applied to the prioritized infrastructure to estimate the proportion of load contribution that reaches a storm drain or creek.

While complete reduction of all bacteria loading from all human sources is likely not feasible, if fully implemented, the load reduction strategies are expected to significantly reduce bacteria loading from the selected human sources. Therefore, as a simplification for this planning-level analysis, a complete reduction of loading was assumed for each unit of load reduction implemented. It should also be noted that rehabilitation of all sanitary sewer pipes and septic systems within a short timeframe is also not likely feasible. Therefore, a 100% removal efficiency is intended to represent a theoretical high-end, where a practical level of implementation is likely to result in a lower removal efficiency.

For watersheds with adequate data (i.e. Chollas Creek, Los Peñasquitos, San Diego River, San Dieguito, San Luis Rey) the calculation of **pre-BMP load** is the sum of several values described in earlier steps or listed in the *Assumptions* section (see Table 8).

$$(Pipe\ lenth)\ x\ (Existing\ pipe\ leakage\ rate)\ x\ (risk\ category\ attenuation\ factor)$$

$$+$$

$$(Total\ volume\ of\ historical\ SSOs)\ x\ (risk\ category\ attenuation\ factor)$$

$$+$$

$$(Number\ of\ septics) x\ (failed\ septic\ discharge\ rate)\ x\ (risk\ category\ attenuation\ factor)$$

The calculation of load reduction percentage is simply the percentage of load contribution from each source based on a high, medium, or low level of implementation of load reduction strategies. An example is provided below (Figure 11).

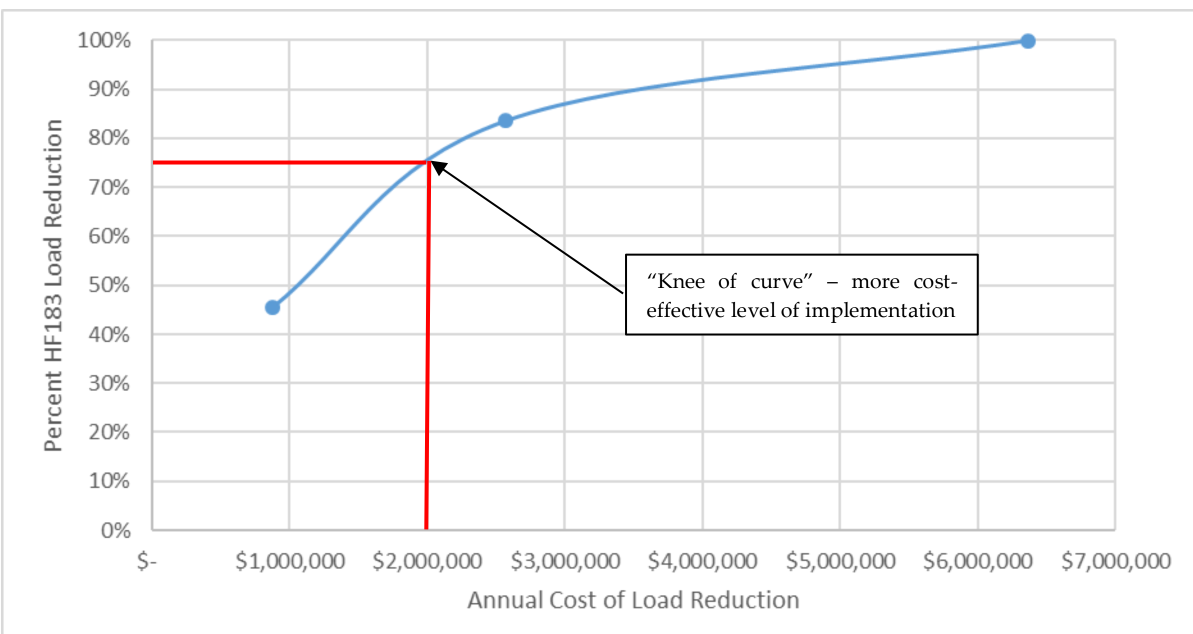


Figure 11. Example graph shows the most cost-effective level of implementation for HF183 load reduction.

ASSUMPTIONS

The most sensitive assumptions focus on leakage rates from sewers, portion of transients that live near creeks and the portion of these sources that reach receiving waters (Table 9). Leakage rates for sewers use a previous study based on measured leakage from known defects and an estimate of the number of defects in County of San Diego. Failure rates of septic systems is 0.7% annually based on a California State University Chico study done in 2003. The portion of sources that reaches receiving waters was estimated with professional judgement and peer reviewed among practitioners in the region. There was agreement with the conceptual use of higher values for high risk infrastructure and lower values for low risk infrastructure. Reviewers felt that numbers could be higher or lower than the assumed values used in the study, but reviewers did not agree on these alternate judgments and did not provide references that could be cited.

Table 9. Assumptions related to load contribution and change estimates

ITEM	ASSUMED VALUE		REFERENCE
Concentration of HF183 in raw sewage (sewer pipes and septic)	10^7 Copies per 100 milliliters		Point Loma Wastewater Treatment Plant influent2
Rate of leakage – Existing sanitary sewer pipes[1]	0.35 gallons/inch-diameter/defect/day		Brown and Caldwell 2005. Average exfiltration rate measured from 6 pipe defects in Orange County.
Frequency of Critical Pipe Defects	1 defect per 10,149 feet of sanitary sewer pipe		Inspection of City of San Diego sanitary sewer pipes from 1998-2005 performed by Hirsch & Co. Accounts for ongoing rehabilitation and replacement of pipes at a rate of 45 miles per year averaged over 100 years.
Rate of Leakage – Post-cured-in-place pipe (CIPP) sanitary sewer pipes	0 gallons/inch-diameter/mile length/day		Leakage from properly rehabbed pipe is expected to be significantly less than before repair and is assumed at zero for the purposes of this analysis.
Loading from Category 1 SSOs – Sanitary Sewer pipes	See Appendix B		SWRCB 2016
Failure rate of septic systems	0.7% of total systems during course of a year. Estimates 1/3 of failed systems could contribute untreated sewage to environment		CSU Chico 2003 County of San Diego, Department of Environmental Health
Rate of untreated septic discharge – Failed septic systems	153 gallons per day per system. Estimates 1/10 of flow from system exits untreated		Brown and Caldwell 2005 County of San Diego, Department of Environmental Health
Rate of untreated septic discharge – New septic system	0 gallons per day per system		Properly operating septic systems are assumed to remove 100% of HF183.
Percentage of load contribution that reaches storm drain or creek (fate and transport factor)[1]	SD County: High Priority – 95% Medium Priority – 55% Low Priority 20%	Orange County: High Priority – 95% Medium Priority – 55% Low Priority – 25%	Assumption factor to account for attenuation of bacteria in soil and interception/retention within watershed. Values were adjusted to calibrate with San Diego River monitoring results at Fashion Valley (Schiff, 2016) and OC Bight study data.
Proportion of transient population defecating directly into the water[1]	SD County: 25%	Orange County: 13%	Assumption based on best professional judgement. This assumption results in an estimated population of 15 out of 300 individuals per day defecating into the river for the San Diego River watershed. Additional data is needed to refine assumption.
Number of days feces accumulates, without HF183 decay	1 day		Email correspondence from Ken Schiff (SCCWRP) (personal communication 2016)
Grams per person per day wet weight fecal mass	126 grams		Rose, 2015
Copies of HF183 per gram fecal material	3.8x10^8 copies		Layton, 2013
Proportion of people who carry HF183 marker	70%		Email correspondence from Ken Schiff (SCCWRP) (personal communication 2016)
Average daily wet weather HF183 load (total copies of HF183 per wet weather day)	SD County: 2.97E+12	Orange County: 3.48E+11	SD County: San Diego River monitoring results at Fashion Valley (Schiff, 2016) Orange County: Unpublished data from Bight '13 Regional Monitoring program. Samples at Aliso Creek sample site.

One major limitation to understand is that the human genetic marker that identifies the human origin of pathogens was sampled in multiple places during a single event in the San Diego River watershed and at the Point Loma Wastewater Treatment Plant. This results in lower certainty about the validation of calculated results to these observed values. Better validation would be possible if sampling events were distributed across a wider range of conditions.

RESULTS

The analysis resulted in load reduction percentages that are specific to each watershed and risk/pollution category of the infrastructure. For example, there would be a 52% load reduction for implementing load reduction strategies on only the high-priority sources in the Los Peñasquitos watershed (see Table 10). An 88% load reduction could be achieved for implementing load reduction strategies on the high and medium risk infrastructure in the Los Peñasquitos watershed. Note that each category of cost and load reduction is additive with the previous: High means that only the riskiest infrastructure is treated, providing the most cost-effective load reductions. High + Medium means that the high and the medium risk infrastructure is treated, providing additional load reduction but a lower load reduction per dollar.

Table 10. Load reduction specific to each watershed

WATERSHED	ESTIMATED ANNUAL COSTS BY CATEGORY			ESTIMATED CUMULATIVE PERCENT LOAD REDUCTION		
	H	H+M	H+M+L	H	H+M	H+M+L
Chollas Creek	$6,160,000	$10,000,000	$20,700,000	94.0%	99.0%	100%
Scripps	$872,000	$2,570,000	$6,37,000	81.0%	96.0%	100%
Tecolote Creek	$1,330,000	$2,430,000	$5,160,000	91.0%	99.0%	100%
San Diego River	$5,910,000	$11,600,000	$24,700,000	92.0%	96.0%	100%
San Dieguito	$839,000	$1,270,000	$3,110,000	78.0%	81.0%	100%
San Luis Rey	$2,540,000	$6,860,000	$16,200,000	91.0%	92.0%	100%
San Marcos	$279,000	$537,000	$1,100,000	90.0%	95.0%	100%
Los Peñasquitos	$1,390,000	$6,480,000	$16,800,000	52.0%	88.0%	100%

H = High Priority; M = Medium Priority; L = Low Priority

* The cost estimates for CIPP rehabilitation of sanitary sewer mains are incremental costs which subtract out the estimated average annual budgets for routine sewer pipe rehabilitation and replacement, based on published capital improvement plan budgets from the City of San Diego, County of San Diego, City of Escondido, and Padre Dam Municipal Water District from 2007 to 2016, where available. Cost estimates for housing of transient populations, replacement of septic systems, and replacement of sewer laterals did not account for routine expenditures.

Uncertainty and Sensitivity

As previously noted, this analysis calibrates results to a single sampling event, thus results may not accurately reflect current conditions. In particular, results tied to specific human sources should be interpreted with an understanding that additional data collection and further refinement may change the findings presented in the human sources inputs analysis. The relative importance of specific sources of sewage entering the watershed during wet weather conditions is unknown as this time but could originate from transient encampments along rivers, sewer infrastructure or other illegal discharges. Thus, these water quality inputs are the least certain for any of the scenarios.

Results of the Human Sources uncertainty analysis, for both HF183 concentrations and costs, are the basis of the low and high cost-effectiveness values. Greater ranges of uncertainty for Human Sources concentrations would affect cost-effectiveness low and high values. The *Benefits Analysis* and *Cost-Effectiveness* sections provide additional information on the cost-effectiveness analysis on pages 117-121.

A sensitivity analysis indicates that doubling the sewer leakage rate does not significantly affect modeled results. Reducing the rate of transient human waste reaching surface waters by 5 percentage points decreases the proportion of transient loading (relative to other sources) substantially. For example, on the San Diego River the percentage of total loading from transients went down by 16%. This example should not be interpreted as providing an accurate range of possible conditions, but rather as an illustration of the variability inherent to this analysis.

Uncertainty

The CBA also includes a substantial effort to provide a broad and quantitative sense of the uncertainty within the CBA results. The approach to this uncertainty calculation is to provide a "best" estimate of actual values, then provide high and low bracket values that can be passed through the remainder of the analyses to show error bars in CBA results focused on units of benefit and cost effectiveness.

For the human sources inputs to the CBA, the best value is the reported value of HF183 copies for the Human Sources: High scenario. The analysis also includes high and low bracket values that are calculated via the 95% Poisson confidence interval and the 5% Poisson interval respectively. These values are provided for three representative watersheds and are considered reasonable to extrapolate to the remaining watersheds. Table 11 shows the bookend values from the uncertainty analysis.

Table 11. Quantitative uncertainty values; HF183 copies and percent load reduction

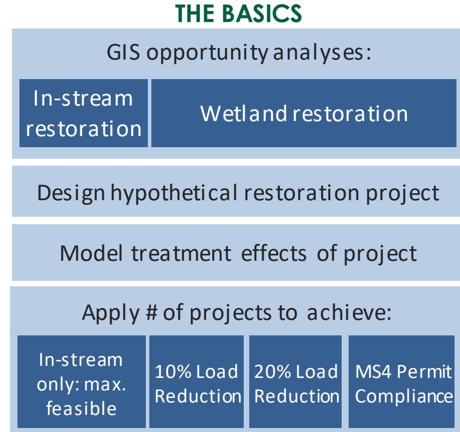
	COPIES OF HF183 (#/100ML.)			PERCENT LOAD REDUCTION		
Watershed	95% Poisson confidence Interval	Best Value	5% Poisson confidence Interval	95% Poisson confidence Interval	Best Value	5% Poisson confidence Interval
San Diego River	4.08E+12	2.97E+12	1.97E+12	92.0%	89.0%	87.0%
Scripps	5.43E+11	4.07E+11	2.86E+11	82.0%	81.0%	73.0%
San Juan Creek	6.66E+11	5.09E+11	3.72E+11	77.0%	69.0%	56.0%

Cost values are considered to be Class 5 estimates in accordance with the Association for the Advancement of Cost Engineering criteria. They are characterized as conceptual level or project viability estimates with expected accuracy values of -50% to +100%. However, costs are based on recent project construction costs from 2014-2016 and include a contingency of 20-30%. They do not include finance and abnormal hazardous waste costs.

STREAM SCENARIOS

The stream scenarios focus on reducing loading of bacteria through stream channel and wetland restoration. These scenarios restore natural stream and riparian habitat function by reducing channelization to increase residence time and infiltration opportunities. In turn, the restoration of natural sediment transport processes and native vegetation improves water quality and removes bacteria. The key results of the analysis are *Enterococcus* concentrations achieved by the stream restoration scenarios on wet weather days (see Figure 12). These results are employed in later analyses to calculate illness reductions and other benefits for each scenario.

THE BASICS



The analysis evaluates scenarios to calculate bacteria loading and cost.

Figure 12. Overview of the stream restoration analysis

- **Stream: Instream Only:** Focuses on in-stream restoration up to the maximum of feasible stream segments on public lands, which includes modifying channel dimensions to improve channel stability and biological habitat.
- **Stream: + 10% Wetland**: In addition to instream projects, includes wetlands along tributaries of the main stream channels in the larger watersheds and both the main stem and tributaries in smaller watersheds to achieve a 10% load reduction.
- **Stream: + 20% Wetland:** In addition to instream projects, includes wetlands to achieve a 20% load reduction.
- **Stream: + MS4:** In addition to in-stream projects, includes wetlands to achieve MS4 permit load reductions based on the Bacteria TMDL.

DATA SOURCES

The analysis uses multiple data sources to define the bacteria removal effectiveness of stream restoration, determine where restoration is feasible, model the effects of hypothetical projects and set load reduction targets.

- 200 studies on FIB removal rates and a feasibility review of various approaches to stream and riparian habitat restoration were used to determine effectiveness of stream restoration projects and comparability of *Enterococcus* to fecal coliform and other FIB. Studies examined the ability of natural and/or artificial wetlands to reduce quantities of FIB. Selected summary reports include
    - Texas Commission on Environmental Quality (2006), which compiled results from 32 studies to identify evidence of reductions in FIB concentration when comparing outflows to inflows (Rifai 2006)
    - Water Environment Research Federation (2010) summarized results of over 140 reports from the International Stormwater BMP Database on BMP treatment techniques to reduce FIB concentrations
    - International studies from Canada (Bastian and Hammer 1993), Czechoslovakia (Vymazal, 1993) and Spain (Reinoso et al. 2008) that focus on reductions in the concentrations of various FIB
- A GIS analysis of potential stream restoration sites uses data from the San Diego Bacteria TMDL Technical Report Appendix E (Maps of Impaired Watersheds) and the SanGIS/SANDAG GIS Data Warehouse. The GIS analysis also uses shape files from the Orange County GIS Public Works Data Set on current parcel ownership, current land use, waterbodies (i.e., stream segments, reaches, tributaries), channel right-of-way, and slope percentage.
- Data and FIB reduction goals from the San Diego MS4 permit, relevant TMDLs, and associated Watershed Quality Improvement Plans were used to establish targets for the number of projects needed in any particular watershed

METHODS

The methods involve research, modeling and analysis to determine bacteria load reductions from stream restoration scenarios. The analysis begins with a literature review of 200 studies to identify the removal rates of bacteria in natural systems. In addition, removal efficiency data from natural treatment systems in Orange County is analyzed. Then, it moves to a feasibility review of restoration approaches for stream and riparian habitat restoration to select suitable practices for additional analysis. Once removal rates and suitable approaches are identified, the analysis models retention times for in-stream and wetland opportunities. The modeling seeks to compare published removal rates for natural systems with the practices identified in the feasibility review.

A GIS analysis then identifies suitable areas for restoration activities. It involves identifying public parcels within or adjacent to streams and tributaries with minimal slope and large areas (i.e. greater than one acre). The GIS analysis 1) identifies suitable practices for the area and 2) identifies the number of feasible sites for both in-stream and wetland projects. The GIS analysis, plus the feasibility review and modeled retention times, provides information to identify hypothetical projects for each stream restoration scenario.

The analysis then applies as many hypothetical projects as necessary to achieve the load reduction goal, unless constraints such as limited public lands and tributaries make that infeasible. In these cases, the watershed falls short of its load reduction goal. The load reduction from implemented projects is then applied to modeled daily *Enterococcus* concentrations, finding the concentrations on wet days. These concentration changes were used to calculate illness change and days of lost recreation. Finally, the analysis estimates associated reduction in nutrients, heavy metals, and sediment that are used in the co-benefits calculations later in the CBA. Wetlands also have average bacteria reduction efficiencies of 50% based on results of the literature review and analysis of Orange County data.

Costs are also provided for each scenario and analyzed in the *Cost Analysis: Results & Discussion* section of this report.

ASSUMPTIONS

The in-stream and wetland scenarios make several sensitive assumptions regarding the structure and performance of practices, their co-benefits, costs, and possible locations. Most importantly, the analysis assumes *Enterococcus* acts like fecal coliform and other bacteria based on the extensive literature review. For the in-stream only scenario, soil infiltration is assumed to be six inches per day with depth-to-groundwater at five feet. The latter assumption means that the stream is assumed to be perched above the groundwater table year-round, likely an over-assumption of infiltration. For off-line wetlands, low flows are assumed to infiltrate at one inch per day and some additional volume is either evaporated or percolated.

Regarding removal of co-pollutants (non-bacteria pollutants), the analysis makes several assumptions based on data available among watersheds. For example, baseline loads for County of San Diego are based on the average wet weather loads from 2007-2015. For Chollas Creek, loads are from the North Fork of Chollas Creek only, as no nutrient monitoring data are available for South Fork. For Orange County watersheds, loads are calculated by multiplying average concentrations for wet weather events in a given year by that year's annual flow. Annual loads are averaged over five years for each nutrient and metal.

Regarding cost estimates, the report makes clear that cost estimates are high-level estimates used for planning purposes. As such, they include a 25% contingency. They also include costs for habitat mitigation, assuming temporary disturbance of protected habitat. No costs for land purchase were included as the sites are all located on public land.

The analysis also only models approaches on public lands. This assumption limits the number of watersheds that can be modeled, omitting Scripps and San Marcos because of their small watershed areas and lack of available public lands. Also, the analysis only includes portions of a watershed that contain impaired waterbodies and are below dams (where dams exist). Finally, only public lands within ¼-mile of these areas are analyzed.

RESULTS AND DISCUSSION

The analysis resulted in load reduction and costs for each watershed and scenario combination, and the area of restoration projects that is necessary to estimate co-benefits. Primary results focus on establishment of a baseline *Enterococcus* load and load reduction rates (%), load reduction and cost for each of the scenarios (see Table 12). Highlighted cells in the table are not able to achieve the goal of the scenario due to land availability limitations. Although costs are included in this table, they are analyzed in the *Cost* section of this document.

The analysis of the Instream Only scenario achieves reduction rates of 0.2% to 1.6% which reflect the number of feasible stream restoration opportunities and the hydraulic characteristics of the watershed. While this approach reduces flow velocity, increasing residence time and thus supporting reductions in bacteria concentrations, the retention times are increased only by minutes under storm flow conditions. Therefore, stream restoration does not result in measurable wet weather bacteria reductions when compared to the 1-3 day required retention time for bacteria removal in engineered systems. These load reductions are generally much lower than those required for MS4 permit compliance.

Wetlands projects increase residence times by 24-76 hours, thus provide substantial treatment. When in-stream restoration is combined with wetland projects eight of 11 watersheds are able to achieve the combined 10% load reduction goal. However, the number of watersheds unable to achieve the 20% load reduction goal lowers to three of 11. Eight of the watersheds are able to achieve the MS4 permit load reduction goal. The three watersheds unable to achieve the scenario load reduction target are generally limited by land use constraints.

Table 12. Results of the stream restoration scenarios

WATERSHEDS	REDUCTION GOAL	STREAM: INSTREAM ONLY			STREAM: +10% WETLAND			STREAM: +20% WETLAND			STREAM: +MS4 COMPLIANCE (50% WETLAND EFFICIENCY)			
		LOAD REDUCTION (%)	ANNUAL ENT* REDUCTION (COLONIES/YR)	TOTAL COST ($M)**	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)	LOAD REDUCTION GOAL PER WQIPS	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)
San Diego Watersheds														
San Diego River	4.30E+15	1.00	4.10E+13	231	10.0	4.40E+14	341	20.0	8.60E+14	456	30.8	30.9	1.33E+15	556
Chollas Creek	1.70E+15	0.200	4.10E+12	60.0	10.0	1.80E+14	101	20.0	2.20E+14	109	28.8	14.2	2.39E+14	109
San Dieguito	6.80E+14	1.10	7.50E+12	48.0	10.0	6.80E+13	73.0	20.0	1.40E+14	103	13.0	14.7	9.97E+13	83.0
Los Peñasquitos	2.90E+15	0.600	1.80E+13	198	10.0	2.90E+14	342	20.0	5.80E+14	497	17.8	17.8	5.17E+13	438
Tecolote Creek	8.40E+14	0.300	2.20E+12	18.0	10.0	6.70E+13	30.0	20.0	6.70E+13	30.0	18.0	8.90	7.43E+13	30.0
San Luis Rey	3.60E+15	0.300	1.00E+13	275	10.0	3.70E+14	660	20.0	5.10E+14	820	15.8	15.9	5.72E+14	820
Orange County Watersheds														
Laguna Coastal Streams	2.50E+14	0.300	6.90E+11	33.0	10.0	2.50E+13	59.0	20.0	3.00E+13	65.0	2.50	2.70	6.61E+12	39.0
Aliso Creek	1.30E+15	1.60	2.10E+13	66.0	10.0	1.30E+14	112	20.0	1.80E+14	130	5.80	5.80	7.67E+13	86.0
Dana Point	2.80E+14	1.20	3.50E+12	6.00	10.0	2.00E+13	12.0	20.0	2.00E+13	12.0	2.50	4.40	1.25E+13	9.00
San Juan	2.60E+14	0.300	6.60E+11	192	10.0	2.60E+13	346	20.0	3.10E+13	378	17.6	13.2	3.41E+13	378
San Clemente	4.80E+14	0.200	1.10E+12	21.0	10.0	4.40E+13	41.0	20.0	4.40E+13	41.0	3.20	4.30	2.07E+13	30.0

* ENT = *Enterococcus*

**$M = Million $

***Green highlighted cells indicate that the scenario does not achieve its load reduction goal

**** "E" is an abbreviation for exponential notation and designates large values.

Stream: + 10% Wetland and Stream: + 20% Wetland scenario results are presented in Table 12. For reported results, the bacteria removal efficiency is assumed to be 50%. Notably, the maximum feasible reduction rates for eight watersheds do not attain the target reductions of 10 or 20%.

UNCERTAINTY ANALYSES

The CBA includes a substantial effort to provide a broad and quantitative sense of the uncertainty within the CBA results. The approach to this uncertainty calculation is to provide a "best" estimate of actual values, then provide high and low bracket values that can be passed through the remainder of the analyses to show error bars in CBA results focused on units of benefit and cost effectiveness.

For the stream restoration inputs to the CBA, there are two separate analyses that provide insight into 1) load reduction bracket values and 2) cost bracket values for the MS4 compliance scenario. While the best estimate value is based on a 50% removal efficiency, both uncertainty analyses use alternative removal efficiencies of 40% and 70% based on the range of literature values. These results show that bacteria removal efficiencies are sensitive assumptions in the analysis but they are useful in bracketing.

Load Reduction Bracket Analysis

The "load reduction bracket" analysis determines the number of projects needed to achieve the MS4 permit required load reductions then varies the removal efficiency while maintaining the same number of wetland projects (see Table 13). The table includes the Stream + MS4 compliance scenario as the best estimate value in the center of the table. This scenario uses the 50% removal efficiency. Low load reduction values are on the left of the table while high load reduction values are on the right side of the table. Results for an example watershed (San Diego River) show a low load reduction of 28.4%, best value of 30.9% and high load reduction of 35.8%. As expected, costs are the same under each case because the number of projects are held constant in this uncertainty analysis.

Table 13. Stream restoration - load reduction bracket analysis

WATERSHEDS	REDUCTION GOAL	# OF PROJECTS	40% WETLAND EFFICIENCY			STREAM: +MS4 COMPLIANCE			70% WETLAND EFFICIENCY		
			LOAD REDUCTION (%)	ANNUAL ENT* REDUCTION (COLONIES/YR)	TOTAL COST ($M)**	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)
San Diego Watersheds											
San Diego River	30.8%	65	28.4%	1.22E+15	$556	30.9%	1.33E+15	$556	35.8%	1.54E+15	$556
Chollas Creek	28.8%	17	12.9%	2.17E+14	$109	14.2%	2.39E+14	$109	16.8%	2.83E+14	$109
San Dieguito	13.0%	7	13.5%	9.17E+13	$83.0	14.7%	9.97E+13	$83.0	17.0%	1.16E+14	$83.0
Los Peñasquitos	17.8%	48	16.3%	4.71E+14	$438	17.8%	5.17E+13	$438	21.0%	6.09E+14	$438
Tecolote Creek	18.0%	4	8.00%	6.69E+13	$30.0	8.90%	7.43E+13	$30.0	10.7%	8.92E+13	$30.0
San Luis Rey	15.8%	109	14.3%	5.14E+14	$820	15.9%	5.72E+14	$820	19.1%	6.88E+14	$820
Orange County Watersheds											
Laguna Coastal Streams	2.50%	2	2.40%	6.03E+12	$39.0	2.70%	6.61E+12	$39.0	3.20%	7.77E+12	$39.0
Aliso Creek	5.80%	7	5.30%	7.09E+13	$86.0	5.80%	7.67E+13	$86.0	6.70%	8.85E+13	$86.0
Dana Point	2.50%	1	4.10%	1.17E+13	$9.00	4.40%	1.25E+13	$9.00	5.00%	1.41E+13	$91.0
San Juan	17.6%	64	12.0%	3.10E+13	$378	13.2%	3.41E+13	$378	15.5%	4.02E+13	$378
San Clemente	3.20%	3	3.90%	1.88E+13	$30.0	4.30%	2.07E+13	$30.0	5.10%	2.45E+13	$30.0

* ENT = *Enterococcus*
**$M = Million $
*** "E" is an abbreviation for exponential notation and designates large values

Cost Bracket Analysis

The "cost bracket" analysis holds the load reduction goal constant then varies the removal efficiency allowing the number of projects vary (Table 14). The table includes the Stream + MS4 compliance scenario as the best estimate value in the center of the table. This case uses the 50% removal efficiency. Low cost values are on the left of the table while high cost values on the right side of the table. Results for an example watershed (San Diego River) show a low cost of $621M best value of $556M and high cost of $546M. As expected, costs vary in each case because the number of projects changes with the removal efficiency.

Table 14. Stream restoration - cost bracket analysis

WATERSHEDS	REDUCTION GOAL	40% WETLAND EFFICIENCY				STREAM: +MS4 COMPLIANCE (50% WETLAND EFFICIENCY)				70% WETLAND EFFICIENCY			
		# OF PROJECTS	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)	# OF PROJECTS	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)	# OF PROJECTS	LOAD REDUCTION (%)	ANNUAL ENT REDUCTION (COLONIES/YR)	TOTAL COST ($M)
San Diego Watersheds													
San Diego River	30.8%	71	28.4%	1.22E+15	$621	65	30.9%	1.33E+15	$556	56	35.8%	1.54E+15	$546
Chollas Creek	28.8%	17	12.9%	2.17E+14	$121	17	14.2%	2.39E+14	$109	17	16.8%	2.83E+14	$121
San Dieguito	13.0%	7	13.5%	9.17E+13	$56.0	7	14.7%	9.97E+13	$83.0	6	17.0%	1.16E+14	$51.0
Los Peñasquitos	17.8%	53	16.3%	4.71E+14	$424	48	17.8%	5.17E+13	$438	41	21.0%	6.09E+14	$364
Tecolote Creek	18.0%	4	8.00%	6.69E+13	$29.0	4	8.90%	7.43E+13	$30.0	4	10.7%	8.92E+13	$29.0
San Luis Rey	15.8%	109	14.3%	5.14E+14	$872	109	15.9%	5.72E+14	$820	90	19.1%	6.88E+14	$777
Orange County Watersheds													
Laguna Coastal Streams	2.50%	3	2.40%	6.03E+12	$20.0	2	2.70%	6.61E+12	$39.0	2	3.20%	7.77E+12	$17.0
Aliso Creek	5.80%	8	5.30%	7.09E+13	$53.0	7	5.80%	7.67E+13	$86.0	6	6.70%	8.85E+13	$47.0
Dana Point	2.50%	1	4.10%	1.17E+13	$7.00	1	4.40%	1.25E+13	$9.00	1	5.00%	1.41E+13	$7.00
San Juan	17.6%	64	12.0%	3.10E+13	$426	64	13.2%	3.41E+13	$378	64	15.5%	4.02E+13	$426
San Clemente	3.20%	3	3.90%	1.88E+13	$20.0	3	4.30%	2.07E+13	$30.0	2	5.10%	2.45E+13	$17.0

* ENT = *Enterococcus*

**$M = Million $

*** "E" is an abbreviation for exponential notation and designates large values

4. BENEFITS ANALYSIS

Benefits represent the valuable goods and services provided by BMPs in each scenario. Each scenario's BMPs affect water quality that determines the public health (number of illnesses) and recreation trips that can be expected under the scenario. The benefits analysis also evaluates co-benefits of BMPs, which are a broad array of environmental and social benefits that can be quantified or at least described, such as water supply, carbon sequestration and habitat enhancement. The quantity of each benefit category (e.g., 5,000 avoided illnesses, 7,500 recreation trips or 10 acres of restored habitat) is calculated for each scenario and then a baseline quantity is subtracted to isolate the benefits that come from the scenario. The quantity of each benefit is valued using best available sources to monetize the total benefits of the scenario. Final monetary results are expressed as net present value (NPV) from all 65 years of the analysis period. For each scenario, benefits quantity is used to calculate cost effectiveness and benefits NPV is combined with cost to calculate net benefits in the *Synthesis of Findings* chapter.

OVERVIEW OF ANALYSIS

The benefits analysis starts with development of baseline service levels and progresses through aggregation of several benefit categories to provide the net present value of all benefits for each scenario. The analysis finishes with a discussion of sensitivity for key variables, consideration of qualitative benefits and notes on additional analyses that were performed (see Figure 13).

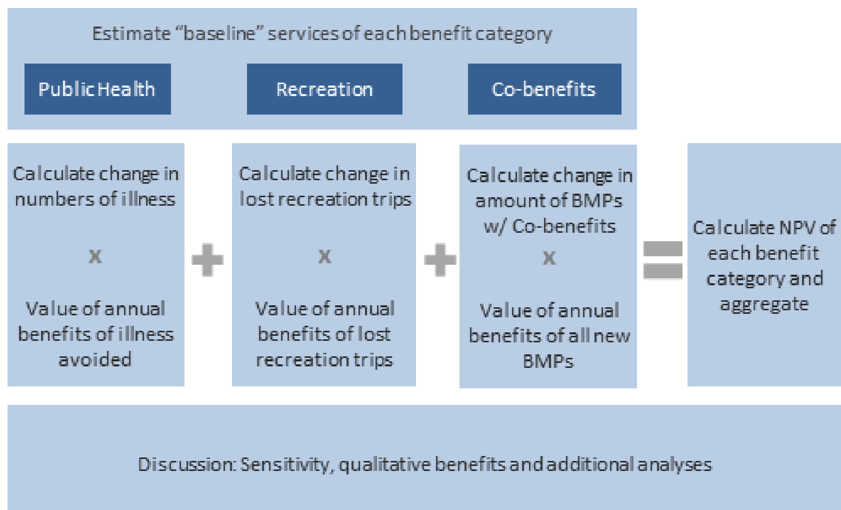


Figure 13. Overview of the steps of the benefits analysis.

Establishing the baseline service levels focuses on creating a model that predicts daily attendance at beaches in the region. This "attendance" model is the tool that estimates underlying supply and demand information on wet days for all scenarios analyzed. This step of the analysis also involves definition of benefit categories including

- **Public Health** – the willingness to pay to avoid illness, direct medical expenditures and avoided work absenteeism are combined in this benefit value. Public health is calculated for gastrointestinal distress in all scenarios and a composite measure of "all infectious symptoms" in some scenarios.
- **Recreation** – the surplus value of lost trips to the beach due to bacteria impairment for a broad group of recreation types. Surplus value is the value received by individuals beyond their expenditures.
- **Co-Benefits** - the non-bacteria water quality benefits in categories such as carbon sequestration, air quality, wildfire risk and other pollutant removal. These benefits are associated primarily with green infrastructure and stream restoration. Many of these benefits are discussed qualitatively.

For each category of benefits the analysis progresses through two steps, represented by the horizontal rows of blue boxes in Figure 14. First, the change in the amount of the baseline quantity is determined for each scenario analyzed. For instance, there are a certain number of illnesses currently due to bacteria exceeding safe limits. Also, in each scenario, a lower number of illnesses is predicted so the difference in illnesses between the baseline and the scenario of interest is calculated. Second, the literature value of the benefit quantity (e.g., an avoided illness) is determined and multiplied by the difference to calculate an annual benefit. To complete the benefit calculation, the three categories of benefits are summed using net present values to determine the total benefits in 2016 dollars for each scenario and each watershed[13].

After the steps above, there is a discussion of supporting analyses that do not directly contribute to the benefits values. Examples of these discussions includes elements of uncertainty for each analysis and consideration of how sensitive the results are to those uncertainties in terms of ultimate monetary value. Additional analyses explore effects of different discount rates, accounting timeframes, climate change and impacts on the transient population that lives near creeks.

ESTABLISHING BASELINE SERVICES

Estimating the baseline service levels focuses on creating the models that predict daily attendance at beaches in the region and defining the level of services in each benefit category (Figure 14). The models include an attendance model and a demand behavior model that estimate daily values for attendance on wet weather days. Baseline service levels are used later in the analysis to calculate a difference in service level for each scenario.

Figure 14. Overview of the methodology for estimating baseline benefit services

NUMBER OF WET WEATHER DAYS

Because the CBA focuses on wet weather effects, the number and type of wet weather days provides important basic information for calculating benefits.

Data Sources

The 25-year timeframe of 1990 to 2015 and the watershed-level storm and wet weather datasets developed for the WQIP serve as the base data for estimating average annual number of wet weather days by wet day type and watershed.

Methods

Wet weather days are categorized as a day with greater than 0.2 inches of rain plus the day after (storm +1), the second day after the rain (storm +2) and the third day after the rain (storm +3). Each of these types of days has a different attendance profile and bacteria concentration because pollutant loads return to normal dry-weather levels rapidly. Each type of wet weather day provides a component of the total benefits in this analysis and benefits for each day type are calculated separately.

Assumptions

This assumes the averages over the 1990-2015 will hold into the future for all watersheds. See the discussion of climate change effects for consideration of sensitivity to this assumption.

[13] Adjustments to 2016 dollars utilize the annual average consumer price index unless otherwise indicated. Bureau of Labor Statistics. https://www.bls.gov/cpi/.

Results

Table 15. Average Annual Wet Days by Watershed

WATERSHED	STORM DAY	STORM DAY +1	STORM DAY +2	STORM DAY +3
San Diego County	16.5	11.3	10.1	8.00
San Luis Rey	25.7	15.9	14.3	12.7
San Marcos	14.4	10.6	9.60	8.80
San Dieguito	14.0	10.2	9.30	8.40
Los Peñasquitos	14.0	10.2	9.30	8.40
San Diego River	15.0	11.4	10.2	9.10
Tecolote Creek	13.8	10.3	9.50	8.60
Scripps	18.3	10.7	8.90	0.000
Orange County	17.0	11.3	9.80	8.90
Aliso Creek	17.4	11.5	10.0	9.00
Dana Point	17.4	11.5	10.0	9.00
Laguna Coastal Streams	17.4	11.5	10.0	9.00
San Clemente	15.4	10.4	9.10	8.40
San Juan	17.4	11.5	10.0	9.00

The annual number of wet days varies somewhat by watershed, but from 1990 to 2015, the number of rainy days is generally less than 20 annually, with about 17 rainy days annually as the average (Table 15). When counting out to three days after rain as wet days, the average is 47 annual wet days for Orange County and 48 for County of San Diego, equating to 13% of days annually on average affected by rain. In general, there is a gradual decline in the number of annual wet days moving to storm+3 because storms can occur less than 3 days apart. The number of wet weather days are used to quantify the value of baseline recreation and public health service levels provided at beaches associated with each watershed.

BEACH ATTENDANCE AND BACTERIA EXPOSURES

The analysis focuses on development of two models to predict normal daily beach attendance and the effect of unhealthy bacteria exposure on beach use during wet weather. The first model is the Beach Attendance Model and the latter is known as the Demand Behavior Model. Only beaches within the boundaries of the watersheds are included. An exhaustive exercise to identify and compile data for these beaches included review of all available beach lists, both spatial and non-spatial, and direct inquiries for each jurisdiction for attendance data. Beach lists and beach characteristics were reviewed by county and city staff. In some cases, individual beach estimates are constrained by seasonal access restrictions.

Data Sources

The same data sources are employed by both models. All available beach-specific attendance data were compiled. This included data requests through all identifiable pathways and for all jurisdictions (city, county, state) operating designated beaches within the two-county region. Beach attendance data are collected and recorded differently by state, county and local beaches across the region, with some beaches providing daily estimates, others monthly, and some having only annual estimates available. Some beaches record the types of users, between swimmers, surfers, and other patrons through counts by lifeguards. A small subset of beaches with public access and formal name designations have no recorded data. The following detailed information is used to parameterize a beach attendance model.

- **Daily Data** – the City of Encinitas (2014 – 2015), the city of San Clemente (2005 -2015), Newport Beach (2005 – 2015), Huntington Beach (2005 – 2016), and Imperial Beach (2006 – 2015).
- **Monthly Data** – San Diego City Beaches, Coronado Beach, and Del Mar.
- **Annual Data** – Solana Beach, Oceanside Beach, and Laguna Beach (at the city level).
- **Dwight et al Data** – The article "Beach Attendance and bathing rates for Southern California beaches" by Dwight et al., published in *Ocean & Coastal Management* in 2007. This paper provides the estimated average attendance from 2000 – 2004 for San Onofre, Carlsbad, South Carlsbad, San Elijo, Cardiff, Torrey Pines, Silver Strand, Baby Beach, Capistrano, Doheny, Poche, San Clemente State Beach, Three Arches, Table Rock, Aliso, Emerald Bay, Salt Creek / Strand Beach, and Sunset Point.
- **Population Projections** – Total beach demand including exposures and trips are scaled using county level population growth projections provided by SANDAG for San Diego County and from the Center for Demographic Research at California State University, Fullerton.[14]

A shapefile of beaches in San Diego and Orange Counties was developed through first compiling land use files for recreation and open space on the coast based on data from SANDAG[15] and Orange County's GIS server[16]. These were cross-referenced with satellite images, Google maps and the list of beach locations available through California Beaches[17] in order to determine the name, ownership and spatial extent of beaches. This was used to calculate characteristics of beaches such as beachfront length and area as well as categorizing beaches by watershed and owner.

Methods

This section of the analysis breaks into two parts: development of a Beach Attendance Model that estimates the number of people participating in beach activities on wet days, and creation of a Demand Behavior Model that predicts how many people will not enter the water or go to the beach on wet weather days due to water quality conditions.

Beach Attendance Model

We undertook the following multi-step procedure to estimate daily attendance for all beaches.

- Complete the Annual Data
  - Estimate annual beach attendance in 2010 for beaches with no attendance data based on geographical characteristics
  - Estimate beach attendance as a cubic function of time
  - Project annual beach attendance for the "Dwight et. Al" and geographically estimated beaches
- Take all annual data and expand using the monthly shares
  - Estimate within-year monthly attendance shares for 2005-2015 using existing monthly data
  - Impute missing months in San Diego City data based on other monthly data
  - Project monthly attendance from annual data and monthly shares
  - Combine these data with existing monthly data

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[14] SANDAG, 2050 Series 13 Regional Growth Forecast; Center for Demographic Research, CSUF, 2015 Orange County Progress Report.

[15] http://www.sandag.org/

[16] http://ocdata.giscloud.com

[17] http://www.californiabeaches.com/

- Take monthly data and expand using daily shares
  - Calculate the within-month share of attendance for everyday from 2005 – 2015
  - Impute missing daily data based on existing daily data sources
  - Project daily attendance from monthly data and daily shares
  - Combine these data with existing daily data.

Daily Data Methods

While not all compiled beaches are in relevant watersheds, the daily beach data inform attendance patterns at beaches in the watersheds. For every month possible, the within-month share of attendance for each day was calculated. For example, 6.3% of the total beach attendance for February 2009 took place on February 1st in County of San Diego. 7.8% of February 2009 beach attendance took place on February 1st in Orange County. This allows calculation of a share for every calendar day from 2005 to 2015 accordingly:

$$S_{dmy}^{daily} = \frac{\sum_i Attend_{idmy}}{\sum_{i,d} Attend_{idmy}}$$

In other words, the share of attendance for day d in month-year my is the ratio of two numbers. The numerator is the number of attendees for all beaches on day d, found by summing over beaches i. The denominator is the number of attendees for all beaches and all days in the same month.

The result of this procedure is a multiplier for every calendar day from 1/1/2005 to 12/31/2015 that can be used to impute monthly data into daily data for beaches that only provided monthly data.

Monthly Data Methods

First, data on monthly beach attendance is useful for understanding how beach attendance varies as seasons change to transform annual data. Specifically, it allows calculation of the fraction of annual attendance that takes place in each month. For example, in 2009, 3.4% of annual attendance took place in February 2009. Conversely, over 21% of the annual attendance in 2009 took place in July. Specifically, the share of attendance in month-year my can be found:

$$S_{my}^{monthly} = \frac{\sum_i Attend_{imy}}{\sum_{i,m} Attend_{imy}}$$

The numerator is simply the sum over all beaches I in month-year my. The denominator is the sum over all beaches I and all months m in year y. These shares allow transformation of attendance data available only annually.

Second, the monthly data for San Diego City is only available for a few years. The observed monthly patterns in the other data allow imputation of the monthly values for all San Diego City beaches. This fills in many gaps that were present in the San Diego City beaches data and allows extension of the window for reasonable attendance data for these beaches.

Annual Data Methods

First, the monthly shares calculated above support development of monthly data from annual data. The monthly data are converted into daily data using the daily shares from the first procedure.

Second, the annual attendance data allow estimation of the long-run patterns in beach attendance. This is useful for estimating beach attendance at beaches that only have one or two data points.

Dwight et al. 2007 Data Methods

A study of beach-specific annual attendance provides estimates for several beaches in the Bacteria TMDL watersheds not available from other sources[18]. The average attendance reported is treated as the value of attendance for 2004. Then, the relationship between time and attendance is modeled using the more detailed data for other beaches. This involves the following model:

$$\ln(Attend_{iy}) = \beta_0 + \beta_1 year_y + \beta_2 year_y^2 + \beta_3 year_y^3 + \epsilon_{iy}$$

This equation assumes that the natural logarithm of attendance is explained by a flexible function of time (cubic). By using the observed relationship between time and attendance, the model charts percentage changes in attendance by year, relative to 2004.

Once the model is estimated, it is used to predict what attendance would have been every year for this set of beaches. The result of this procedure is estimates of annual beach attendance from 2005 – 2015 for these beaches. Once complete, these data are applied to the procedure described above to estimate daily attendance data.

Beaches with No Data

Despite all efforts, there remained several existing beaches for which no data on attendance could be identified. Data on the location and size of all beaches is available though from Geographic Information Systems (GIS) obtained from San Diego and Orange Counties. For beaches that have existing data and using a representative year, 2010, a model estimates the relationship between beach attendance and the physical characteristics of the beach: location, waterfront length, perimeter, and area. 2010 represents an average of years 2005 to 2015 for estimating attendance at these beaches, and utilizes data from all available years for beaches with attendance data. In this way 2010 attendance levels are not the only basis for the model estimates, but rather the model output. Population growth rates are applied separately later in the analysis.

Specifically, a model regressed beach attendance in 2010 on 2nd order polynomials for area, perimeter, and waterfront length; a dummy variable for County of San Diego; and the distance to the nearest city center:

$$Attend_i = \alpha_0 + \alpha_1 Area_i + \alpha_2 Area_i^2 + \alpha_3 Perim_i + \alpha_4 Perim_i^2 + \alpha_5 waterfront_i + \alpha_6 waterfront_i^2 + \delta SDC_i + \gamma dist_i + \eta_i$$

This econometric model explains approximately 41% of the variation in beach attendance. This model is the basis for predicting the 2010 attendance for the beaches with no other attendance data available[19].

Visitor Type

Some beaches include counts by lifeguards of patron type, namely surfers, swimmers, and other patrons. Age and other defining characteristics are not available for any beach counts in the lifeguard count data obtained. Seasonal proportions of the three visitor types are applied to all beaches to estimate the number of exposures, namely the sum of surfers and swimmers. Surfers and swimmers are generally a minority of visitors where such data are available. For example, for the average of 2010 to 2015 at Del Mar Beach, January visitors are 4.4% swimmers, 15.3% surfers, with the remainder not entering the ocean. In the same data, July visitors are 23.3% swimmers and 12.5% surfers (Figure 15). Visitor type is incorporated in the analysis only to separate those exposed to the water (surfers and swimmers) from those who are not (all others).

[18] Dwight, R., Brinks, M., SharavanaKumar, G. and Semenza, J., 2007. Beach attendance and bathing rates for Southern California beaches. *Ocean & Coastal Management*, *50*(10), pp.847-858.

[19] This model is used for the following beaches: Bermuda Beach, Bird Rock Beach, Boomer Beach, Calumet Beach, Camino de la Costa, Campland, Dana Point Headlands, La Jolla Caves, La Jolla Strand, Mission Point, Monarch, Riviera Shores, Santa Clara Point, Ski Park, South Shores, and Enchanted Cove.

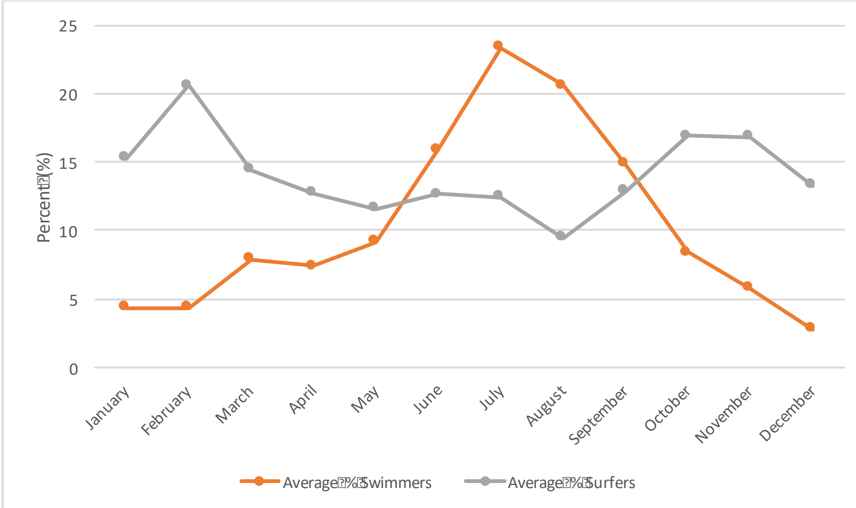

Figure 15. Graph shows the number of seasonal surfers and swimmers at Del Mar Beach, 2010-2015. The majority of exposures during cold months come from surfers, and the majority of exposures during warm months come from swimmers.

Demand Behavior Model

A multiple linear regression analysis was applied to estimate the effect that wet weather events and the associated water pollution illness risk have on beach usage behavior. It is very difficult to separate the effect of bad weather and the effect of risk of illness on the decision to go to the beach on a storm day. However, the heightened risk of illness remains for several days after the conclusion of the storm. Accordingly, the model is used to measure the drop-in attendance that occurs in the several days after a storm. Furthermore, the daily water quality data show very few storm days that become safe to swim (*Enterococcus* levels of less than 104 per 100 ml), considering the allowance for 22% exceedance rate across all wet days and the highest concentrations on storm days.

To model attendance behavior during wet weather, the model must control for the time of year, the day of the week, the weather conditions and ocean conditions for every day. Econometric techniques "hold constant" these confounding factors to isolate the effect of concern. Through interviews and review of publicly available data and guidance on beach safety, it is assumed that beachgoers know that it is considered unsafe to enter the ocean on storm days and the three following days. The model is designed to identify the share of beachgoers that would have gone to the beach on one of the three days following a storm if all other conditions are the same (weather, surf, month, day of the week, etc.) but for the storm occurrence. To identify the impact of illness risk on beach attendance, ideally the model compares attendance on a clear, warm Saturday in January to attendance on a clear, warm Saturday in January in which it rained the day before. The intuition is that everything about the day in question is identical except for one day comes after a storm. Any difference in attendance should be attributable to the perceived illness risk.

This hypothetical comparison is conducted using multiple linear regression analysis. Regression allows control for the month, day of the week, temperature, wind, sunshine, and other confounding factors. The model is the following:

$$\ln(Attend_{it}) = \alpha_0 + \alpha_1 WEEKDAY_t + \alpha_2 MONTH_t + \alpha_3 BEACH_i + \alpha_4 PRECIP_{it} + \alpha_5 TEMP_{it} + \alpha_6 RAIN_{it} + \alpha_7 CLOUDY_{it} + \alpha_8 RAIN1_{it} + \alpha_9 RAIN2_{it} + \alpha_{10} RAIN3_{it} + \alpha_{11} RAIN4_{it} + \alpha_{12} RAIN5_{it} + \epsilon_{it}$$

The model regresses the natural logarithm of attendance for a given day on a set of weather (*PRECIP*, *TEMP*, *CLOUDY*) and spatial controls (BEACH) and a set of variables that indicate whether that observation occurred on a wet weather day, one day after wet weather, two days after wet weather, and so on (*RAIN*, *RAIN1*, *RAIN2*, *RAIN3*, *RAIN4*, *RAIN5*). This procedure allows us to separately estimate the impact on attendance for the days following a wet weather event. To be clear, the set of wet weather variables are mutually exclusive. For example, if it rains two days in a row, both days would be labeled as having rained "today". In this example, the second day would not be considered both "rained today" and "rained one day ago."

Table 16: Beach Attendance Regression: Weather Variables

	ESTIMATE	STANDARD ERROR	*p*-VALUE
Precipitation (Inches)	-0.170	0.160	0.290
Mean Temperature	0.020	0.000	0.000
Rain	-0.680	0.110	0.000
Cloudy	-0.080	0.010	0.000
Rain One Day Ago	-0.290	0.090	0.000
Rain Two Days Ago	-0.180	0.110	0.110
Rain Three Days Ago	-0.330	0.100	0.000
Rain Four Days Ago	-0.250	0.070	0.000
Rain Five Days Ago	-0.230	0.080	0.010

Obs: 730, R-Sq: 0.680

F-statistic: 55.467, df = (27; 702)

Table 16 shows the results of the linear regression for the weather-related variables. Since the dependent variable is the natural logarithm of attendance, one can interpret these coefficients as percent changes. For example, an additional inch of rain would lower attendance 17%. However, since the *p*-value for this estimate is large, it is not considered a significant effect.

Wet weather has a significant impact on attendance. On rainy days, attendance drops 68%. Unfortunately, as described earlier, it is difficult to separate the effect of the unpleasant weather from the increased risk of illness. However, on the day following a rain event, attendance is 29% lower. In fact, for the five days following a wet weather event, attendance falls 29%, 18%, 33%, 25%, and 23%, respectively. The differences between these impacts is not statistically significant, so one cannot infer that there is something special about the third day after a rain event relative to the second day. However, one can infer that wet weather events have a significant impact on attendance long after the rain stops.

This model does not differentiate between type of visitor. It is likely that a high proportion of foregone trips after storms are by visitors who would have entered the ocean, but it is possible that others forego trips as well, such as companions to surfers. Therefore, the estimates of foregone trips by wet day and watershed are not disaggregated by visitor type, and all foregone trips are counted. This model is only used to estimate attendance for recreation benefit calculations, and does not factor into the exposure or public health benefit calculations.

Surfer Behavior Model

As a secondary test of surfers specifically in terms of response to water quality improvements, this analysis included development of a surfer behavior model utilizing the detailed surfing trip, weather, and surf condition data collected as part of the Surfer Health Study. These results do not directly modify the overall beach attendance and behavior modeling described above, but is a secondary check on the validity of those aggregate measures to surfers specifically. It takes advantage of the availability of these detailed data.

Table 17: Surfer Response Model

	ESTIMATE	STD. ERROR	T VALUE	PR(>|T|)
(Intercept)	-44.7	38.20	-1.17	0.240
Rain	-17.9	5.69	-3.15	0.00
Rain Yesterday	-11.0	6.85	-1.61	0.110
Rain 2 Days Ago	-10.2	5.17	-1.98	0.050
Rain 3 Days Ago	-3.15	4.57	-0.690	0.490
Surf Height	3.73	2.08	1.79	0.080
Tide Height	0.230	1.77	0.130	0.900
LOLA Surf Max	2.99	3.26	0.920	0.360
LOLA Swell	-3.44	3.87	-0.890	0.380
LOLA Period	1.68	0.620	2.72	0.010
Temperature	0.210	0.350	0.600	0.550
Monday	-7.58	4.90	-1.55	0.120
Saturday	18.80	7.52	2.50	0.010
Sunday	4.29	5.23	0.820	0.410
Thursday	-1.64	4.03	-0.410	0.690
Tuesday	-12.3	3.79	-3.25	0.000
Wednesday	-9.71	3.81	-2.55	0.010
CloudCover	-0.410	0.610	-0.670	0.500
Tourmaline	11.4	2.63	4.34	0.000
Hour	7.16	7.14	1.00	0.320
Hour ^ 2	-0.340	0.330	-1.02	0.310

Using data from the Surfer Health Study, a model of surfer attendance as a function of weather, days of the week, surf characteristics, time of day, and importantly, wet weather events was developed. The SHS gathered attendance data at Tourmaline and Ocean Beaches in County of San Diego, along with measurements of the tide and surf height (Figure 16). The model combined these data with weather records and outputs of the LOLA model maintained by Surfline.com. The LOLA model predicts characteristics of the surf that can influence decisions of surfers whether or not to surf on a particular day.

Using all of these characteristics of surf conditions, weather conditions, and temporal conditions, the model provides a regression to measure the impact of wet weather on surfing participation in the days following a storm. Linear regression allows isolation of the impact of wet weather while controlling for surf quality, weekend/weekdays, and other weather conditions.

Table 17 contains the output of the following regression:

$$Surfers_{it} = \beta_0 + \beta_1 RAIN_t + \beta_2 RAIN_{t-1} + \beta_3 RAIN_{t-2} + \beta_4 RAIN_{t-3} + \beta_5 SURFQUAL_{it} + \beta_6\, TEMP_t + \beta_7 DAYOFWEEK_t + \beta_8 TOURMA_i + \beta_9 HOUR_{it} + \beta_{10} HOUR_{it}^2 + \beta_{11} CLOUD_t + \epsilon_{it}$$

The number of surfers at beach *I* on day *t* is a function of when it rained last, a vector of surf characteristics, the temperature, day of the week, a dummy variable for Tourmaline Beach, and a quadratic function of the hour of the day when the observation was made. Data are for Tourmaline Beach and Ocean Beach.

From the table, one can see that controlling for all other characteristics, a rainy day reduces surfer participation by approximately 18 surfers. This is statistically significant at the 0.1% level. One day after a wet weather event, attendance is 11 surfers lower, but this is only significant at the 11% level. On the next day, attendance is still 10 surfers lower than normal. By the third day post wet weather, attendance returns to normal, and there is no decline in activity.

These results suggest that wet weather (or associated warnings and forecasts) acts as a deterrent for some surfers up to two days after the wet weather event. The evidence suggests that some surfers are responsive to the wet weather advisories.

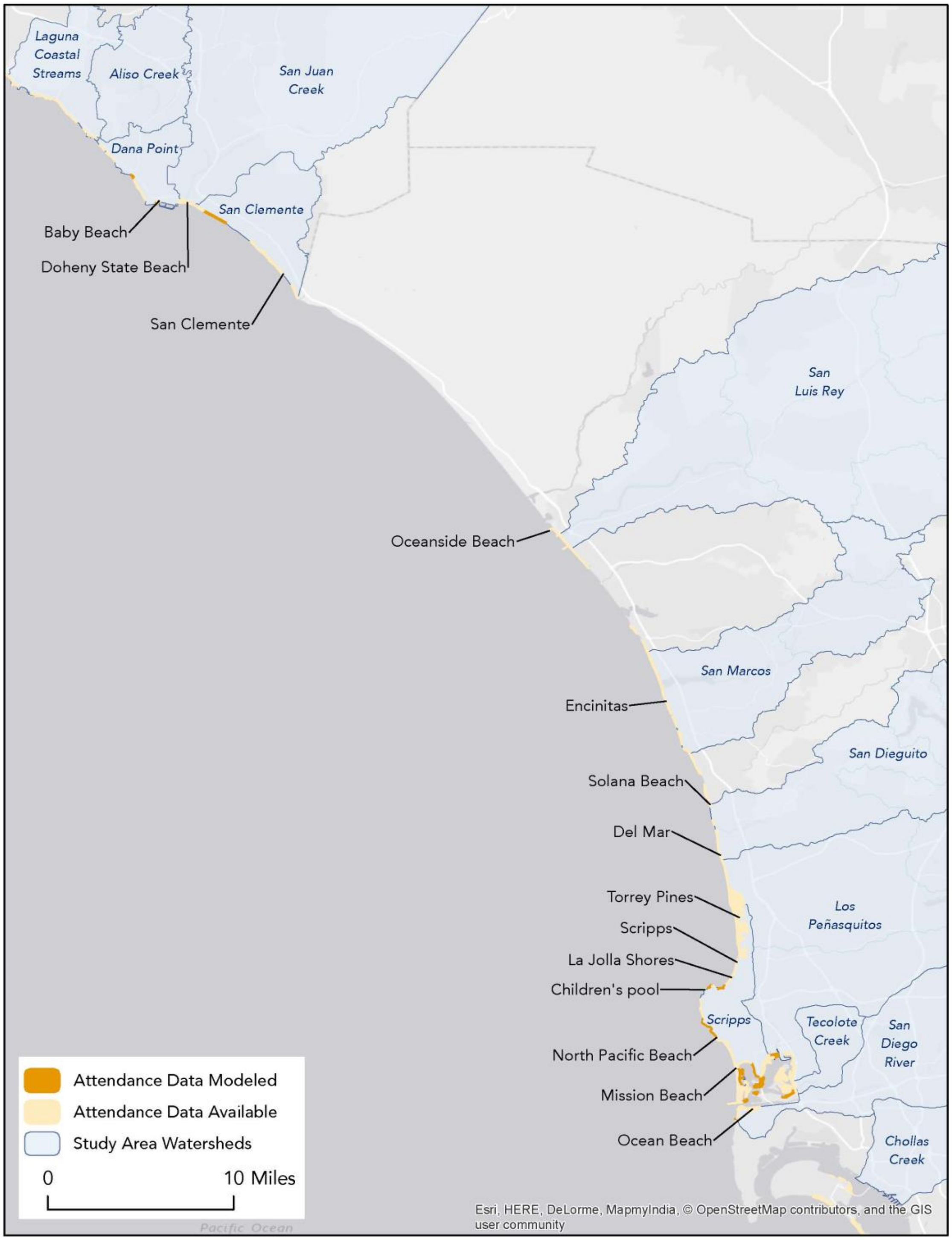

Figure 16: Map shows beaches associated with the Bacteria TMDL watersheds. For major beaches, attendance data are available, but for other, generally less popular beaches, attendance data were estimated based on beach characteristics and patterns in attendance at beaches with data.

Assumptions

Estimation of watershed-specific visits and foregone trips due to illness risk requires several assumptions. A central assumption is that attendance patterns are consistent across beaches, within total levels of annual visitation and by visitor type. It is possible that the beaches lacking attendance data experience less attendance than comparable beaches. The beaches with no data are smaller, and assumptions for estimating their visitation levels have been vetted with locals familiar with those beach usage levels and patterns. The visitation patterns are assumed to increase over time according to county-level population growth projections. It is generally best to interpret the results in aggregate at the watershed level, or even better across all watersheds, to account for beach-specific error that can occur in these model estimates.

A potentially substantial assumption is that beach visitors are not choosing substitute beaches with lower illness risk during and following storms, but forgoing trips completely. The model of daily visits related to storm days is an average across all beaches with daily data, so this would require a bias in these beaches to be perceived to be less safe after storms than other beaches. The general public health information campaign doesn't differentiate across sites, but rather discourages swimming and surfing at all beaches following storms. So applying the model results to scenarios addressing watersheds unequally might be less appropriate if visitors understand risk differences and choose lower risk beaches. But if risk is generally reduced proportionally across nearby watersheds, and easy opportunities to change to lower risk beaches do not exist, the results should be a robust estimate of visits and potential additional trips resulting from water quality improvements.

Results

The models provide tools for estimating attendance levels and attendance patterns across all beaches by wet day type and beach visitor type (exposed or not to water). The model incorporates patterns from beaches where data exist to estimate patterns for beaches without data available. Results for this stage of the analysis include for each watershed 1) the number of wet weather days by 2) the number of exposures (surfers and swimmers) by wet day type (storm, storm +1, storm +2, storm +3) and 3) the number of foregone trips on each non-storm wet day.

The next set of results for this step in calculating the health benefits is the number of exposures in terms of swimmers and surfers per watershed and per wet day. Scripps watershed is estimated to have the highest number of exposures by a wide margin across all wet day categories (Figure 17). Note that estimated exposures for San Juan, Laguna Coastal Streams and Tecolote Creek are always in the hundreds or less per wet day, and Chollas Creek does not directly affect any swimming or beachgoing activity. Generally, the exposure pattern, based on the model developed based on recorded daily beach data, is that the highest number of exposures during a storm cycle is on the storm day itself, while the lowest is the day after the storm, although variation across wet days is relatively low.

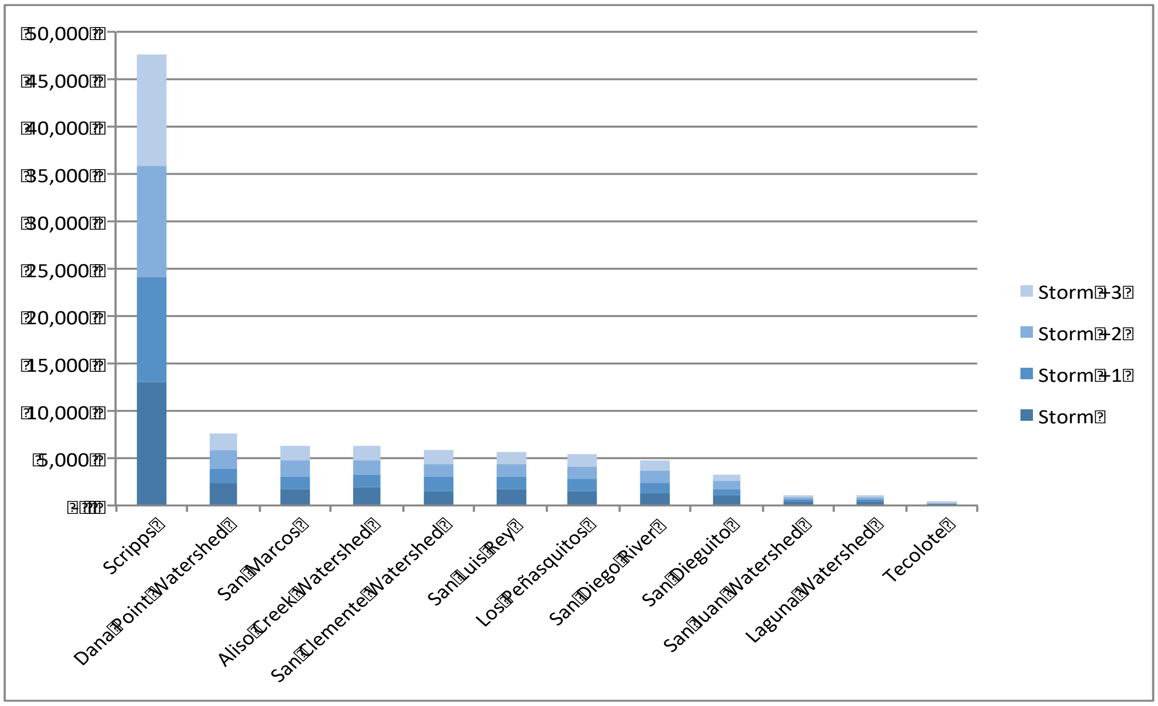

Figure 17. The average number of exposures on the day of a storm and the three following days is highest in Scripps watershed. These daily exposures are estimated to increase with population growth in the future.

Similar patterns for exposures exist for estimates of foregone trips due to low water quality by watershed (Figure 18). Note that the storm day itself is not included, as beachgoing behavior during storms is considered too difficult to statistically divide trips foregone due to weather conditions rather than water quality. Similar to exposures, Scripps can see tens of thousands of trips affected by water quality on wet days, while other watersheds see thousands to hundreds of trips affected.

When considering the total number of beach visits during the year for the Bacteria TMDL watersheds, the exposures and lost trips make up a small percentage of total beach visits (Figure 19). Of the 150 million annual beach visits, only 3% occur during wet weather, and less than one percent involve exposure via swimming and surfing. Slightly fewer trips are seen as affected by water quality (including non-swimmers as well). These 1.15 million foregone trips at $39.68 are worth $46 million in 2016 (value of trip explained in the next section). This sets an upper limit on the potential recreation benefit from making wet weather safe to swim based on this analysis. And using baseline illness rates for all wet weather exposures, the total annual wet weather GI illness attributable to water pollution exposure is 17,703 in 2016, which equates to $4.7 million in costs at $263.10 per illness (value explained in the next section), also representing a ceiling for the maximum annual benefit achievable through water quality improvements for GI illness reduction. These numbers increase with population growth over time.

For reference and consideration of overall beach estimates, 2016 County of San Diego total population was 3.3 million in 2016 and Orange County total population was 3.2 million[20]. While not accounting to non-local visitors and recognizing that these watershed beaches do not cover all beaches in the two counties, the 150 million annual trips do represent over 20 annual trips per resident. So, this beach attendance estimation exercise does seem unlikely to be a substantial underestimate. To the extent scenarios would have water quality benefits at more distant beaches beyond the watersheds though, the results could underrepresent

[20] U.S. Census Bureau. QuickFacts. census.gov/quickfacts.

the overall level of benefit. There is no strong basis in current available science though to extend these effects beyond the geographical ranges included in this study.

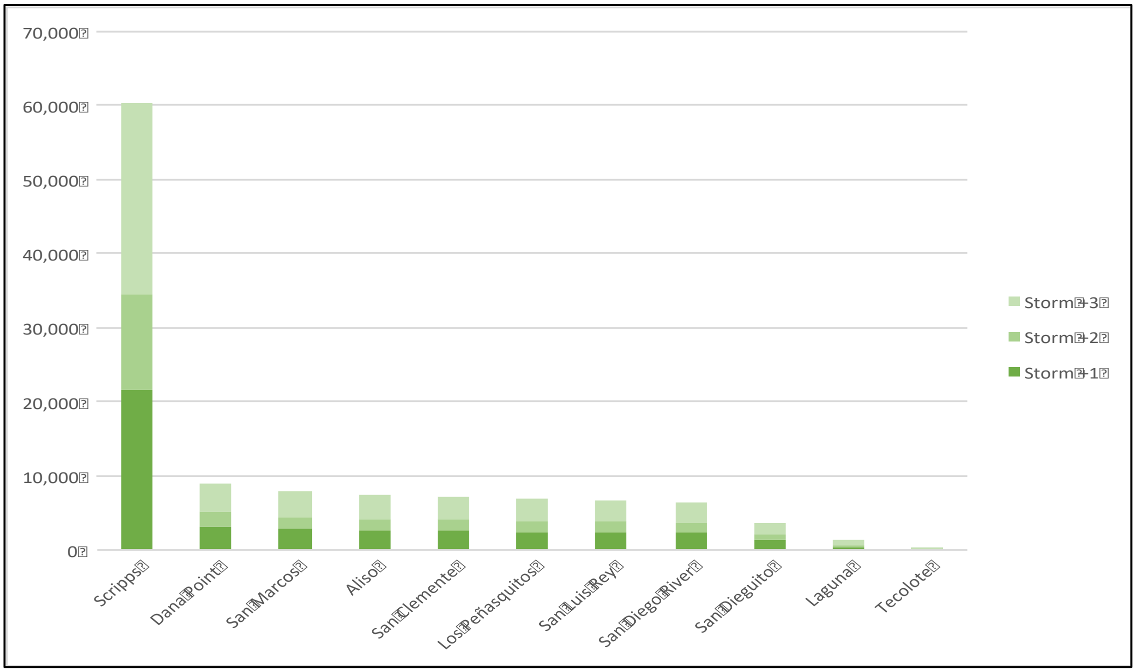

Figure18. The number of lost beach trips on the three days following a storm when water quality is unsafe for swimming is highest in Scripps watershed. These daily lost trips per unsafe wet day increase with population growth in the future.

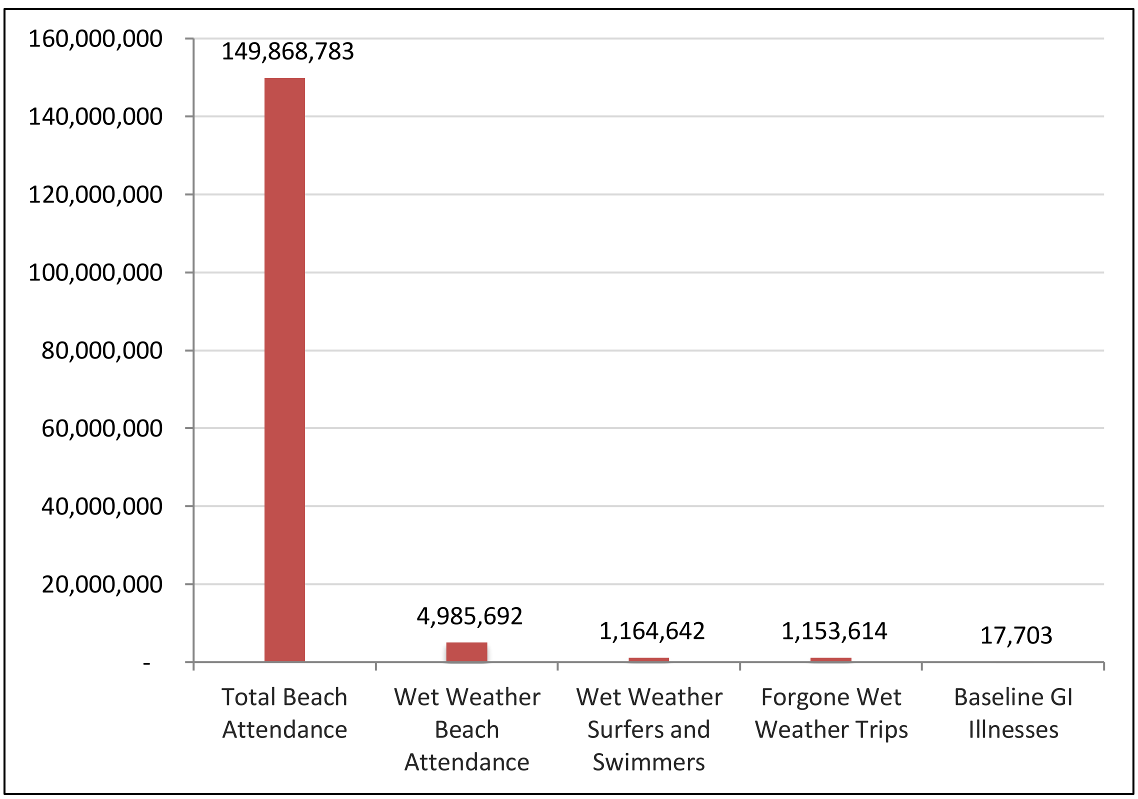

Figure 19. Total annual beach attendance is two orders of magnitude greater than wet weather beach attendance, showing the reduced portion of total beach usage affected by water quality benefits under the scenarios in this study. The share of these wet weather beach trips responsive to improvements in water quality, or that result in illness, is lower still.

PUBLIC HEALTH BENEFITS

Water quality has a direct effect on the public's use and enjoyment of San Diego's beaches. Pathogen-contaminated beaches affect the health of exposed users, with potentially cascading negative impacts on the region's recreation and tourism economy. The economic consequences of treating those who become ill from pathogen-contaminated water include healthcare costs and lost economic productivity.

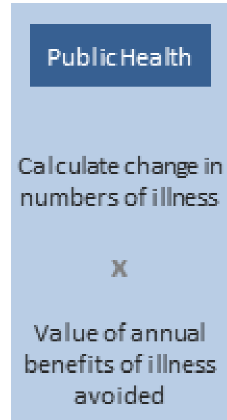

Figure 20. The basis of the methodology for public health benefits is to calculate the reduction in illnesses relative to the baseline, and multiply by the value of avoiding these illnesses.

CALCULATE CHANGE IN NUMBERS OF ILLNESS

The change in illness numbers is a product of the number of exposures times the illness rates that can be predicted given the level of harmful bacteria present in the water (see Figure 20). The analysis establishes a baseline illness rate using robust epidemiological studies that were recently completed in the analysis area. Gastrointestinal illness and a group of "all infectious symptoms" are analyzed separately to provide a range of benefit values.

Data Sources

- **Surfer Health Study (SHS)** - Steele, et al., 2016[21] Provides dilution studies that are used to determine dilution effects on stormwater bacteria inputs to the marine environment. It also identifies concentrations of FIB, viruses and human pathogens in stormwater, which provides the basis for assessing the ability of stormwater BMPs to control these pathogens as a means of reducing illness in surfers and swimmers.
- **QMRA Study** – Soller, et al., 2016[22] estimated the risks of gastrointestinal (GI) illness from exposure to pathogen-contaminated ocean water during wet weather using a quantitative microbial risk assessment (QMRA) model. By describing the impacts of stormwater BMPs on the pathogen concentrations at stormwater discharge sites, and applying the QMRA model and data for other variables as estimated by Soller, et al., one can estimate the impacts of stormwater BMPs on surfer and swimmer illnesses (Appendix E).
- **Given et al., 2006**,[23] provides information on risks of GI illness at 28 beaches along the coastline in Los Angeles and Orange Counties. This study was used to support extrapolation of results to other populations.
- **Atiyal et al., 2013**,[24] describe the impacts of improved stormwater controls on beach attendance at 26 beaches in Southern California.

[21]Steele, J., A.J. Griffith, R. Noble, and K. Schiff. 2016 (draft). Quantification of pathogenic viruses and bacteria, host source markers, and fecal indicator bacteria in stormwater discharging to surfing beaches in San Diego, California. April 20. Submitted and being considered for publication.

[22] Soller, J., M. Schoen, J. Steele, J. Griffith, and K. Schiff. 2017. Wet weather recreational water gastrointestinal illness risks—quantitative microbial risk assessment harmonization with an epidemiological investigation. Water Research. Vol. 121, No. 15: 280-289.

[23] Given, S., L. Pendleton, and A. Boehm. 2006. "Regional public health cost estimates of contaminated coastal waters: A case study of Gastroenteritis at Southern California Beaches," *Environmental Science & Technology.* Vol. 40, No. 16: 4851 – 4858.

[24] Atiyah, P., L. Pendleton, R. Vaughn, and N. Lessem. 2013. "Measuring the effects of stormwater mitigation on beach attendance," Marine Pollution Bulletin. Pages 1 – 7.

Methods

The number of illness avoided for each scenario are calculated by multiplying the number of exposures by the difference in illness rate between the scenario of interest and the baseline. The GI and any infection symptom illness rates are developed using *Enterococcus*-illness relationships from the Surfer Health Study for stormwater and stream restoration scenarios. GI illness rates are calculated with the QMRA model for the human sources scenarios. Any infectious symptom illness rates for human sources scenarios are based on applying the proportion of GI illness to any infectious symptom illness rates for the 2010 TMDL Scenario for each watershed.

The section above provides the data for number of exposures via results of the Demand Behavior Model. More detail on calculation of illness rates is described below and accompanying referenced technical reports in the appendices.

ILLNESS RATE CALCULATIONS

This section describes analyses conducted to estimate illnesses from recreational exposures during wet weather periods in San Diego and southern Orange Counties. Illness rates are calculated for multiple scenarios, evaluated independently, and defined by varying rates of BMP implementation and illness incidence (i.e., infection total out of total population). The BMP scenarios include stormwater, human sources, and stream, which evaluate the benefits of installing green infrastructure, reducing septic leakage, and installing wetlands, among other practices. The health analysis, which is consistent with the Quantitative Microbial Risk Assessment (QMRA) components of the Surfer Health Study (SHS), evaluates incidence of 1) gastrointestinal (GI) illness and 2) any infectious symptoms (AIS). Results demonstrate average health benefits for installing BMPs regionally across evaluated watersheds.

Data Sources

The illness rate calculations are based on modeling data for various points-in-time and anticipated endpoints. Baseline conditions are defined by the results of stormwater models of *Enterococcus* wet weather daily concentrations from 1/2/1990 to 12/31/2014. In the stormwater scenarios, BMP implementation rates are defined as those necessary to achieve goals of the 2010 TMDL, 2012 REC Criteria, and water quality objectives for study areas. The stream restoration scenario uses the MS4 compliance goal for FIB reduction to define one of its scenarios. Also, the human sources scenarios use the human sources team's engineering calculations for human contamination from sewer mains, sewer laterals, septic systems, and transient encampments. All endpoints are defined by the epidemiological and QMRA components of the Surfer Health Study for GI and AIS.

Methods

While there are many similarities among scenarios, each is conducted independently and has slightly different technical methodologies.

The analysis includes five stormwater scenarios (i.e., 2010 TMDL, 2012 REC Criteria, Move Compliance Locations, Flow-based Suspensions, Adjust All Beach WQO). For GI illness, the stormwater analysis

- Uses as baseline the Enterococcus wet weather daily modeling results for 1/2/1990 through 12/31/2014. ENT concentrations are the estimated daily concentrations at a point in the watershed that is not tidally influenced.
- Derives an estimated dilution factor for each watershed to estimate ENT concentrations at the recreation sites. The dilution factor is necessary to equate SHS results, which correspond to ENT densities at recreation sites, to stormwater modeling that represents upstream ENT densities.
- Applies the dilution factor to the estimated daily concentrations.
- Computes illness levels for each wet day based on the GI illness/ENT relationship from the SHS, for baseline conditions and each of the stormwater scenarios.

- Summarizes the geometric mean ENT concentrations and predicts additional GI illness levels for the 72-hour period after the storm
- Summarizes results

For the AIS stormwater analysis, the methodology is the same except the GI illness/ENT relationship is instead calculated as the "AIS/ENT relationship".

The stream restoration scenario includes one "in-stream" and three "off-line" scenarios, which include the in-stream practices and wetlands to achieve 1) an additional 10% load reduction, 2) an additional 20% load reduction, and 3) reduce loads to achieve the MS4 compliance goal. For each scenario, the analysis

- Uses, as baseline, the *Enterococcus* wet weather daily modeling results for ½/1990 through 12/31/2014
- Reduces baseline ENT densities by values provided by stream restoration experts to estimate average daily concentrations in watersheds that are not tidally influences and likely locations for in-stream and off-line BMPs
- Applies the dilution factor from the stormwater scenarios to the average daily concentrations
- Computes illness levels for each day using the SHS GI illness/ENT relationship
- Summarizes the geometric mean ENT concentrations and predicts additional GI illness levels for the 72-hour period after the storm
- Summarizes results

The AIS stream restoration analysis is the same as the GI analysis, except the GI illness/ENT relationship is instead calculated as the "AIS/ENT relationship".

Finally, for the Human Source scenario, the methodology is generally the same as the stormwater and stream restoration scenarios. However, the Human Source scenario uses the QMRA model from the SHS rather than the SHS epidemiological relationships, since the relationship of fecal contamination from human sources to adverse health effects is more direct than the diffuse sources evaluated in the stormwater and stream restoration scenarios.

The QMRA model uses concentrations as an input to describe changes in morbidity and is calculated as[25]:

$$Pill_{p,b} = DR_p\left(V * C_{p,b} * Dil_b\right) * M_p$$

Where

$Pill_{p,b}$ is the probability of illness

DR_p is the dose-response function for pathogen p

V is the volume of water ingested

$C_{p,b}$ is the pathogen concentration at discharge point b

Dil_b is the estimated dilution at beach b

M_p is morbidity for pathogen p

Changing the pathogen concentrations ($C_{p,b}$) in the QMRA model generates changes in illness probability to the at-risk population. Thus, the human source scenario County of San Diego GI illness methodology

- Estimates the relative contribution of sewer mains, sewer laterals, septic systems, and transient encampments for each watershed
- Parses the QMRA model into four components using relative contributions

[25] Soller, J., M. Schoen, J. Steele, J. Griffith, and K. Schiff. 2016. *Wet weather recreational water gastrointestinal illness risks—quantitative microbial risk assessment harmonization with an epidemiological investigation*. Submitted and being considered for publication.

- Characterizes BMP effectiveness as the predicted load reduction for high, high+medium, and high+medium+low scenarios for each watershed in the analysis
- Reduces norovirus (NoV) density in the QMRA model to account for the speed of rehabilitating high priority site sewer mains
- Runs the QMRA model for the contribution sources under the three load reduction scenarios (i.e., high, high+medium, high+medium+low)
- Documents findings

The Orange County GI illness methodology follows the methodology conducted for San Diego but assumes that all of the contamination comes from the sewer components.

Assumptions

A key consideration for calculating illness rates is that results are only applicable for average health benefits for BMP implementation regionally across all of the watersheds evaluated. Thus, due to the coarse-scale of the available health data, sub-regional decisions regarding BMP implementation, such as choosing one level of BMP implementation in one watershed and another level in a different watershed, are not supported.

Another important assumption is that the proportions between reductions in GI illness and any infectious symptom illness rates for stormwater controls are the same for human source scenarios. Without greater understanding of the human sources and their pollutant loads, more specific calculations are not available.

For the analysis, the BMP scenario under consideration is assumed to contribute all of the fecal contamination causing the observed level of illness during the SHS and the SHS results are assumed to apply in each of the watersheds. For example, in considering stormwater BMPs, it is assumed that observed level of excess illnesses during the SHS (average ~12 illnesses per 1000) is completely attributable to stormwater flows and reduction in stormwater fecal contamination could yield reductions in illness levels. The analyses characterize those illness reductions. This approach yields an upper bound estimate of health benefit for each BMP scenario since all of the observed illnesses are effectively (numerically) available for reduction through the BMP(s). In reality, it is likely that the illness causing fecal contamination comes from a combination of stormwater and human sources. However, an integrated stormwater/human source contamination analysis was beyond the scope of this analysis primarily due to the myriad uncertainties associated with in-depth modeling of this sort.

Results and Discussion

Overall, the stormwater scenarios do not result in dramatic declines in illness rates (Table 18 and Table 19). This directly leads to relatively low changes in total illnesses annually for stormwater BMP scenarios. Across the watersheds, the 2010 TMDL scenario provides the greatest total reduction in illness rates. Analyzing the scenario-specific illness rates on average for County of San Diego and Orange County in Table 18 and Table 19, the lack of decline in illness rates in comparison to baseline is notable. For Orange County, declines are very low, and for both counties, some of the stormwater scenarios involve almost no decline in illness rate. This is due to very low change in *Enterococcus* concentrations for those scenarios. Those watersheds and scenarios with low changes in concentrations and low changes in illness rates involve the least overall investment in total load reduction, and therefore the lowest costs across scenarios and watersheds as well.

Table 18. Average Infection Rates for County of San Diego

	ILLNESS	BASELINE	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSION	ADJUST ALL BEACH WQO	STREAM: INSTREAM ONLY	STREAM: +10% WETLAND	STREAM: +20% WETLAND	STREAM: +MS4
Storm Day	GI	19.2	17.5	17.6	19.2	19.0	18.5	18.4	17.6	17.1	17.3
Storm +1	GI	11.4	10.1	10.2	11.3	11.2	10.8	12.0	11.4	11.0	11.2
Storm +2	GI	4.30	3.60	3.60	4.30	4.20	3.90	5.60	5.20	4.90	5.00
Storm +3	GI	2.00	1.50	1.50	2.00	1.90	1.70	2.60	2.40	2.20	2.20
Storm Day	All Other	16.9	15.3	15.4	16.9	16.8	16.3	16.1	15.3	14.8	15.1
Storm +1	All Other	10.2	9.20	9.30	10.2	10.1	9.70	10.1	9.50	9.20	9.40
Storm +2	All Other	5.00	4.50	4.50	5.00	5.00	4.70	4.50	4.20	4.00	4.10
Storm +3	All Other	2.50	2.10	2.10	2.50	2.40	2.30	2.30	2.10	2.00	2.00

Table 19. Average Infection Rates for Orange County

	ILLNESS	BASELINE	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSION	ADJUST ALL BEACH WQO	STREAM: INSTREAM ONLY	STREAM: +10% WETLAND	STREAM: +20% WETLAND	STREAM: +MS4
Storm Day	GI	16.2	16.1	16.1	16.2	16.2	16.2	16.1	15.4	15.3	15.3
Storm +1	GI	9.20	9.10	9.20	9.20	9.20	9.20	9.20	8.70	8.60	8.60
Storm +2	GI	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.50	2.50	2.50
Storm +3	GI	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.600	0.600	0.600
Storm Day	All Other	13.8	13.7	13.7	13.8	13.8	13.8	13.8	13.1	13.0	13.0
Storm +1	All Other	7.80	7.80	7.80	7.80	7.80	7.80	7.80	7.30	7.30	7.30
Storm +2	All Other	2.80	2.70	2.70	2.80	2.80	2.80	2.70	2.50	2.50	2.50
Storm +3	All Other	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.400	0.400	0.400

Illness rates decline more under the human sources scenarios than under the stormwater and stream scenarios (Table 20 and Table 21). The human sources illness rates as calculated in the QMRA model have a baseline illness rate across all wet days of 15.2 per 1000 exposures. However, the baseline and all human sources scenarios are scaled down to normalize to the SHS observed relationship of 12.2 illnesses per 1000.

Table 20. Human Sources Scenarios Illness Rates Normalized to 12.2 GI Baseline, San Diego County, by Watershed and Illness

WATERSHED	ILLNESS	CURRENT	HIGH	HIGH + MEDIUM	HIGH + MEDIUM + LOW
San Luis Rey	GI	12.2	3.10	1.40	0.000
San Marcos	GI	12.2	1.50	0.700	0.000
San Dieguito	GI	12.2	3.00	2.60	0.000
Los Peñasquitos	GI	12.2	6.30	1.70	0.000
San Diego River	GI	12.2	1.70	0.600	0.000
Tecolote Creek	GI	12.2	1.30	0.200	0.000
Chollas Creek	GI	12.2	0.700	0.200	0.000
Scripps	GI	12.2	2.60	0.600	0.000
San Luis Rey	All Other	10.9	2.70	1.20	0.000
San Marcos	All Other	11.3	1.40	0.700	0.000
San Dieguito	All Other	10.6	2.60	2.20	0.000
Los Peñasquitos	All Other	10.2	5.30	1.40	0.000
San Diego River	All Other	10.1	1.40	0.500	0.000
Tecolote Creek	All Other	10.1	1.10	0.100	0.000
Chollas Creek	All Other	10.1	0.600	0.100	0.000
Scripps	All Other	10.1	2.10	0.500	0.000

Table 21. Human Sources Scenarios Illness Rates Normalized to 12.2 GI Baseline, Orange County, by Watershed and Illness

WATERSHED	ILLNESS	CURRENT	HIGH	HIGH + MEDIUM	HIGH + MEDIUM + LOW
Aliso Creek	GI	12.2	2.70	0.800	0.000
Dana Point	GI	12.2	3.10	1.30	0.000
Laguna Coastal Streams	GI	12.2	7.90	6.90	0.000
San Clemente	GI	12.2	3.00	1.00	0.000
San Juan	GI	12.2	4.00	3.00	0.000
Aliso Creek	All Other	10.5	2.30	0.700	0.000
Dana Point	All Other	10.6	2.70	1.10	0.000
Laguna Coastal Streams	All Other	10.6	6.80	6.00	0.000
San Clemente	All Other	10.3	2.50	0.800	0.000
San Juan	All Other	10.1	3.30	2.40	0.000

VALUE BENEFITS OF ILLNESS AVOIDED

The health benefit analysis uses illness valuations reported in the literature of the medical costs and lost work productivity. To calculate the total benefits of avoided illness in a scenario, costs per illness are multiplied by the reduction in illness rates and then multiplied by the number of exposures attributed to each scenario.

Data Sources

This section of the analysis employs many of the data sources used to calculate *Changes in Illness Rate*, and wet weather exposures described in the previous section. Additional data sources include literature on illness focusing on the series of journal articles below:

- **Machado and Mourato, 2002** - Estimates a willingness-to-pay value for avoiding marine water exposure gastrointestinal illness which serves as the lower bound for the value of avoided gastrointestinal illness.
- **Deflorio-Barker et. Al, 2017** – Estimates the full costs of marine water exposure gastrointestinal illness for a range of assumptions, the highest of which provide an upper estimate for the value of avoided gastrointestinal illness.
- **Alsarraf et. Al, 1999** – Measuring the indirect and direct costs of acute otitis media (ear infection) in young children. This study provides the high value of all infectious symptoms.

Calculations also rely upon county-level population growth projections described earlier.

Methods

Value of an Illness Avoided

The appropriate value to apply for an avoided illness is the willingness-to-pay among individuals who would have experienced illness but for the improvement in water quality. Willingness-to-pay (WTP) to avoid the illness should capture all of the financial and non-financial costs of illness including medical care, lost work or lost leisure time, and pain and suffering. The illness category of primary focus in this analysis is the general category of gastrointestinal (GI) illness (or gastroenteritis). In general, the literature focuses on the aggregate public health costs to society in terms of time and medical care. Furthermore, USEPA's research and similar suggest that illnesses from marine exposure differ from freshwater exposure. One study, by Machado and Mourato, does exist estimating WTP for marine-based GI illness[26]. It used a contingent valuation survey of residents of Lisbon, Portugal. The survey focused on eliciting WTP to avoid illness symptoms associated with typical marine exposure-induced GI illness, namely nausea, vomiting, diarrhea, and restrictions on some activities for one day. The average value for WTP to avoid these GI illness symptoms, adjusted via the Consumer Price Index for medical care, is $78.92 in 2016 dollars.

Intuitively when considering time, suffering, and medical expenses, this value seems low. Again, it is an average value, and possibly reflects that a short-term illness of this sort can typically be managed without loss of wages or medical expenses. For sensitivity though, this analysis also utilizes a recent assessment of the costs of GI illness from swimming in marine and freshwater that includes: 1) cost of medicine (over-the-counter and prescription), 2) costs of medical visits, and 3) value of time missed from work or leisure[27]. The average cost per case ranged from $46.18 to $263.10 in 2016 dollars with the range based on variation in assumptions of value of leisure time and medical visit costs. This analysis applies $263.10 as an upper range value for comparison of GI avoided illness value Table 22.

This analysis also estimates changes in other illnesses as identified in the SHS and calculated using QMRA model results. For other non-GI illness, the most prevalent and statistically-correlated illness reported in the SHS is earaches or ear infection, with other statistically significant illnesses including wound infections and other infectious symptoms. Therefore, to recognize this range of illnesses, this analysis uses the WTP identified for GI illness described above as a lower bound, and a value for costs associated with ear infection

[26] Machado, F. and Mourato, S., 2002. Evaluating the multiple benefits of marine water quality improvements: how important are health risk reductions. *Journal of Environmental Management*, *65*(3), pp.239-250.

[27] DeFlorio-Barker, S., Wade, T., Jones, R., Friedman, L., Wing, C., & Dorevitch, S. 2017. Estimated Costs of Sporadic Gastrointestinal Illness Associated with Surface Water Recreation: A Combined Analysis of Data from NEEAR and CHEERS Studies. *Environmental Health Perspectives*, *125*(2), 215–222. http://doi.org/10.1289/EHP130

among children as an upper bound. While it is unlikely that children make up a sizable portion of the population experiencing illness from wet weather exposure, the expenses in terms of medical care and time would be relevant to an adult as well. This also provides sensitivity consideration with respect to children illness. The one identifiable study analyzing the cost of an ear infection used a cohort of young children and considered costs of medicine and parental time[28]. The study estimated a value of $2,629.82 per illness ($2016 CPI medical care adjusted). This value serves as an upper bound for other (non-GI) illness values.

Table 22. Avoided Illness Benefit Values ($2016).

BENEFIT	VALUE (LOW)	VALUE (HIGH)
Avoided GI Illness	$78.9	$263
Avoided Any Non-GI Infectious Sickness	$78.9	$2,630

Calculation of Annual Illness Benefits

Calculation of average annual benefits of avoided illness (i.e. public health benefits) is a straightforward process of multiplication. This calculation uses the data sources and assumptions described in the earlier parts of this section.

For each scenario, the illness avoided benefit calculation follows the step of multiplying the number of exposures (surfers and swimmers) for that watershed and wet day type by the annual number of wet days of that type in that watershed, multiplied by the change in illness rate relative to the baseline (so the number of fewer illnesses per 1000 exposures), multiplied by the value of an avoided illness (Figure 21).

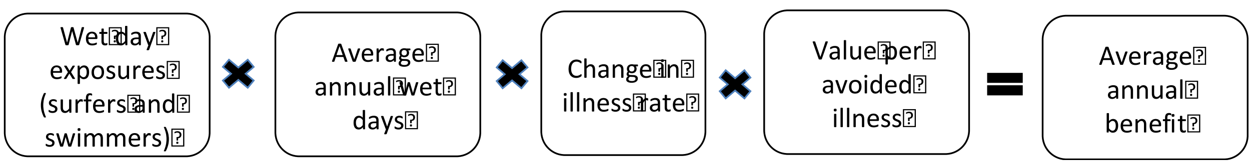

Figure 21. Calculating the average annual benefit of avoided illnesses for each scenario involves the number of exposures on wet days, how the illness rate for these exposures changes in comparison to the baseline, and assigning a value for avoided illnesses.

This involves the calculation of illness rates as an average across all of each category of wet day (storm, +1, storm +2, storm +3) for each scenario. This is an average of the 25 years of daily estimates (from stormwater technical memo) calibrated to the SHS results for illnesses above baseline. For the human sources scenarios, all wet days are averaged together, so there is one illness rate for each scenario that covers all wet days.

Benefits by scenario are summed over time, with benefits scaled to accumulate proportional to completion of scenario implementation based upon cost timing. For example, scenarios completed by 2031 scale benefits up proportionally starting in 2017 and reaching full annual benefit by 2031. Results tables include a 3% discount rate; later sensitivity analyses include variation on discounting. Benefits are scaled proportionately to population growth, assuming beach use and resulting exposure (and potential avoided illness) increase at the rate of county population growth.

Human Source scenario illness rates are not yet available for Orange County watersheds at the time of this draft writing.

[28] Alsarraf, R., Jung, C.J., Perkins, J., Crowley, C., Alsarraf, N.W. and Gates, G.A., 1999. Measuring the indirect and direct costs of acute otitis media. *Archives of Otolaryngology–Head & Neck Surgery*, *125*(1), pp.12-18.

Assumptions

Since illness rates can vary among age groups, with some groups being more susceptible to certain illnesses than others, this analysis considered the effects among various groups that would come into contact with bacteria concentrations. For example, a recent meta-analysis of data compiled from 13 separate cohort studies by Arnold et al. investigated the risk specific to children of gastroenteritis due to water exposure, based on the hypothesis that children spend more time in water, swallow more water, and have less developed immune systems than adults. The study found greater water exposure and association between water pollution and illness among children than adults. However, USEPA's official guidance on the 2012 Recreation Water Quality Criteria indicates that research suggests no difference in illness rates for children ten years old and under than adults for marine water exposure, although there is higher child illness for freshwater exposure.

The illness rates used in this study, derived from the Surfer Health Study, are primarily based on illness among surfers, who, based on the amount of exposure and water inadvertently swallowed while surfing, are considered to experience above average total pathogen exposure while in the water. Furthermore, particularly young children were not observed as experiencing immersive exposure during storms of wet days during the Surfer Health Study.

In addition, this analysis does not include exposures or illness risk at beaches outside of the Bacteria TMDL watersheds, nor exposures during dry weather (more than three days after a storm). This analysis does not account for variation in pathogen concentrations as a function of flow or volume (storm severity), but rather applies averages by wet day type.

Results and Discussion

The analysis results calculate 2.2 million infectious illnesses occur during wet weather based on water exposure in the Bacteria TMDL watersheds over the 65-year timeframe starting in 2017. Over that same 65-year timeframe, the 2010 TMDL scenario would avoid 121,000 of those illnesses, the most avoided of any of the stormwater or stream scenarios. However, the human sources scenarios all provide more than ten times the number of avoided illnesses. This wide difference is directly due to the magnitude of the reduction in illnesses per 1000 exposures. All human sources scenarios result in the majority to all wet weather illnesses eliminated, while stormwater and stream restoration scenarios only achieve a small reduction in the percentage of illnesses per 1000 exposures. At the extreme, the Human Sources: High+Med+Low scenario drops the illness rate per 1000 exposures to zero across all wet days, including the day of the storm. The feasibility and certainty of such a dramatic reduction in illnesses warrants further investigation in the future. Some illnesses do still occur during the timeframe prior to 2031 while the human sources scenarios are still under implementation and have not reached full functional potential.

Table 23. All Infectious Illnesses Avoided, Stormwater Scenarios, 65 Years

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	115,000	105,000	1,630	10,700	33,700	89,300	98,300
Orange County	6,380	5,960	3,030	3,030	3,300	4,910	5,420
Grand Total	121,000	111,000	4,650	13,800	37,000	94,200	104,000

Table 24. All Infectious Illnesses Avoided, Stream Scenarios, 65 Years

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	2,130	24,300	43,900	35,600
Orange County	5,200	21,600	24,000	24,000
Grand Total	7,330	45,800	68,000	58,600

Table 25. All Infectious Illnesses Avoided, Human Sources Scenarios, 65 Years

REGION	HIGH	HIGH + MED	HIGH + MED + LOW
San Diego County	1,280,000	1,530,000	1,640,000
Orange County	345,000	415,000	471,000
Grand Total	1,630,000	1,940,000	2,110,000

The sum of the 65-year stream of benefits by scenario for avoided GI illness ranges from a low of $117 to 389 thousand for the Move Compliance Locations scenario to $5 to 19 million for the human sources. When expanding the benefits to include all infectious illness, the same scenarios increase to a minimum low value of $133 thousand for the Move Compliance Locations scenario and a maximum high value of $201 million for the Human Sources: High+Med+Low scenario.

Table 26. Health Benefits, GI Illness Avoidance, Stormwater Scenarios, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSION	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051	CIP SCHEDULE
San Diego County								
Low	$1,460,000	$1,350,000	$29,200	$154,000	$438,000	$953,000	$1,100,000	$953,000
High	$4,870,000	$4,490,000	$97,000	$514,000	$1,460,000	$3,180,000	$3,670,000	$3,180,000
Orange County								
Low	$136,000	$130,000	$87,000	$87,000	$91,300	$88,000	$102,000	$87,700
High	$454,000	$434,000	$292,000	$292,000	$304,000	$292,000	$339,000	$292,000
Grand Total								
Low	$1,600,000	$1,480,000	$117,000	$242,000	$529,000	$1,040,000	$1,200,000	$1,040,000
High	$5,330,000	$4,930,000	$389,000	$806,000	$1,760,000	$3,470,000	$4,010,000	$3,470,000

Table 27. Health Benefits, GI Illness Avoidance, Stream Scenarios, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: + MS4
San Diego County				
Low	$44,700	$365,000	$651,000	$518,000
High	$149,000	$1,220,000	$2,170,000	$1,730,000
Orange County				
Low	$117,000	$360,000	$399,000	$399,000
High	$391,000	$1,200,000	$1,330,000	$1,330,000
Grand Total				
Low	$162,000	$725,000	$1,050,000	$917,000
High	$540,000	$2,420,000	$3,500,000	$3,160,000

Table 28. Health Benefits, GI Illness Avoidance, Human Source Scenarios, 65 Years (3% Discount Rate)

REGION	HIGH	HIGH + MED	HIGH + MED + LOW
San Diego County			
Low	$19,600,000	$23,600,000	$25,300,000
High	$65,300,000	$78,700,000	$84,400,000
Orange County			
Low	$5,370,000	$6,470,000	$7,340,000
High	$17,900,000	$21,600,000	$24,500,000
Grand Total			
Low	$25,000,000	$30,100,000	$32,600,000
High	$83,300,000	$100,000,000	$109,000,000

Table 29. Health Benefits, All Illness Avoidance, Stormwater Scenarios, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSION	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County							
Low	$3,260,000	$2,990,000	$46,100	$305,000	$955,000	$2,120,000	$2,450,000
High	$64,800,000	$59,100,000	$662,000	$5,520,000	$18,700,000	$42,200,000	$48,800,000
Orange County							
Low	$184,000	$172,000	$87,000	$87,000	$95,000	$118,000	$137,000
High	$2,050,000	$1,830,000	$291,000	$292,000	$430,000	$1,320,000	$1,530,000
Grand Total							
Low	$3,400,000	$3,160,000	$134,000	$392,000	$1,050,000	$2,240,000	$2,590,000
High	$66,800,000	$61,000,000	$953,000	$5,810,000	$19,100,000	$43,500,000	$50,300,000

Table 30. Health Benefits, All Infectious Symptoms Avoidance, Stream Scenarios, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: + MS4
San Diego County				
Low	$60,400	$689,000	$1,250,000	$983,000
High	$674,000	$12,000,000	$22,000,000	$17,200,000
Orange County				
Low	$150,000	$622,000	$692,000	$692,000
High	$1,480,000	$9,950,000	$11,100,000	$11,100,000
Grand Total				
Low	$210,000	$1,310,000	$1,940,000	$1,680,000
High	$2,150,000	$22,000,000	$33,700,000	$28,300,000

Table 31. Health Benefits, All Infectious Symptoms Avoidance, Human Sources Scenarios, 65 Years (3% Discount Rate)

REGION	HIGH	HIGH + MED	HIGH + MED + LOW
San Diego County			
Low	$36,500,000	$43,500,000	$46,700,000
High	$122,000,000	$145,000,000	$156,000,000
Orange County			
Low	$9,980,000	$12,000,000	$13,600,000
High	$33,300,000	$40,100,000	$45,400,000
Grand Total			
Low	$46,500,000	$55,500,000	$60,300,000
High	$155,000,000	$185,000,000	$201,000,000

The three scenarios based on changing the timing of implementation demonstrate how the benefits accrue over time and how the delay in implementation decreases total benefits. Figure 22 shows how with discounting, the 2010 TMDL scenario reaches a higher annual value than the 2051 or CIP Schedule scenarios, and the downward trajectory in annual value due to discounting is joined by each of the other two scenarios when they reach full implementation. The annual values are the same for all three scenarios after the CIP Schedule scenario reaches full function, but the area under each curve shows when and how the 2010 TMDL scenario achieves a greater total value, and the effect of delayed implementation on total benefit.

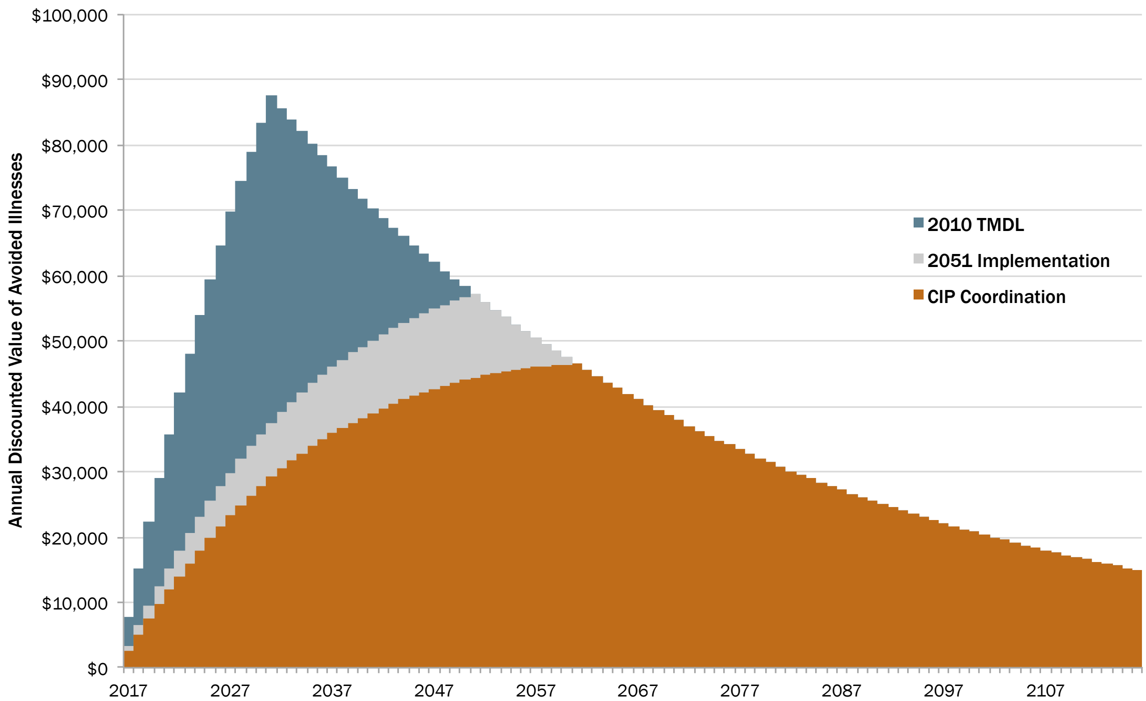

Figure 22. Observing the annual benefits for the three scenarios that vary only by timing of implementation, all three scenarios eventually reach a common annual benefit trajectory. Due to discounting, the annual benefits decline over time, and the highest annual benefit is achieved only by the first scenario to full implementation, the 2010 TMDL scenario.

RECREATION BENEFITS

The recreation benefit analysis uses the estimates of foregone or lost recreation beach trips by non-storm wet weather day and watershed, combined with increases in safe days in terms of *Enterococcus* water concentrations to identify the annual number of expected additional beach trips by scenario, and the value of these trips to the beach visitor in terms of net benefit beyond their trip costs, known as consumer surplus.

Data Sources

The central data sources for this analysis are the lost trip estimates based on the Beach Demand Model described earlier, combined with the daily *Enterococcus* concentrations for stormwater scenarios and load reductions for the stream and, human sources scenarios. The beach trip value estimate is based on the paper:

- Lew & Larson 2005. Provides a value for net benefit (consumer surplus) for the average trip to a beach in County of San Diego. The value serves as the per-trip benefit for additional beach trips gained.
- Calculations also rely upon county-level population growth projections described earlier.

Methods

The overall approach for valuing the recreation benefits provided by water quality improvements under each scenario is:

1. Quantify the change in water quality relative to the baseline in terms of number of days safe for exposure to water

2. Calculate the number of increased trips relative to baseline visitation due to improvement in water quality
3. Monetarily value the benefits of increased trips associated with the change in water quality based on individual net benefit per additional beach trip (consumer surplus).

The County of San Diego's Department of Environmental Health (DEH) and the Orange County Health Care Agency base beach advisories and closures on levels of fecal indicator bacteria (FIB) (*Enterococcus* and *E. coli*) in water samples based on EPA standards.[29] The recreation benefits are based on changes in number of days that are safe to swim, interpreted as days changes in the number of wet weather (non-storm) days that are above the 104 *Enterococcus* per 100 ml concentration. This is considered the threshold for safe swimming[30]. The estimated number of beachgoers who do not choose to visit the beach due to water quality issues, as based on the model described above that controls for other characteristics of wet days, is considered the set of trips foregone, and that those trips would occur if under a scenario, the water quality is safe. This assumes that in the future when it becomes safe to swim at the beach on a wet day, people are informed and change their behavior. These visits are not disaggregated by beach patron type, and can include non-swimmers, recognizing that some surfers or swimmers might have companions that would similarly follow suit on decisions for that day to not go to the beach. Also, as described above, these foregone trips are not calculated for storm days directly, because it is not possible to isolate the share of trips that are not occurring on storm days due to water quality rather than weather conditions.

The analysis includes a dilution factor for each watershed. The dilution factor is the translation of the instream *Enterococcus* measurement calculated by the WQIP stormwater models that is day-watershed-scenario specific to ocean concentrations where swimming and surfing occur, and is used to translate all scenario instream concentrations to beach concentrations for that watershed. Initially the intention was to calculate this based on the actual beach monitoring *Enterococcus* measurements corresponding to modeled instream concentrations. After reviewing all available monitoring data at beaches in the Bacteria TMDL watersheds, insufficient data exist for wet weather monitoring observations. The next-best approach for dilution relies upon the stormwater model calibration that the 2010 TMDL scenario model parameterization assumes a 22% exceedance rate overall across all wet days, as allowed by permit. The analysis solves for the dilution factor that sets the 2010 TMDL scenario daily *Enterococcus* levels to exactly be in exceedance 22% of wet days over the 25-year modeled timeframe. This generates a different dilution factor for each watershed. This calculated watershed-specific dilution factor is then applied consistently across all analyses.

Daily concentration data are not available for human sources scenarios. Daily safe swimming conditions are estimated by taking the distribution of improvements with respect to baseline achieved under the 2010 TMDL scenario, and scaling those changes to equal the same overall change in illness rates. Therefore, the safe wet day estimate for human sources scenarios is proportional to those under the 2010 TMDL scenario, but scaled for the greater improvements in illness rates.

[29] County of San Diego, Department of Environmental Health, Beach Water Quality. *Land and Water Quality Division. Beach and Bay Monitoring Program*. www.sdbeachinfo.com/#.
[30] USEPA. 2012. Recreational Water Quality Criteria.

Figure 23. Calculating the average annual value of beach trips gained for each scenario involves the number of trips forgone on unsafe wet days, calculating the number of additional safe days for swimming and the value per gained trip.

For recreation trips, the general calculation of multiplying the number of wet day foregone trips (calculation described above) for that watershed and wet day type by the annual number of wet days of that type in that watershed, multiplied by the annual change safe days relative to the baseline, multiplied by the value of a beach trip (Figure 23). This calculation does not include storm days, but only the three days following storms. And safe here is defined as less than a 104 (per 100 mL) *Enterococcus* concentration.

Recreation trip value

The appropriate value to apply to additional beach trips due to improvements in water quality is the net benefit of a trip beyond the costs of the trip. This is known as consumer surplus. Fortunately, a valid study exists that directly estimated the net benefit to beachgoers of the value of beach recreation per trip. Lew and Larson developed a travel cost model based on data from a telephone survey of County of San Diego households[31]. This type of model assesses actual recreation activity and the cost of such trips across households at various distances from a recreation site to estimate a demand model for beach users. Based on their results, the average net benefit (consumer surplus) per beachgoer, per beach day was $39.68 in 2016 dollars (Consumer Price Index adjusted). This value represents the average net benefit beyond expenditures including time and travel expenses. Half of trips are worth more than this, and half are less. Individuals can have multiple trips that might decline in value as the number of trips increases, so even for an individual the value per trip can vary.

Assumptions

The applicability of the dilution translation of instream concentrations to beach concentrations is a major assumption, given the complexity of the dynamics that affect pathogen transport, survival, and multiplication when entering the ocean. Furthermore, this analysis assumes that beachgoers will learn to know when it is safe to go to the beach in the days immediately after storms, even though public education campaigns have emphasized the general rule to stay out of the ocean after storms for three days.

This approach assumes that the daily distribution of pathogen loads estimated by the WQIP stormwater models as a function of storm severity and stream volume is a good estimate of how stream restoration and human source load reductions would be distributed across wet days.

The trip value assumes that the general beach trip activity measured and valued by Lew and Larson is applicable to the types of wet weather trips that are sensitive to water quality improvements.

The analysis assumes that human sources safe swimming conditions are proportional to 2010 TMDL scenario safe swimming conditions.

Results

Recreation benefits follow similar patterns to public health benefits across scenarios. The change in beach trips resulting from safe water quality conditions is much more dramatic than the change in illnesses for the health benefits. This is because less than 5% of surfers and swimmers would get sick due to exposure in the baseline for storm days, but 100% of the trips by those responsive to water quality are lost when the

[31] Lew, D., and Larson, D. 2005. Valuing recreation and amenities at County of San Diego beaches. *Coastal Management*, *33*(1), 71-86.

ocean is unsafe. While health benefits resulting from water quality improvements are reduced as a result of the small fraction of exposures that actually result in an illness, all additional beach trips resulting from improved water quality provide value. And while the value per trip is lower than the value per avoided illness, the value of increased trips is much greater than the values of avoided illnesses due to the number of trips that would have been lost under baseline conditions without water quality improvements.

The analysis results calculate 12 million beach trips lost in the Bacteria TMDL watersheds over the 65-year timeframe starting in 2017 due to unsafe swimming conditions at beaches. Over that same 65-year timeframe, the 2010 TMDL Scenario would allow 1.6 million of those trips to occur because of wet days that become safe to swim, that would have been unsafe under baseline conditions. This analysis does not include any estimate for increased trips on rainy days, and only estimates increased trips on days following storms.

Table 32. Additional Beach Trips, Stormwater Scenarios, 65 Years

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	1,620,000	1,400,000	16,000	157,000	654,000	1,260,000	1,390,000
Orange County	39,800	37,000	0.000	0.000	7,960	31,000	33,800
Grand Total	1,660,000	1,450,000	16,000	157,000	662,000	1,290,000	1,420,000

Table 33. Additional Beach Trips, Stream Scenarios, 65 Years

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	25,700	394,000	741,000	752,000
Orange County	143,000	409,000	462,000	462,000
Grand Total	169,000	802,000	1,200,000	1,210,000

Table 34. Scenarios Additional Beach Trips, Human Source, 65 Years

REGION	HIGH	HIGH + MED	HIGH + MED + LOW
San Diego County	8,440,000	8,480,000	8,480,000
Orange County	2,228,000	2,240,000	2,410,000
Grand Total	10,700,000	10,700,000	10,900,000

Over ten million trips would be saved under the human source scenarios. This is nearly ten times the number of additional beach trips under the stormwater or stream restoration scenarios. This is due to the same results that generate an even greater discrepancy across scenario types for number of avoided illnesses, as described earlier. The degree of water quality improvement assumed under the human sources scenarios is such to drop illness rates so that nearly all days provide safe swimming conditions, with the H+M+L scenario results dictating that all days become safe and no trips are lost. Some trips are still lost over the timeframe prior to 2031 while the human sources scenarios are still under implementation and have not reached full functional potential.

The key factor for recreation benefits is the increase in safe swimming days by scenario. The decrease in unsafe swimming days on wet days in comparison to baseline conditions is the basis for calculating the number of additional beach trips, and their corresponding value. In baseline conditions, there are on average 2.80 days unsafe for swimming on the day following a storm in County of San Diego, 2.46 in Orange County. The largest improvements are under the human source scenarios, and the 2010 TMDL Scenario. The gains in safe days and estimated increased beach trips over 50 years translate to $20 million for the 2010 TMDL Scenario, and over $150 million under the human sources scenarios. Note that the annual unsafe swimming days is upon full scenario implementation, and consequently the values for Compliance by 2051 and CIP Schedule would be the same as for the 2010 TMDL scenario.

Table 35. Average Annual Unsafe Swimming Days, Stormwater Scenarios

REGION	BASELINE	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO
San Diego County						
Storm +1	2.80	2.09	2.15	2.79	2.73	2.49
Storm +2	0.910	0.610	0.640	0.910	0.860	0.730
Storm +3	0.570	0.450	0.470	0.570	0.560	0.530
Orange County						
Storm +1	2.46	2.43	2.44	2.46	2.46	2.46
Storm +2	1.00	0.980	0.990	1.00	1.00	1.00
Storm +3	0.300	0.300	0.300	0.300	0.300	0.300

Table 36. Average Annual Unsafe Swimming Days, Stream Scenarios

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County				
Storm +1	2.61	2.28	2.09	2.43
Storm +2	0.750	0.640	0.530	0.710
Storm +3	0.600	0.570	0.530	0.600
Orange County				
Storm +1	2.44	2.14	2.06	2.06
Storm +2	0.880	0.720	0.700	0.700
Storm +3	0.230	0.220	0.210	0.210

Table 37. Average Annual Unsafe Swimming Days, Human Sources Scenarios

REGION	BASELINE	HIGH	HIGH + MED	HIGH + MED + LOW
San Diego County				
Storm +1	2.73	0.0300	0.000	0.000
Storm +2	0.860	0.000	0.000	0.000
Storm +3	0.550	0.000	0.000	0.000
Orange County				
Storm +1	2.46	0.0600	0.0400	0.000
Storm +2	0.890	0.0400	0.0200	0.000
Storm +3	0.290	0.0200	0.000	0.000

Table 38. Recreation Benefits, Stormwater Scenarios, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$23,100,000	$20,100,000	$233,000	$2,240,000	$9,330,000	$15,100,000	$17,400,000
Orange County	$578,000	$543,000	$0.00	$0.00	$116,000	$372,000	$431,000
Grand Total	$23,700,000	$20,600,000	$233,000	$2,240,000	$9,440,000	$15,500,000	$17,900,000

Table 39. Recreation Benefits, Stream Scenarios, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$367,000	$5,620,000	$10,600,000	$10,700,000
Orange County	$2,080,000	$5,930,000	$6,710,000	$6,710,000
Grand Total	$2,440,000	$11,600,000	$17,300,000	$17,400,000

Table 40. Recreation Benefits, Human Sources Scenarios, 65 Years (3% Discount Rate)

REGION	HIGH	HIGH + MED	HIGH + MED + LOW
San Diego County	$121,000,000	$122,000,000	$129,000,000
Orange County	$32,600,000	$32,700,000	$36,800,000
Grand Total	$154,000,000	$155,000,000	$166,000,000

These results are sensitive to the dilution factor, which affects the number of unsafe days by scenario. Less dilution translates to more unsafe days by wet weather type. Applying a consistent dilution factor across all scenarios for a particular watershed reduces the effect of this sensitivity, but given the 2.8 baseline unsafe annual storm +1 days in County of San Diego represents only 25% of all storm +1 days in County of San Diego, less assumed dilution would increase the number of unsafe days, and the corresponding proportional number of gained days under scenarios improving water quality.

Note that these recreation benefits are only based on water quality improvements at beaches, and do not include secondary/co-benefits of recreation improvements such as through improved trail conditions or scenery, or new trail opportunities at the restoration sites.

CO-BENEFITS

The non-bacteria water quality benefits that scenarios provide are known as co-benefits. This analysis quantifies and values co-benefits to the extent the existing data and literature allow. In cases where data and literature do not facilitate quantification, a qualitative description of the supply and value of co-benefits is provided. In general, co-benefits are generated through components of stormwater scenarios that utilize green stormwater infrastructure (GSI) and stream restoration. Although non-structural stormwater strategies were considered, the net effect of these programs is too speculative to quantify so they are not quantified. No quantitative co-benefits have been identified for sewer and septic controls, but depending on the specifics of controls on pollutant loads originating from transient communities, there are potential co-benefits, although potential unintended consequences from transient efforts could arise as well.

CO-BENEFITS BACKGROUND AND TERMINOLOGY

The stormwater BMPs modeled in this analysis are generally implemented via green stormwater infrastructure techniques. The USEPA describes green stormwater infrastructure as:

> *"a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure—conventional piped drainage and water treatment systems—is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits."*[32]

The GSI at issue in this analysis includes green streets, bioretention facilities, sometimes referred to as rain gardens, and streamside buffers. The specific GSI strategies that would be implemented under each alternative have not been specifically defined, nor their geographic location specified. In general, they likely would be implemented in the lower reaches of the watersheds, in areas where land is available, such as in residential neighborhoods and lower-density commercial and industrial areas.[33] This analysis relies on these assumptions. Our analysis focused on the four watersheds for which GSI BMPs were included in stormwater scenarios: Los Peñasquitos, Tecolote Creek, the San Diego River and Chollas Creek. Data for GSI BMPs represent acres of bioretention, green streets, or a combination of the two.

The stream scenarios emphasize habitat restoration, focusing on in-channel improvements and off-line wetland restoration.[34] The goal of the in-channel improvements is to increase infiltration and retention in the stream channel, so channel widening is the primary habitat improvement. Based on input from designers associated with the stream restoration analysis, it is assumed that riparian habitat in a 50-foot buffer around the stream channel (25 feet on either side) would also be improved through invasive plant removal and replanting with native species.[35] Similarly, the wetland improvements would directly increase water retention and infiltration, and secondarily provide habitat improvements through invasive species removal and native species plantings. Both riparian and wetland projects could include recreational components (e.g., trails, interpretive signs, etc.) although these costs are not included and therefore the benefits not included in this analysis. The specific locations of the projects have not been identified, but the stream restoration scenario analysis identifies the ideal locations of projects to be public parcels along tributaries of main stems that are not heavily urbanized.

This analysis also considered the potential benefits associated with non-structural BMPs. The non-structural BMPs could include programmatic improvements to existing implementation and enforcement efforts, public education and communication efforts, street sweeping, and a host of other potential actions that don't require on-the-ground infrastructure improvements. In general, the economic benefits associated with these non-structural BMPs were difficult to identify and describe incrementally: in most cases, departments are already pursing these strategies, so changes under the Bacteria TMDL may include increasing budget or effort to emphasize some strategies over others. The net effect on co-benefits is too speculative to identify, so this analysis did not attempt to further quantify or describe the benefits under this category of BMPs.

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[32] USEPA. *What is Green Infrastructure?* https://www.USEPA.gov/green-infrastructure/what-green-infrastructure.

[33] Personal communication with Tetra Tech staff.

[34] ESA. 2017. *DRAFT Development of the San Diego Bacteria TMDL Cost Benefit Analysis Inputs for Stream and Riparian Habitat Restoration San Diego and Orange Counties.* County of San Diego. January.

[35] Personal communication with David Pohl, ESA Associates.

CATEGORIES OF CO-BENEFITS ASSESSED

For the stormwater and stream scenarios, the co-benefits analysis included assessments of economic benefits associated with changes in these categories:

- **Water supply**
- **Carbon sequestration**
- **Air quality**
- **Property values**
- Human health and well-being
- Flood control
- **Wildfire risks**
- **Riparian habitat**
- Recreation and amenities
- **Other pollutant removal**

For the categories in bold the analysis provides quantitative estimates of benefits for at least one scenario, because sufficient data is available to estimate both physical changes arising from the BMP and an economic value associated with the physical change. For the other categories, the economic literature strongly suggests that the actions would generate an economic benefit, but data were not sufficient to estimate the benefit value at a local level.

The analysis of each co-benefit type includes description of data sources, methods, assumptions and results.

WATER SUPPLY

To the extent that stormwater scenarios facilitate the availability of water for beneficial uses, or reduce demand for existing water supply (similar to conservation), the scenarios can provide water supply benefits in terms of the additional water supply made available. While there is interest in directly capturing stormwater for municipal water supply purposes, it is not currently practiced and not included in this analysis.[36]

Data Sources

The analysis of water supply relies on input from technical experts responsible for modeling the stormwater scenarios to characterize the potential effects of stormwater scenarios on infiltration.

The data presented in the *Arundo Donax Distribution and Impact Report* prepared in 2011 by the California Invasive Plant Council[37] are also applied to estimate the net water savings from removing invasive species and replacing them with native species.

Methods

The estimated value of water available to augment stream flows is based on the average value of water transactions for environmental purposes between 1982 and 2011 in California, revealing a society-level willingness-to-pay for instream flow.[38] The value, reported in 2011 dollars, was $122 per acre foot. After conversion to 2016 dollars using the CPI, the value used in this analysis is $130 per acre foot.

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[36] Any stormwater capture for water supply purposes would need to be designed and costs estimated to evaluate for any scenarios, and is not part of this study.

[37] California Invasive Plant Council. 2011. *Arundo donax Distribution and Impact Report.* State Water Resources Control Board. March. Retrieved February 17, from http://www.cal-ipc.org/ip/research/arundo/Arundo%20Distribution%20and%20Impact%20Report_Cal-IPC_March%202011.pdf

[38] Hanak, E. and E. Stryjewski. 2012. *California's Water Market, by the Numbers: Update 2012.* Public Policy Institute of California. November.

The water supply improvements could only be quantified for the stream restoration scenarios. Water supply changes resulting from GSI BMPs are discussed qualitatively in the *Results & Discussion* section below. The analysis of water supply changes related to restoration employed the following method.

Based on information from the literature, the total extent of *Arundo donax* is estimated by watershed. The literature provided two estimates: one for current extent, one for peak levels assuming no treatment. To produce a conservative estimate, this analysis only used the current extent numbers. In all but one instance, the acreage of current *Arundo donax* extent was less than the acreage of restoration proposed in each scenario, so this analysis included the full extent. Where restoration acreage was less than *Arundo donax* current extent, it uses the total acres of restoration instead of current extent. The analysis relied on to describe extent also described the amount of water use reduction by replacing *Arundo donax* with native vegetation, over a 10-year period. The annual water-use reduction is then calculated by watershed based on these data.

The benefit of water use reduction is calculated over 20, 50, and 100 years, assuming a phased approach where 5 projects are completed each year, and each project takes 5 years to reach completion. Each scenario has a different number of projects required to meet the water quality goals in each watershed, so the number of years required to achieve full implementation is different for each scenario and watershed combination. The first benefits are achieved in year 5 of the analysis, and increases until the maximum number of projects and acres are reached. Depending on the watershed and scenario, this takes anywhere from 1 year to 44 years. Future values are discounted using a 3% discount rate and a variable discount rate.

Results and Discussion

Water supply improvements could arise through the BMPs implemented in each scenario by increasing infiltration and/or removing high-water demand vegetation and replacing it with lower-water demand native species. While some residents do rely on groundwater, groundwater wells for water supply are generally located in the upper reaches of the watersheds. The exact location of BMPs that promote infiltration (e.g., GSI BMPs) is uncertain, but likely would be concentrated in the lower reaches of the watersheds, in areas not proximate to domestic or agricultural wells. Additionally, any infiltration that occurs would likely be shallow, and would not contribute to improvements in deep aquifer levels. Therefore, the scenarios are unlikely to result in economic benefits related to water supply improvements for domestic, industrial, or agricultural purposes. Finally, while the opportunity to divert stormwater for municipal supply is a growing desire throughout the state, this co-benefit was not considered.

The BMPs associated with all stormwater and stream restoration scenarios are likely to result in stormwater infiltration which may contribute to shallow-aquifer augmentation and improvements in base flows in riparian areas. The level of base flow improvement was not modeled specifically, so this analysis cannot quantitatively value the increase in stream flows. In theory, however, improvements in stream flows are likely to produce environmental benefits by improving habitat quality for the County's sensitive species.

The study by the California Invasive Plant Council of the costs and benefits of removing *Arundo donax* estimated the water-use benefit associated with *Arundo donax* removal in several of the watersheds relevant to this study (San Diego River, San Dieguito, Miramar, and San Luis Rey).[39] Table 41 presents the economic value of water supply improvements associated with *Arundo donax* removal in these watersheds. The level of benefit reported in Table 42 is limited either by the acres of *Arundo donax* currently existing in the watershed, or the acres of in-stream or offline restoration proposed, whichever is lower. In most cases, the acres and benefits are limited by current *Arundo donax* extent, rather than the number of acres proposed for

[39] California Invasive Plant Council. 2011. *Arundo donax* Distribution and Impact Report. State Water Resources Control Board. March. Retrieved February 17, from http://www.cal-ipc.org/ip/research/arundo/Arundo%20Distribution%20and%20Impact%20Report_Cal-IPC_March%202011.pdf

restoration, which is why the values are similar across each scenario. This likely represents an underestimate of benefits, because untreated *Arundo donax* extent increases annually (barring significant active removal), which increases the potential area for invasive species removal over time.

Table 41: Water Supply Co-Benefit Values Across Counties, Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Orange County	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Grand Total	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000

Table 42: Water Supply Co-Benefit Values Across Counties, Stream Scenario, 65 Years (3% Discount Rate)

COUNTY	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$10,700,000	$12,500,000	$12,600,000	$11,800,000
Orange County	$0.000	$0.000	$0.000	$0.000
Grand Total	$10,700,000	$12,500,000	$12,600,000	$11,800,000

CARBON SEQUESTRATION

The benefits of carbon sequestration can be quantified for the GSI included in certain stormwater scenarios. Carbon sequestration resulting from stream restoration scenarios are discussed qualitatively in the *Results* section below. The analysis of carbon sequestration co-benefits employed the following method.

Data Sources

The analysis of carbon sequestration co-benefits relied on the following data sources.

- Stormwater engineers who modeled the stormwater scenarios provided the acres of GSI BMPs per watershed for four watersheds: Los Peñasquitos, Tecolote Creek, San Diego River and Chollas Creek.
- The tree density per acre of BMP based on data provided in the City Heights Urban Greening Plan[40], and a manual on water efficient landscape design for the County of San Diego.[41]
- *Tree Guidelines for Coastal Southern California Communities* – the quantity of carbon sequestered per tree, by tree size, is described in a report on the benefits and cost of trees in coastal communities in southern California[42].
- The social cost of carbon is based on cost estimates provided by the US Interagency Work Group on Social Cost of Carbon.[43]

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[40] KTU+N. 2014. *City Heights Urban Greening Plan*. Prepared for the City of San Diego Planning Department. Aug 5.
[41] County of San Diego. 2010. *Water Efficient Landscape Design Manual County of San Diego*. Department of Planning and Land Use.
[42] McPherson, E.G., et al. 2000. *Tree Guidelines for Coastal Southern California Communities*. Western Center for Urban Forestry Research and Education USDA Forest Service, Pacific Southwest Research Station. A Publication of the Local Government Commission. January.
[43] USEPA. 2015. *USEPA Fact Sheet Social Cost of Carbon*. December. https://www3.USEPA.gov/climatechange/Downloads/USEPAactivities/social-cost-carbon.pdf.

- Tree density is based on San Diego specific descriptions of GSI implementations and landscape design manuals.[44] These manuals report a range of planning widths for GSIs. Based on these ranges, this analysis used planning widths of four- and eight-feet to convert from acres of GSI BMPs to linear lengths.

Methods

Tree density per acre of GSI BMP: The number of large, medium and small trees per acre of BMP are estimated based on the canopy diameter of mature trees and assuming a tree density of 50% large, and 25% medium trees and small trees, respectively. The green street and rain garden planning areas are estimated using four and eight feet wide designs, as described in City Heights Urban Greening Plan.[45]

Amount of carbon sequestered per tree, by tree size: McPherson et al. (2000)[46] report the amount of carbon sequestered per tree, by tree size, per five-year increment of tree growth, over forty years. This analysis extrapolated carbon quantities sequestered between the five-year data points. This analysis holds sequestration benefits constant after 40 years. It is assumed tree replanting happens between years 51 and 60, with 10% replanting per year. This analysis assumes a tree-mortality rate of 1% per year for the first five years and 0.5% thereafter.

Value of sequestered carbon: USEPA reports the value of sequestered carbon as the avoided costs of future damage (e.g., flooding) attributed to concentrations of atmospheric carbon. USEPA reports these data in five-year increments. This analysis extrapolated data for years between these data points. The USEPA reports the present values of the social cost of carbon using a 3% discount rate.

This analysis then multiplied the trees per acre of GSI BMP, by tree size, times the tons of carbon sequestered, by tree size, times the social cost of carbon, discounted back to 2016 dollars, times the acres of GSI BMP per watershed. It scales the number of acres of GSI BMPs over time based on the implementation schedules (e.g., 2031, 2051, 2061).

Results

The carbon sequestration co-benefits happen as trees planted as part of GSI BMPs absorb and fix carbon. The amount of carbon fixed increases with tree size and age. Table 43 and Table 44 shows the results of this analysis of the value of carbon sequestered, by stormwater scenario and implementation schedule. The analysis included four-foot and eight-foot planting width assumptions. Results for analyses are shown using the four-foot assumption. Results from analysis using the eight-foot assumption are basically half the value of those for the four-foot assumption.

Results for the 2010 TMDL 2031 implementation and 2012 REC Criteria 2031 Implementation are roughly similar; with 2010 TMDL results slightly greater. Among the three implementation schedules for the 2010 TMDL scenario, benefits are greatest for the 2031 implementation schedule, declining through the 2051 and 2061 schedules. This is the expected result as it takes more years to reach full benefits.

The Adjust All Beach WQO scenario has the same number of acres of GSI BMPs, and thus the same results, which are a fraction of the results for the 2010 TMDL or 2012 REC scenarios.

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[44] County of San Diego. 2001. *Water Efficient Landscape Design Manual*. Department of Planning and Land Use. February; KTU+A. 2014. *City Heights Urban Greening Plan*. Prepared for City of San Diego Planning Department. Contract H125568. August 5.

[45] KTU+N, 2014.

[46] McPherson et al. 2000.

Table 43. Carbon Sequestration Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$6,910,000	$6,210,000	$0.000	$0.000	$1,690,000	$3,520,000	$6,170,000
Orange County	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Grand Total	$6,910,000	$6,210,000	$0.000	$0.000	$1,690,000	$3,520,000	$6,170,000

Table 44. Carbon Sequestration Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$0.000	$0.000	$0.000	$0.000
Orange County	$0.000	$0.000	$0.000	$0.000
Grand Total	$0.000	$0.000	$0.000	$0.000

Stream restoration projects would also likely have a positive impact on carbon sequestration, arising from an increased density of vegetation in the riparian areas after habitat mitigation activities. However, data are unavailable to quantify the physical changes because of the preliminary design stage of the projects.

AIR QUALITY

Air quality benefits happen as trees absorb pollutants and particulate matter. Absorption increases with tree size and age. Data allow a general estimate for air quality improvements provided by urban trees. McPherson et al. report:

> *Urban trees provide air quality benefits by* **1)** *absorbing pollutants such as ozone and nitrogen oxides through leaf surfaces,* **2)** *intercepting particulate matter (e.g., dust, ash, pollen, smoke),* **3)** *releasing oxygen through photosynthesis, and* **4)** *transpiring water and shading surfaces, which lowers local air temperatures, thereby reducing ozone levels.*

The analysis of air quality co-benefits employed the similar data to that described above for carbon sequestration. It relies on the per-tree air quality benefits and values as reported in McPherson et al. 2000. This is multiplied by trees per acre of GSI BMP, specific to tree size, times the acres of GSI BMP per watershed discounted back to 2016 dollars. Air quality changes resulting from stream restoration BMPs are discussed qualitatively in the *Results* section below, but design details do not allow estimates of tree quantities for these scenarios.

Data and Methods

The analysis of air quality co-benefits relied on the following data sources.

- Stormwater engineers who modeled the stormwater scenarios provided the acres of GSI BMPs per watershed for four watersheds: Los Peñasquitos, Tecolote Creek, San Diego River and Chollas Creek.
- The tree density per acre of BMP based on data provided in the City Heights Urban Greening Plan[47], and a manual on water efficient landscape design for the County of San Diego.[48]

[47] KTU+N. 2014. *City Heights Urban Greening Plan*. Prepared for the City of San Diego Planning Department. Aug 5.

[48] County of San Diego. 2010. *Water Efficient Landscape Design Manual County of San Diego*. Department of Planning and Land Use.

- *Tree Guidelines for Coastal Southern California Communities* – the value of air quality benefits per tree is described in a report on the benefits and cost of trees in coastal communities in southern California[49].
- Tree density is based on San Diego specific descriptions of GSI implementations and landscape design manuals.[50] These manuals report a range of planning widths for GSIs. Based on these ranges, this analysis used planning widths of four- and eight-feet to convert from acres of GSI BMPs to linear lengths.

Results

Table 45 and Table 46 below shows the results of the analysis of the value of air quality improvements, by stormwater scenario and implementation schedule. As with the results for the analysis of benefits of carbon sequestered, this analysis reports results using the four-foot planting width assumption. Results for analyses using the eight-foot assumption are approximately half the results for analyses using the four-foot assumption.

Air quality benefits by stormwater scenario and implementation schedule follow the same pattern described above for carbon. Benefits for the 2010 TMDL and 2012 REC implementation are roughly similar; with benefits for the 2010 TMDL scenario slightly greater. Benefits for the three implementation schedules for the 2010 TMDL scenario are greatest for 2031 implementation, declining through the 2051 and 2061 schedules. Benefits for the Adjust All Beach WQO scenarios are only a fraction of the 2010 TMDL or 2012 REC scenarios.

Table 45: Air Quality Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$24,000,000	$21,600,000	$0.000	$0.000	$5,850,000	$12,400,000	$19,100,000
Orange County	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Grand Total	$24,000,000	$21,600,000	$0.000	$0.000	$5,850,000	$12,400,000	$19,100,000

Table 46: Air Quality Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$0.000	$0.000	$0.000	$0.000
Orange County	$0.000	$0.000	$0.000	$0.000
Grand Total	$0.000	$0.000	$0.000	$0.000

Stream restoration scenario projects would also likely have a positive impact on air quality, arising from an increased density of vegetation in the riparian areas after habitat mitigation activities. Data are unavailable to quantify the physical changes because of the preliminary design stage of the projects,

[49] McPherson, E.G., et al. 2000. *Tree Guidelines for Coastal Southern California Communities*. Western Center for Urban Forestry Research and Education USDA Forest Service, Pacific Southwest Research Station. A Publication of the Local Government Commission. January.

[50] County of San Diego. 2001. *Water Efficient Landscape Design Manual*. Department of Planning and Land Use. February; KTU+A. 2014. *City Heights Urban Greening Plan*. Prepared for City of San Diego Planning Department. Contract H125568. August 5.

however. Analyses would apply the same economic method and value described above to estimate the economic benefit of air quality improvements, should data become available for these scenarios.

PROPERTY VALUES

Vegetation intensive GSI BMPs, such as green streets and rain gardens, have a visual appeal. This appeal benefits adjacent properties because markets incorporate this appeal into property transactions and market values. People generally will pay a slight premium for properties adjacent to GSI BMPs, relative to comparable properties not adjacent to a visually appealing streetscape.

Data Sources

Data sources for the analysis of the beneficial impacts of street trees and green areas in the built urban environment on adjacent property values included the following.

- General descriptions of green streets provided in the City Heights Urban Greening Plan.
- Netusil et al 2011. Estimated impacts of street trees and green areas on adjacent property values based on studies reported in the academic literature[51].
- Mean property values for neighborhoods in the watersheds in the study area using data from Property Radar.[52]

Impacts of GSI BMPs on property values are estimated assuming the BMPs would be placed in residential neighborhoods and include trees and other landscape vegetation. A literature review found no specific studies of the impacts of green streets or street trees on property values in San Diego or Orange Counties. The analysis estimated these benefits using a high-low range of values summarized from the review of the literature.[53] The literature reports a range of impacts of GSI BMPs on property values of positive 0.75 to 6.8% increase in value. To be conservative, this analysis applies a range of 0.75 to 3.0% in our analysis. Property-value benefits increase as the acres of GSI BMPs increase over time as described above for the implementation schedules.

Methods

The property value analysis is limited to stormwater scenarios involving GSI BMPs. Property value changes resulting from stream restoration BMPs are discussed qualitatively in the *Results* section below. To the extent stream restoration would improve property values as well these benefit estimates are likely to be underestimates. The analysis of property value co-benefits employed the following methods.

Miles of GSI BMP: Converted the acres of GSI BMPs into street lengths assuming planning widths of four and eight feet.

Average impacts on property values: Assumed that street trees and green streets in the built urban area increase the values of adjacent properties between 0.75 and 3%. Tables report the midpoint result between 0.75 and 3% below. Table 47 and Table 48 contain detailed results.

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[51] Netusil, N., Z. Levin and V. Shandas. 2011. *Valuing Green Infrastructure in Portland, Oregon*. Association of Environmental and Resource Economists 2011 Summer Conference, Seattle, WA, June 10; Dill, J. et al. 2010. *Demonstrating the Benefits of Green Streets for Active Aging: Final Report to USEPA.* Agreement Number: CH-83421301. November 30; Ward, B., E. MacMullan, and S. Reich. 2008. *The Effect of Low-Impact-Development on Property Values*. Sustainability 2008. ECONorthwest. Water Environment Federation.

[52] Property Radar. No data. http://www.propertyradar.com/.

[53] Netusil, N., Z. Levin and V. Shandas. 2011. *Valuing Green Infrastructure in Portland, Oregon*. Association of Environmental and Resource Economists 2011 Summer Conference, Seattle, WA, June 10; Dill, J. et al. 2010. *Demonstrating the Benefits of Green Streets for Active Aging: Final Report to USEPA.* Agreement Number: CH-83421301. November 30; Ward, B., E. MacMullan, and S. Reich. 2008. *The Effect of Low-Impact-Development on Property Values*. Sustainability 2008. ECONorthwest. Water Environment Federation.

Property values in study area: Property parcel data from Property Radar are the basis to estimate average density of single family homes (SFH) and average property value per mile of roadway, by drainage area.

Implementation of GSI BMPs follow linearly through completion dates for schedules —2031, 2051, and 2061. The analysis holds property value benefits constant after full implementation of GSI BMP acres. That is, GSI provides a one-time benefit to adjacent property values. The property values are discounted back to 2016 dollars.

The calculation involves multiplication of the average property value per SFH by average density of SFH per mile, times miles of roadway, times 0.75 and 3%. Although a hedonic analysis was conducted, it is not used.

Results

Table 47 and Table 48 below reports the results of the analysis of the property-value benefits of the GSI BMPs in the study. It lists results by stormwater scenario and implementation schedule. Benefits are a one-time increase in property values. Benefits across acres of BMPs are additive, but benefits across time *for the same acre* are not. That is, it is assumed that once a green street is installed, it benefits adjacent property values *once*. The acres of GSI BMPs increase over time as described by the 2031, 2051, and 2061 implementation schedules.

As described above, results are reported for the four-foot planting width. Results for the eight-foot width are approximately half the value of results for the four-foot width.

Results for 2010 TMDL scenario are generally comparable, though greater than results for 2012 REC 2031 implementation schedule. Results by implementation schedule for 2010 TMDL decline from 2031, to 2051, 2051, to 2061. This is the expected result because acres implemented—and benefits generated—per years decline across the three implementation schedules.

Table 47: Property Value Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$232,000,000	$209,000,000	$0	$0	$61,700,000	$159,000,000	$180,000,000
Orange County	$0	$0	$0	$0	$0	$0	$0
Grand Total	$232,000,000	$209,000,000	$0	$0	$61,700,000	$159,000,000	$180,000,000

Table 48: Property Value Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$0	$0	$0	$0
Orange County	$0	$0	$0	$0
Grand Total	$0	$0	$0	$0

Restoration projects that enhance the amenity value of riparian areas adjacent to residential property may positively affect property values, for the same reasons that GSI BMPs do: by enhancing the attractiveness of the surrounding environment. Researchers have found that the relationship between property values and natural green spaces is general neutral to positive, and may vary depending on neighborhood characteristics. For example, researchers found that in Ohio, proximity to green space was a significant influencer of property value for middle and high priced houses, but the lower end of the property market showed no significant effect.[54] Research from Austin, Texas, found that houses adjacent to a greenbelt had a positive or neutral effect on property value: two subdivisions showed a positive effect, while one did not.[55] Increasing accessibility to the natural areas, such that they become a recreational as well as a visual amenity may also contribute to property values: in Austin, one subdivision nearby an accessible greenbelt showed an increase in value, while others did not. Insufficient data were available about the location of the stream restoration projects proximate to residential areas to quantify the impact on property values, but based on research performed elsewhere, the effect is likely greater than zero. It is most likely to be positive for dramatic visual improvements in natural green space adjacent to middle and higher-valued neighborhoods.

HUMAN HEALTH AND WELLBEING (NON-WATER QUALITY BASED)

Current data collection and analytical methods do not support quantifying the connection between urban green space improvements (such as those in the stormwater and stream scenarios) and human health and well-being at the regional or watershed level. Researchers have quantified some of these benefits at the national level.[56] The available literature does support the qualitative conclusion that trees and green spaces in urban areas supply these types of benefits and that the volume of benefits are non-zero and positive. Humans interacting with trees and green spaces (e.g., walking along greenways), and the impacts of greening urban areas on social conditions (e.g., reduced crime) are the mechanisms by which benefits accrue.[57] Much of the academic literature is composed of primary studies conducted by Kathleen Wolf of the University of Washington.[58] Dr. Wolf discussed her research results and their applications to the San Diego area with the CBA team.

Recent research into the human health and well-being benefits of both the GSI BMPs and stream restoration projects in the study include the following.[59]

Improved Birth Weight —Research results show an association between increased tree canopy and proximity to open spaces and reduced incidence of low birth weight babies. Improved birth weights help reduce related health care expenditures.

Reduced ADHD—Studies indicate that interactions with nature or green spaces can help reduce attention deficit hyperactivity disorder (ADHD) symptoms. Reduced ADHD symptoms can help reduce ADHD treatment costs.

Improved School Performance—Research results show that improved access to, and views of nature can help improve the performance of high school students. Improved school performance can help increase graduation rates, which improves students' earning potential later in life.

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[54] Liu, S. and D. Hite. 2013. *Measuring the Effect of Green Space on Property Value: An Application of the Hedonic Spatial Quantile Regression.* Presentation at the Southern Agricultural Economics Association (SAEA) Annual Meeting, Orlando, Florida, 3-5 February 2013.
[55] Nicholls, S. and J.L. Crompton. 2005. "The Impact of Greenways on Property Values: Evidence from Austin, Texas." *Journal of Leisure Research* 37(3): 321-341.
[56] Wolf, K. M. Measells, S. Grado, and A. Robbins. 2015. "Economic values of metro nature health benefits: A life course approach," *Urban Forestry & Urban Greening* 14 (2015): 694-701.
[57] Wolf et al., 2015; Wolf, K. 2016. *Economic Benefits of Trees & Greenspace*. 2016 Western Planner & Montana Association of Planners Joint Conference. Great Falls. August.
[58] Wolf, K., et al. 2015. "Economic Values of Metro Nature Health Benefits: A Life Course Approach." *Urban Forestry & Urban Greening*. 14: 694-701.
[59] Wolf et al., 2015; Wolf, 2016.

Reduced Crime—Several studies show a relationship between greening urban areas and levels of criminal activity. Increased green areas are associated with reduced economic costs associated with violent and non-violent crimes.

Reduced Cardiovascular Disease—Several studies show a link between cardiovascular mortality and exposure to green space, with increased exposure to trees and other greenery correlated with lower incidence of cardiovascular disease. Reduced incidence of disease helps reduce related health care costs and lost worker productivity.

Collectively this literature does suggest that the greater the incorporation of vegetation and green space in a stormwater or stream restoration scenario, the greater the mental health benefits are likely to be. Techniques do not exist yet however to identify the incremental change in these benefits with incremental changes in the total amount of natural amenities for a region. Therefore, monetary value estimates are not feasible at this time.

FLOOD CONTROL

This analysis characterizes the flood-control potential of GSI BMPs and stream restoration projects based on conversations with technical staff who designed the scenarios for this analysis. Data are insufficient to quantify potential effects on flooding. To describe the economic value of flood control, this analysis involved review of the literature and news reports of flooding in the region. Note that BMPs likely to affect flooding are only part of scenarios for San Diego County watersheds.

The majority of flood events in the County of San Diego happen from either large weather systems generated out in the Pacific Ocean, or from localized thunderstorms. Both types of events can cause widespread flooding on the County's western slopes and in urban areas. Average, seasonal rainstorms can also cause flooding as a result of inadequate drainpipes or debris-clogged channels. Shallow flooding happens in flat areas that lack adequate drainage or runoff channels.

The County's flood-exposure risk from a 1% or hundred-year flood include the following (all dollars in 2016 $s).[60]

- Population at risk: over 21,000
- Structures at risk: over 6,650
- Value of structures at risk: $1.9 Billion
- Critical facilities and infrastructure at risk: 130
- Value of critical facilities and infrastructure at risk: $970 million.

Data are not available that would allow calculation of the flood mitigation benefits of the riparian restoration and stormwater GSI BMPs in this study in terms of reduced risk or volume of flood events. The County's flood management plan, however, includes both types of projects among the recommended flood-mitigation measures. Studies of the stormwater-absorption benefits of trees in the San Diego area found that trees can change the runoff hydrograph and help reduce the total runoff volume. From the experience of other locations in the United States. subject to flash flooding comparable to that in San Diego, flash flood events can quickly overwhelm the stormwater-absorption capacity of GSI BMPs. Once this happens the BMPs no longer provide stormwater or flood mitigation benefits.

[60] County of San Diego. 2007. Floodplain Management Plan. http://www.sandiegocounty.gov/dpw/floodcontrol/floodcontrolpdf/floodplainmanagementplan.pdf

Given this limitation, this analysis estimates that the riparian restoration and GSI BMPs in the study provide limited, positive flood-mitigation benefit values. The available data do not allow calculation of this value.

WILDFIRE RISKS

Stream restoration can reduce wildfire risk by removing fire-prone vegetation, specifically invasive non-native species.

Data Sources

This analysis uses the change in wildfire risk from removing *Arundo donax* through habitat improvement as reported in the *Arundo donax Distribution and Impact Report*[61] It also relies on that report to describe the avoided costs of wildfire events. That report derives fire impacts based on events initiated by *Arundo donax* in the San Luis Rey watershed, and extrapolates to other watersheds based on *Arundo donax* extent.

This analysis of reduced wildfire risk assumes that an annualized benefit accrues each year.

Methods

This analysis quantifies changes in wildfire risk for the Restoration BMP scenarios. GSI BMPs are unlikely to generate changes in wildfire risk. The analysis of changes in the risk related to wildfire employed the following method.

Wildfire risk is primarily driven by removal of *Arundo donax,* a densely vegetated, flammable invasive species that chokes waterways and inhibits natural firebreaks. Based on information from the literature, the total current extent of *Arundo donax* by watershed can be estimated. The literature provides two estimates: one for current extent, one for peak levels assuming no treatment. To produce a conservative estimate, this analysis only used the current extent numbers. In all but one instance, the acreage of current *Arundo donax* extent was less than the acreage of restoration proposed in each scenario, so the full extent is included in the analysis. Where restoration acreage was less than *Arundo donax* current extent, the analysis includes the total acres of restoration instead of current extent. The referenced report also described the fire incidence over a 10-year period, based on actual data from the San Luis Rey watershed.

The report quantified wildfire costs, and presented the reduced costs by watershed over 10 years, considering the decreased incidence of wildfire given *Arundo donax* removal. The costs include $50,000 in suppression costs and $20,000 per acre of *Arundo* habitat burned and $80,000 per acre of native vegetation burned (in 2011). This analysis converted these dollars to 2016 dollars, and converted the 10-year value to an annual value.

The analysis calculated the benefit of reduced wildfire risk reduction over 20, 50, and 100 years, assuming a phased approach where 5 projects are completed each year, and each project takes 5 years to reach completion. Each scenario has a different number of projects required to meet the water quality goals in each watershed, so the number of years required to achieve full implementation is different for each scenario and watershed combination. The first benefits are achieved in year 5 of the analysis, and increase until the maximum number of projects and acres are reached. Depending on the watershed and scenario, this takes anywhere from 1 year to 44 years.

Results

The stream restoration scenarios are the only scenarios that would have a measurable effect on wildfire risk reduction. They accomplish this primarily through the removal of highly flammable invasive species in the

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61 California Invasive Plant Council. 2011. *Arundo donax Distribution and Impact Report.* State Water Resources Control Board. March. Retrieved February 17, from http://www.cal- ipc.org/ip/research/arundo/Arundo%20Distribution %20and%20Impact%20Report_Cal-IPC_March%202011.pdf

riparian corridor. The restoration scenarios would all have a similar magnitude of benefit, because the benefit is limited by the current acres of *Arundo donax* rather than the acres of project restoration included in each scenario.

Table 49: Wildfire Risk Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATOINS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$0	$0	$0	$0	$0	$0	$0
Orange County	$0	$0	$0	$0	$0	$0	$0
Grand Total	$0	$0	$0	$0	$0	$0	$0

Table 50: Wildfire Risk Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$20,500,000	$19,900,000	$19,000,000	$21,100,000
Orange County	$0.000	$0.000	$0.000	$0.000
Grand Total	$20,500,000	$19,900,000	$19,000,000	$21,100,000

RIPARIAN HABITAT

The supply of riparian habitat was estimated based on the modeling results presented in the Draft Riparian Restoration Report, Tables 8-9 and based on personal communication with stream restoration staff. The value of the change in the supply of Riparian Habitat was estimated based on the cost of restoration projects. The economics team discussed with stream restoration expert's staff about the costs for the projects included in Stream scenarios 1 and 2, and adjusted the values to account for the portion of the project involving riparian habitat improvement (the projects emphasis on in-channel improvements required substantial dredging, which is costly and doesn't directly contribute to streamside habitat improvement). The costs are high-level engineering costs, and include a 50% contingency. The low end of the range comes from the estimated cost to treat an acre of *Arundo donax*, as reported in the *Arundo Donax Distribution and Impact Report* prepared in 2011 by the California Invasive Plant Council.[62]

This analysis of habitat benefits assumes that 5 projects are completed each year, and each project takes 5 years to reach full implementation. Benefits accrue for each project at full implementation.

Areas of restoration for each scenario are taken directly from the Draft Riparian Restoration Report.[63] Acres of improved habitat for in-stream improvements are quantified based on the linear feet per project, multiplied by a 50-foot buffer, multiplied across the number of projects reported. The analysis used the "area needed for off-line tributary wetlands" column of data from Table 9 of the Draft Riparian Restoration Report for the acres of wetland habitat.

Stream restoration design scenarios would include removal of invasive species and replanting native species in the riparian zone following in-channel and wetland improvements. For in-stream work included in all stream restoration scenarios, it is assumed habitat restoration would occur within 25-feet of both sides

[62] California Invasive Plant Council. 2011. *Arundo donax Distribution and Impact Report*. State Water Resources Control Board. March. Retrieved February 17, from http://www.cal- ipc.org/ip/research/arundo/Arundo%20Distribution %20and%20Impact%20Report_Cal-IPC_March%202011.pdf

[63] ESA. 2017. *DRAFT Development of the San Diego Bacteria TMDL Cost Benefit Analysis Inputs for Stream and Riparian Habitat Restoration San Diego and Orange Counties.* County of San Diego. January.

of the stream channel, resulting in a 50-foot riparian buffer. For off-channel wetland improvements, it is assumed habitat improvements would be incorporated for all project site acres included in the analysis.

Methods

This analysis quantified improvements in riverine habitat associated with the stream restoration BMPs. Although GSI BMPs also may improve habitat for some of the same species that benefit from improvements to riverine habitat, these benefits are discussed qualitative in the results below. The analysis of improvements in habitat employed the following methods.

The area of habitat improvement estimated is based on the data presented in the Draft Riparian Restoration Report.[64] To quantify the habitat acres affected by the in-channel projects, a 25-foot buffer is assumed on either side of the stream channel, for a total buffer width of 50 feet. For off-line wetland restoration, the analysis used the total area required, as presented in Table 9. Stream restoration staff confirmed that habitat restoration, and invasive species removal specifically, likely would be strategies required subsequent to the channel shaping and wetland construction activities described in the Draft Riparian Restoration Report, and would be included in the project costs described in that report. Additionally, the in-channel improvements would likely result in positive impacts to the adjacent riparian areas. The acres of restoration are reported by watershed.

To estimate the value of the habitat improvements, the analysis reviewed local habitat restoration costs for similar habitat improvements. These costs are indicative of the local willingness to pay for riverine habitat benefits. Though it doesn’t necessarily indicate the direct value of the stream of ecosystem services produced by an acre of improved habitat, presumably the perceived value of these services is at least the restoration cost on average (or projects wouldn’t be funded). The regional costs of habitat restoration vary considerably, based on the project type, location, and other factors. Based on a survey of 17 restoration projects implemented in Southern California, most of them riparian and wetland restoration projects, per-acre restoration costs (exclusive of land acquisition) ranged from approximately $2,000 per acre to $1.5 million per acre. The average per-acre project cost was approximately $175,000, and the weighted average was approximately $27,000. Larger projects (based on acres) produced smaller per-acre costs, indicating that economies of scale drive project costs down and relative project size matters. For projects in the sample that were less than 10 acres in size (similar in scale to the projects included in the Stream Riparian Restoration scenarios, the average cost per acre was approximately $350,000. This value is higher than the costs to remove *Arundo donax* and replace it with native vegetation, as reported in the *Arundo donax Distribution and Impact Report* at $25,000 per acre (in 2011$). Converted to 2016 dollars and rounded to the nearest thousand, this cost is $27,000 per acre. The Draft Riparian Restoration Report includes per-acre wetland restoration costs of $600,000. These costs are feasibility-level costs and have a 50% contingency built in. They also include planning, engineering design, CEQA, permitting, implementation, and operations and maintenance at 20% of the total cost. This cost does not include land acquisition or the opportunity cost of land used for the Restoration BMPs. Because we are estimating only the habitat benefits associated with these restoration projects, we use $350,000 per acre, which is considerably lower than the $600,000 per-acre predicted cost to complete these projects, and in-line with costs for projects with habitat restoration goals completed in Southern California.

The economic benefit of habitat improvements is calculated using a phased approach where 5 projects are completed each year, and each project takes five years to reach completion. Each scenario has a different number of projects required to meet the water quality goals in each watershed, so the number of years required to achieve full implementation is different for each scenario and watershed combination. The first

[64] ESA 2017. January draft and revised tables sent 2/28/17.

benefits are achieved in year 5 of the analysis, and increase until the maximum number of projects and acres are reached. Depending on the watershed and scenario, this takes anywhere from 1 year to 44 years.

Results

The stream restoration scenarios would produce improvements in the quality and quantity of riverine habitat available in San Diego and Orange Counties. The value of that improvement is represented by the cost to implement similarly-sized projects with riparian and wetland habitat restoration goals elsewhere in Southern California, approximately $350,000 per acre. The benefits phase in based on an expected project completion rate of 5 projects per year, with individual projects taking 5 years to complete. The value of changes in riparian habitat are directly related to the number of acres of habitat restored in each scenario. Thus, the benefits are highest for the Instream + 20% wetland scenario, which has the most acreage that would be restored, and lowest for the instream scenario, which has the least acres of riparian habitat that would be restored.

Table 51: Riparian Habitat Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$0	$0	$0	$0	$0	$0	$0
Orange County	$0	$0	$0	$0	$0	$0	$0
Grand Total	$0	$0	$0	$0	$0	$0	$0

Table 52: Riparian Habitat Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$103,000,000	$402,000,000	$573,000,000	$352,000,000
Orange County	$50,800,000	$157,000,000	$176,000,000	$176,000,000
Grand Total	$154,000,000	$559,000,000	$750,000,000	$528,000,000

Habitat improvements may also arise from the GSI BMPs, which increase the quantity and density of urban green space. These projects typically produce lower quality habitat: the habitat is less complex and less connected to other green spaces because of the distribution throughout neighborhoods and the relatively small size of each installation. That does not mean the value of the habitat produced is zero, but it effects on species, especially sensitive species, is likely less valuable than the habitat improvements described above. These values rely heavily on an assumption that stream restoration scenarios could be designed in a way to provide the types of habitat functional improvement targeted by habitat restoration projects.

RECREATION AND AMENITIES

The in-stream and off-line wetland restoration projects could produce recreation and amenity benefits, especially since projects likely would be located on public land. The available project design level is not detailed enough to determine specific recreation features or locations that would be added, but restoration costs are sufficient to support basic trail construction and interpretive signage. Furthermore, legal access restrictions for wetland and floodplain areas would limit permitted usage. Based on this limited information, data are not sufficient to quantify an increase in recreation supply or relate it to current demand for new or expanded recreation facilities.

Some of the stream restoration scenario projects would likely include recreation access and amenities, such as trails, benches, overlooks, and interpretive signage. These features are often built into projects as they reach the final design phases, often involving a broad range of stakeholders interested in leveraging resources to satisfy multi-purpose community interests. The range of costs included for these projects are wide enough that they likely would support modest recreational development as part of the habitat mitigation (personal communication with ESA staff). Thus, it is likely that the stream restoration scenarios would generate economic benefits associated with recreation. It is not feasible at this time to quantify this benefit because limited detail exists to describe the location and scope of the recreational improvements, their proximity to populations who would use them, and their proximity and/or connectivity to other recreational resources. However, economic research in California has demonstrated that recreation is valuable to the state's residents: Californians are willing to pay almost $18 for a day of hiking to over $40 for a day of mountain biking.[65] Projects that provide recreational opportunities in areas where they are currently scarce, but nearby populations who have expressed demand for them would likely generate the highest level of economic benefit.

OTHER POLLUTANT REMOVAL GOALS

The stream restoration and stormwater scenarios would produce benefits by removing pollutants other than bacteria, including sediment, metals (e.g., antimony, arsenic, cadmium, chromium copper, lead, nickel, selenium, and zinc), and nutrients including phosphorous and nitrogen. Many of the watersheds in the study area are listed on California's 303(d) list for being water-quality limited for these pollutants. While only the Los Peñasquitos watershed has an established TMDL for sediment and Chollas Creek watershed for copper lead and zinc, TMDLs to address these pollutants in the other watersheds are in development. This implies that there is demand for removal, and any removal this project would accomplish would produce value, either directly for water users or through avoided costs for those who would be responsible for controlling pollution in the future.

Methods

This analysis relied on discussions with stormwater experts and their modeling results to describe the effect of the stormwater and stream restoration BMPs on other pollutant loading, focusing on those watersheds and pollutants that are listed on California's 303(d) list. The analysis relies on discussions and modeling results from stream restoration technical memo describe the effect of stream restoration BMPs on other pollutants, again focusing on those watersheds and pollutants that are listed on California's 303(d) list. To determine indicators of economic value, a literature review was conducted to describe the direct benefits and avoided costs of reducing these pollutants. For sediment, watershed-level cost estimates of the damage from sediment, are reported by Hansen and Ribaudo.[66] Hansen and Ribaudo calculate costs by watershed area in 14 categories, 13 of which are relevant to the watersheds included in this analysis:

- Irrigation Ditches and Canals
- Marine Recreational Fishing
- Marine Fisheries
- Flood Damages
- Road Drainage Ditches
- Municipal and Industrial Water Use
- Municipal Water Treatment

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[65] BBC Research and Consulting. 2011. *California Outdoor Recreation Economic Study: Statewide Contributions and Benefits.* California State Parks.

[66] Hansen, L. and M. Ribaudo. 2008. *Economic Measures of Soil Conservation Benefits: Regional Values for Policy Assessment.* USDA ERS. Technical Bulletin No. 1922. September.

- Steam Power Plants
- Soil Productivity
- Dust Cleaning
- Water-Based Recreation
- Navigation
- Reservoir Services

Benefits and costs of nutrient pollution and removal summarized by USEPA.[67] Limited data are available to describe the benefits and costs of removing metals from stormwater.

The analysis quantified the value of removing pollutants identified on California's 303(d) list other than bacteria for both the GSI BMPs and the Restoration BMPs. To quantify the value of removing other pollutants of interest, wet-weather pollution load reduction estimates for each category of BMPs and restoration approach are applied.

For sediment (total suspended solids or TSS), the tons of sediment removed through BMPs are quantified by taking the wet-weather percent load reduction value by scenario generated by stormwater and stream restoration modeling results, and multiplying it by available information on baseline annual sediment pollution loading (the stream restoration modeling results were already reported in terms of pounds per year, so the analysis converted pounds to tons). This value is multiplied by the per-ton economic value of sediment removal generated by Hansen and Ribaudo[68] for the San Diego watershed area.

The other pollutants with established TMDL are dissolved Copper, Lead, and Zinc in Chollas Creek. The literature review found no data on the economic costs or benefits of removing dissolved copper, lead, and zinc from stormwater.

Pollutants the BMPs would address that do not yet have established TMDLs but are identified on California's 303d list for watersheds in the study area include phosphorous and nitrogen (nutrients). As with sediment (TSS) modeling results from stormwater and stream restoration experts describe the total load reduction resulting from BMPs. The economic value of removing nutrients varies considerably depending on concentration, uses of the receiving water, and source of the pollution. Benefits and costs of nitrogen and phosphorous pollution removal from non-point sources are summarized by USEPA.[69] This analysis calculated an average cost per pound of nitrogen and phosphorous removal across all structural and non-structural BMPs of approximately $2,800 per pound of nitrogen and approximately $8,900 per pound of phosphorous.

In total, this analysis measures the benefits associated with these pollutants in two ways, based on the available data: for sediment, it uses a value that represents the direct benefits associated with keeping sediment out of the waterway. For nutrients (nitrogen and phosphorous) it uses the cost of controlling these pollutants from urban runoff through structural and non-structural BMPs. Because the costs vary widely across BMPs, it took an average cost per pound removed across all BMPs, as reported by USEPA.[70] It only quantifies the benefit arising from pollutants controlled during wet-weather conditions. Should the same BMPs control pollutants during dry-weather conditions, the benefit would be greater than reported below.

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[67] U.S. Environmental Protection Agency, Office of Water. 2015. *A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution.* USEPA 820-F-15-096. May.

[68] Hansen, L. and M. Ribaudo. 2008. *Economic Measures of Soil Conservation Benefits: Regional Values for Policy Assessment.* USDA ERS. Technical Bulletin No. 1922. September.

[69] U.S. Environmental Protection Agency, Office of Water. 2015. *A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution.* USEPA 820-F-15-096. May.

[70] U.S. Environmental Protection Agency, Office of Water. 2015. *A Compilation of Cost Data Associated with the Impacts and Control of Nutrient Pollution.* USEPA 820-F-15-096. May.

Results

All stormwater and stream restoration scenarios would produce reductions in sedimentation, with values shown in Table 53 and Table 54 below. The value of the benefit is based on removal benefits calculated across 13 categories, as described in the data section. The greatest benefit, accounting for almost half of the total sediment benefit, is from water-based recreation. Marine commercial and recreation fisheries is the next highest benefit.

Table 53: Sediment Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$191,000	$184,000	$3,800	$30,500	$99,200	$84,000	$138,000
Orange County	$0	$0	$0	$0	$0	$0	$0
Grand Total	$197,000	$184,000	$3,800	$30,500	$99,200	$60,100	$142,000

Table 54: Sediment Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$3,320	$74,100	$122,000	$46,300
Orange County	$12,300	$224,000	$236,000	$260,000
Grand Total	$15,600	$298,000	$358,000	$307,000

All stormwater and stream restoration scenarios would produce reductions in both phosphorous and nitrogen, with values shown in the Table 55 below. The value of the benefit is based on costs of controlling each pollutant, through structural and non-structural BMPs designed to address non-point sources of the pollution. It is possible the value shown overestimates the costs required to control Nitrogen and Phosphorous: if the same BMP can capture both pollutants adequately, the cost of control would only need to be counted once. However, if different BMPs are required to control each nutrient, then these values would be in the range of actual avoided costs.

Table 55: Phosphorous and Nitrogen Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$145,000,000	$139,000,000	$2,260,000	$22,400,000	$83,500,000	$99,000,000	$112,000,000
Orange County	$0	$0	$0	$0	$0	$0	$0
Grand Total	$145,000,000	$139,000,000	$2,260,000	$22,400,000	$83,500,000	$99,000,000	$112,000,000

Table 56: Phosphorous and Nitrogen Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$27,600,000	$51,800,000	$74,500,000	$55,000,000
Orange County	$0	$0	$0	$0
Grand Total	$27,600,000	$51,800,000	$74,500,000	$55,000,000

SUMMARY OF CO-BENEFITS

Table 57 and Table 58 below report total co-benefits summed across watersheds, by scenario, over the 65-year timeframe discounted at 3%. Based on these results the 2010 TMDL scenario has the greatest total co-benefits of the stormwater scenarios, but the stream restoration scenarios have greater co-benefits, particularly Instream +20%. Co-benefits range up to over $800 million at the highest for these analyses over the 65-year timeframe.

The stacked bars in Figure 24 show the individual contribution of each co-benefit to the 65-year totals, calculated using the 3% discount rate. This chart indicates that three co-benefits—property value, riparian habitat and removal of nitrogen and phosphorous—account for the large majority of total benefits. Riparian habitat, in scenarios stream + 10%, stream + 20%, and MS4, has the largest amount of any co-benefit. Property values provide the next largest amount of co-benefits in the 2010 TMDL, 2012 REC criteria, Compliance by 2051 and CIP Coordination scenarios. Nitrogen and Phosphorous is the third-largest co-benefit, in the same scenarios described above for property values.

Given the dominant contribution of habitat, property value, and other pollutant removal co-benefits to the total amount of co-benefits, uncertainties and sensitivities specific to the other co-benefits would have little effect on total co-benefit results. Factors to take into account that could affect riparian habitat results include:

- The estimated habitat value is based on habitat restoration costs derived from recent riparian and wetland projects implemented in Southern California. This value is on the upper end of the middle of the range, accounting for the smaller footprint (less than ten acres) of the proposed projects. Actual value of the habitat could be higher or lower depending on specific project designs.
- Estimating habitat benefits through an avoided cost approach in combination with direct estimation of some of the benefits of restoration (particularly Arundo donax removal) may ultimately overestimate the total benefits of the restoration scenarios. The overall effect of this potential double-counting on the analysis, however, is likely inconsequential because the habitat benefit is so large compared to other estimated benefits of restoration.

Factors to take into account that could affect property value results include:

- Results reported in the economics literature indicate an upper bound of property value benefits from street tree and related GSI BMPs of approximately 7%. This analysis limited the upper bound to 3%. To the extent that actual property value benefits exceed our limited upper bound, this analysis underestimates this benefit.
- The actual location of BMPs is unknown at this time. This analysis uses average housing density and value in the watersheds. To the extent that BMPs are installed in locations with housing densities and property values less than, or greater than, the averages in this analysis, the results will under or over-estimate this benefit.

Factors to take into account that could affect other pollutant removal results include:

- Uncertainty in modeling results that estimate total load reductions for wet weather conditions also applies to uncertainty in the economic valuation. Load reductions may underestimate total load reduction, because dry weather reductions are not included in the estimate.
- The economic value associated with sediment reduction is derived from a model that estimates sediment damage reduction by watershed. Depending on the location of the sediment removal BMP, actual economic benefits may or may not materialize in all categories that the model quantifies. The effect on the overall analysis arising from this uncertainty is minor, however, because the total value associated with sediment reduction is relatively small.

- The economic value associated with nitrogen and phosphorous is derived from BMP implementation costs per pound of pollutant for both structural and non-structural urban runoff control BMPs. The range of these values is very large (ranging from a few cents per pound to over $10,000 per pound). The actual avoided cost associated with this pollutant reduction will depend on the ultimate mix of BMPs that would have been required to control these pollutants at a given time a place: it could be lower or higher than the average cost we used in the analysis.
- The value may overestimate the total benefit associated with removing nitrogen and phosphorous to the extent that the same BMPs could be used to remove both nitrogen and phosphorous. The estimate of the cost to remove nitrogen and phosphorous independently are summed. If the analysis only took the higher of the two estimates, the value could be 40% lower.

Ultimately while these co-benefits are not necessarily the full extent of total co-benefits, they are generally subject to design and implementation. Therefore, the extent of actual co-benefits will depend both on the care and intention taken when siting, designing, and implementing projects to achieve these benefits, but also the demand and scarcity for those effects.

It is likely that there could be some co-benefits from human sources scenarios as well, including other pollutants. At this time, other pollutants that could also be addressed by actions under the human sources scenarios have not been identified nor aligned with existing TMDLs to demonstrate specific objectives and value to their control. It is likely though that other water quality benefits would exist. Depending on how transient population sources are addressed, there could be substantial human welfare benefits if quality of life or public safety improves for transient and neighboring communities. The net effect on transients cannot be estimated at current levels of definition and understanding of transient effects at this time.

Table 57. Total Co-Benefit Values Across Counties, By Stormwater Scenario, 65 Years (3% Discount Rate)

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County Total	**$412,000,000**	**$376,000,000**	**$2,260,000**	**$22,500,000**	**$153,000,000**	**$277,000,000**	**$320,000,000**
Air Quality	$24,000,000	$21,600,000	$0.000	$0.000	$5,850,000	$12,400,000	$19,100,000
Carbon Sequest.	$6,910,000	$6,220,000	$0.000	$0.000	$1,690,000	$3,520,000	$6,170,000
Nitrogen and Phosph.	$149,000,000	$139,000,000	$2,260,000	$22,400,000	$83,500,000	$102,000,000	$115,000,000
Property Value	$232,000,000	$209,000,000	$0.000	$0.000	$61,700,000	$159,000,000	$180,000,000
Riparian Habitat	$0	$0	$0	$0	$0	$0	$0
Sediment	$197,000	$184,000	$3,800	$30,479	$99,000	$60,089	$142,000
Water Use/Supply	$0	$0	$0	$0	$0	$0	$0
Wildfire Risk	$0	$0	$0	$0	$0	$0	$0
Orange County Total	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Air Quality	$0	$0	$0	$0	$0	$0	$0
Carbon Sequest.	$0	$0	$0	$0	$0	$0	$0
Nitrogen and Phosph.	$0	$0	$0	$0	$0	$0	$0
Property Value	$0	$0	$0	$0	$0	$0	$0
Riparian Habitat	$0	$0	$0	$0	$0	$0	$0
Sediment	$0	$0	$0	$0	$0	$0	$0
Water Use/Supply	$0	$0	$0	$0	$0	$0	$0
Wildfire Risk	$0	$0	$0	$0	$0	$0	$0
Grand Total	**$412,000,000**	**$376,000,000**	**$2,260,000**	**$22,500,000**	**$153,000,000**	**$277,000,000**	**$320,000,000**

Table 58. Total Co-Benefit Values Across Counties, By Stream Scenario, 65 Years (3% Discount Rate)

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County Total	**$162,000,000**	**$486,000,000**	**$680,000,000**	**$440,000,000**
Air Quality	$0	$0	$0	$0
Carbon Sequest.	$0	$0	$0	$0
Nitrogen and Phosph.	$27,600,000	$51,800,000	$74,500,000	$55,000,000
Property Value	$0	$0	$0	$0
Riparian Habitat	$103,000,000	$402,000,000	$573,000,000	$352,000,000
Sediment	$3,320	$74,000	$122,000	$46,300
Water Use/Supply	$10,700,000	$12,500,000	$12,600,000	$11,800,000
Wildfire Risk	$20,500,000	$19,900,000	$19,000,000	$21,100,000
Orange County Total	**$50,800,000**	**$157,000,000**	**$176,000,000**	**$176,000,000**
Air Quality	$0	$0	$0	$0
Carbon Sequest.	$0	$0	$0	$0
Nitrogen and Phosph.	$0	$0	$0	$0
Property Value	$0	$0	$0	$0
Riparian Habitat	$50,800,000	$157,000,000	$176,000,000	$176,000,000
Sediment	$12,300	$224,000	$236,000	$260,000
Water Use/Supply	$0	$0	$0	$0
Wildfire Risk	$0	$0	$0	$0
Grand Total	**$213,000,000**	**$643,000,000**	**$856,000,000**	**$616,000,000**

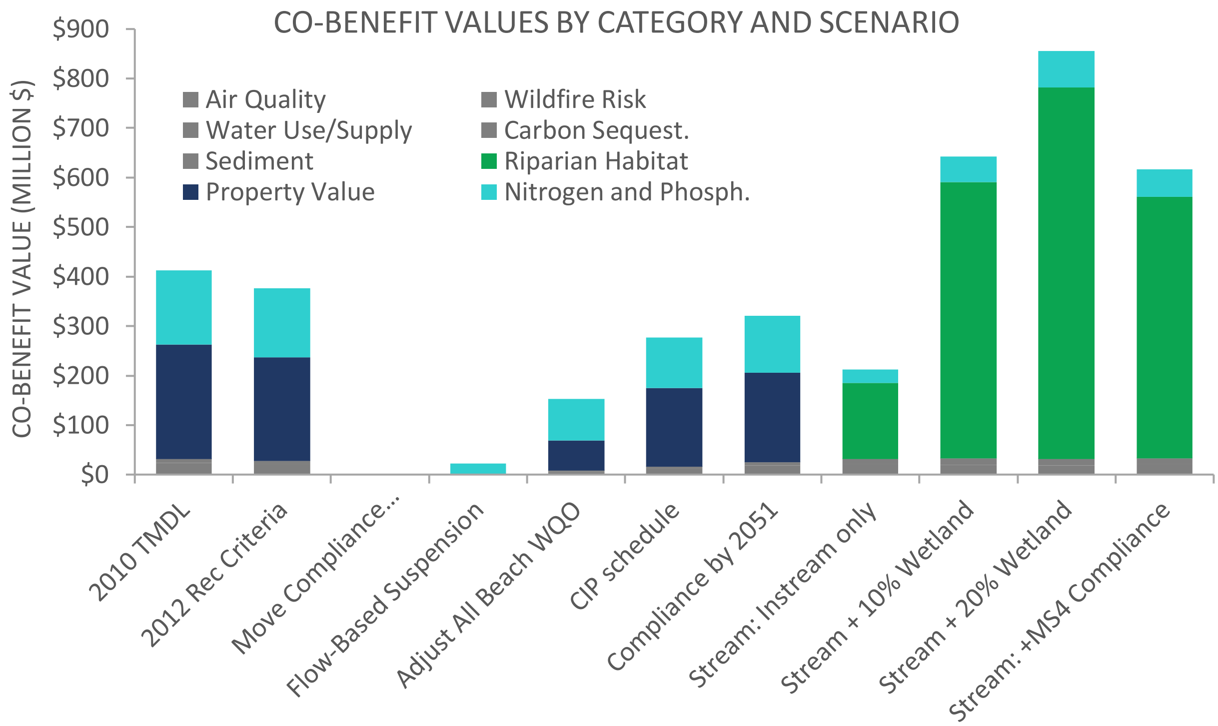

Figure 24: Total co-benefits discounted over 65 years are greatest for stream restoration scenarios due to high values for providing habitat. Stormwater scenario benefits are most attributable to amenities estimated by increasing property value, and avoided costs for other co-pollutant control.

Non-Monetary Co-Benefit Measures

The co-benefit valuation estimates rely upon measurement of non-water quality pathways that stormwater projects can provide additional benefits. In some cases these sources of co-benefits can be quantified in non-monetary units. Trees are an important source of co-benefits, contributing to air quality, carbon sequestration, and improved property values (Table 59). Of importance to note is that the number of trees provided by the 2010 TMDL scenario and its two variations of delayed implementation provide the same number of trees and homes benefiting from amenities, but for different overall timeframes, with the 2010 TMDL scenario providing these benefits the soonest and at full capacity for the longest over the 65-year timeframe. Of importance to note is that these analyses assume no structural green stormwater infrastructure such as trees, bioretention, or green streets under stormwater scenarios for Orange County watersheds due to the sufficiency of programmatic approaches in those watersheds.

Habitat generated is the primary source of co-benefits from stream restoration scenarios (Table 59). The Instream +20% Wetland Scenario provides the most total habitat, and consequently the most total co-benefits for stream restoration scenarios.

Table 59. Total Non-Monetary Co-Benefit Units, By Stormwater Scenario

REGION	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County							
Air Quality	6,580-18,900 trees	5,920-17,000 trees	--	--	1,600-4,6109 trees	6,580-18,900 trees	6,580-18,900 trees
Carbon Sequest.	6,580-18,900 trees	5,920-17,000 trees	--	--	1,600-4,610 trees	6,580-18,900 trees	6,580-18,900 trees
Nitrogen	2,370,000 lbs	2,280,000 lbs	37,300 lbs	368,000 lbs	1,360,000 lbs	1,760,000 lbs	1,960,000 lbs
Phosphorus	454,000 lbs	438,000 lbs	6,960 lbs	70,200 lbs	264,000 lbs	336,000 lbs	375,000 lbs
Property Value	24,000 properties	21,000 properties	--	--	5,940 properties	24,000 properties	24,400 properties
Riparian Habitat	--	--	--	--	--	--	--
Sediment	35,400 tons	83,600 tons	1,730 tons	13,900 tons	45,200 tons	14,000 tons	29,000 tons
Water Use/Supply	--	--	--	--	--	--	--
Wildfire Risk	--	--	--	--	--	--	--
Orange County							
Air Quality	--	--	--	--	--	--	--
Carbon Sequest.	--	--	--	--	--	--	--
Nitrogen	--	--	--	--	--	--	--
Phosphorus							
Property Value	--	--	--	--	--	--	--
Riparian Habitat	--	--	--	--	--	--	--
Sediment	--	--	--	--	--	--	--
Water Use/Supply	--	--	--	--	--	--	--
Wildfire Risk	--	--	--	--	--	--	--

Table 60. Total Non-Monetary Co-Benefit Units, By Stream Scenario

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County				
Air Quality	--	--	--	--
Carbon Sequest.	--	--	--	--
Nitrogen	--	--	--	--
Phosphorus				
Property Value	--	--	--	--
Riparian Habitat	407 acres	1,830 acres	2,760 acres	1,580 acres
Sediment	--	--	--	--
Water Use/Supply	270,000 acre feet	335,000 acre feet	353,000 acre feet	322,000 acre feet
Wildfire Risk	--	--	--	--
Orange County				
Air Quality	--	--	--	--
Carbon Sequest.	--	--	--	--
Nitrogen	--	--	--	--
Phosphorus				
Property Value	--	--	--	--
Riparian Habitat	183 acres	618 acres	713 acres	713 acres
Sediment	--	--	--	--
Water Use/Supply	--	--	--	--
Wildfire Risk	--	--	--	--

TOTAL QUANTIFIED BENEFITS

For stormwater scenarios, co-benefits are the most substantial source of benefit in San Diego County watersheds, followed by health benefits using the upper end health benefit values (Table 61). There are no monetized co-benefits from stormwater scenarios for Orange County. The monetized benefits are highest for the 2010 TMDL scenario at nearly $500 million over 65 years, discounted.

Table 61. Total Quantified Benefits (Health, Recreation and Co-Benefits) in $ Millions, by Stormwater Scenario (3% Discount)

COUNTY	2010 TMDL	2012 REC CRITERIA	MOVE COMPLIANCE LOCATIONS	FLOW-BASED SUSPENSIONS	ADJUST ALL BEACH WQO	CIP SCHEDULE	COMPLIANCE BY 2051
San Diego County	$495	$455	$3.00	$30.0	$181	$331	$383
Health	$65.0	$59.0	$1.00	$6.00	$19.0	$42.0	$49.0
Recreation	$23.0	$20.0	$0.000	$2.00	$9.00	$15.0	$17.0
Co-Benefits	$408	$376	$2.00	$22.0	$153	$274	$317
Orange County	$3.00	$2.00	$0.000	$0.000	$1.00	$2.00	$2.00
Health	$2.00	$2.00	$0.000	$0.000	$0.000	$1.00	$2.00
Recreation	$1.00	$1.00	$0.000	$0.000	$0.000	$0.000	$0.000
Co-Benefits	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000	$0.000
Grand Total	$498	$458.0	$3.00	$30.0	$181	$333	$385

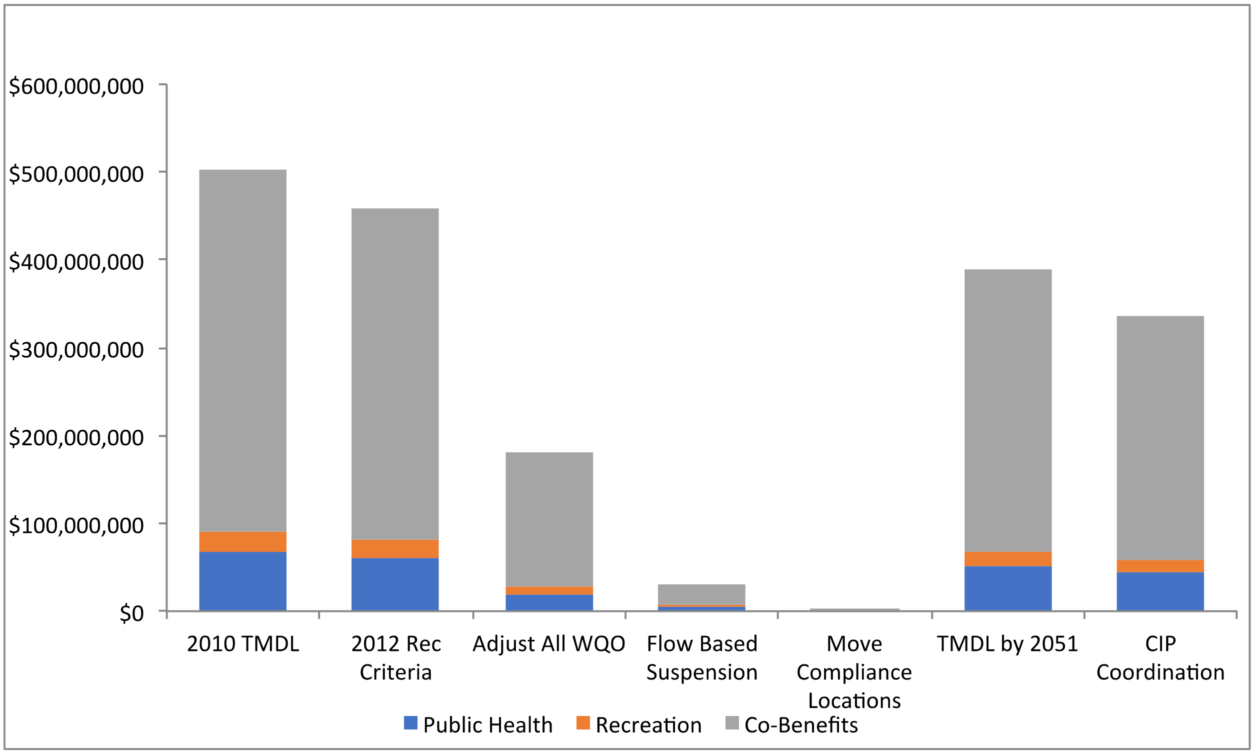

Figure 25: Total benefits for stormwater scenarios discounted over the 65-year timeframe are greatest for the 2010 TMDL scenario, reaching roughly half a billion dollars. Across all stormwater scenarios, co-benefit values are greater than the sum of public health and recreation benefits.

For stream restoration scenarios, co-benefits dominate for both San Diego County and Orange County. In total, the Instream + 20% Wetland Scenario has the highest total monetized benefit value over 65 years at over $900 million (discounted).

Table 62. Total Quantified Benefits (Health, Recreation and Co-Benefits) in $ Millions, By Stream Scenarios

REGION	STREAM: INSTREAM ONLY	STREAM: + 10% WETLAND	STREAM: + 20% WETLAND	STREAM: +MS4
San Diego County	$163	$504	$712	$468
Health	$1.00	$12.0	$22.0	$17.0
Recreation	$0.000	$6.0	$11.0	$11.0
Co-Benefits	$162	$486	$680	$440
Orange County	$54.0	$173	$194	$194
Health	$1.00	$10.0	$11.0	$11.0
Recreation	$2.00	$6.00	$7.0	$7.00
Co-Benefits	$51.0	$157	$176	$176
Grand Total	$217	$677	$906	$662

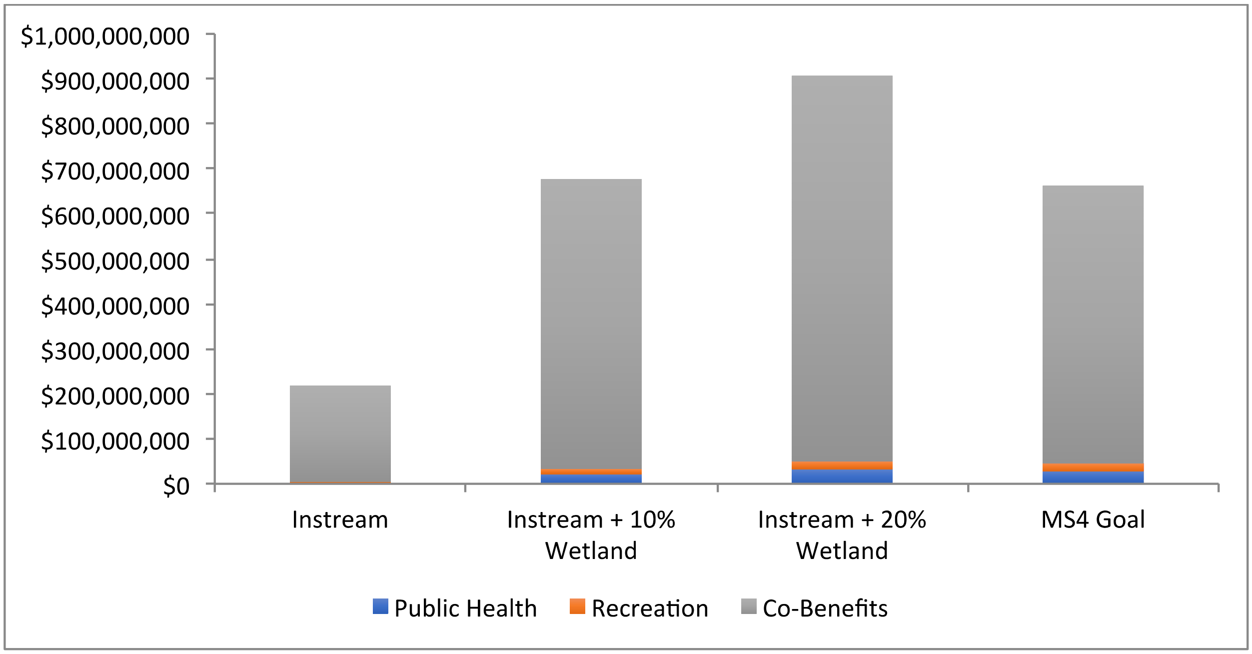

Figure 26: Total benefits for stream restoration scenarios discounted over the 65-year timeframe are greatest for the Stream: + 20% Wetland scenario, reaching nearly a billion dollars. This is attributable to the high potential value of co-benefits, due to habitat creation. Across all stream restoration scenarios, co-benefit values are greater than the sum of public health and recreation benefits.

Among the three human sources scenarios, there are no quantified co-benefits, and recreation and health benefits are quite close in value using the high end of health benefits. The High + Medium + Low Scenario has the greatest total benefit values at $340 million. The sum of health and recreation benefits among human sources scenarios are greater than for stormwater or stream restoration scenarios, but the addition of co-benefits dramatically increase the total benefits to greater than human sources scenario totals.

Table 63. Total Quantified Benefits (Health and Recreation) in $ Millions, By Human Sources Scenarios

REGION	HIGH	HIGH + MED	HIGH + MED + LOW
San Diego County	$226	$247	$264
Health	$105	$125	$134
Recreation	$121	$122	$129
Orange County	$61.0	$67.0	$76.0
Health	$29.0	$35.0	$39.0
Recreation	$33.0	$33.0	$37.0
Grand Total	$288	$314	$340

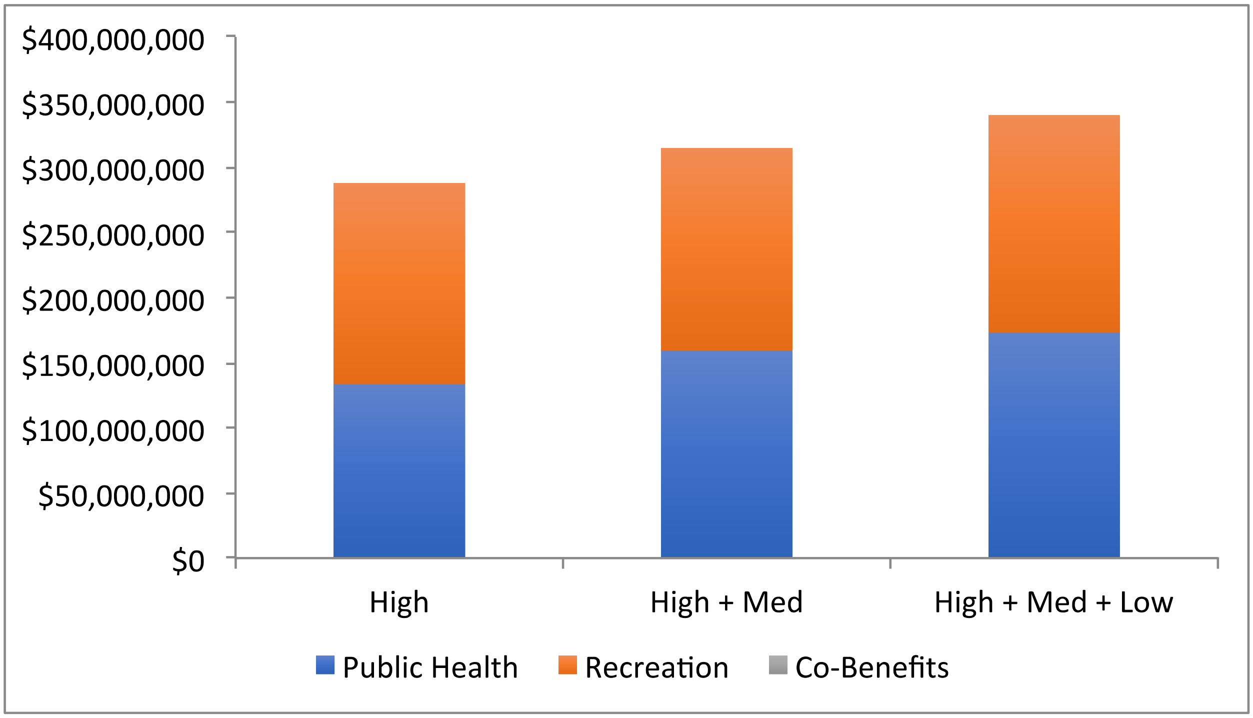

Figure 26: Human sources scenarios total benefits discounted over the 65-year timeframe range between $250 and $350 million. There are no co-benefits valued for the human sources scenarios. These public health and recreation benefits are an order of magnitude greater than the same benefits for the stormwater and stream restoration scenarios.

BENEFITS DISCUSSION

CLIMATE CHANGE CONSIDERATIONS

Climate change research suggests that storm intensities in southern California are likely to increase, but total precipitation is expected to stay the same. This would suggest fewer total storm days.[71] Furthermore, while inland temperatures are likely to rise, coastal temperatures are not expected to increase as much[72]. This suggests a lack of evidence to suggest widespread changes in total beach attendance rates. However, there is a recognition that there is greater uncertainty and less predictability for precipitation patterns as a result of climate change. Regional climate experts expect greater inter-annual variability in precipitation, suggesting there might be more storms in high storm years than currently, and fewer storms in low storm years than currently.

So while the number of storms and potential benefits of reduced pathogen levels might increase in some years due to climate change, currently the expectation is that on average there is a balancing reduction in storms for other years. This suggests no specific change in storm patterns that would affect results of these

[71] Berg, N., Hall, A., Sun, F., Capps, S., Walton, D., Langenbrunner, B. and Neelin, D., 2015. Twenty-first-century precipitation changes over the Los Angeles region. *Journal of Climate*, *28*(2), pp.401-421; Schwartz M, A Hall, and F Sun, 2015: Mean surface runoff insensitive to warming in a key Mediterranean-type climate: a case study of the Los Angeles region. Journal of Climate, in review.

[72] Sun, F., D. Walton, and A. Hall, 2015: A Hybrid Dynamical–Statistical Downscaling Technique. Part II: End-of-Century Warming Projections Predict a New Climate State in the Los Angeles Region. Journal of Climate, 28, 4618–4636.

benefit analyses as currently constructed. Fewer large storms would suggest higher flows, which tend to correlate with higher pollutant concentrations, and while a larger share of all wet days might be unsafe, the total number of unsafe days annually might be less or the same. Furthermore, with fewer wet days, the number of opportunities for BMPs to make water safe to enter declines, suggesting potentially lower benefits based on these calculations. If temperatures do increase along the coast, this could increase total demand and corresponding benefits associated with beach usage (public health and recreation). But in total future climate conditions are uncertain and cannot be readily incorporated into these analyses. Therefore, climate change should be considered a force that could increase or decrease the value of any scenario investments in this study.

One limitation of these analyses is that the illness rates are not calculated separately for each storm based on storm severity, but rather are based on an average of each wet day category (storm, storm +1, etc.). In general, the more intense the storm, the higher the illness rate. If a storm is more intense, the number of illnesses per exposures would likely increase. Thus, even if there are fewer storms, if they are more intense, the resulting number of illnesses might go up, go down, or stay the same.

Sea level rise would also potentially change the quality and accessibility of some beaches. This could increase the overall scarcity of beach opportunities and the importance and value of beach recreation opportunities on the margin. It could also affect the distribution across communities of impacts, if beach recreation opportunities decline more in some areas than others. It might also decrease beach recreation participation during and immediately after storms due to storm swells if beach size or safety is reduced.[73]

Collectively these ambiguities and uncertainties revealed by current climate change science for the region suggest that the timing, frequency, and magnitude of storm events that can lead to illnesses and lost beach trips are likely to vary more than previously and otherwise. The application of any change though consistently across all scenarios dampens the potential effect on benefit calculations, as benefits are based on differences between scenarios and the effects of climate change would have the same directly effects on all scenarios.

FRESHWATER RECREATION, SUBSISTENCE AND EXPOSURE

The Bacteria TMDL and CBA are focused on marine and freshwater. Thus, it is reasonable to consider benefits and effects of populations that engage with freshwater to consider if there are quantifiable benefits. It is particularly important to consider freshwater due to the higher concentrations of bacteria and pathogen in those waterbodies due to the fact that these waterbodies do not experience the substantial dilution that occurs in marine waters examined elsewhere in the CBA.

In order to calculate benefits for recreation on the rivers and streams in the Bacteria TMDL watersheds of the wet weather water quality improvements that would be generated by scenarios in this analysis, a number of conditions and data would be necessary. There would need to be measures of recreation or similar activity on or along the rivers and creeks during wet weather, and there would need to be evidence that this activity is responsive to changes in water quality that would occur under these water quality improvement scenarios. Through extensive investigations and queries across all identifiable user groups, there was no evidence for measurable levels of recreation activity on the rivers and creeks that could see participation levels increase during wet weather events due to water quality improvements. Similarly, there was no evidence for measurable levels of recreation activity that involve swimming levels of exposure during wet weather events and the associated higher flows on the rivers and creeks.

[73] Barnard, P.L., O'Reilly, Bill, van Ormondt, Maarten, Elias, Edwin, Ruggiero, Peter, Erikson, L.H., Hapke, Cheryl, Collins, B.D., Guza, R.T., Adams, P.N., and Thomas, J.T., 2009, The framework of a coastal hazards model; a tool for predicting the impact of severe storms: U.S. Geological Survey Open-File Report 2009-1073, 21 p.

Residents of and visitors to the San Diego region have minimal access to fresh bodies of water in which swimming is feasible and legal. According to a report produced for the San Diego Regional Water Quality Board, the law prohibits swimming in the area's lakes. In some of the reservoirs, such as El Capitan and San Vicente, the law does permit waterskiing, wakeboarding, and similar activities in which full body immersion occurs infrequently and for a limited duration. However, no designated swimming beaches exist.

Swimming does take place in some of the creeks in the watershed. However, no creek or stream has a formally designated swimming area. Per the report, most creek and stream swims happen at sites located in the upper watershed, above the reservoirs. The most popular swimming spot – Cedar Creek Falls – is just north of Four Corners and entirely within the Capitan Grande Reservation.[74] No data were identified to estimate where or how much of this swimming happens during wet weather events.

Some of the waterways such as the San Diego River, can support paddlesports such as canoeing, kayaking, and paddleboarding. Most of this activity involves little direct exposure, much less than swimming. The exception would be more whitewater-oriented paddling during higher storm flows, but there is no evidence of substantial participation in this type of activity on the affected waterways. American Whitewater, a whitewater boating advocacy organizations and provider of a national database on rivers does list Los Peñasquitos Creek, but describes the run as not likely worth paddling more than once[75]. Other stretches are also likely navigable during high flows, but there is no evidence for high or consistent usage or interest.

Several stretches of rivers and creeks under the Bacteria TMDL do have adjacent trails that see considerable recreation, exercise, and travel/commute usage. While clarity and smell can affect demand and value from this recreational usage, it does not tend to involve direct contact, or avoidance due to bacteria alone. Co-benefits though could exist to the extent that pathogen controls under the scenarios would also reduce sediment and nutrients, contributing to improved water clarity. There is no evidence though to support scenario-specific estimates of changes in recreation that would be affected by the amount and duration of effects of these scenarios on water aesthetics.

There is some fishing activity on these waterways, including the San Diego River. After considerable data and literature review, and numerous queries to regional experts, no basis could be found for estimating effects on the quality or safety of fishing resulting from reduced bacteria levels. Fishing can involve substantial water exposure, but fishing conditions are typically at their worst during storm events.

A related issue would be that if encouraging more recreation that involves direct exposure or entry to waterways during storms, safety issues could arise, such as increased drowning risk for people inexperienced with high flow, turbulent, or flooding conditions on rivers and streams.

Collectively, these issues suggest little evidence to support estimation of monetary values specific to the control scenarios. There are likely unquantified benefits though for people who appreciate and visit the waterways of County of San Diego and Orange County, and would experience benefits from observing or knowing that the water is cleaner during storms.

Transient Health and Subsistence

Transient populations likely have exposure to water in some of the Bacteria TMDL watersheds, particularly where transient camps exist as along the San Diego River. For the 2016 WeAllCount assessment of the total

[74] Bernstein, Brock B. "San Diego River Watershed Monitoring and Assessment Program." Waterboards.ca.gov. January 2014. Accessed December 13, 2016.

[75] American Whitewater. 2017. National Whitewater Inventory. https://www.americanwhitewater.org/content/River/view/

number of transients in County of San Diego estimated 8,692 people, with 295 sleeping in the woods or outdoor encampment[76]. The San Diego River Park Foundation closely monitors transient encampments along the San Diego River, with a general long-term estimate of approximately 300 residing in that vicinity. There are likely transient camps in other watersheds though, or could be in the future.

The transient population living along the San Diego River do likely use the river. It wouldn't be appropriate to suggest encouraging this population to make greater use of the river, given their potentially substantial contribution to the bacteria load. But if this population does experience exposure to the water during wet weather events, this undiluted pollutant load does likely generate high rates of illness among those exposed. This would hold for any other near-stream transient populations as well.

The results of the Surfer Health Study and associated QMRA modeling are not calibrated to the freshwater, high bacteria concentrations that would be found in the river near the transient camps during wet weather events. But using the SHS Enterococcus concentration-illness ratio extended to the undiluted water conditions, the baseline illness rate ranges from 167 illnesses per 1000 exposures on storm days down to 106 on Storm +3, while the 2010 TMDL scenario has equivalent values of 149 to 94. Assuming fully half of the transient population along the San Diego River is exposed to the water every wet day (150 exposures per wet day) and given the number of wet days annually, the 2010 TMDL scenario would reduce transient illnesses by 107 annually.

COST-EFFECTIVENESS

Results of the benefit and cost analyses can be compared to provide estimates on the cost-effectiveness of scenarios. Cost-effectiveness, which compares cost per benefit unit of scenarios, is helpful for determining activities that could provide the greatest benefit per expenditure over the 65-year analysis period. Since TMDL strategies prioritize improvements in public-health (i.e., avoided illnesses) and reductions in forgone beach days due to unsafe water conditions, these benefit categories are evaluated. Additionally, uncertainty analysis informs error bars that highlight potential ranges in cost-effectiveness findings.

Data Sources

The cost effectiveness analysis uses the cost values provided in technical memos for Stormwater, Human Sources, and Stream scenarios. It also uses illness rates and additional beach trips calculated in the benefits analysis.

Methods

In general, the analysis follows the same steps to calculate cost-effectiveness of both avoided illnesses and additional beach trips. Benefit units are expressed per million dollars.

To calculate avoided infectious illnesses per one million dollars invested, the analysis separately divides avoided infectious illnesses (AI) and additional beach trip (ABT) values by total cost (TC)

$$Avoided\ Infectious\ Illness\ Per\ \$Million = \left(\frac{AI}{TC}\right)$$

$$Additional\ Beach\ Trips\ Per\ \$Million = \left(\frac{ABT}{TC}\right)$$

Results

For both public health and recreation, the Human Sources: High scenario is many times more cost-effective than other scenarios (Table 42). Human Sources scenarios evaluate the reduced loads from installing sewer

[76] County of San Diego Regional Task Force on the Homeless. 2016. WeALLCount Point-in-Time Count. County of San Diego. http://www.rtfhsd.org/wp/wp-content/uploads/2016/06/Comprehensive-Report-2016-final.pdf

pipes, repairing leaking septic tanks and assisting transient populations. Thus, they are efficient at removing human Norovirus and other pathogens that are high risk for swimmers. Conversely, the 2010 TMDL scenario does not focus on human sources but rather removes fecal indicator bacteria from a variety of sources including animals. As a result, it removes Bacteria TMDL pollutants from broader sources that may not pose as immediate threats to human health.

The CIP Schedule scenario is also relatively cost-effective because it coordinates BMP installation with other planning and construction activities to reduce costs and improve efficiency. The Compliance by 2051 scenario, which extends the Bacteria TMDL compliance deadline, also provides greater cost-effectiveness from reducing annual costs and achieving compliance over a longer period of time. Stream scenarios rely on limited availability of public lands to reduce bacteria loads and have high costs for restoration projects, reducing their cost-effectiveness compared to other scenarios.

Results are adjusted with error values, which are explained further in the *Uncertainties in Benefit Quantification* section below.

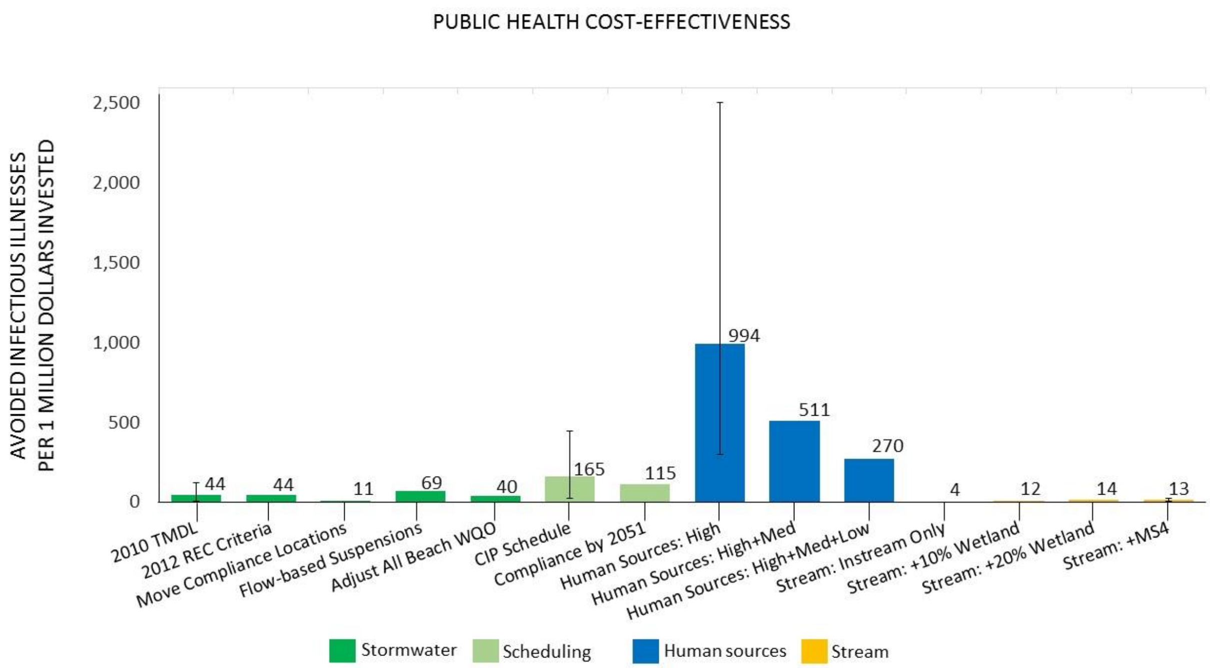

Figure 27: A chart showing number of illnesses avoided throughout the 65-year analysis period per million dollars invested. Human Sources scenarios (blue bars) provide many times greater cost-effectiveness compared to other scenarios. Whiskers indicate the ranges of uncertainty calculated using appropriate methods for each scenario; creating statistical high and low bracket values based on the important drivers of uncertainty in each scenario’s benefits and costs.

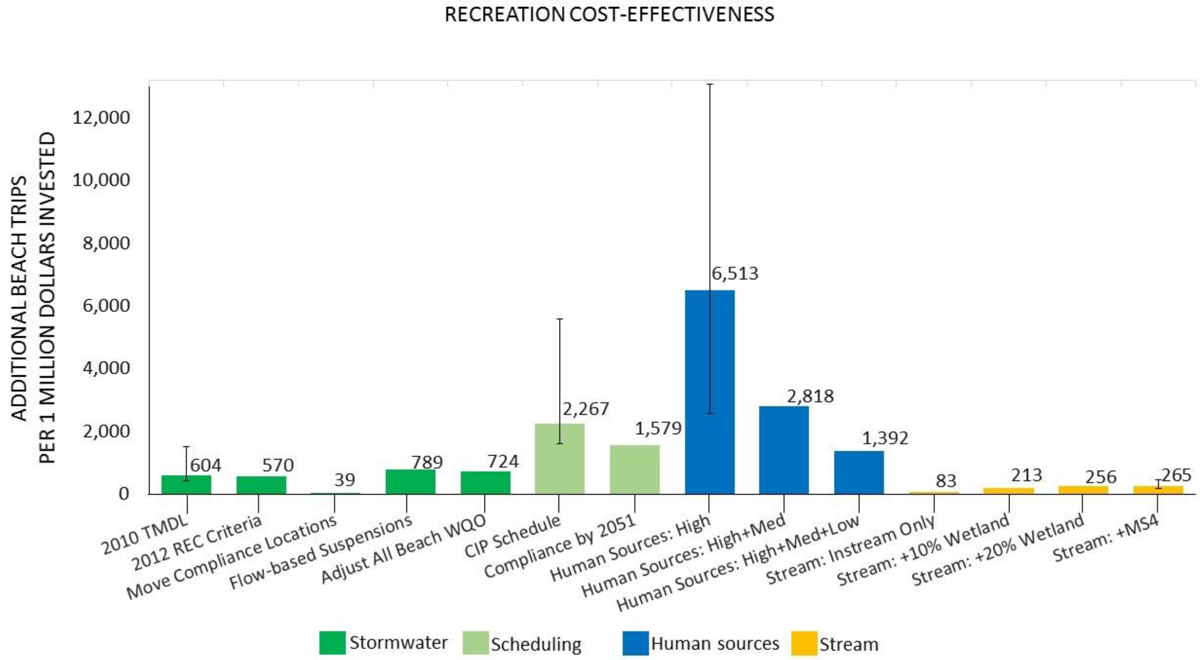

Figure 28: A chart showing number of additional beach trips throughout the 65-year analysis period per million dollars invested. Human Sources scenarios (blue bars) provide many times greater cost-effectiveness compared to Stormwater scenarios (green bars). Whiskers indicate the ranges of uncertainty calculated using appropriate methods for each scenario; creating statistical high and low bracket values based on the important drivers of uncertainty in each scenario's benefits and costs.

Table 64. Cost-Effectiveness 65-Year Totals

SCENARIO	AVOIDED INFECTIOUS ILLNESSES PER $1 MILLION DOLLARS INVESTED	ADDITIONAL BEACH TRIPS PER $1 MILLION DOLLARS INVESTED
2010 TMDL	44.10	604
2012 REC Criteria	43.8	570
Move Compliance Locations	11.2	39.3
Flow-based Suspensions	69.2	789
Adjust All-Beach WQO	40.4	724
CIP Schedule	165	2,270
Compliance by 2051	115	1,580
Human Sources: High	994	6,510
Human Sources: High+Med	511	2,820
Human Sources: High+Med+Low	270	1,400
Stream: Instream Only	3.59	82.6
Stream: +10% Wetland	12.2	213
Stream: +20% Wetland	14.4	256
Stream: +MS4	12.80	267

UNCERTAINTIES IN BENEFIT QUANTIFICATION

The recreation and health benefit calculations rely upon numerous data sources, models, and calculations that vary by scenario and watershed. Consequently, uncertainties in the data and methods arise from the varied level of accuracy of the data by scenario and watershed. In general, though, assumptions or data limitations that affect all scenarios equally should have less effect on the results, particularly in a screening context comparing between scenarios, than assumptions that affect individual scenarios differently. Relatedly, given that benefits are calculated as marginal or incremental to the baseline, parameters that are applied after this marginal analysis, namely the value of trips and the value of avoided illness, are of increased importance to the final benefit quantities. Uncertainty values are important for establishing high- and low cost-effectiveness values.

Dilution Factors

Dilution factors are one area of uncertainty, as consistent monitoring data do not exist for wet days to translate instream water quality concentrations to locations where exposures occur in the ocean at beaches. The dilution calculations are most appropriately considered on average across all watersheds and beaches. But for example, if the dilution factor for one watershed (translation of instream *Enterococcus* concentrations to beach/marine concentrations) is say 20% too high, the fact that it is applied consistently across scenarios lessens the impact on final results, because the baseline and scenarios are all shifted in the same direction. However, after calculating the number of fewer illnesses for a scenario in comparison to the baseline for that watershed, the value of the illness is then applied *ex post* and its full magnitude reflected in the benefit value for scenarios. The health benefit calculations are more sensitive to changes in the monetary value per illness, than in factors applied prior to the marginal analysis such as the dilution factor or the number of exposures.

The use of a lower dilution factor than those applied in this recreation analysis increases the share of wet days in exceedance and unsafe for swimming under baseline conditions. Of the six County of San Diego watersheds with historical exceedance data, all have high enough of exceedance rates to suggest lower dilution factors and more total unsafe wet days than based on the approach applied in this analysis, calibrating to 22% exceedance rate under the 2010 TMDL scenario. For the 2010 TMDL scenario, recalibrating these 6 watersheds increases the 65-year recreation value by about $2.8 million, but the direction of change is not consistent. Scripps goes down by $2.3 million while San Luis Rey goes up by nearly $4 million. Collectively this uncertainty on dilution factors can have real implications for illness and safe swimming conditions, but given the application of any one dilution factor to all scenarios for a watershed, and the emphasis on marginal changes between watersheds, there is not a clear answer as to the effect on the benefit calculations of a change in specific uniform directional change in dilution rates. It does appear to be an important area of uncertainty.

Public Health Uncertainty Analysis

The public health uncertainty analysis accounts for uncertainty in illness rates and water quality effects by developing high and low “bracket” values that are above and below the “best” value calculated in the main CBA analysis. It adjusts the water quality input data for the 2010 TMDL, Stream: +MS4, and Human Sources: High scenarios for a representative subset of watersheds. While specific methods vary for each scenario, resulting illness rates are used to calculate avoided illness benefits by extrapolating the percent change between baseline and scenario conditions for the subset of watersheds to all watersheds for each scenario.

The Stormwater public health uncertainty analysis includes San Diego River, Scripps and San Juan. For these watersheds, daily concentrations are sorted individually by the day of, and following three days after, storm events based on a 25-year data set. Using concentration data, risk values of predicted illnesses/1000 exposures are calculated for low, best and high values for both baseline and 2010 TMDL scenarios, with low and high values at the respective 5th and 95th percentile confidence levels. To account for uncertainty in the QMRA and other models such as LSPC, the low and high 2010 TMDL scenario values are subtracted from the best baseline value. By comparing the extremes in the scenario to the baseline average the uncertainty analysis demonstrates conditions that could occur compared to those that are occurring. Since the uncertainty analysis compares extreme scenario values to best baseline values, some risk values can exceed baseline risk values. The analysis assumes that scenario risk values equal baseline risk values in these cases, as policy makers in practice would be unlikely to take actions that lead to greater illness risks. Resulting values are applied to the benefits analysis, which finds total illnesses over the 65-year project period.

For the sum of the three watersheds under the 2010 TMDL scenario uncertainty analysis, the low counts are a 78.9% percent decrease in the number of avoided illnesses over 65 years, and the high counts are a 87.3% percent increase in the number of avoided illnesses.

Table 65. Public Health Uncertainty Analyses, Stormwater, Avoided GI Illnesses, 65 Year Totals

WATERSHED	2010 TMDL LOW	2010 TMDL BEST	2010 TMDL HIGH
San Diego River	6,720	8,870	11,400
Scripps	0	22,900	47,400
San Juan	0	66	680

Stream scenarios focus on the San Diego River, Los Peñasquitos and San Juan watersheds for the Stream: + MS4 scenario and the analysis evaluates ranges of load reduction efficiencies for engineered wetlands based on a literature review. Low brackets equal 40% load reduction efficiency, best values equal 50% and high brackets equal 70%. The bracket values are analyzed in the same way as baseline conditions, with the differences among low, best and high values evaluated to find total illness numbers. For the Stream: +MS4 Scenario, the low counts are a 7.4% decrease in the number of avoided illnesses, and the high counts are a 15.4% increase.

Table 66. Public Health Uncertainty Analyses, Stream, Avoided GI Illnesses, 65 Year Totals

WATERSHED	STREAM: +MS4 LOW	STREAM: +MS4 BEST	STREAM: +MS4 HIGH
San Diego River	10,900	11,800	13,500
Scripps	--	--	--
Los Peñasquitos	4,600	5,080	6,070
San Juan	1,460	1,540	1,710

Finally, the Human Sources public health uncertainty analysis involves the Human Sources: High scenario for San Diego River, Scripps and San Juan. Load reduction values are calculated three times for the 5th percentile (low bracket), best value and 95th percentile (high bracket). Results are calibrated with HF183 loading values and normalized according to the QMRA percent reductions for human components. Resulting values are the basis of total illness calculations. The highest reduction in illnesses effectively eliminates all illnesses at full implementation. The low counts are a 39.9% reduction from the best value, and the high counts are a 26% increase relative to the best values.

Table 67. Public Health Uncertainty Analyses, Human Sources, Avoided GI Illnesses, 65 Year Totals

WATERSHED	HUMAN SOURCES: HIGH (LOW)	HUMAN SOURCES: HIGH (BEST)	HUMAN SOURCES: HIGH (HIGH)
San Diego River	30,000	48,600	56,400
Scripps	266,000	443,000	561,000
San Juan	5,140	9,200	13,700

Recreation Uncertainty Analyses

A similar set of uncertainty analyses were conducted for recreation benefits, with the same three scenarios and representative watersheds analyzed for high and low bracket values around the best value calculated in the main CBA.

For Stormwater and Stream scenario types, the analysis uses the 2010 TMDL and Stream: +MS4 scenarios in the San Diego River, Scripps and San Juan. For these analyses, fecal coliform concentrations are translated to *Enterococcus* concentrations at beaches. To calculate low brackets, best values and high brackets, the dilution rate in the same subset of watersheds is reduced by 10% (low bracket) and increased by 10% (high bracket). The Stormwater and Stream Restoration uncertainty analyses did not generate new daily water quality data that can be used to calculate changes in safe swimming days for recreation.

In general, decreasing the dilution rate increases *Enterococcus* concentrations at beaches and increases the baseline number of unsafe days. Further, it also increases the opportunities for water quality improvements to increase beach trips. In contrast, increasing the dilution rate decreases dilution concentrations and reduces opportunities for increased beach trips. In some cases, however, changing the dilution rate can cause changes in both baseline and water quality control scenarios so the directional relationship does not hold. At the extreme, with no dilution, even with water quality improvements, most days could stay unsafe. Further, with extremely high dilution, baseline days are all safe so there is no change and potential to increase trips with water quality improvements. Based on the subset of sampled watersheds however, for the 2010 TMDL scenario, the increased dilution lowers the number of trips gained by 0.9%, and decreasing dilution increases the number of trips gained by 71.5%. For the Stream: +MS4 scenario, increasing dilution by 10% decreases trips gained by 5.4%, and decreasing dilution increases trips gained by 4.7%.

Table 68. Recreation Uncertainty Analyses, Stormwater and Stream Restoration, Gained Beach Trips, 65 Year Totals

WATERSHED	2010 TMDL 10% INCREASED DILUTION	2010 TMDL BEST	2010 TMDL 10% DECREASED DILUTION	STREAM: +MS4 10% INCREASED DILUTION	STREAM: +MS4 BEST	STREAM: +MS4 10% DECREASED DILUTION
San Diego River	656,000	654,000	945,000	606,000	616,000	641,000
Scripps	511,000	525,000	1,080,000	--	--	--
Los Peñasquitos	--	--	--	4,860	29,400	32,900
San Juan	4,570	2,430	1,520	35,300	37,800	42,000

For the Human Sources scenario type, recreation benefits are calculated for San Diego River, Los Peñasquitos and San Juan. Daily data used for stormwater scenarios is transformed in proportion to illness reductions. The total regained trips under the Human Sources scenarios are similar to the total number of lost trips because nearly all of the bacteria load is assumed to be removed. The San Diego River watershed under these calculations eliminates all lost trips feasible, while the Scripps watershed eliminates them for both the best value and high bracket. Effectively, all of the load causing unsafe conditions is eliminated for the highest reduction analysis, putting the high bracket value nearly identical to the H+M+L scenario. These calculations generate a 20.6% reduction in regained trip counts for the low bracket value, and a 0.2% increase for the high bracket value.

Table 69. Recreation Uncertainty Analyses, Human Sources, Gained Beach Trips, 65 Year Totals

WATERSHED	HUMAN SOURCES: HIGH (LOW)	HUMAN SOURCES: HIGH (BEST)	HUMAN SOURCES: HIGH (HIGH)
San Diego River	1,180,000	1,180,000	1,180,000
Scripps	3,431,000	4,660,000	4,660,000
San Juan	182,000	191,000	205,000

Cost-Effectiveness Uncertainty Analyses

The cost-effectiveness analysis accommodates uncertainty by calculating cost-effectiveness for the low and high values of each scenario, based on ranges from the cost, public health and recreation uncertainty analyses. It provides high and low brackets for the 2010 TMDL, CIP Schedule, Human Sources: High and Stream: +MS4 scenarios. These high and low brackets are represented as whiskers on the figures in the *Executive Summary* and *Synthesis of Findings*.

For cost values, which provide a basis for both the public health and recreation cost-effectiveness calculations, the uncertainty analysis varies components of total costs, including portions of capital and operations and maintenance values. Each scenario type is calculated to include low, best and high values. For the 2010 TMDL and CIP Schedule scenarios, an uncertainty factor is added to the low, best, and high values to account for additional cost uncertainty arising from the method used to calculate BMP implementation costs in some watersheds. Since all watersheds have not been modeled for their costs, average costs from modeled watersheds are extrapolated to determine costs for BMP implementation. In these watersheds, the costs of BMP implementation are based on average values of other watersheds. Uncertainty factors of 26% (low bracket) and 35% (high bracket), which correspond respectively to the 25th and 75th percentile wage values for Bureau of Labor Statistics Installation, Maintenance, and Repair Occupations category, are applied to the cost values for the Stormwater scenario.[77]

To calculate the low bracket for avoided illnesses per million dollars invested, total low-estimate illness totals are divided by the high total cost.

$$Avoided\ Infectious\ Illness\ Per\ \$Million\ Low = \left(\frac{Total\ Avoided\ Illness\ (low\ bracket)}{Total\ Cost\ (high\ bracket)}\right)$$

The formula accounts for extremes in cost-effectiveness among scenarios. By dividing low illness totals by high costs, the analysis captures situations where the greatest possible cost would achieve the least amount of avoided illnesses.

Similarly, to calculate the high bracket for avoided illnesses per million dollars invested, total high-estimate illness totals are divided by the low total cost.

$$Avoided\ Infectious\ Illness\ Per\ \$Million\ High = \left(\frac{Total\ Avoided\ Illness\ (high\ bracket)}{Total\ Cost\ (low\ bracket)}\right)$$

[77] Bureau of Labor Statistics. 2017. "Occupational Employment and Wages, May 2016 - 49-0000 Installation, Maintenance, and Repair Occupations". Available at https://www.bls.gov/oes/current/oes490000.htm.

Again, by dividing by low costs, the analysis accounts for activities that would avoid the most illnesses for the least amount of money. This represents the most extreme cost-effective actions possible.

Table 70. Cost-Effectiveness Public Health Uncertainty, 65-Year Totals

SCENARIO	AVOIDED INFECTIOUS ILLNESSES PER 1 MILLION DOLLARS INVESTED (LOW)	AVOIDED INFECTIOUS ILLNESSES PER 1 MILLION DOLLARS INVESTED (HIGH)
2010 TMDL	6.58	122
CIP Schedule	25.1	445
Human Sources: High	299	2,500
Stream: +MS4	8.00	23.8

Recreation calculations follow the same approach with

$$Additional\ Beach\ Trips\ Per\ \$Million\ Low = \left(\frac{Additional\ Beach\ Trips\ (low\ bracket)}{Total\ Cost\ (high\ bracket)}\right)$$

$$Additional\ Beach\ Trips\ Per\ \$Million\ High = \left(\frac{Additional\ Beach\ Trips\ (high\ bracket)}{Total\ Cost\ (low\ bracket)}\right)$$

The *Executive Summary* and *Synthesis of Findings* include recreation cost-effectiveness figures.

Table 71. Cost-Effectiveness Recreation Uncertainty 65-Year Totals

SCENARIO	ADDITIONAL BEACH TRIPS PER 1 MILLION DOLLARS INVESTED (LOW)	ADDITIONAL BEACH TRIPS PER 1 MILLION DOLLARS INVESTED (HIGH)
2010 TMDL	424	1,530
CIP Schedule	1,610	5,580
Human Sources: High	2,590	13,100
Stream: +MS4	179	459

SENSITIVITIES IN BENEFIT QUANTIFICATION

Certain sections of the benefit analysis are sensitive to input data, which could lead to different numeric results. Though the numeric results may change, findings and trends are unlikely to be affected.

Discounting

The long-term perspective in this analysis when considering the 65-year timeframe and or longer increases the effect of discounting in calculation of net benefits. But the fact that costs are not front-loaded but rather increase and then maintain over time means that the common scenario of high upfront costs and a long future stream of benefits does not hold here. Applying the declining discounting approach described at the beginning of the *Benefits Analysis* section slightly decreases the present value of benefits during early years, and increases the present value of benefits in later years. The net effect is a slight (~ 2% for the 2010 TMDL scenario) decrease in values summed over the first 20 years, a smaller decrease summed over 50 years (~ 1%) and an increase if summed out through 100 years (~ 6%). None of these ranges are sufficient to affect overall benefit and cost relative magnitudes.

And while a lower or declining discount rate increases the present value of benefits, it has the same effect on costs, muting the effect in terms of net benefits (benefits minus costs). The relatively uncommon condition for long-term projects whereby the costs proportionately match benefits over time means that the relative comparison of costs and benefits is relatively insensitive to the choice of a constant vs. declining discount rate in terms of benefits. The disparity between benefits and costs, and the increasing magnitude of costs, means that the benefits minus cost net over time is more heavily influenced than the benefits alone, because with a greater discount rate for distant years, the lower the magnitude of the net costs of a scenario. This is discussed in more detail in the *Synthesis of Findings*.

5. COST ANALYSIS

Costs for the full 65-year analysis period are essential to fairly calculate the net benefits and cost-effectiveness of each scenario. The cost analysis (1) converts basic costs provided by engineering experts into programmatic, capital and operations and maintenance (O&M) components and (2) annualizes them so they can extend through the analysis period before they are compared to benefits. This more detailed cost information enables a fair comparison of benefits to costs and can be used by decisionmakers to understand the types of costs, potentially affecting preferences for a scenario. The technical memos for water quality inputs in Appendices A—C provide detailed cost data for each scenario.

KEY DEFINITIONS

The following terms are used to describe the cost analysis methodology and results. For each scenario a compliance year, load reduction target and cost to achieve the load reduction target is defined.

- **Load Reduction (LR):** Based on modeling results identified in the Data Sources section, a LR target is identified for each watershed for each scenario.
- **Cost:** For each scenario, the cost of achieving the identified LR through the implementation of BMPs is determined through models and extrapolation identified in the Data Sources section.
- **Compliance Year:** Each scenario will achieve a specified LR by the compliance year. Due to limitations of certain scenarios, the maximum LR achieved may not meet the compliance requirement identified by the Bacteria TMDL.

To determine the cost of each scenario over the 65-year analysis period, and to enable comparison of costs and benefits, capital, programmatic and O&M costs are quantified and reported on an annual basis for each scenario. These cost categories are defined in detail below.

- **Programmatic costs:** Costs associated with establishing and maintaining programmatic BMPs, such as education, outreach, and street sweeping.

SCENARIO TYPE	SOURCE OF PROGRAMMATIC BMP COST	LR ACHIEVED
Stormwater	Modeled and non-modeled nonstructural BMPs	0 - 10.5%
Human Sources	Cost values provided do not differentiate between cost categories	n/a
Stream Restoration	None; stream scenarios are based on the implementation of structural BMPs only	n/a

- **Capital costs:** Costs associated with implementing structural BMPs.
- **Operation and maintenance (O&M) costs:** Costs associated with operating and maintaining structural BMPs to maintain the LR achieved from implementation. There are no O&M costs associated with programmatic BMPs.

SCENARIO TYPE	SOURCE OF STRUCTURAL BMP COST	LR ACHIEVED
Stormwater	Multiuse treatment areas (MUTAs), green infrastructure and green streets BMPs	10.5% -Target
Human Sources	Cost values provided do not differentiate between cost categories	n/a
Stream Restoration	In-stream restoration and off-line wetlands	0% -Target

The total cost of each scenario over the analysis period (2017-2081) is the cost of achieving the required LR (referred to as compliance cost) and the cost of maintaining the required LR (referred to as ongoing cost).

Compliance cost includes annual capital, programmatic, and O&M costs. Ongoing cost includes annual programmatic and O&M costs (Figure 29).

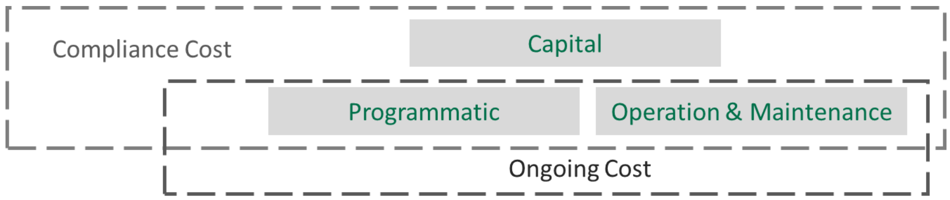

Figure 29. Specific cost categories are combined to calculate compliance costs and ongoing costs.

- **Compliance Cost:** The cost of achieving the required LR in each watershed for a scenario by the compliance deadline. The compliance cost is equal to the sum of the annual programmatic, capital, and O&M costs from the first year of compliance action to the compliance deadline (Figure 30).

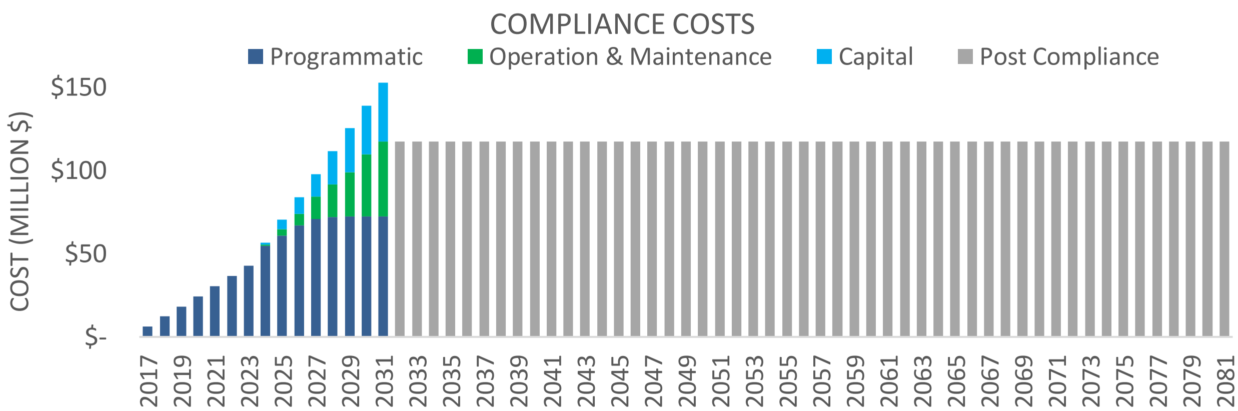

Figure 30. A time series highlighting compliance costs in color. Implementation of BMPs begins in 2017 and continues until the compliance deadline (2031). Implementations of structural BMPs incurs capital costs (light blue bar), and operation of programmatic BMPs incurs programmatic costs (dark blue bar). O&M costs are incurred (green) each year BMPs must be maintained.

- **Ongoing costs:** Annual ongoing costs are equal to the sum of programmatic and O&M costs in the compliance year. These costs are the same each year after the deadline. The total ongoing cost for a scenario is the sum of the annual ongoing cost from the year after the compliance deadline to the year where full benefits are realized (2081) (Figure 31).

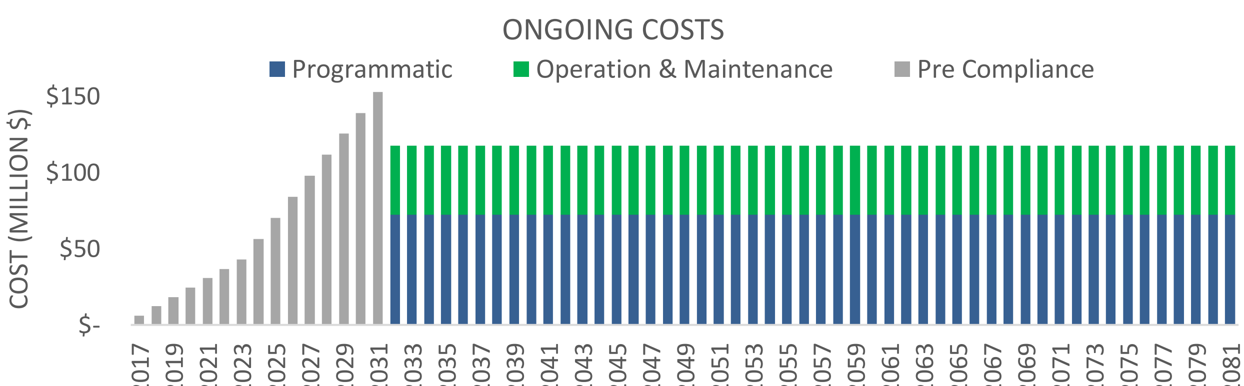

Figure 31: A time series highlighting ongoing costs in color. Programmatic BMPs (dark blue bar) continue to operate after the compliance deadline (2031). O&M costs are incurred (green bars) each year structural BMPs must be maintained.

DATA SOURCES

The information contained within the following data sources (the LR and cost for each watershed by scenario) is used to annualize costs and then calculate the total cost for each scenario over the compliance period.

- **Stormwater scenarios:** Costs and LRs required for compliance for each stormwater scenario in each watershed for both San Diego and Orange Counties.[78]
- **Stream scenarios**: Costs and LRs required for compliance for both San Diego and Orange County watersheds for the stream scenarios.[79]
- **Human Sources scenarios:** Costs and LRs for both San Diego and Orange County watersheds for the human sources scenarios.[80]
- **CIP Scenario:** The USEPA study Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices is used to determine potential project savings from aligning stormwater and CIP projects.[81]
- **CIP Scenario:** The City of San Diego's Watershed Asset Management Plan is used to determine the proportion of project costs which are typically O&M versus capital costs.[82]

METHODS

Annual discounted costs for the human sources scenarios are provided using a 3% discount rate. Costs are not divided into programmatic, O&M and capital cost categories.

Determine annual costs for the Stormwater, Scheduling and Stream scenarios

The total LR and cost are known for each of the stormwater, timing and stream restoration scenarios in each watershed. The following methodology is used to annualize these costs (Figure 32).

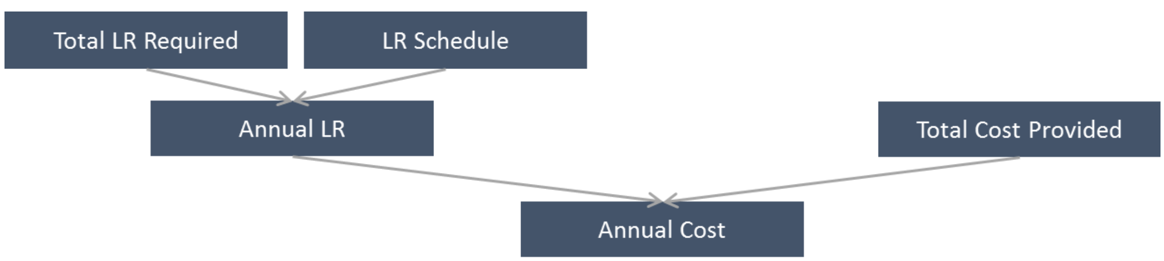

Figure 32: The total LR required for each scenario, cost of achieving this LR, and the LR schedule are all inputs to determining the cost each year for each scenario.

1. The % LR achieved each year is determined by multiplying the total LR by the scheduled LR % according to the LR schedule (see *Assumptions* section).

[78] Boschen, Clint, and Vada Yoon. *Bacteria CBA: Technical Approaches and Work Products to Support the Evaluation of Stormwater Implementation Scenarios and Other Analyses*. N.p.: TetraTech, n.d. Word.
[79] ESA. *Development of the San Diego Bacteria TMDL Cost Benefit Analysis Inputs for Stream and Riparian Habitat Restoration San Diego and Orange Counties*. Tech. N.p.: n.p., 2017. Print.
[80] Skutecki, Lisa. *County of San Diego Bacteria Total Maximum Daily Load Cost-Benefit Analysis Technical Memorandum No. 1*. Tech. N.p.: Brown & Caldwell, n.d. Print.
[81] Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. USEPA. December 2007. https://nepis.USEPA.gov/Exe/ZyPDF.cgi/60000LWT.PDF?Dockey=60000LWT.PDF
[82] City of San Diego Watershed Asset Management Plan Table 7-3. Phase I and Phase II City of San Diego CLRP Opinions of Probable Cost https://www.sandiego.gov/sites/default/files/legacy/stormwater/pdf/wamp2013.pdf

$$LR\,\%\,Year_i = Scheduled\ LR\,\%\,Year_i \times Total\ LR\,\%$$

2. Annual cost is determined based on the LR achieved in that year. Achieving the total LR would incur the associated total cost. Therefore, achieving some portion of the total LR incurs a proportional cost.

$$Cost\ Year_i = \left(\frac{LR\,\%\,Year_i}{Total\ LR\,\%}\right) \times Compliance\ Cost$$

Determine annual costs for the Human Sources scenarios

The methodology to annualize costs for the human sources scenario is determined and performed so the resulting annual costs are available for this cost analysis. The following steps outline the methodology for annualizing costs for the human sources scenarios. The methodology for annualizing costs varies by loading source due to the characteristics of each source.

1. Septic System loading remediation costs are presented in annual costs and present-day dollars and therefore require no further analysis to be annualized.
2. Sewer Main loading costs are annualized by first determining the present value of the total cost. Sewer mains are assumed to have a 50-year life-span and therefore are replaced every 50 years. The second time sewer mains are replaced (over a hundred-year timeframe) will be at the end of the first 50 years. Because this cost is in the future the present value cost must be determined.
$$Present\ value\ = Total\ Cost_{replaced\ i=1}\ + Total\ Cost_{replaced\ i=51} \times (1.03^{-50})$$
3. Remediation of Sewer Lateral loading and loading from transient populations are already in present value dollars.

4. Sewer main, sewer lateral and transient population costs are then annualized.
$$Annualized\ present\ value\ = \frac{0.03 \times ((1+0.03)^{100})}{((1+0.03)^{100}) - 1}$$

$$Annualized\ Cost\ = NPV\ Cost \times Annualized\ present\ value$$

Determine programmatic costs for the Stormwater and Scheduling scenarios

Stormwater scenario annual costs are divided into the three cost categories: programmatic, O&M, and capital based on the % LR in each year (Figure 33).

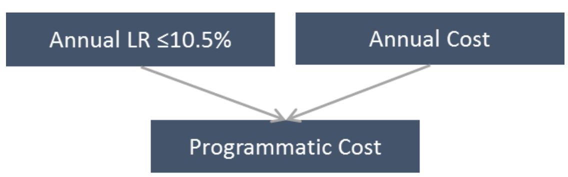

Figure 33: LRs ≤10.5% incur programmatic costs for the stormwater and timing scenarios. Annual programmatic costs are calculated using the annual percent LR and the annual cost.

1. If the LR in $Year_i$ is less than or equal to 10.5%, the entire cost for that year will be programmatic.
$$Programmatic\ Cost\ Year_i = Cost\ Year_i$$
2. If the LR in $Year_i$ is greater than 10.5%, the programmatic costs will be proportional to a 10.5% LR.
$$Programmatic\ Cost\ Year_i = \left(\frac{10.5\% \times Compliance\ Cost}{Total\ LR\ \%}\right)$$

Determine O&M and capital costs for the Stormwater, Scheduling and Stream scenarios

Divide annual costs between the O&M and capital cost categories based on the cost schedule (Figure 34). For the Stormwater and timing scenarios, programmatic costs are subtracted and the remaining annual costs are O&M and capital costs. Stream scenario costs are based on the implementation, operation, and maintenance of structural BMPs. The Stream scenarios don't include any programmatic BMPs and therefore have no programmatic costs.

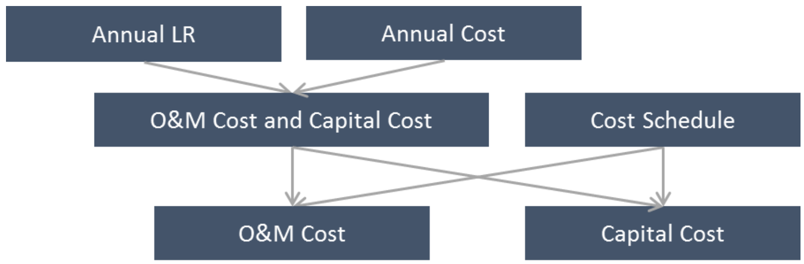

Figure 34: Annual LR, annual cost, and the cost schedule are used to determine annual O&M and capital costs.

1. Annual capital improvement and O&M costs are determined through the following method
   a. For stormwater and timing scenarios, if the LR in $Year_i$ is less than 10.5%, there are no capital costs, all costs are programmatic.
   b. For stormwater and timing scenarios, if the LR in $Year_i$ is greater than 10.5% then the programmatic cost in $Year_i$ is subtracted from the cost in $Year_i$. The remaining cost is a combination of capital and O&M costs.
   c. For stormwater, timing and stream scenarios, the portion of the annual cost attributable to each of these two categories is based on the cost schedule (see *Assumptions* section). This schedule identifies the percent of costs that are capital vs O&M each year.

$$Capital\ Cost\ Year_i = (Cost\ Year_i - Programmatic\ Cost\ Year_i) \times \%\ Capital\ Year_i$$
$$O\&M\ Cost\ Year_i = (Cost\ Year_i - Programmatic\ Cost\ Year_i) \times \%\ O\&M\ Year_i$$

Discount annual costs for the Stormwater, Scheduling and Stream scenarios

To determine the net present value (NPV) of future costs, cost results for each scenario, except the Human Sources scenarios, are discounted using a 3% discount rate. The Human Sources scenario costs have already been discounted.

D = discount rate T = year(s) after compliance began

$$NPV = Cost_{T0} + Discount\ Rate_{T1} \times Cost_{T1} + D_{T2} \times C_{T2} \ldots + D_n \times C_n$$
$$Discount\ Rate_T = \frac{1}{(1+0.03)^T}$$

Determine total compliance and ongoing costs for all scenarios (Stormwater, Scheduling, Stream and Human Sources)

Once the annual cost for each category is known, the costs can be summed over the appropriate years to determine the total compliance and ongoing cost.

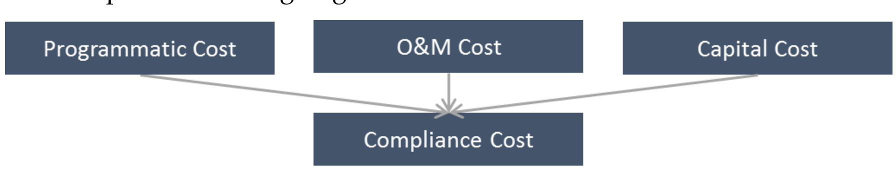

Figure 35: Annual programmatic, O&M and capital costs are summed from the first year of implementation (2017) to the compliance deadline to determine the total compliance cost.

1. Sum annual costs to determine the compliance cost for each scenario (Figure 35)
   a. Sum annual programmatic, O&M and capital costs from 2017-2031 to determine the compliance cost for each of the stormwater scenarios, from 2017-2051 to determine the

compliance cost for the Compliance by 2051 scenario, and from 2017-2061 to determine the compliance cost for the CIP Schedule scenario.

b. Sum annual O&M and capital costs from 2017-2031 to determine the compliance cost for the Stream scenario.

c. Sum annual Human Sources scenario costs from 2017-2031 to determine the compliance cost for the Stream scenario.

Figure 36: Annual programmatic and O&M costs are summed from the first year after the compliance deadline to the end of the analysis period (2081) determine the total compliance cost.

2. Sum annual costs to determine the ongoing cost for each scenario (Figure 36)
    a. Sum annual programmatic and O&M costs from 2032-2081 to determine the ongoing cost for each of the stormwater scenarios, from 2052-2081 to determine the ongoing cost for the Compliance by 2051 scenario, and from 2062-2081 to determine the ongoing cost for the CIP Schedule scenario.
    b. Sum annual O&M costs from 2032-2081 to determine the ongoing cost for the Stream scenario.
    c. Sum annual Human Sources scenario costs from 2032-2081 to determine the ongoing cost for the Stream scenario.

ASSUMPTIONS

The methodology implemented to determine cost analysis results is based on a series of assumptions.

- The LR schedule shows what portion of the required LR is achieved each year (Figure 37). This schedule was developed based on conversations with City of San Diego, County of San Diego, and Orange County staff to ensure the rate of LR over time represents the actions that would be taken by these jurisdictions. The LR schedule assumes that the rate of BMP implementation is slow initially as programs are established, halfway through the compliance period the rate of implementation increases as funding is secured and the implementation process is streamlined, this rate of implementation is then maintained throughout the remainder of the compliance period to reduce fluctuation in jurisdictional budgets.
    - For scenarios with a 2031 compliance deadline, the LR increases by 4%/year over the first 6 years. The LR rate then increases to 9%/ year for the remaining 8 years.
    - For the Compliance by 2051 scenario, the LR increases by 1.5% a year over the first 16 years. The rate of LR then increases to 4.14% a year for the remaining 18 years.
    - For the CIP Schedule scenario, the LR increases by 1.32% a year over the first 19 years. The rate of LR then increases to 3.01% a year for the remaining 24 years.

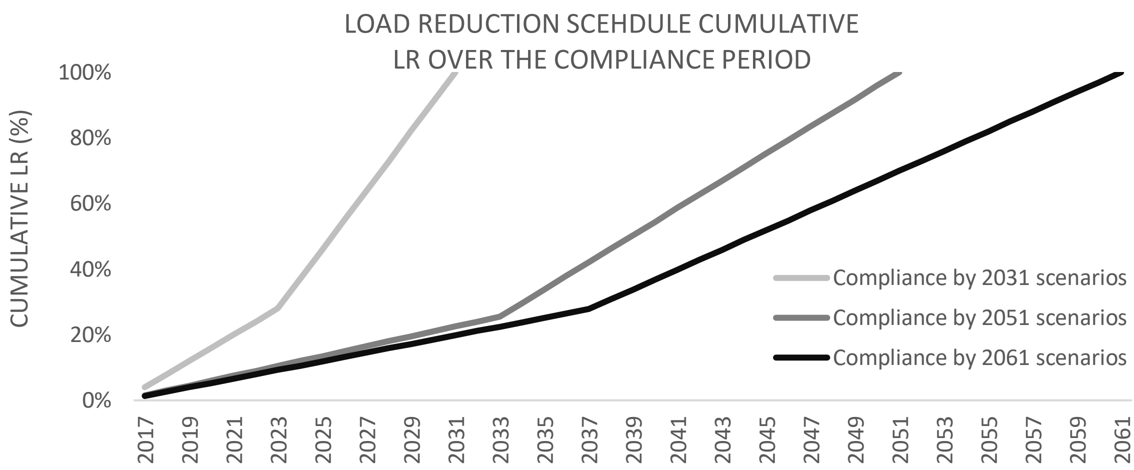

Figure 37: The percent of the required load reduction achieved each year increases from the first year of implementation to the compliance deadline according to the load reduction schedule.

- It is possible for a scenario to have one or more watersheds with zero LR required and greater than zero cost. Zero LR is required when a watershed for a particular scenario is already in compliance. Costs are greater than zero because of the expenditures required to maintain compliance.
- The cost schedule determines what proportion of costs are capital versus O&M in each year. There are no O&M costs the first year (2016) because O&M costs can only begin the year after BMPs are implemented. For the Stormwater, Human Sources, and timing scenarios the compliance period capital costs decrease from 100% to 46% and O&M costs increase from 0% to 54% over time (Table 47). The cost proportions change in steps every three years. The ratio of capital and O&M costs is based on research identifying this as the typical proportion of capital versus O&M costs for a BMP.[83]

Table 72. Cost schedule indicating the percent of O&M versus Capital costs each year for the Stormwater and Timing scenarios.

	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6
Percent at each step						
Capital Costs	100%	80.0%	70.0%	60.0%	50.0%	46.0%
O&M Costs	0.000%	20.0%	30.0%	40.0%	50.0%	54.0%
Number of years at each step						
Stormwater and Human Sources scenarios	1	3	3	3	3	3
Compliance by 2051	1	7	7	7	7	6
CIP Schedule	1	9	9	9	9	8

- For the Stream scenarios the compliance period capital costs decrease from 100% to 80% and O&M costs increase from 0% to 20% over time (Table 48). The ratio of capital and O&M costs is the Stream scenario technical memo.[84]

[83] Transportation and Stormwater Department Watershed Asset Management Plan. Table 7-3. Phase I and Phase II City of San Diego CLRP Opinions of Probable Cost. July 19, 2013 https://www.sandiego.gov/sites/default/files/legacy/stormwater/pdf/wamp2013.pdf

[84] ESA. *Development of the San Diego Bacteria TMDL Cost Benefit Analysis Inputs for Stream and Riparian Habitat Restoration San Diego and Orange Counties*. Tech. N.p.: n.p., 2017. Print.

Table 73. Cost schedule indicating the percent of O&M versus Capital costs each year for the Stream scenarios.

	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Percent at each step					
Capital Costs	100%	95.0%	90.0%	85.0%	80.0%
O&M Costs	0.000%	5.00%	10.0%	15.0%	20.0%
Number of years at each step					
Stream scenarios	1	4	4	3	3

- CIP scenario results are based on a potential cost savings from the alignment of planned capital improvement projects and stormwater BMP implementation. Based on literature review, the potential cost savings is a 25% reduction in capital costs. According to an USEPA study, on average there is a 25% reduction in LID project cost compared to conventional development costs.[85] Cost savings are only possible for structural BMPs therefore, there is no cost savings for programmatic costs. Additionally, there are no cost savings for O&M costs because once implemented, the BMPs must be maintained.

RESULTS AND DISCUSSION

The following results of the cost analysis inform decision makers about which scenarios are most expensive. Additionally, results indicate whether the majority of costs will be incurred to meet the LR target, or to maintain the LR achieved after the compliance deadline. Cost results presented are calculated over a 65-year period with a 3% discount rate to enable comparison with benefit results.

Total scenario cost

The total cost of each scenario is the sum of programmatic, capital, and O&M costs in both San Diego and Orange counties over the 65-year analysis period. **Total cost results indicate the least expensive scenarios are Stormwater and Timing scenarios** (Figure 38). Specifically, the Flow-based Suspensions scenario is least expensive. The Move Compliance Locations and CIP Schedule scenarios have the next lowest cost. This result likely occurs because both the Flow-based Suspensions and Move Compliance Locations scenarios reduce the required LR compared to the 2010 TMDL scenario. As a result, the cost to achieve the required LR is lower. The cost of the CIP Schedule scenario is low because of the extended compliance timeline. The LR for the CIP Schedule is the same as the Bacteria TMDL schedule, but under the CIP Schedule scenario there are 30 additional years to meet the LR requirement. As a result, the cost expended each year is lower, and costs are discounted over a longer timeframe.

Total cost results indicate the Human Sources are the most expensive. Specifically, the Human Sources: High+Med+Low scenario is far more expensive than the other scenarios. This scenario is reducing 100% of loading by implementing BMPs addressing high, medium, and low priority loading sources. Other scenario types only reduce loading to the extent necessary to meet regulatory requirements. Additionally, addressing all three priority sources requires implementing a high number of expensive BMPs over a large area.

[85] Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices Table 2. Summary of Cost Comparisons Between Conventional and LID approaches https://nepis.USEPA.gov/Exe/ZyPDF.cgi/60000LWT.PDF?Dockey=60000LWT.PDF

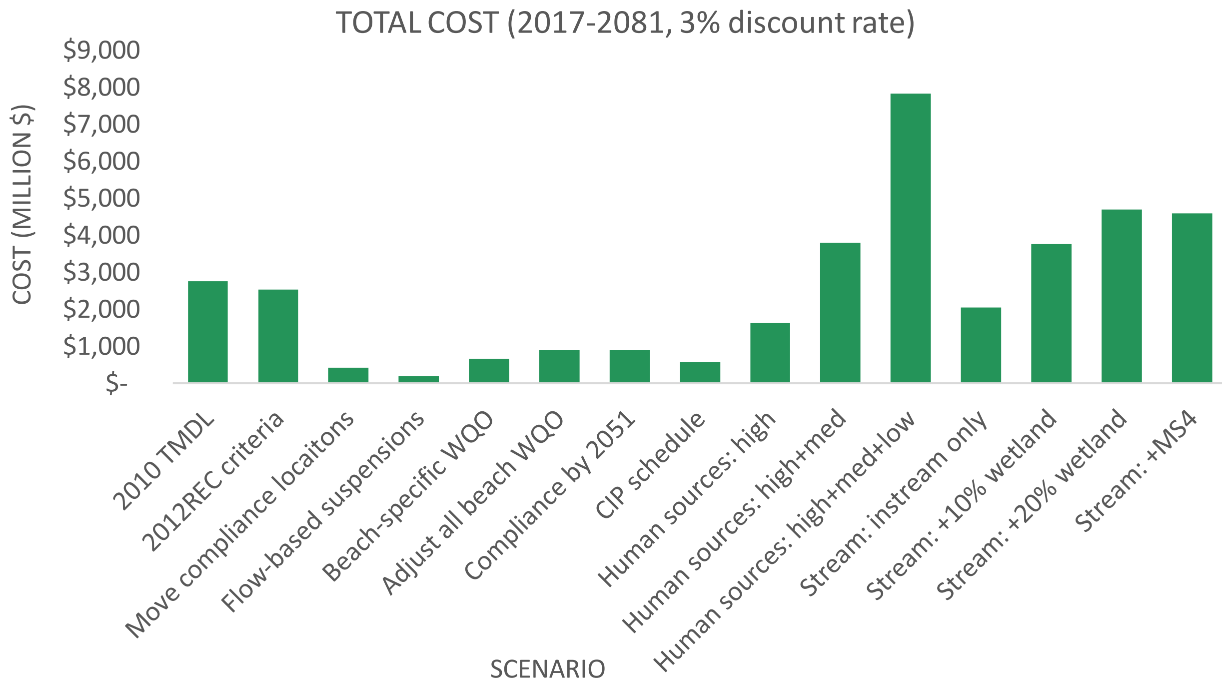

Figure 38: The total cost of meeting the required load reduction through the implementation and maintenance of BMPs is highest for the Human Sources: High+Med+Low scenario and lowest for the Flow-based Suspensions scenario.

Annual scenario cost

The average annual cost of each scenario is the total cost of each scenario over the analysis period divided by 65 years. The ratio of costs between scenarios is the same for average annual cost and total cost. Average annual costs indicate to permittee how much they can expect to pay each year under each scenario to achieve the required LR.

Annual cost results indicate the least expensive scenarios are Stormwater and Scheduling scenarios (Figure 39). Specifically, the Flow-based Suspensions scenario is least expensive on an annual basis. **Annual cost results indicate the Human Sources are the most expensive.** Specifically, the Human Sources: High+Med+Low scenario is far more expensive on an annual basis than the other scenarios. The rationale for why these scenarios are the most or least expensive is described above under the Total Cost header.

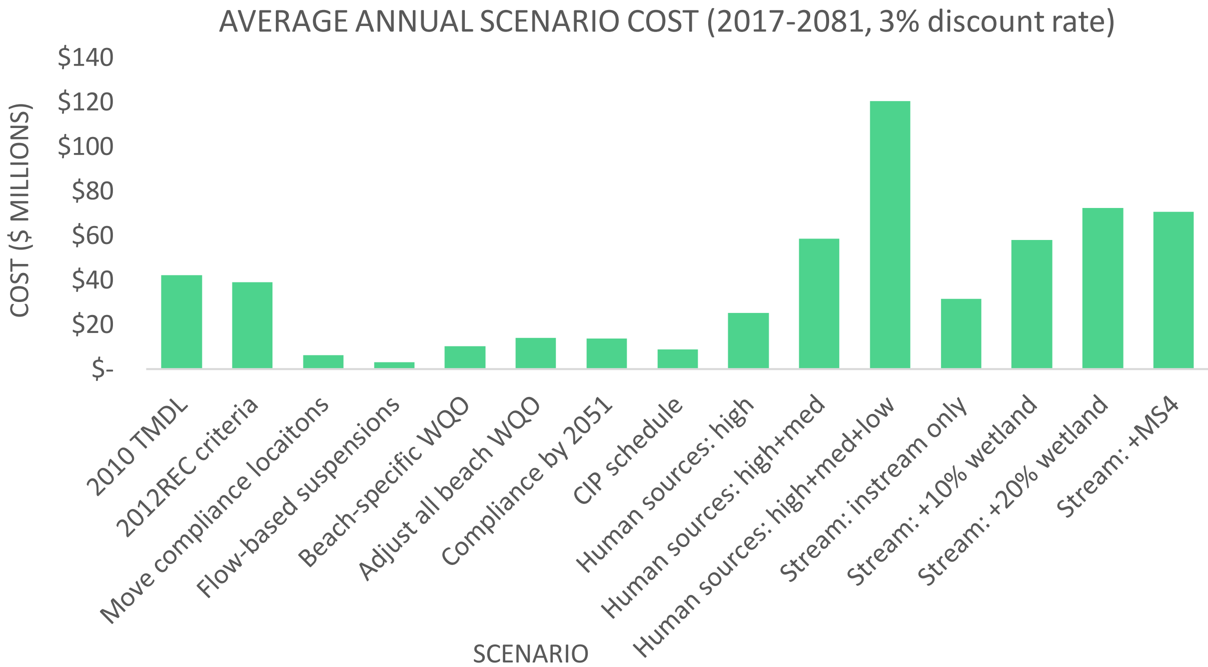

Figure 39: The average annual cost of meeting the required load reduction through the implementation and maintenance of BMPs is highest for the Human Sources: High+Med+Low scenario and lowest for the Flow-based Suspensions scenario.

Compliance and Operations and Maintenance Costs

Total scenario costs are based on the sum of compliance and annual ongoing costs. Compliance costs include programmatic, capital, and O&M costs from the first year of implementation (2017) until the compliance deadline. Ongoing costs include programmatic and O&M costs from the compliance deadline to the end of the analysis period.

Comparing compliance and ongoing costs indicates to permittee how much they can expect to pay to achieve the required LR, versus how much they will pay in the future to maintain this LR. Scenarios with a higher proportion of compliance costs incur more costs initially and less costs farther in the future. The opposite is true for scenarios with a higher proportion of ongoing costs.

The Stream and Timing scenarios have the lowest proportion of ongoing costs compared to compliance costs assuming a 65-year analysis period (Figure 40). For the CIP Schedule scenario, 71% of the total cost of this scenario will be incurred by the compliance deadline of 2061. Because the CIP Schedule scenario is calculated over a long timeframe annual costs, and therefore ongoing costs, are low. For the Stream scenarios, 59% of the total cost of this scenario will be incurred by the compliance deadline of 2031. Compliance costs are low for the Stream scenarios for two reasons. First, there are no programmatic costs because the stream scenarios are based on structural, not non-structural BMPs. Second, O&M costs for the stream scenarios are only 20% of annual costs and capital costs are 80% of annual cost. In comparison, O&M costs are 56% of annual costs for the other scenarios.

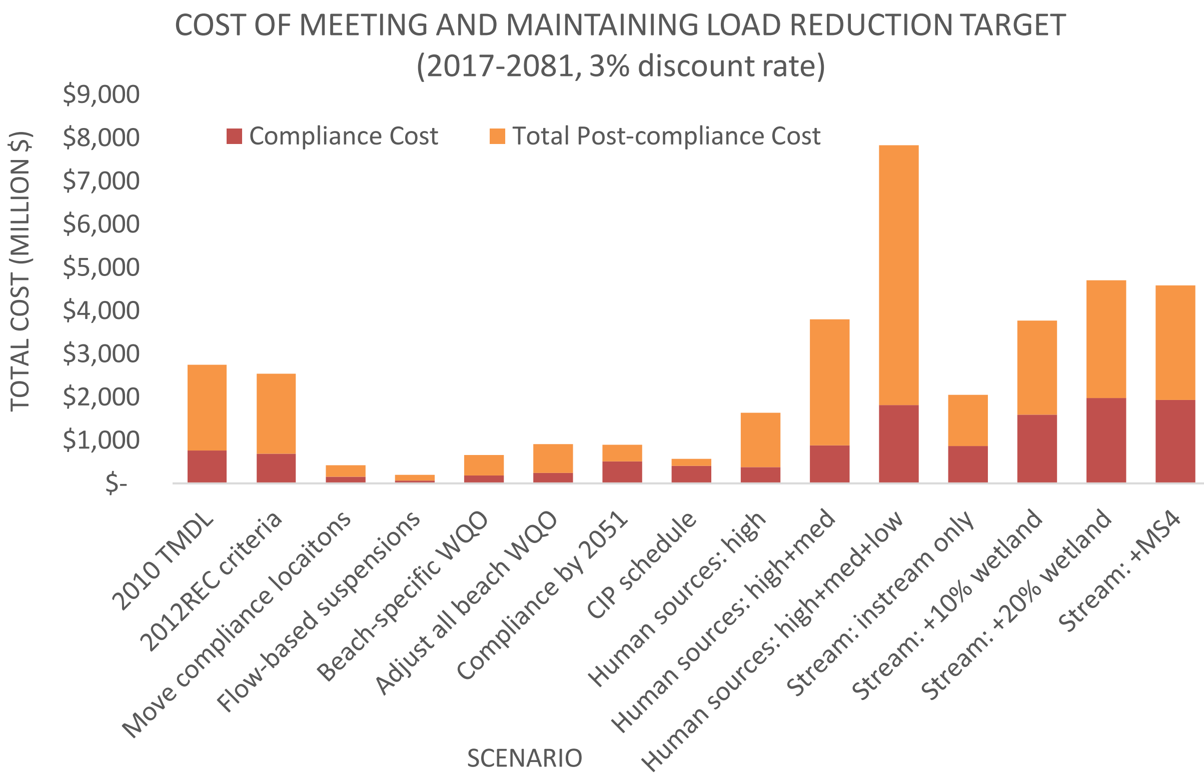

Figure 40. The combined cost of meeting and maintaining compliance is highest for the Human Sources: High+Med+Low scenario. For the Stormwater and Human Sources scenarios compliance costs are a higher portion of total cost than ongoing costs. The reverse is tru for the Schedule and Stream scenarios.

Cost by category

The total cost of each scenario can be divided into the three cost categories (programmatic, capital and operation and maintenance). **For scenarios where no watershed requires greater than a 10.5% LR, all costs will be programmatic** (Figure 41). For scenarios where greater than a 10.5% LR is required in at least one watershed, there will be capital and operation and maintenance costs in addition to programmatic costs. For the Stormwater and Timing scenarios many watersheds have just over a 10.5% LR. Therefore, programmatic costs are high and capital costs are very low for these scenarios.

The four stream scenarios implement only structural, not non-structural BMPs. Therefore, the stream scenarios have no programmatic costs, but only capital and operation and maintenance costs. Additionally, O&M costs are only 20% of annual cost for the stream scenarios compared to 56% of other scenarios. The human sources scenarios are not broken down by cost category. Therefore, the graph only shows the total cost for the human sources scenarios.

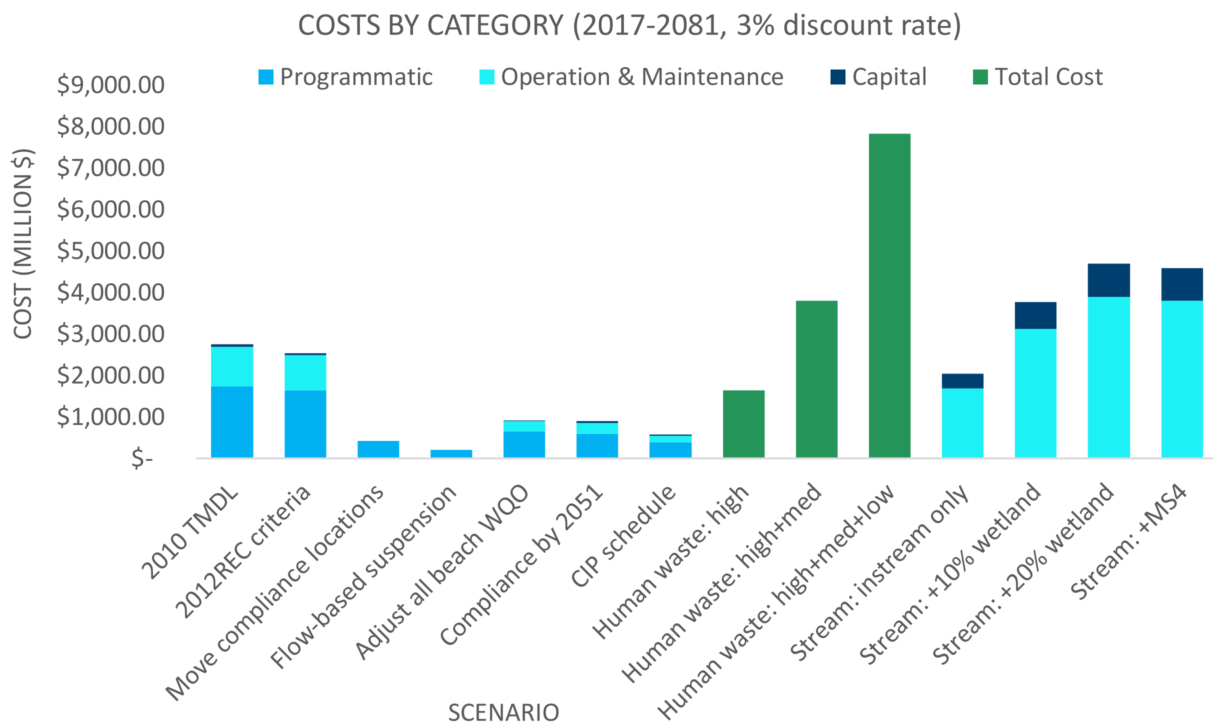

Figure 41. O&M cost are the highest proportion of total cost for the Stream scenarios. Programmatic costs are highest proportion of total cost for the Stormwater and Timing scenarios.

Cost by region

The CBA includes watersheds in both San Diego and Orange counties. **On average across all scenarios 14% of total costs are from Orange County watersheds and 86% of costs are from San Diego Watersheds** (Figure 42). Costs from Orange County watersheds range from 0.9% of total scenario cost for the Adjust All Beach WQO scenario to 29% of total scenario cost in the Human Sources: High+Med+Low scenario. Costs from San Diego County watersheds range from 71% of total scenario cost for the Human Sources: High+Med+Low scenario to 99% of total scenario cost for the Adjust All Beach WQO scenario.

There are many potential explanations for substantially lower costs in Orange County watersheds. LRs required are substantially lower for the Orange County watersheds compared to the San Diego watersheds. Therefore, the cost to achieved the required LR is much lower for Orange County watersheds. For the human sources scenarios in San Diego watersheds the transient population count is about five times higher and the total length of sanitary sewer mains is about double values in Orange County watersheds. Additionally, the SSO spill volume for the human sources scenarios is about 50% greater in San Diego watersheds. Lastly the daily load contributions are 15% higher for the human sources scenarios in the San Diego Watersheds.

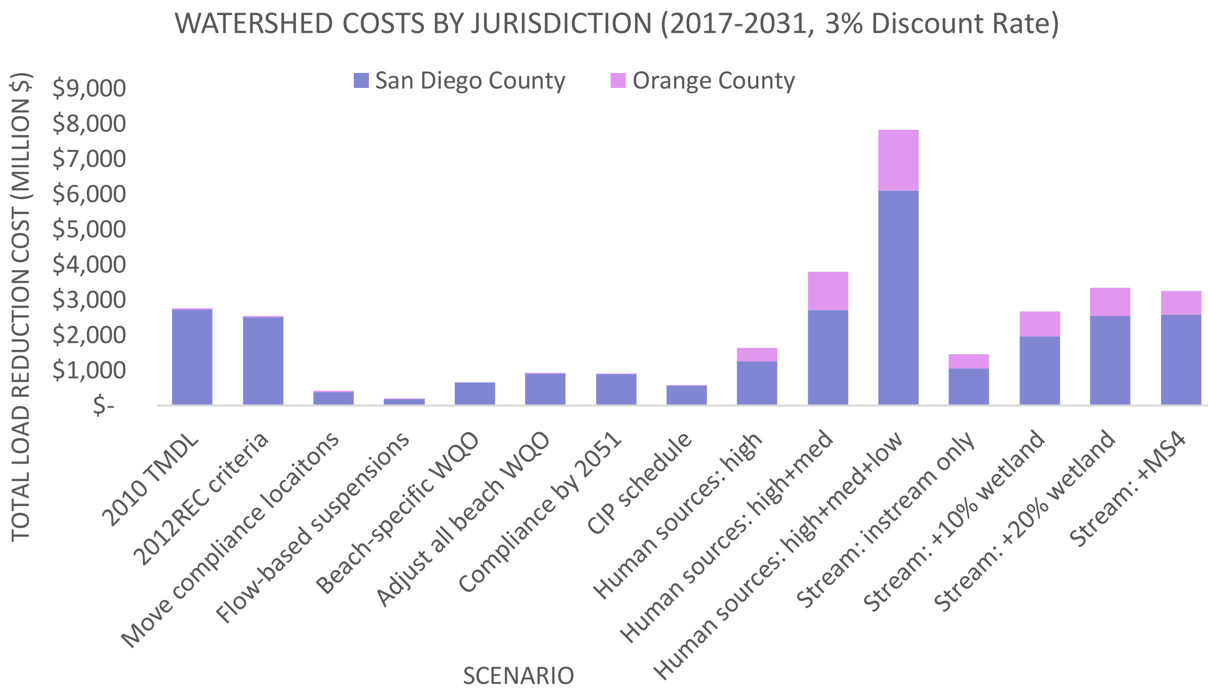

Figure 42. County of San Diego costs are a substantially higher poriton of total cost in all watersheds compared to Orange County costs.

SENSITIVITY ANALYSIS

Each scenario type is based on a series of potentially sensitive assumptions used to determine the cost in each watershed for each scenario over the compliance period (2017-2031). Meaning, variations in these assumptions will result in a large change in cost. Some assumptions may be based on a large body of high confidence research, other assumptions may be based on best professional judgements. Assumptions which are based on best professional judgement and which cause a large change in cost estimates may have an impact on results if varied. Where data is available, this sensitivity is characterized in the **Input Data Sensitivity** section for each scenario type.

The cost in each watershed for each scenario over the compliance period (2017-2031) is annualized and extended to 2081 based on several assumptions. If results are sensitive to these assumptions, variations in the assumptions could cause large changes in results such as the total cost of each scenario over the analysis period (2017-2081). This sensitivity is characterized in the **Annualization Sensitivity** section for each scenario type.

STORMWATER AND SCHEDULING SCENARIOS

Input Data Sensitivity

A sensitivity analysis on cost input data provided for the Stormwater scenarios was not available. The assumptions and limitations of the analysis implemented to produce this cost data are detailed in technical memo Appendix A.

Annualization Sensitivity

The cost analysis methodology assumes the percentage of capital versus O&M costs each year. The underlying assumption is that capital costs decrease over time after implementation begin and O&M costs increase until on average capital costs are 44% of annual costs and O&M costs are 56%. The uncertainty analysis examines the change in total cost if the average annual percent capital vs O&M costs are reversed so average capital costs are 56% of annual costs and O&M costs are 44%. The results are then compared. Across the stormwater and timing scenarios there is on average a 3.35% increase in total scenario cost from reversing the average percent capital versus O&M costs (Figure 43). All scenarios have less than a 6% change in cost.

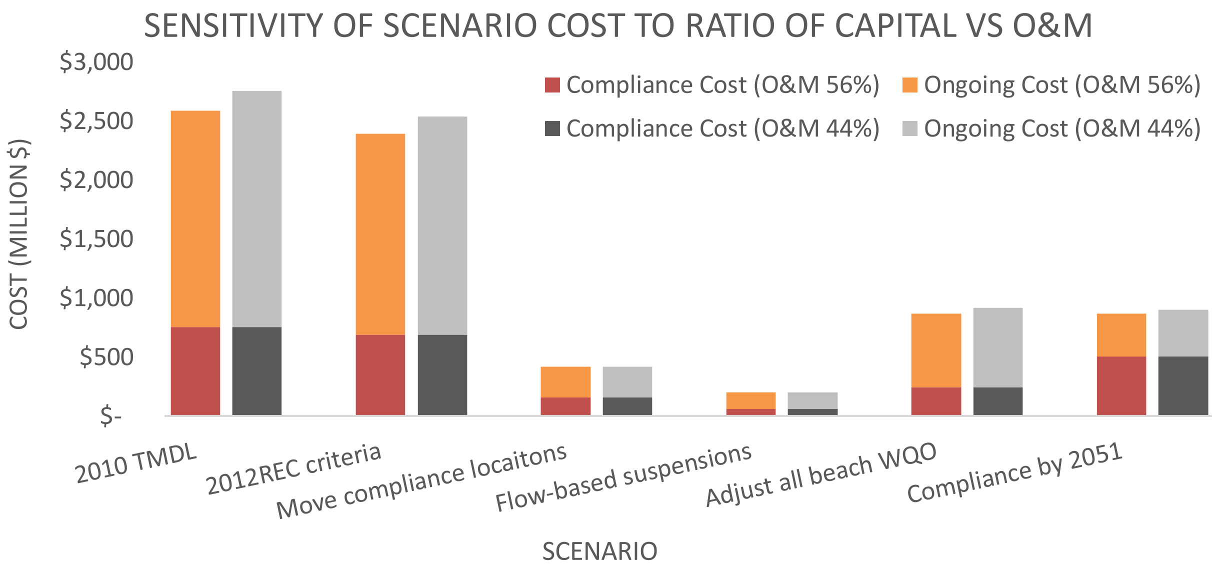

Figure 43. Sensitivity analysis results indicate there is on average about a 3% change in total cost from increasing average annual capital costs and decreasing average annual O&M costs. Orange and red bars show total cost after changing the ratio of capital and O&M costs. Light and dark grey bars show the original total cost of each scenario. The difference in cost between the two bars for each scenario is the sensitivity of the total scenario cost to changes in the ratio of capital to O&M costs.

The cost analysis methodology assumes the potential cost savings from aligning capital improvement projects and stormwater BMPs is 25%. The uncertainty analysis examines the change in total cost of the CIP scenario if the potential cost savings each year is increased to 40%. The results are then compared Figure 44. There is a 1.14% change in cost between the original and modified CIP scenario. Changing the potential cost savings by 15% only results in a 1% reduction in total cost because the cost savings only applies to annual capital costs which are a small portion of total annual cost.

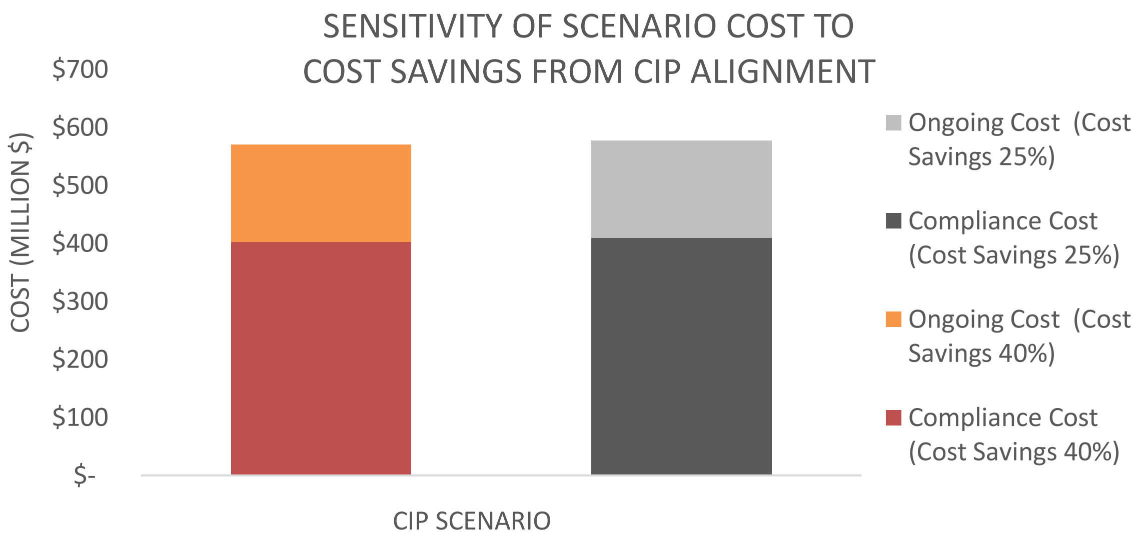

Figure 44. Sensitivity analysis results indicate there is about a 1% change in total cost from increasing potential cost savings from alignment of CIP and stormwater BMP implementation. Orange and red bars show total cost the CIP Schedule scenario assuming a 40% savings in annual capital costs. Light and dark grey bars show the original scenario cost based on a 25% cost savings. The difference in cost between the two bars is the sensitivity of the total scenario cost to the potential capital cost savings from alignment of BMP and CIP project implementation.

STREAM SCENARIOS

Input Data Sensitivity

Stream Restoration scenario data provided includes a sensitivity analysis around the Stream: +MS4 scenario which examines the cost of meeting MS4 permit requirements. The sensitivity analysis provided includes three different reduction efficiencies which are classified as low= 40%, medium =60%, and high = 70% removal efficiency. It should be noted that for Chollas Creek and Tecolote Creek MS4 LR goals are not met. The sensitivity analysis also varies the number of projects implemented from 289-340 to achieve the LR. Results of this sensitivity analysis indicate there is on average a 3.3% change in project cost with each 10% increase in wetland removal efficiency and 13% change in the number of projects. Additional sensitivity analyses are included in the technical memo (Figure 46).[86]

[86] ESA. *Summary of enteroccocus load reduction and costs uncertainty analysis for the restoration approach. Tech, N.p. 2017*

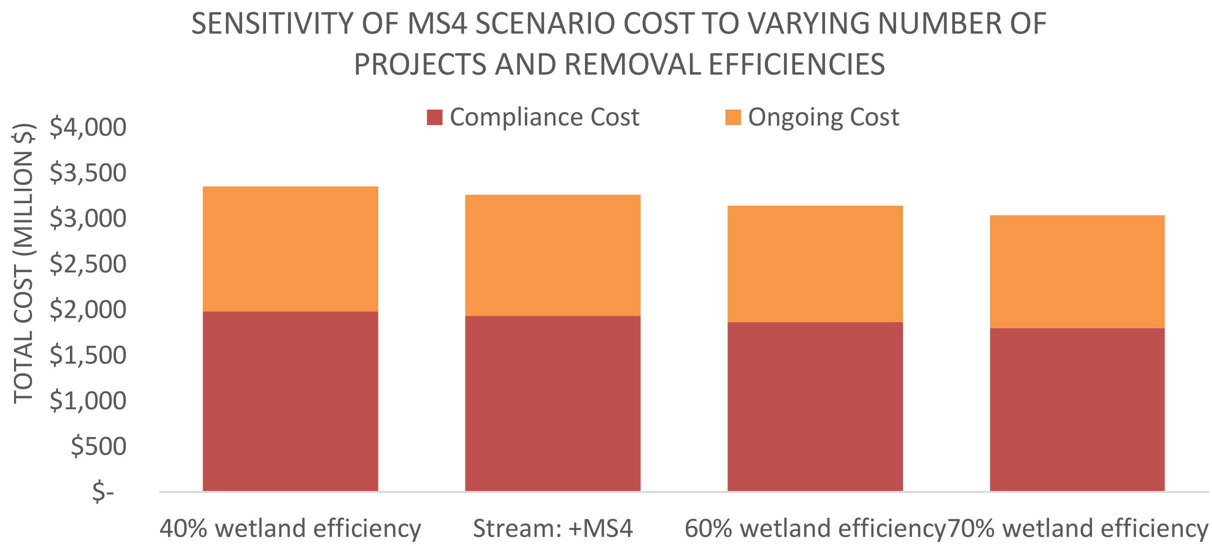

Figure 46: Bars indicate alternatives to the Stream: + MS4 scenario with varying wetland removal efficiency and varying the number of projects implemented to achieve the required load reduction. Varying the number of projects varies the scenario cost. Difference in bar height indicates the sensitivity of total scenario cost to changing these two inputs.

Annualization Sensitivity

The percentage of capital versus O&M costs each year is based on assumptions in the Stream scenarios technical memo. Capital costs decrease over time after implementation begins and O&M costs increase until capital costs are 80% of annual costs and O&M costs are 20%. The uncertainty analysis examines the change in total cost if the annual percent capital cost is changed to 60% and O&M costs are changed to 40%. Results indicate that total scenario cost increase by 41% for each scenario (Figure 47).

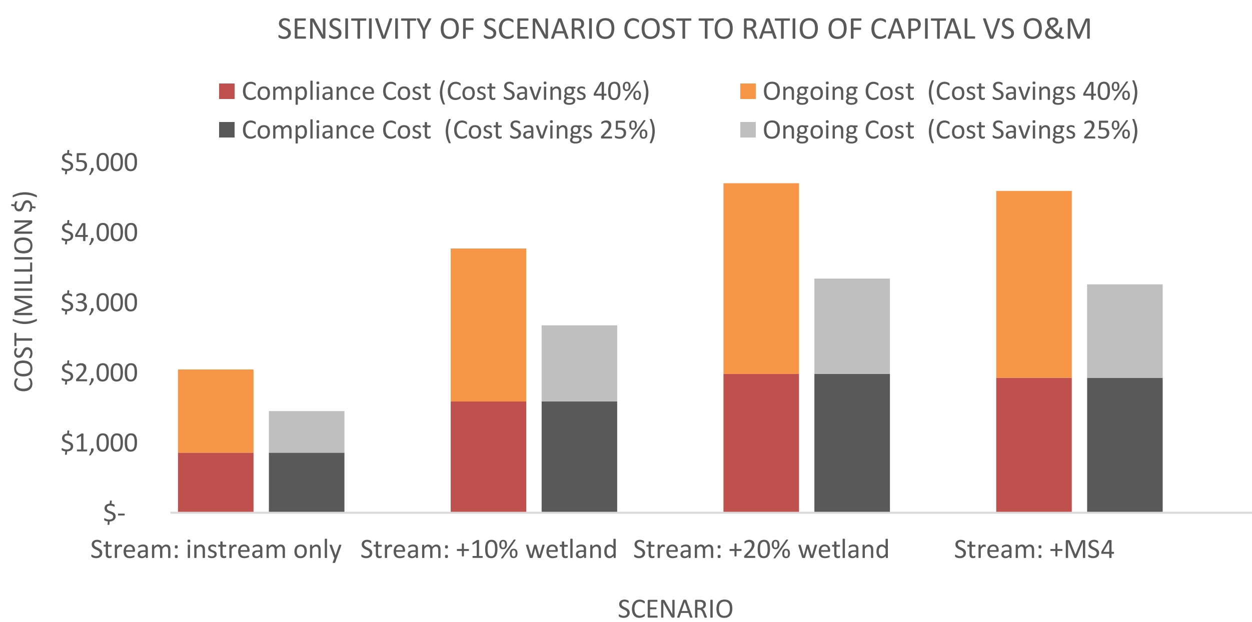

Figure 47: Sensitivity analysis results indicate there is a 41% change in total cost from increasing average annual O&M costs and decreasing average annual capital costs. Orange and red bars show total cost after changing the ratio of capital and O&M costs. Light and dark grey bars show the original total cost of each scenario. The difference in cost between the two bars for each scenario is the sensitivity of the total scenario cost to changes in the ratio of capital to O&M costs.

HUMAN SOURCES SCENARIOS

Input Data Sensitivity

The human sources analysis included three scenarios to examine how costs vary with the inclusion of different combinations of high, medium, and low priority sources of HF183. One scenario includes only the high priority sources, another includes the high and medium priority sources, and the last includes the high, medium, and low priority sources. Analyzing these three scenarios reduces uncertainty about the cost of reducing HF 183 loading. Results indicate there is a 57% increase in cost from the high to high + medium scenario and a 51% increase in cost from the high + medium to the high + medium + low scenario (Figure 48).

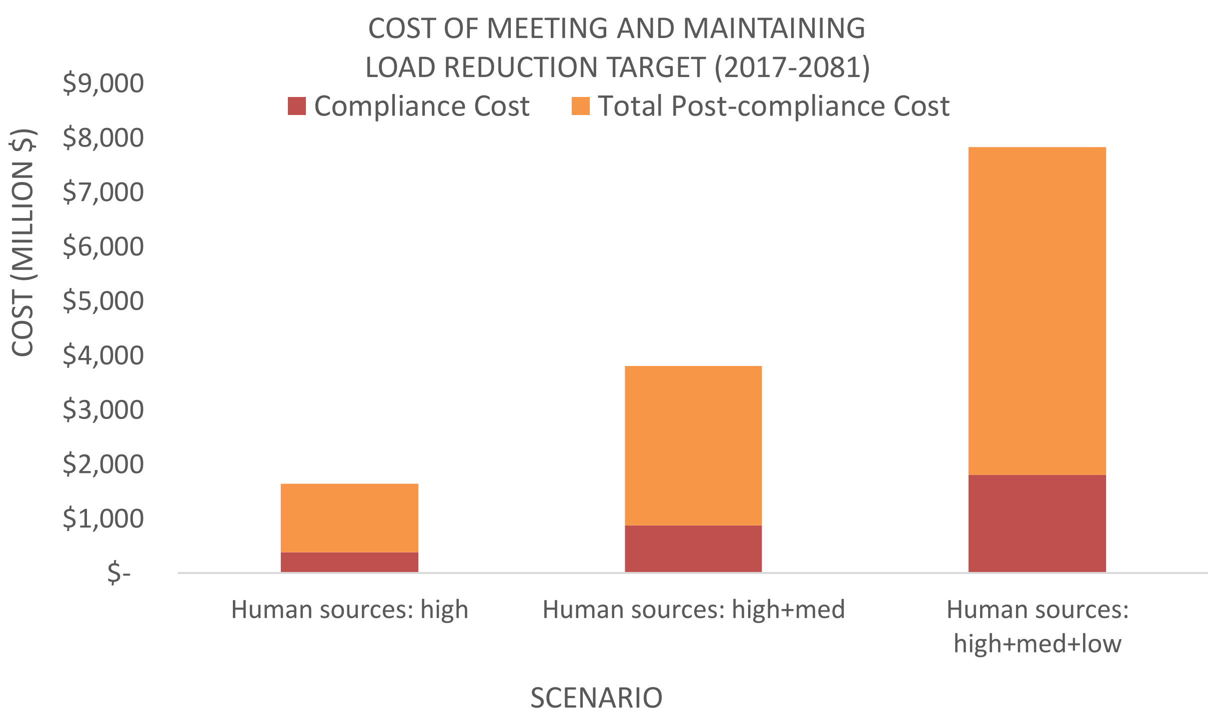

Figure 48: Several variations of the human sources scenario are considered. The Human Sources: High scenario targets only the highest priority sources of loading. The Human Sources: High+Medium+Low scenario targets all priority level. Bar height indicates how total scenario costs change based on the priority sources included.

Annualization Sensitivity

The technical memo for the human sources scenarios which provides input data to the cost analysis classifies the methodology it uses as a Class 5 estimate according to the Association for the Advancement of Cost Engineering International criteria. Expected accuracy for Class 5 estimates typically ranges from -50 to +100%, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. Reducing cost values provided in the technical memo by 50% and increasing these values by 100% results in a linear change in total cost over the analysis period (Figure 49).

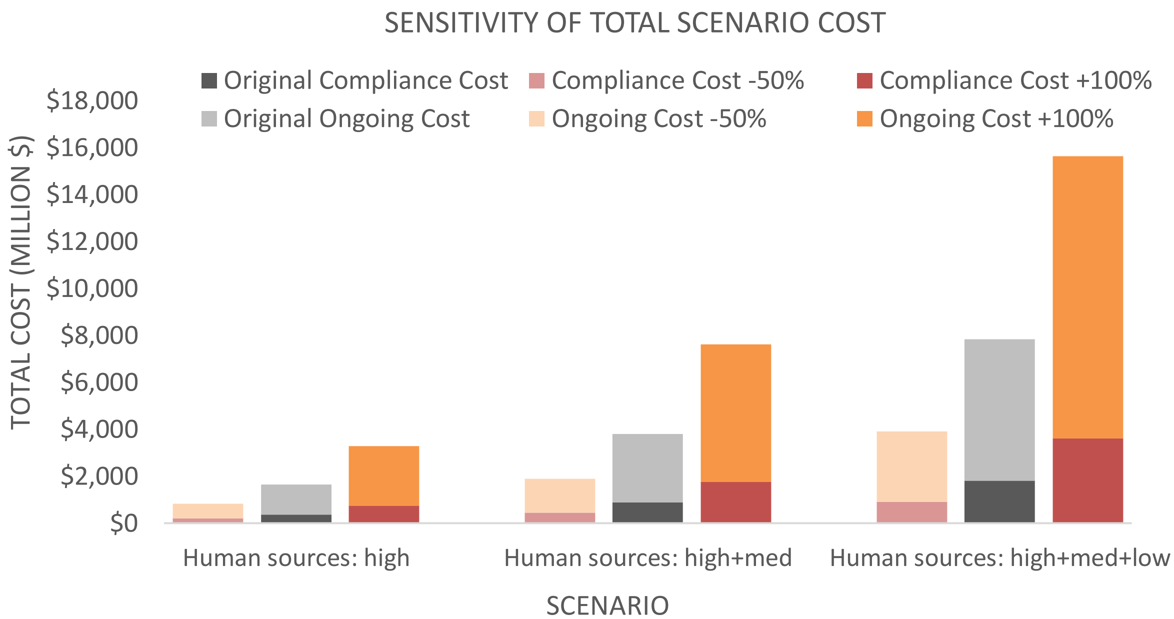

Figure 49: The methodology used to determine Human Sources scenario costs is considered a Class 5 estimate. Therefore, costs could fluctuate by -50-100%. Light orange and red bars indicate the total scenario cost after decreasing costs by 50%. The dark orange and red bars indicate total scenario cost after increasing total cost by 100%. Grey bars indicate the original scenario cost.

6. NEXT STEPS

Results and findings about cost-effectiveness, net benefits, benefit quantities and cost types provide information to decision makers as they consider alternatives for making San Diego's waters swimmable and fishable. While uncertainty analysis and sensitivity testing show high confidence in cost-effectiveness and net benefit findings, additional research could reduce numeric uncertainty in water quality input data and numeric results of the CBA. This section provides insight from project team members, including the Steering Committee, TAC and consulting team about ongoing and potential future research that could reduce uncertainty and enhance numeric results.

FOLLOW UP STUDIES

Follow-up studies are already underway to address the findings of the CBA and recommendations from the TAC, as well as progress toward compliance with the Bacteria TMDL. These studies provide additional insight and clarification to CBA assumptions and data that could be used in future, related analysis.

Testing for human microbial markers such as HF 183 in receiving waters can identify bacteria that are specifically from humans. Scientists agree that human sources of bacteria have a higher likelihood of causing illness than most animal or naturally occurring bacteria. This past year, field investigations using HF 183 during wet and dry conditions found and mitigated identified human sources. Generally speaking, permittees have started testing in the waterways at the base of the watershed catchment to trace human sources of bacteria upstream through the tributaries and eventually through the network of pipes and conveyances of the stormwater system and sometimes the sanitary sewer collection system. Although these detailed field sampling protocols are time intensive and expensive, initial studies have borne results. For example, the City of San Diego has found two broken private laterals that allowed raw sewage to infiltrate into the stormwater conveyance system, broken irrigation lines that washed sewage wastes from the broken laterals further downstream and illegal discharges from commercial facilities.

In 2017, formal tracking of winter season recreational activities at the beach have been conducted at Ocean Beach, one of San Diego County's most popular beaches. Beach observers recorded the estimated age of beach users, the recreational activity and the duration of the activity between the hours of 8am and 5pm after four storm events and the 3 subsequent days. Preliminary results from this project suggest that surfing accounts for the vast majority of winter season recreational activity where head immersion is likely. The USEPA 2012 Recreational Water Quality Criteria Recommendations are designed to protect human health during recreational activities with a high degree of body contact with water because head immersion and ingestion are likely.

Reconsideration of the REC-1 Objective and Bacteria TMDL

In support of the Regional Water Quality Control Board's Recreational Uses Project of the 2014 Triennial Review of the Basin Plan, permittees subject to the San Diego Bacteria TMDLs will submit a proposal for recommended changes to the Bacteria TMDLs. These proposed changes will consider the results of recent scientific studies, the updated bacteria objectives proposed by the California State Water Resources Control Board, and other lines of evidence that include this CBA. The Regional Water Board will consider the permittees recommendations in their reconsideration and updates to the Bacteria TMDL.

RECOMMENDATIONS FOR FUTURE RESEARCH

In addition to ongoing studies, additional research in new fields could inform future analysis regarding changes to the Bacteria TMDL. Recommendations are organized by scenario types and analysis sections, with some areas applying to all scenarios. For example, all scenarios would benefit from more granular data on peoples' response to unsafe days. The Stormwater scenario types could benefit from more observed, site-specific results instead of modeled bacteria removal and additional information on local costs for implementing and maintaining BMPs. For the Human Sources scenario, several research areas, including additional insight into the effect of prioritizing septic systems versus sewer mains or sewer mains versus laterals, extrapolating health risk model to region-wide beaches and focusing on bacteria causing illnesses rather than indicator bacteria, could provide greater accuracy and specificity for concentrations. Stream scenarios would benefit from field testing of infiltration rates and an understanding of the opportunities for additional restoration downstream from new retention practices upstream, while the benefits analysis could refine values from additional research on BMPs' riparian habitat functions and peoples' responses to improved beach conditions. Table 74 provides additional detail on these research areas.

Table 74. List of potential future studies

	RESEARCH PROJECT IDEA	GOAL	POTENTIAL EFFECT ON CBA NUMERIC RESULTS
All Scenarios			
1	Quantify region-wide beach visitation during wet and dry weather, including the mix of local residents, tourists, and age groups	Improve exposure and recreation estimates for benefit calculations	Medium
2	Once pathogen and bacteria loading from human sources during wet weather are quantified, re-do watershed modeling to account for land use runoff sources.	Update models such that they have a more realistic representation of sources for purposes of selecting controls and evaluating benefits.	Medium to Large
Stormwater Scenarios			
3	BMP effectiveness testing for pathogens and indicator bacteria in the San Diego Region	Provide more realistic estimates for BMP's ability to reduce health effects from stormwater and achieve TMDL compliance	Medium
4	Site-specific cost estimation in non-WQIP modeled watersheds	Provide more accurate costs for implementing green infrastructure and other BMPs in watersheds where previous cost modeling did not occur	Small
Human Sources Scenarios			
4	Quantify pathogen and bacteria loading from human sources during wet weather	Prioritize among sewer, septic, transient population remediation options	Medium
5	Stormwater dilution measurements and/or modeling in the nearshore ocean	Enables extrapolation of health risk models region-wide beaches	Large
6	Apply better indicators of human health to improve confidence of the analyses, such as actual pathogens or human waste, instead of relying on fecal indicator bacteria	Focus on pathogen sources rather than indicator bacteria	Large
Stream Scenarios			
7	Conduct a more thorough assessment of infiltration potential for restoration projects	Evaluate whether assumed infiltration rates are achievable and would not result in other issues (geotechnical, rising water tables and increased sanitary system inflow and infiltration, increased groundwater flows mobilizing pollution, etc.)	Small
8	Determine effects on Stream scenarios from ongoing efforts to implement hydromodification controls in the watershed	Determine whether strategies to comply with MS4 permit and meet local demands for freshwater will increase stormwater retention and reduce downstream erosion providing additional area for stream restoration	Small
Benefits Analysis			
9	Determine type of riparian habitat benefits from BMPs	Better understand effects of BMPs on functions of riparian habitat	Medium
10	Understand peoples' response to improved wet weather beach conditions	Assess response time for behavior change due to efforts for increasing beach safety	Small

APPENDIX A: STORMWATER SCENARIOS TECHNICAL MEMO

TETRA TECH

MEMO

To:	Cost Benefit Analysis (CBA) Steering Committee
Cc:	Ruth Kolb, City of San Diego; Jo Ann Weber, County of San Diego
From:	Tetra Tech CBA Team
Date:	May 9, 2017
Subject:	Bacteria CBA: Technical Approaches and Work Products to Support the Evaluation of Stormwater Implementation Scenarios and Other Analyses

1.0 INTRODUCTION

A Cost Benefit Analysis (CBA) was conducted to evaluate the costs and benefits of meeting the targets established based on the 2010 Bacteria TMDL for Beaches and Creeks in the San Diego Region (2010 Bacteria TMDL) and various alternative scenarios to help guide future TMDL and implementation efforts. To support development of the CBA, Tetra Tech worked closely with the CBA Steering Committee and Municipal Separate Storm Sewer System (MS4) permittees to estimate stormwater costs and the associated benefits for each scenario. This technical memorandum summarizes the approaches, modeling information, and key data/assumptions that were used to develop the following CBA work products:

1. Estimated bacteria load reduction (LR) and cost of compliance for each CBA scenario
2. Literature review of Best Management Practice (BMP) bacteria removal efficiency
3. Effects of annual weather patterns on BMP efficiency (year-over-year [YOY] analysis)
4. Additional data to support the analysis of CBA benefits and other pollutant co-benefits

The approaches discussed in the following sections were designed to meet the following objectives:

- Provide data needed to support the evaluation of each CBA scenario
- Develop a consistent approach to estimate the compliance cost for each scenario, including the following steps:
    - Calculate the change in LR and associated cost for each scenario
    - Compare the results of each scenario to the costs associated with meeting the 2010 Bacteria TMDL (e.g., Water Quality Improvement Plan [WQIP] costs)
    - Utilize current WQIP modeling results to extrapolate to non-modeled watersheds
- Evaluate BMP benefits over time, considering changes in weather and flow patterns each year. Also, review available literature and local BMP studies to assess BMP effectiveness for different bacteria indicators (fecal coliform vs. *Enterococcus*)
- Provide additional data and guidance to support the analysis of benefits and co-benefits

Several of the San Diego WQIPs included detailed watershed modeling to support the identification of numeric goals, strategies, implementation schedules, and BMP cost estimates in some cases. The City of San Diego and other MS4 permittees supported the use of modeling to quantitatively assess pollutant LR needs and identify the most cost-effective BMP strategies in the following watersheds: Los Peñasquitos, Scripps (part of the Mission Bay WQIP), Tecolote (part of the Mission Bay WQIP), San Diego River, and Chollas (selected as the highest priority

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watershed in the San Diego Bay WQIP). The models and other information that was used to develop these WQIPs provided the foundation for the CBA stormwater implementation scenario analyses. The models provided the ability to estimate the LR and associated cost for each of the adjust bacteria regulatory endpoint scenarios using a consistent framework and set of assumptions. Table 1 summarizes the Bacteria TMDL watersheds and availability of modeling and cost information to support the CBA analyses. See Section 7 for more information on the modeling. For watersheds that do not include detailed modeling and cost information, standardized approaches were developed to provide the required outputs, as described in the following sections.

Table 1. 2010 Bacteria TMDL watersheds

Watershed Name	Watershed Name Abbreviation	WQIP Cost	Note
San Joaquin Hills HSA (901.11)/Laguna Beach HSA (901.12)	Laguna Beach	Not available	Non-WQIP modeled watershed
Aliso HSA (901.13)	Aliso	Not available	Non-WQIP modeled watershed
Dana Point HSA (901.14)	Dana Point	Not available	Non-WQIP modeled watershed
Lower San Juan HSA (901.27)	San Juan	Not available	Non-WQIP modeled watershed
San Clemente HA (901.30)	San Clemente	Not available	Non-WQIP modeled watershed
San Luis Rey HU (903.00)	San Luis Rey	Not available	Non-WQIP modeled watershed
San Marcos HA (904.50)	San Marcos	Not available	Non-WQIP modeled watershed; focus on the TMDL drainage area (Cottonwood Creek subwatershed)
San Dieguito HU (905.00)	SDG	Not available	Non-WQIP modeled watershed
Miramar Reservoir HA (906.10) - Los Peñasquitos	Los Pen	Available for all jurisdictions in the watershed	WQIP modeled watershed
Scripps HA (906.30)	Scripps	Available	WQIP modeled watershed; includes ASBS drainage area; excludes Mission Bay drainage area
Tecolote HA (906.50)	Tecolote	Available for the entire watershed (City of San Diego only)	WQIP modeled watershed
Mission San Diego HSA (907.11)/Santee HSA (907.12) - San Diego River watershed	SDR	Available for the City of San Diego only	WQIP modeled watershed; Lower SDR only
Chollas HSA (908.22)	Chollas	Available for the City of San Diego only	WQIP modeled watershed

The CBA evaluated a range of scenarios that have different cost and benefit implications. These scenarios were grouped into three main categories for analysis: 1) adjust bacteria regulatory endpoints, 2) adjust strategy for achieving bacteria LRs, and 3) change schedule of compliance. Tetra Tech primarily focused on the regulatory endpoint scenarios, but also provided key information and recommendations to support the other scenarios.

2.0 COMPLIANCE COSTS AND APPROACHES

2.1 GENERAL FRAMEWORK

The following general framework was used to estimate the LR and compliance cost for each CBA scenario and watershed. As shown in Figure 1, the WQIP models that were developed by Tetra Tech for the City of San Diego were used to estimate the LR and cost for the WQIP watersheds. For the watersheds which were not modeled (i.e., non-WQIP modeled watersheds), information from the WQIP watersheds was extrapolated to estimate the LR and compliance cost associated with each scenario. See Section 7 for the models used in the WQIP and non-WQIP watersheds. The YOY BMP efficiency analysis utilized the modeling results to evaluate the impact of changing weather and flow conditions over time for each of the scenarios.

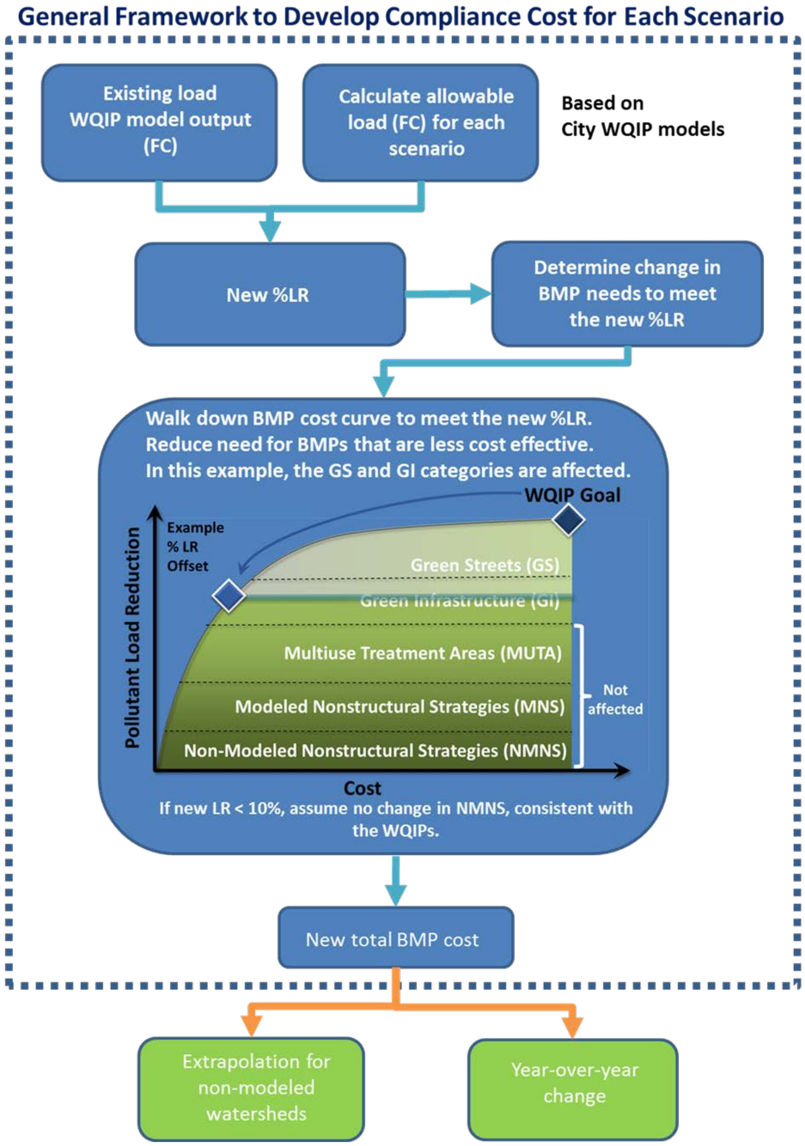

Figure 1. General framework to estimate LR and total BMP cost for each CBA scenario

2.2 APPROACHES FOR THE WQIP WATERSHEDS

LR and cost information for each scenario were derived using the WQIP models[1] to provide a consistent basis for the analysis. During development of the WQIPs, costs were estimated to achieve compliance with the San Diego Basin Plan WQO of 400 colonies/100ml for fecal coliform. Several CBA scenarios focus on compliance with recently proposed *Enterococcus* concentrations based on USEPA's 2012 Recreational Water Quality Criteria[2] or the Surfer Health Study (SHS; Schiff et al. 2016). In order to compare the costs for these scenarios with the WQIP costs, the *Enterococcus* endpoints for these scenarios were converted to fecal coliform-based WQOs. Note that the health risk relationship between gastrointestinal illness and fecal coliform bacteria typically differs from the risk relationship with *Enterococcus*. In addition, although *Enterococcus* and fecal coliform bacteria are routinely used to assess human health risk from recreational use, they represent indicators or surrogates for the presence of human pathogens. In fact, many of the pathogens of interest are not bacteria. Due to these limitations, the scenario results should be interpreted with care, as with any analysis that is based on indicator organisms.

The approaches that were used to derive fecal coliform-based WQOs for these adjust bacteria regulatory endpoint scenarios are summarized in Table 2.

Table 2. CBA scenarios and associated fecal coliform-based WQOs

Scenario	Description	Fecal coliform WQO endpoint (colonies/100ml)	Fecal coliform WQO is based on
2010 TMDL via WQIP	WQIP costs associated with meeting the 2010 Bacteria TMDL	400	Current fecal coliform WQO in the San Diego Basin Plan. This scenario provides the baseline cost for comparison to all other scenarios
2012 REC criteria	USEPA 2012 Recreational Water Quality Criteria	565	Based on USEPA's 2012 Recreational Water Quality Criteria and associated data (i.e., NEEAR[3] data). Note that an *E. coli* concentration of 100 (colonies/100ml) is the geometric mean and an *E. coli* concentration of 320 (colonies/100ml) is the 90th percentile of the NEEAR data based on an estimated additional gastrointestinal illness rate of 32 per 1,000 primary contact recreators (32/1,000). 565 (colonies/100ml) is the 97th percentile of the NEEAR *E. coli* data. Use of the 97th percentile value was recommended as an equivalent not-to-exceed value (personal communication with Jeff Soller and Ken Schiff). This recommendation was based on a typical sampling regime and the use of *E. coli* data as a surrogate for fecal coliform, given that the NEEAR data do not contain fecal coliform measurements (personal communication with Jeff Soller and Ken Schiff). In general, fecal coliform-health risk is closer to the

[1] See Section 7 for more information on the modeling.
[2] "[US]EPA has released its 2012 recreational water quality criteria recommendations...These recommendations are intended to serve as guidance to states, territories and authorized tribes in developing water quality standards to protect swimmers from exposure to water that contains organisms that indicate the presence of fecal contamination." (https://www.epa.gov/sites/production/files/2015-10/documents/rec-factsheet-2012.pdf)
[3] During development of the 2012 Recreational Water Quality Criteria, USEPA conducted the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR).

Scenario	Description	Fecal coliform WQO endpoint (colonies/100ml)	Fecal coliform WQO is based on
			E. coli-health risk relationship than *Enterococcus*. See Table 3 more on the percentile calculations.
Move compliance locations	2010 Bacteria TMDL; move wet-weather compliance location down-coast based on winter recreational use	400	Current fecal coliform target in the San Diego Basin Plan. Apply a dilution factor (DF) to fecal coliform concentrations to estimate the required LR. No change in the fecal coliform WQO. DF of 22 was applied. Further details on the derivation of the DF are provided following this table.
Flow-based regulatory suspension	2010 Beach TMDL; suspend compliance with REC-1 requirements under high flow condition	400	Current fecal coliform target in the San Diego Basin Plan. Apply high flow suspension (HFS) methodology used in the Los Angeles Region Basin Plan. Apply HFS for days with greater than or equal to a 0.5 inch rainfall, plus the next 24 hours following the rain event. Apply to all fresh waterbodies, rather than focus on certain concrete-lined channels (as specified in the Los Angeles Basin Plan) for CBA comparison purposes.
Create beach-specific WQO	Using SHS data; site-specific LR goals for the study beaches (Ocean Beach and Tourmaline)	2,215	Beach-specific WQO based on SHS results; only apply to the SHS watersheds (SDR at Ocean Beach and Scripps at Tourmaline Surfing Park). 2,215 (colonies/100ml) is the 97th percentile of fecal coliform data at 32/1,000 from the SHS. Note that the SHS reported an *Enterococcus* concentration of 175 (colonies/100ml) and a fecal coliform concentration of 61 (colonies/100ml) associated with 32/1,000; thus, the 97th percentile was calculated using fecal coliform (61 colonies/100ml) assumed as the geometric mean and the standard deviation of fecal coliform data from the SHS. Use of the 97th percentile value was recommended as an equivalent not-to-exceed value (personal communication with Jeff Soller and Ken Schiff). See Table 4 for more on the percentile calculations.
Adjust wet-weather beach WQO	Using SHS data; site-specific LR goals for all beaches	2,215	Beach-specific WQO based on SHS results; apply to all watersheds

For all scenarios, the compliance location was defined as the watershed outlet above the tidal prism, with no consideration of tidal mixing and dilution. The exception is the 'move compliance locations' scenario, which is based on achieving compliance at a point further downcoast based on winter recreation use patterns, where dilution is expected. Also, the LR calculation included consideration of natural sources of bacteria that may not cause human health risk through incorporation of an allowable exceedance frequency (AEF) based on previous reference studies in the region. An allowable exceedance load (AEL) was calculated based on a 22% AEF for wet weather exceedance days (sum of the loads from the 22% highest exceedance days). The 2010 Bacteria TMDL and subsequent planning efforts (Comprehensive Load Reduction Plans [CLRPs] and WQIPs) followed the same approach, which utilized the watershed model loading results (freshwater; outlet of each watershed) to provide a conservative LR estimate that does not consider tidal mixing along with applying the 22% AEF. This approach was used to develop the CBA scenarios to be consistent and allow for comparison across scenarios.

Table 3. Percentile calculation of the USEPA 2012 Recreational Water Quality Criteria NEEAR data for use in developing the '2012 REC criteria' fecal coliform endpoint (565)

Fecal Indicator Bacteria (FIB)	Geometric Mean (GM)	Statistical Threshold Value (STV)	95th	97th	99th	Calculation
Enterococcus	30	110	159	202	317	Use USEPA 2012 SD =0.44
E. coli (as fecal coliform surrogate*)	100	320	455	565	852	Use USEPA 2012 SD = 0.4

* No fecal coliform data were collected as part of the USEPA NEEAR study to develop USEPA 2012 Recreational Water Quality Criteria.
SD = standard deviation

Table 4. Percentile calculation of the SHS data for use in developing the 'Create beach-specific WQO' and 'Adjust wet-weather beach WQO' fecal coliform endpoint (2,215)

FIB	At the additional gastrointestinal illness rate of 32/1,000 people	90th	95th	97th	99th	Calculation
Enterococcus	175[A]	2,674	5,791	9,567	24,686	Applied the SD from the SHS *Enterococcus* data, excluding data from discharge stations (OBDIS and TDIS): SD=0.923943
Fecal coliform	61[B]	705	1,411	2,215	5,187	Same as above, but for fecal coliform: SD=0.829454

SD = standard deviation
[A] See Figure 2 for SHS *Enterococcus* concentration and additional gastrointestinal illness rate for wet weather.
[B] See Figure 3 for SHS fecal coliform concentration and additional gastrointestinal illness rate for wet weather.

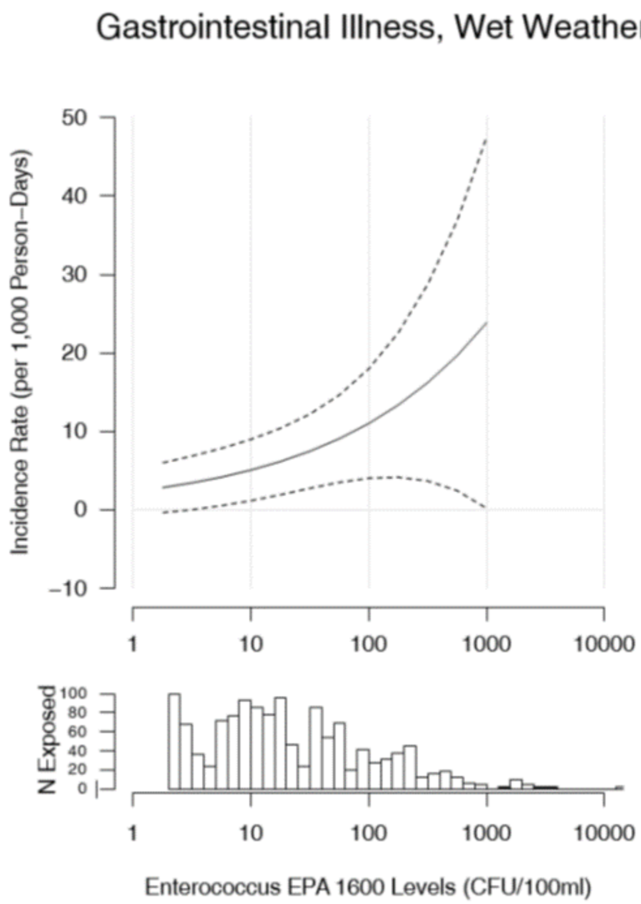

Figure 2. Additional gastrointestinal illness rates associated with *Enterococcus* concentrations measured during wet weather periods, predicted from a log-linear model among surfers at Tourmaline Surfing Park and Ocean Beach, San Diego, CA during the winters of 2013-14 and 2014-15.

Wet weather was defined as >0.25 cm of rain in 24 hours. Dashed lines indicate 95% confidence intervals and histograms show the distribution of *Enterococcus* exposure in the population; Source, Figure 4 at p. 26 of the SHS (Schiff et al., 2016).

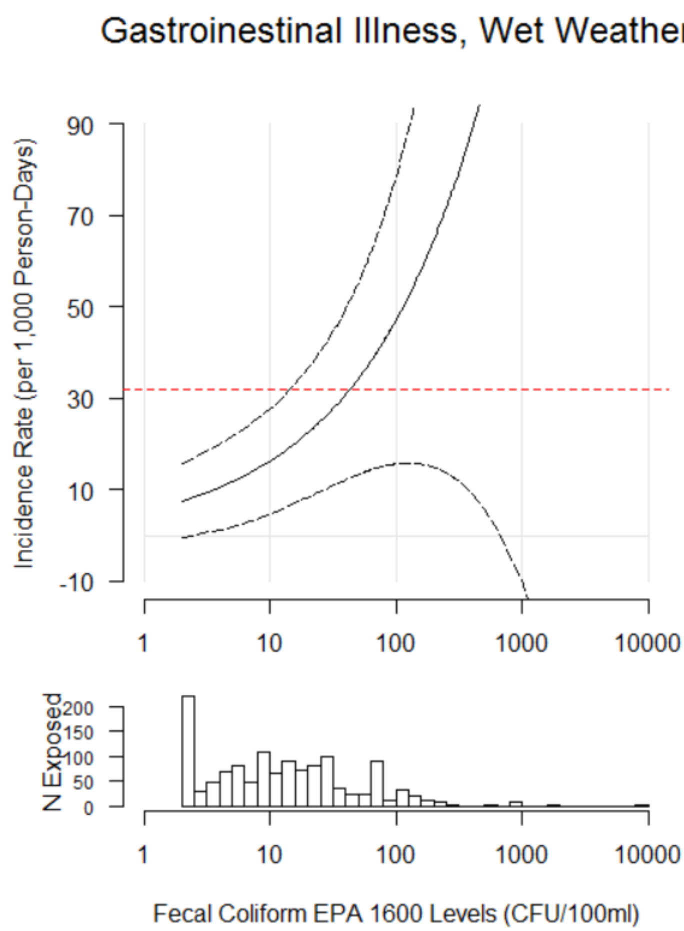

Figure 3. Additional gastrointestinal illness rates associated with fecal coliform concentrations measured during wet weather periods, predicted from a log-linear model among surfers at Tourmaline Surfing Park and Ocean Beach, San Diego, CA during the winters of 2013-14 and 2014-15.

Wet weather was defined as >0.25 cm of rain in 24 hours. Dashed lines indicate 95% confidence intervals and histograms show the distribution of *Enterococcus* exposure in the population. Red dashed line indicates the 32 additional gastrointestinal illness per 1,000 people. This plot was generated using SHS fecal coliform data and R scripts download from the public site https://osf.io/hvn7s via personal communication with one of SHS authors, B. Arnold. Note that the SHS report presented only an *Enterococcus* plot and no fecal coliform plot.

For the 'move compliance locations' scenario, a DF of 22 was derived using SHS fecal coliform data and the following approach, which was based on the SHS Quantitative Microbial Risk Assessment (QMRA) assumptions and calculations.

1) Dry weather data were excluded (only analyzed wet weather data).
2) Data from OB1 which is the ocean monitoring site closest to the Ocean Beach discharge site (OBDIS) were excluded, consistent with the DF calculation using *Enterococcus* data performed in the SHS QMRA (Figure 4). Note that in the 'move compliance location' scenario, the DFs were calculated based on the fecal coliform data because the scenario endpoint is fecal coliform-based.
3) Only data from the sampling period when all seven sites (OB2, OB3, OB4, OBDIS, T1, T2, and TDIS) were sampled, were used to calculate DFs. This period (12/3/14 – 3/5/15) yielded 17 observations per site.
4) DFs were calculated by dividing the discharge concentration by the concentration at an ocean monitoring site on the same date (e.g., the fecal coliform concentration on 3/2/15 was 4,800 (colonies/100ml) at OBDIS and 14 (colonies/100ml) at OB2. Thus, the DF at OB2 on 3/2/15 was 4,800/14 = 343).

5) Data from each of the ocean monitoring sites were analyzed separately (OB2, OB3, OB4, T1, and T2).
6) The median of DFs at each site were calculated (e.g., the median DF at OB3 and OB4 are 80 and 109, respectively). The medians DFs among the five sites range from 22 to 109.
    - o The DF of 85 reported in the SHS represents the median of the median values among the sites for *Enterococcus*: "The median dilution factors among ocean monitoring sites ranged from 25 to 150 relative to the discharges. We used these median values in the QMRA for the lower and upper bounds of a triangular distribution, with a most likely value of 85, which was the median among all sites." (p. 102 of the SHS [Schiff et al. 2016])
7) The DF of 22 (based on the SHS fecal coliform data) is the minimum of the median DFs among the sites. The minimum was selected, instead of the median (as was done in the SHS QMRA), to provide a more conservative estimate of dilution for the 'move compliance locations' scenario.

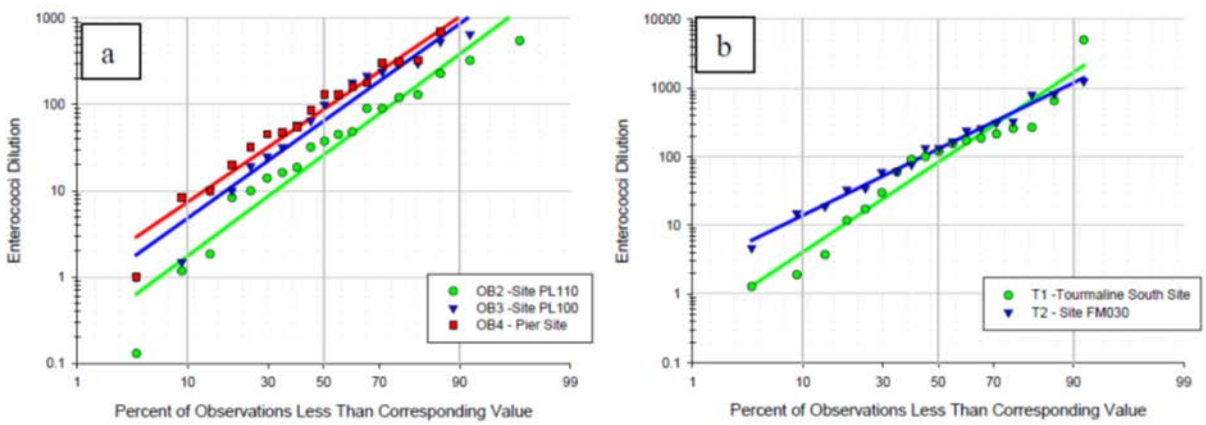

Figure 4. Dilution estimates using *Enterococcus* data in the SHS QMRA. Source: Figure 2 on p. 102 of the SHS report (Schiff et al. 2016). Note that OB1 was excluded in the DF calculation as shown in Plot a.

For each scenario, the following steps were performed to estimate scenario-specific compliance costs.

- Determine the fecal coliform-based WQO endpoint
- Calculate the fecal coliform-based allowable load
- Calculate the required LR and LR% (with an AEF of 22%) based on Water Year (WY) 2003, which is the representative (average) rainfall year that was used to develop the WQIPs
- Follow the general framework (Figure 1) to calculate the compliance cost
- As noted previously, tidal mixing was not considered in the modeling in order to provide a conservative LR estimate and because the models were calibrated based on available upstream monitoring data, consistent with the 2010 Bacteria TMDL and subsequent planning efforts. In other words, the compliance point is located at the outlet of each watershed above the tidal prism (freshwater discharge before tidal mixing and dilution occurs), except for the 'move compliance locations' scenario. See Section 5.2 for additional discussion on tidal extent.

Assumptions used to estimate WQIP scenario costs:

- Costs were estimated to achieve wet weather compliance which is the limiting condition, consistent with the WQIP assumptions. Wet weather BMPs will also help reduce dry weather impacts, along with dry weather specific strategies (irrigation runoff reduction, dry weather diversions, etc.)
- The total cost was not reduced below the cost associated with implementation of non-modeled non-structural strategies (estimated NMNS LR=10%), consistent with the WQIP assumptions. When the target LR% was below 10%, the NMNS cost was held fixed.

- WQIP costs are based on Fiscal Year (FY) 16-31. Note that the implementation period for Los Pen is FY16-35, while the implementation period for the rest of the WQIP watersheds is FY16-31. As a reminder, the LRs and LR% were based on WY2003 while the compliance costs are based on the compliance period.
- Los Pen: the estimated LRs and costs for the different jurisdictions were combined to develop a composite cost curve for the entire watershed
- SDR: applied the WQIP model that was developed for the lower watershed (City of San Diego jurisdictional area) to calculate the LR% goal and total cost for the entire watershed
- Chollas: applied the same approach as SDR to calculate the total cost
- Scripps: The WQIP cost includes the NMNS cost and previously planned BMP costs; therefore, the WQIP cost is not proportional to the LR%.

2.3 EXTRAPOLATION APPROACH FOR THE NON-WQIP MODELED WATERSHEDS

As discussed in the general framework, information from WQIP modeled watersheds was extrapolated to estimate the LR and cost for the non-modeled watersheds (Orange County watersheds, San Luis Rey, San Marcos, and SDG) for each CBA scenario.

The extrapolation approach for the non-modeled watersheds is summarized below:

- LR estimation
    - Watershed models were developed to support the 2010 Bacteria TMDL. These models were used to simulate existing conditions for the time period 1990–2002 and the LRs required to meet applicable WQOs (i.e. TMDL condition). The TMDL models were developed prior to the WQIP models and have different model land uses, hydrology, and water quality parameters.
    - The TMDL models were updated to better represent water quality and hydrology based on an improved weather representation and updated parameters based on the WQIP models. Model updates included:
        - Precipitation and potential evapotranspiration data
        - Improved hydrology parameterization, including irrigation representation
        - Improved water quality (bacteria) parameterization
    - After the model updates were completed, the updated TMDL models were run for the representative time period (WY2003) to produce a daily output water quality time series the estimate the existing load, allowable load, required LR, and target LR%.
    - See Section 7 for more information on the modeling.

- Compliance cost estimation
    - A composite cost curve (Figure 5) from all the WQIP cost curves was developed and used to estimate scenario costs for the non-WQIP modeled watersheds.
    - The composite cost curve was adjusted to be consistent with the baseline load for each non-WQIP modeled watershed to estimate cost. This step was needed to normalize the composite cost curve for each watershed. See the composite cost curve (Table 5) and an example of the adjusted composite cost curve for the San Luis Rey watershed (Table 6).
    - The compliance cost for each scenario was estimated by walking down the cost curve following the approach discussed in Section 2.1 General Framework.

Table 5. Composite cost curve inputs

BMP Category	Composite cost curve (not adjusted)				
	Aggregate fecal coliform LR (mass; # x 10^9)	Fecal coliform LR (%)	Cumulative fecal coliform LR (%)	Aggregate cost ($M)	Aggregate unit cost ($M/# x 10^9)
NMNS	450,976	10.00%	10.00%	19.182	0.000043
MNS	16,499	0.50%	10.50%	76.936	0.004663
MUTA	215,391	5.80%	16.30%	253.811	0.001178
GI	248,765	6.30%	22.60%	170.865	0.000687
GS	756,381	21.80%	44.40%	1138.948	0.001506

GS (green street), GI (green infrastructure), MUTA (multiuse treatment area), MNS (modeled non-structural strategies), and NMNS (non-modeled non-structural strategies) according to the WQIPs
LR, load reduction
#, number of colonies
M, million

Table 6. Adjusted composite cost curve for the San Luis Rey watershed

BMP Category	San Luis Rey watershed- Adjusted composite cost curve			
	Cumulative fecal coliform LR (%)	Baseline fecal coliform load (# x 10^9) for San Luis Rey	Adjusted cost[A] ($M)	Cumulative cost ($M)
NMNS	10.00%	1,442,855	6.14	6.14
MNS	10.50%		30.76	36.9
MUTA	16.30%		98.89	135.78
GI	22.60%		62.71	198.49
GS	44.40%		474.46	672.95

GS (green street), GI (green infrastructure), MUTA (multiuse treatment area), MNS (modeled non-structural strategies), and NMNS (non-modeled non-structural strategies) according to the WQIPs
LR, load reduction
#, number of colonies
M, million
[A] Adjusted cost = Baseline fecal coliform load for the San Luis Rey watershed × Aggregate unit cost (from Table 5) × Fecal coliform LR% (from Table 6)

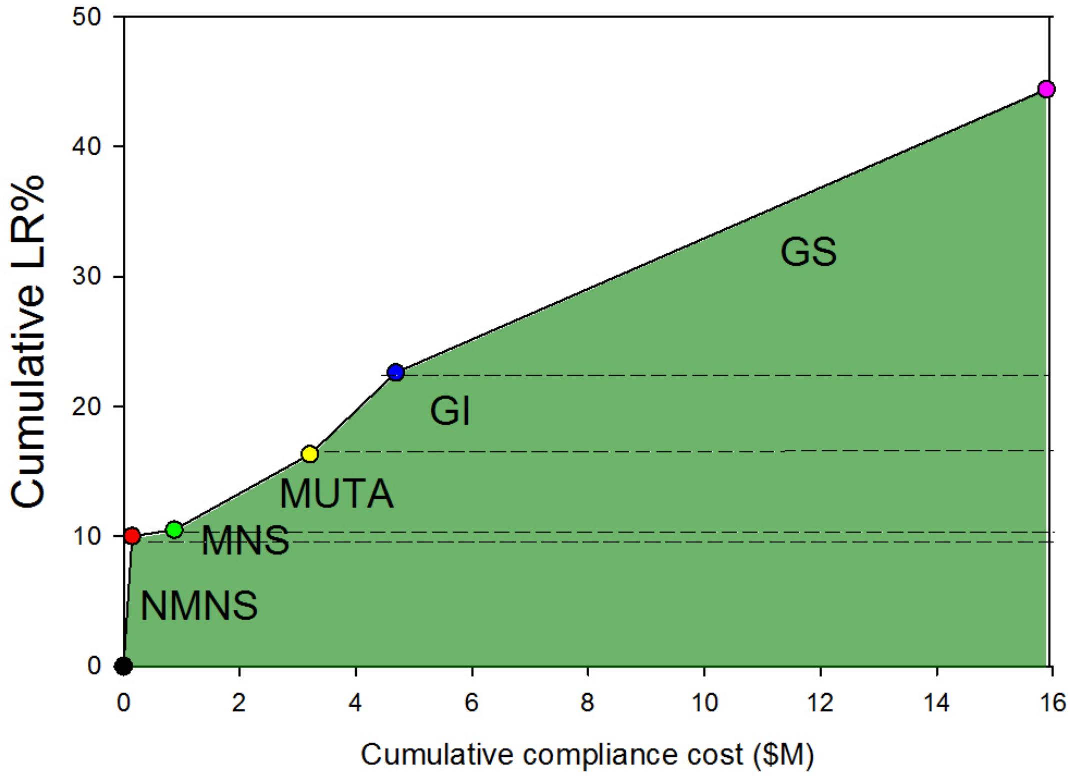

Figure 5. Composite cost curve
BMP categories (from the WQIPs): GS (green street), GI (green infrastructure), MUTA (multiuse treatment area), MNS (modeled non-structural strategies), and NMNS (non-modeled non-structural strategies)

2.4 CBA SCENARIO LR% AND COSTS

The resulting LR% and compliance costs for the CBA adjust regulatory endpoint scenarios are summarized in Table 7.

Table 7. LR% and compliance costs

Watershed Name	Scenario Name	LR%	Compliance Cost ($M)
Laguna Beach	2010 TMDL via WQIP	2.5	0.24
	2012 REC criteria	2.4	0.24
	Move compliance locations - DF 22	0	0.24
	Flow-based regulatory suspension	0	0.24
	Adjust wet-weather beach WQO - all watersheds	1.3	0.24
Aliso	2010 TMDL via WQIP	5.7	1.31
	2012 REC criteria	5.5	1.31
	Move compliance locations - DF 22	0	1.31

Watershed Name	Scenario Name	LR%	Compliance Cost ($M)
	Flow-based regulatory suspension	0	1.31
	Adjust wet-weather beach WQO - all watersheds	3	1.31
Dana Point	2010 TMDL via WQIP	2.5	0.33
	2012 REC criteria	2.4	0.33
	Move compliance locations - DF 22	0	0.33
	Flow-based regulatory suspension	0	0.33
	Adjust wet-weather beach WQO - all watersheds	1.3	0.33
San Juan	2010 TMDL via WQIP	17.6	9.14
	2012 REC criteria	14.3	6.28
	Move compliance locations - DF 22	0	0.38
	Flow-based regulatory suspension	0.1	0.38
	Adjust wet-weather beach WQO - all watersheds	0	0.38
San Clemente	2010 TMDL via WQIP	3.2	0.63
	2012 REC criteria	3.1	0.63
	Move compliance locations - DF 22	0	0.63
	Flow-based regulatory suspension	0	0.63
	Adjust wet-weather beach WQO - all watersheds	2	0.63
San Luis Rey	2010 TMDL via WQIP	15.8	127.81
	2012 REC criteria	13.87	94.93
	Move compliance locations - DF 22	0	6.14
	Flow-based regulatory suspension	1.72	6.14
	Adjust wet-weather beach WQO - all watersheds	0.27	6.14
San Marcos	2010 TMDL via WQIP	11.5	0.22
	2012 REC criteria	10.8	0.17
	Move compliance locations - DF 22	0	0.02
	Flow-based regulatory suspension	0	0.02
	Adjust wet-weather beach WQO - all watersheds	0.2	0.02
SDG	2010 TMDL via WQIP	13.04	23.93
	2012 REC criteria	11.59	16.61
	Move compliance locations - DF 22	0	1.82
	Flow-based regulatory suspension	1.24	1.82
	Adjust wet-weather beach WQO - all watersheds	0.25	1.82
Los Pen	2010 TMDL via WQIP	17.76	255.22
	2012 REC criteria	17	241.39
	Move compliance locations - DF 22	0.41	8.51
	Flow-based regulatory suspension	2.89	8.51
	Adjust wet-weather beach WQO - all watersheds	8.5	8.51
Scripps*	2010 TMDL via WQIP	10.47	4.32
	2012 REC criteria	9.6	4.32
	Move compliance locations - DF 22	0.1	4.32
	Flow-based regulatory suspension	0.6	4.32

Watershed Name	Scenario Name	LR%	Compliance Cost ($M)
	Create beach-specific WQO - SDR and Scripps only	2.9	4.32
	Adjust wet-weather beach WQO - all watersheds	2.9	4.32
Tecolote	2010 TMDL via WQIP	17.9	30.97
	2012 REC criteria	17.2	29.45
	Move compliance locations - DF 22	0.2	1.94
	Flow-based regulatory suspension	1	1.94
	Adjust wet-weather beach WQO - all watersheds	8.9	1.94
SDR	2010 TMDL via WQIP	30.8	413.83
	2012 REC criteria	29.8	395.77
	Move compliance locations - DF 22	0.16	10.7
	Flow-based regulatory suspension	5.91	10.7
	Create beach-specific WQO - SDR and Scripps only	20.6	234.06
	Adjust wet-weather beach WQO - all watersheds	20.6	234.06
Chollas	2010 TMDL via WQIP	28.75	140.35
	2012 REC criteria	27.9	131.44
	Move compliance locations - DF 22	0.25	3.73
	Flow-based regulatory suspension	4.25	3.73
	Adjust wet-weather beach WQO - all watersheds	19.3	60.52

* Note the Scripps WQIP cost is not proportional to the LR%. The cost is consistent with the assumption to hold the 10% NMNS LR fixed (no reduction below the associated cost); therefore, the cost cannot be reduced further in the other scenarios. This explains why the Scripps cost is same for all the scenarios in Table 7.

3.0 REVIEW OF BMP BACTERIA REMOVAL EFFICIENCY

The CBA examined various scenarios that are based on achieving either a fecal coliform (e.g., WQIP scenario) or *Enterococcus* (e.g., USEPA 2012, SHS) regulatory endpoint. As discussed previously, the compliance cost for each of the scenarios (i.e., BMP cost) was estimated based on the modeled LR to meet the associated fecal coliform endpoint for consistency. Scenarios that focus on achieving an *Enterococcus* endpoint were translated to an equivalent fecal coliform endpoint to allow for comparison of the CBA scenario results and because the existing BMP cost information from the WQIPs is based on achieving a fecal coliform LR endpoint. This approach assumes that BMPs equally treat fecal coliform and *Enterococcus* loads, which is consistent with the WQIP assumptions. In other words, BMP removal rates in the WQIPs represent bacteria in general and are not specific to a particular indicator. The CBA Steering Committee requested a review of this assumption, in particular whether existing BMP studies might demonstrate a difference in removal performance between fecal coliform and *Enterococcus*, and if so, whether an adjustment factor could be developed to translate fecal coliform LR to *Enterococcus* LR to more accurately reflect possible differences in BMP removal efficiency.

To address this question, various databases and literature were reviewed. This section summarizes the literature and database review of existing BMP studies that provide information on bacteria removal efficiencies in order to determine whether there are significant and consistent differences in BMP effectiveness between fecal coliform and *Enterococcus*, and whether it is appropriate and feasible to develop an adjustment factor. Table 8 present the list of BMP studies and data reviewed and a summary of the findings.

Table 8. Review of BMP studies and data for the BMP removal efficiency of fecal coliform and *Enterococcus*; studies in bold indicate paired data were examined.

BMP Studies and Data	Findings
Urban Water Resources Research Council (UWRRC) evaluation of International Stormwater BMP Database (UWRRC 2014)	In 2014, the Urban Water Resources Research Council (UWRRC)[4] compiled BMP performance data from the International Stormwater BMP Database[5]. The UWRRC performed a statistical analysis on the data compiled to determine if there was a statistical difference between the inlet and outlet data for fecal indicator bacteria (FIB). The analysis shows a wide variation in event mean concentration (EMC) data for both fecal coliform and *Enterococcus* and may indicate a certain degree of variation in the performance of the BMPs for fecal coliform and *Enterococcus*. While the report provides an overview of general BMP performance, it is intended as a guide for MS4 managers but not to provide a comparison of FC and *Enterococcus*. As acknowledged in the report, the analysis was done mostly on a limited amount of data, thus the analysis should be considered preliminary. For reasons summarized below, the analysis does not provide an accurate comparison between fecal coliform and *Enterococcus* reduction performance: • The authors defined statistical differences between the inlet and the outlet data using a *p* value of 0.1, which is double the typically accepted *p* value of 0.05. This is "due to the preliminary nature of

[4] www.uwrrc.org
[5] www.bmpdatabase.org

BMP Studies and Data	Findings
	these analyses and the lack of large amounts of data" (p. 170 of UWRRC [2014]). • The International Stormwater BMP Database, used as the primary source for the analysis, includes data compiled from a wide range of different sources. As a result, the inlet and outlet data were not paired. Inlet and outlet data from different storm events, different individual BMPs, different locations, and different years were compared as acknowledged in the UWRRC report (pp. 168 and 169). • Because the inlet and the outlet data were not paired, there is significant variation which makes it difficult to draw conclusions on the difference in BMP performance between fecal coliform and *Enterococcus*. For instance, inlet data collected in Texas were compared to outlet data collected in Wilmington, NC, potentially introducing significant variation caused by geographic conditions and temporal conditions rather that differences in BMP performance. The UWRRC report acknowledges the importance of paired data: "If the data are collected in "pairs," such as for concurrent influent and effluent samples, or for concurrent above and below samples, then the more powerful and preferred paired tests can be used." (p. 125) • Differences in the EMC data of the UWRRC Evaluation are highly influenced by differences in influent and effluent concentrations among different storms and geographic locations, as well as the BMP design configuration including depth of the soil media rather than actual differences in BMP performance. This is supported by several sources including Hathaway, J.M et al. (2011) and Chandrasena, G.I. et al.(2014) and also acknowledged in the UWRRC report (pp. 168 and 169). No paired inlet-outlet study was found that reported fecal coliform and *Enterococcus* EMC data collected for the same storm event from the same BMP.
Davies, C. M. and H. J. Bavor 2000	• Paired data: fecal coliform and *Enterococcus* removal was evaluated in the same wetland BMP (GI) and the same wet pond BMP (MUTA) • GI: fecal coliform reduction (79%) was similar to the *Enterococcus* reduction (85%). • MUTA: fecal coliform reduction (-2.5%; increase) was much lower than the *Enterococcus* reduction (23%).
Krometis, L. H et al. 2009	• Paired data: fecal coliform and *Enterococcus* removal was evaluated in the same wet pond BMP • Fecal coliform reduction (31%) was similar to the *Enterococcus* reduction (36%).

BMP Studies and Data	Findings
43rd Street and Logan Avenue Bioretention and Filtration Performance Study - Final Study Report (City of San Diego 2016)	• Bioretention and filtration BMP at the 43rd and Logan Avenue location in the City of San Diego • Paired data: both fecal coliform and *Enterococcus* data were available. • No significant difference between fecal coliform (72%) and *Enterococcus* (81%) removal via the BMP. • The fecal coliform and *Enterococcus* reduction fluctuated among different storm events. • Neither fecal coliform nor *Enterococcus* had consistent higher or lower removal via the BMP.
Stormwater Bacteria BMPs (Excel file forwarded by Chris Crompton, County of Orange)	• The dataset only contains fecal coliform and *E. coli* data, no *Enterococcus* data. • When fecal coliform and *E. coli* (as a surrogate for *Enterococcus*) were compared, % removal ranged from negative to 99% and was not consistent.
Los Pen WMA WQIP and Comprehensive Load Reduction Plan, Appendix K - Strategy Selection and Compliance Analysis	• Bacteria reduction via street sweeping was not shown in Table K-2: Street Sweeping Program. The concentration of bacteria in the removed sediment is estimated as 5.21 x10^6 colonies per pound of street sediment based on Pitt (1985). • Fecal coliform reduction via catch basin cleaning was presented only for fecal coliform in Table K-4: 6.13 MPN/kg (Tetra Tech 2012)
Proposition 84 Grant Evaluation Report: Assessing Pollutant Reductions to Areas of Biological Significance (Schiff and Brown 2015)	• This study presents estimated load reduction via BMPs for *Enterococcus*, *E. coli*, and total coliform but not fecal coliform. • BMPs discussed are primarily membrane filters and only presented information for a few vegetated swales. • Estimated wet-weather load reductions from the BMPs are summarized in Table 4.2-1 of this report, which shows that overall all three bacterial loads increased (negative reduction), with no apparent difference existed among the three indicator bacteria.

Overall, this review indicates that there is a limited number of field studies that have examined the removal of different bacteria indicators, in particular for *Enterococcus*. Further, the comparisons of fecal coliform and *Enterococcus* removal were often based on non-paired data. For example, only three studies are currently available that evaluated paired data. The UWRRC evaluation of the International Stormwater BMP Database used data that were collected and reported from a variety of sources and studies performed in a variety of geographical locations (Seattle, Texas, North Carolina, Virginia, etc.) over a long range of time (1999 through 2015). Because the International BMP database does not present the data as paired studies, it is not an appropriate source for comparing BMP performance for specific constituents. While the entire composite dataset does indicate that there is a difference in the reduction between fecal coliform and *Enterococcus*, it is likely that the variation was caused by differences in influent and effluent concentrations, geographic locations, temporal variations, and BMP design configurations rather than BMP performance alone. Further analysis of the raw data from existing datasets, including the data submitted to the International BMP Database, would likely be useful only if paired studies can be identified. All of the three paired BMP studies demonstrated that that BMP performance between fecal coliform and *Enterococcus* was similar: GI data from Davies and Bavor 2000, MUTA data from Krometis, L. H et al. 2009, and the City of San Diego 2016.

It should also be noted that the BMP mechanisms that most effectively remove fecal coliform are the same for all bacteria indicators, including *Enterococcus*, and include desiccation due to wet and dry cycles, sorption to different media types, predation due to protozoa and other grazers within the microbial community, changes in flow regimes that improve settling, and UV inactivation due to sunlight exposure and daylighting of structural BMPs (UWRRC 2014, Hunt et al 2012, Hathaway 2010, Krometis, L. H et al 2009, Davies, C. M., and Bavor, H. J. 2000). Literature sources indicate that there may be differences in survival/die-off; however, there is minimal research from BMPs that can be used to accurately quantify a difference at this time.

Due to the extremely limited availability of paired data, it is currently not feasible to evaluate the difference in BMP removal efficiencies for fecal coliform and *Enterococcus* and to develop an adjustment factor which can be applied to convert fecal coliform-based compliance costs to *Enterococcus*-based compliance costs.

4.0 YEAR-OVER-YEAR BMP EFFICIENCY ANALYSIS

A BMP efficiency analysis (i.e., YOY analysis) of the water quality benefits provided by structural BMPs was performed to estimate changes in BMP efficiency (i.e., LR) over time due to different weather patterns. The purpose of this analysis was to estimate changes in the benefits provided by structural BMPs over time, which are primarily affected by changes in weather and associated flow conditions.

General assumptions include:

- Focus on structural BMPs only
- Full implementation of all BMPs at the beginning of the simulation (i.e. not phased over the compliance schedule)
- NMNS BMPs were assumed to provide a consistent 10% LR each year, regardless of weather conditions
- The modeling period was from WY1990 – WY2015.

The analysis was conducted using a pilot watershed as follows:

- Chollas Creek was selected as the pilot watershed, with the assumption that the analysis can be generally applied to other watersheds in the region based on the following:
  - Structural BMP efficiency is driven by two factors: amount of runoff captured and the pollutant loading within that runoff. Runoff quantity is dictated by the impervious surfaces within a watershed and BMPs are placed to treat only developed areas, not undeveloped lands. Large open spaces that may be present in other watersheds would not be targeted for structural BMPs and thus do not impact the analysis. To address undeveloped areas, nonstructural control measures would be necessary if erosion or other factors exist that mobilize pollutants from undeveloped areas (e.g., plantings, installing mats for erosion control).
  - Pollutant loading from impervious land uses share a similar pattern across the region. The amount of runoff captured in a BMP is also dependent on timing. If two storm events occur back to back, then the BMP may not be able to effectively treat the second storm event. If the storm events occurred further apart, an increase in performance would likely be observed. In addition, a higher intensity event typically has larger peaks that fill a BMP faster and thus could reduce BMP performance. The YOY analysis was conducted over a long time period to remove individual event performance and evaluate long term average BMP performance.
- Water quality time-series data

    - Generated an hourly water quality simulation time series for the watershed via the Loading Simulation Program in C++ (LSPC) watershed modeling system
    - Model output was used to drive the BMP LR simulations.
    - 10% of the simulated load was removed for each time step to account for the NMNS LR benefit
- Structural BMP representation
    - Developed a generic storage/infiltration BMP design, which is generally representative of structural BMPs in the watershed
    - Distributed BMPs were assumed
        - Distributed BMPs are designed to capture and infiltrate/treat stormwater runoff. Centralized BMPs are often located in the stream channel or directly adjacent to the stream, whereas distributed BMPs are dispersed throughout the watershed on the landscape and can provide stormwater treatment in series.
- Annual LR% from WY1990 – WY2015
    - Determined the appropriate diversion rate to the BMP based on the treated impervious areas
    - Scaled up/down (optimized) the BMP size to provide the required target LR% for WY2003, which is the WQIP representative year (WQIP baseline load is the modeled WY2003 load)
        - Target LR%: the BMP was sized to ensure a 28.7% reduction in WY2003 (per the WQIP).
        - The volumes and footprints shown were associated with this size (Figure 6).
        - Other key assumptions for the BMP:
            - No depth to groundwater issues: BMPs require a separation from the groundwater by a recommended 10 feet. It was assumed that the groundwater was more than 10 feet below from the invert of the BMP
            - BMP media infiltration = 5 in/hour
            - Background infiltration[6] = 0.01 in/hour
            - Bacteria decay = 0.05 1/hour[7]
            - Underdrain bacteria % redux[8] = 60%
                - The default removal rate of 60% was selected to be consistent with the WQIP modeling methodology. This value is based on a previous literature review (Hathaway et al. 2009, Hathaway et al. 2011, Hunt and Lord 2006, Hunt et al. 2008).
    - Conducted a long-term BMP water quality simulation using an optimized BMP size
    - Summarized the annual LR% achieved from WY1990 to WY2015;
        - Note that WY1990 and WY2015 contain partial data because time-series water quality data start Jan 1, 1990 and ends Dec 31, 2014.
    - Weather conditions varied throughout the simulation period, which affected BMP efficiency.

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[6] The infiltration rate of the natural soils below the BMP
[7] The rate used in the WQIP for bacteria, including fecal coliform and *Enterococcus*
[8] The bacteria reduction within the BMP prior to exit through the underdrain

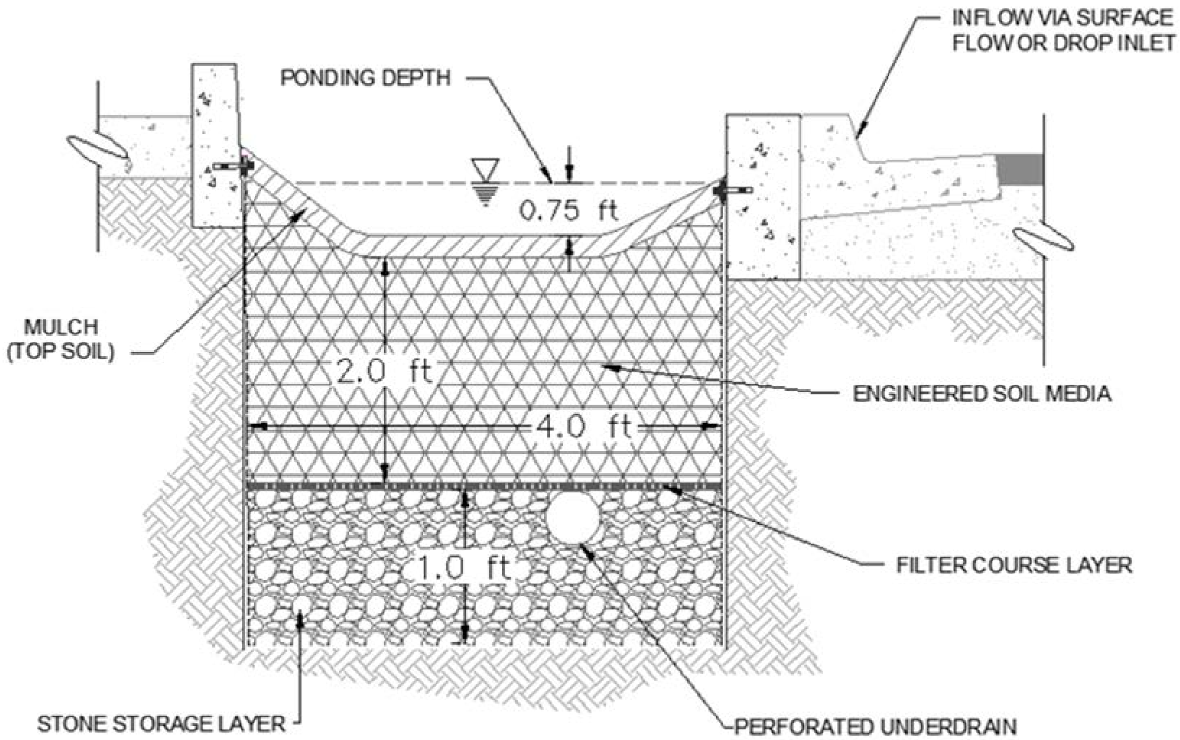

Figure 6. Assumed Cross Section of BMP in the YOY analysis

- Efficiency factors
  - Developed annual BMP efficiency factors based on the estimated annual LR% (Table 9).
- The annual BMP efficiency factors were applied to adjust the time-series *Enterococcus* modeling results, which are input data generated for the health benefit analysis of the CBA. The time-series modeling approach is discussed in the following section (5.1).

Table 9. YOY analysis: Annual LR% and BMP efficiency factors

Water Year (WY)	LR%	BMP Efficiency Factor[1]
1990[2]	30.37%	1.06
1991	29.11%	1.01
1992	28.72%	1.00
1993	25.99%	0.91
1994	28.63%	1.00
1995	27.04%	0.94
1996	31.49%	1.10
1997	28.44%	0.99
1998	27.92%	0.97
1999	31.15%	1.09
2000	29.31%	1.02
2001	30.35%	1.06
2002	31.50%	1.10
2003	28.70%	1.00
2004	31.04%	1.08

Water Year (WY)	LR%	BMP Efficiency Factor[1]
2005	26.14%	0.91
2006	30.50%	1.06
2007	31.06%	1.08
2008	31.90%	1.11
2009	27.07%	0.94
2010	29.05%	1.01
2011	28.07%	0.98
2012	30.86%	1.08
2013	29.61%	1.03
2014	33.25%	1.16
2015[2]	28.81%	1.00

[1] Rounded to two decimal places
[2] WY1990 and WY2015 contain partial data because time-series water quality data start Jan 1, 1990 and ends Dec 31, 2014

5.0 INPUT DATA FOR BENEFIT ANALYSIS

5.1 TIME-SERIES WATER QUALITY DATA

Time-series modeling output for *Enterococcus* and precipitation were generated for all the watersheds for the CBA adjust regulatory endpoint scenarios to support the public health risk calculation (change in illness rate). Instream *Enterococcus* concentrations were simulated directly by the watershed models, as described in Section 7.4.

Time-series *Enterococcus* concentration data were modeled daily and summarized annually.

- Annual *Enterococcus* concentration data
  - o Generated for four different versions
    1) Flow-weighted: annual concentrations are flow-weighted averages and were not adjusted based on the YOY annual BMP performance results.
    2) Geometric mean: annual concentrations are geometric means and were not adjusted based on the YOY BMP performance results.
    3) Flow-weighted and BMP adjusted: annual concentrations are flow-weighted averages and were adjusted based on the YOY BMP performance results via application of the annual BMP efficiency factors, as discussed in Section 4.
    4) Geometric mean and BMP adjusted: annual concentrations are geometric means and were adjusted based on the YOY BMP performance results via application of the annual BMP efficiency factors, as discussed in Section 4.
  - o An example demonstrating how the modeled *Enterococcus* concentrations were adjusted (by applying the annual BMP efficiency factors) is summarized below and the example calculation is presented in Table 10:
    - ▪ Example of BMP efficiency factor applied to the 2010 TMDL via WQIP scenario
    - ▪ BMP performance was analyzed for LR% annually (LR% column)
    - ▪ Applied an adjustment factor directly to the LR% and concentration to calculate revised LR% and *Enterococcus* concentrations

Table 10. An example of the calculation of annual *Enterococcus* concentrations adjusted for annual BMP performance

WY	*Enterococcus* concentration (colonies/100 mL)		LR%	BMP Efficiency Factor	Revised LR%	*Enterococcus* concentration (colonies/100 mL)
	Baseline	2010 TMDL via WQIP Scenario				2010 TMDL via WQIP Scenario Adjusted for the Annual BMP Efficiency
1990	35,249	25,115	28.70%	1.06	30.40%	24,522
1991	15,363	10,946	28.70%	1.01	29.20%	10,883
1992	21,760	15,504	28.70%	1.00	28.80%	15,499
1993	13,395	9,544	28.70%	0.91	26.00%	9,907
1994	26,757	19,064	28.70%	1.00	28.70%	19,083
1995	15,449	11,008	28.70%	0.94	27.10%	11,264
1996	36,032	25,673	28.70%	1.10	31.50%	24,666
1997	23,148	16,493	28.70%	0.99	28.50%	16,552
1998	19,289	13,743	28.70%	0.97	28.00%	13,893
1999	38,479	27,417	28.70%	1.09	31.20%	26,471
2000	26,105	18,600	28.70%	1.02	29.40%	18,439
2001	27,423	19,539	28.70%	1.06	30.40%	19,084
2002	62,477	44,516	28.70%	1.1	31.60%	42,762
2003	20,660	14,721	28.70%	1.00	28.70%	14,721
2004	28,252	20,130	28.70%	1.08	31.10%	19,466
2005	12,512	8,915	28.70%	0.91	26.20%	9,235
2006	39,208	27,936	28.70%	1.06	30.60%	27,229
2007	30,490	21,724	28.70%	1.08	31.10%	21,003
2008	29,012	20,671	28.70%	1.11	32.00%	19,739
2009	16,915	12,052	28.70%	0.94	27.10%	12,328
2010	21,576	15,373	28.70%	1.01	29.10%	15,297
2011	16,139	11,499	28.70%	0.98	28.10%	11,600
2012	36,939	26,319	28.70%	1.08	30.90%	25,518
2013	25,531	18,191	28.70%	1.03	29.70%	17,958
2014	26,430	18,831	28.70%	1.16	33.30%	17,626
2015	21,955	15,643	28.70%	1.00	28.90%	15,617

- Each of the four versions of the annual *Enterococcus* concentration datasets include the following:
  - Baseline daily time series of wet-days, including: date, precipitation, flow, and *Enterococcus* concentration modeled
    - Wet-days were defined as 0.2 inch rainfall over 24 hours and the following three days.
  - Average annual wet-weather *Enterococcus* concentrations were generated as follows:
    - Scenario specific daily average wet-day *Enterococcus* concentration by WY with allowable exceedances excluded from the average and summary statistics (mean, median, 25th and 75th percentiles, minimum, and maximum) across WYs; we recommended the use of this version.

- Daily *Enterococcus* concentration data
    - Generated for two separate weather conditions: 1) wet-weather only and 2) all weather (wet + dry weather)
    - Generated for two different versions: 1) not adjusted based on YOY BMP performance efficiency and 2) adjusted based on YOY BMP performance efficiency.
    - The daily average wet-day *Enterococcus* concentrations were calculated as follows:
        - Baseline daily flow and *Enterococcus* concentration output were generated using the updated Bacteria TMDL Reopener Models (City of San Diego 2016a) and the updated 2010 TMDL Model for WQIP and non-WQIP watersheds, respectively; see Section 7.4 for more details on the model versions.
        - Wet days and allowable exceedance days were flagged in the baseline time series
        - Baseline daily wet-day concentrations were adjusted per scenario by applying the applicable scenario LR%.
        - Note that the 2010 Bacteria TMDL and WQIPs focused on annual load reduction. WQIP BMP needs were based on meeting the required annual load reduction (based on WY2003 as a representative year). Average annual daily concentrations calculated, as described above, consistent with this annual performance concept; however, adjusted daily concentrations were not modeled explicitly. The daily concentrations for each scenario are based on the daily baseline flow and concentrations and the annual LR% removal to achieve compliance with each scenario. The calculated daily concentrations were recommended to estimate relative differences in values (e.g., health risks) among the scenarios, but are not appropriate to describe daily BMP performance for each of the scenarios. The LR% from each scenario was applied to the wet day results, although we continued to recommend using annualized results, if possible (for the reasons discussed above).
        - Although all weather (dry- and wet-weather) data were generated to support the CBA health risk benefit analysis, we recommended caution with extrapolating these wet weather-based results to dry conditions, recognizing the modeling limitations for dry weather (e.g., limited continuous dry-weather monitoring data used for calibration of the models) and the understanding that the CBA scenario endpoints (and the corresponding BMP LR%s and costs) are specific to addressing wet weather critical conditions only.

- Scripps: daily and annual *Enterococcus* data were generated for the two subwatersheds that drain to Tourmaline, as well as for the entire Scripps watershed (excluding the Mission Bay drainage).

Precipitation data: a list of the precipitation stations and data were provided for the CBA analysis, as discussed below.

- Daily precipitation data for the entire modeling period for both wet and dry weather for all the watersheds
- Summary of rain gages used for the CBA input data
- List of rain gages for the daily and annual *Enterococcus* data generation
- List of rain gages used for model development

5.2 TIDAL RANGES

As discussed previously (Section 2.2), the WQIP modeling did not consider tidal mixing and dilution, consistent with the 2010 Bacteria TMDL modeling. To confirm this, the tidal ranges in Chollas, Los Pen, SDG, Tecolote, and SDR and proximity to the mass loading stations (that were used to support model development and calibration) were evaluated. Data on tidal elevations were obtained from NOAA online (https://tidesandcurrents.noaa.gov/map/), which were used to create high tide boundary maps. Figure 7 is an example of the tidal influence map for SDR. The map indicates that OBDIS (a discharge site used in the SHS) would be affected during all high-tide periods, while the MLS (SDR mass loading station) would be unaffected by tidal influence. Based on this finding, we recommended that an appropriate dilution factor be applied to the time-series *Enterococcus* data for calculation of the public health risk (illness rate) information for each scenario.

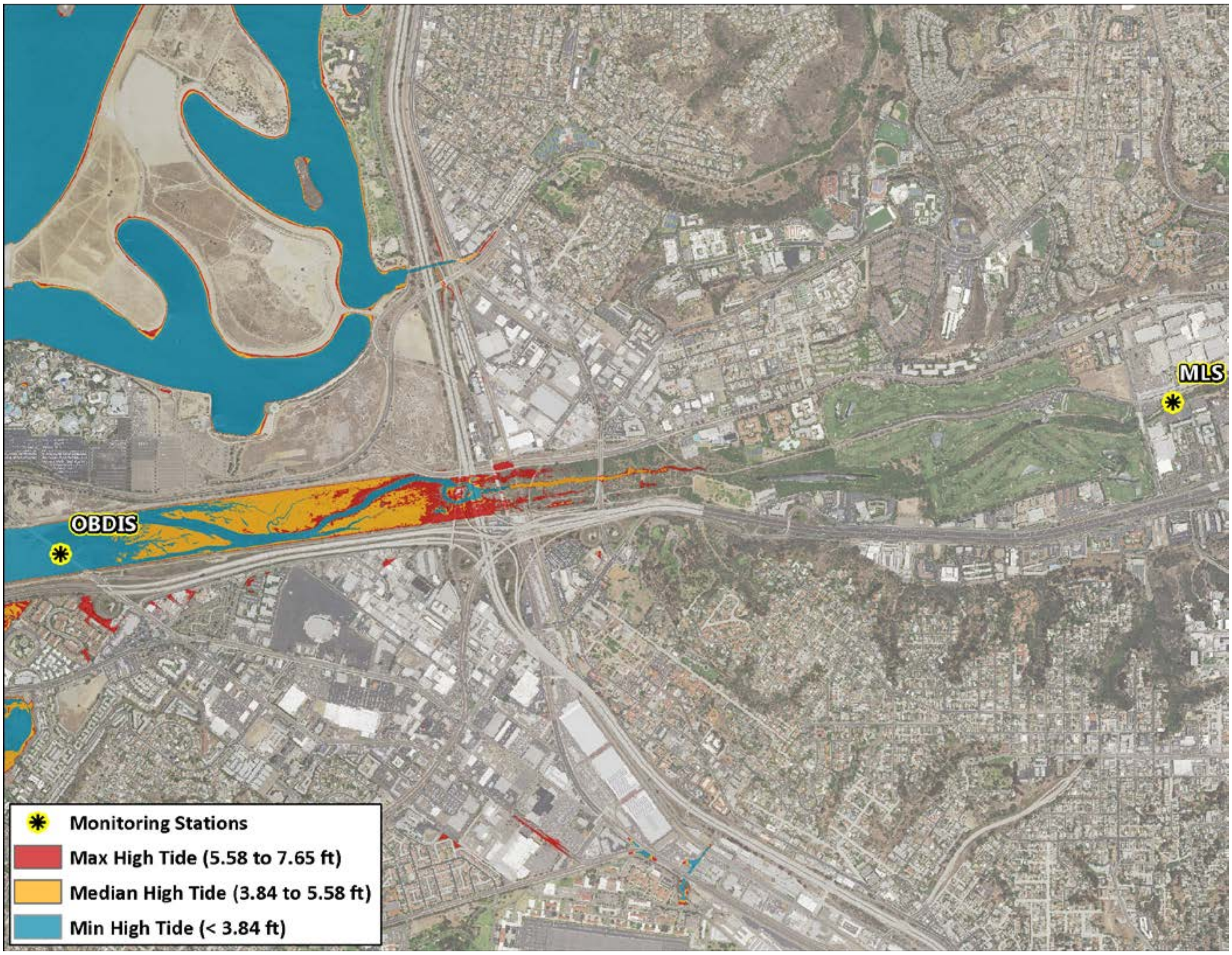

Figure 7. Tidal influence map of the downstream portion of SDR

5.3 INPUT DATA FOR ANNUAL COST ESTIMATES

Input data provided for the CBA annual cost estimation including the following:

- WQIP BMP implementation schedules (interim and final numeric goals)
- Estimated BMP project cost savings for the City of San Diego
- City of San Diego WQIP watershed GI and GS BMP phasing schedules: Tecolote, SDR, Chollas, and Los Pen
- Annual costs for City of San Diego WQIP watersheds: These estimated costs are only for City jurisdictional areas within SDG, Los Pen, Tecolote, Chollas, and SDR. The costs include GF (General Fund) = O&M (operation and management) costs and CIP (Capital Improvement Projects) = Construction Costs. Note that construction costs also include planning/design costs for some years.

Assumptions and approaches to develop the WQIP BMP implementation schedules and cost savings are summarized below.

- BMP Implementation schedule:
  - An average BMP implementation schedule was developed based on the fecal coliform LR% schedule from the following WQIP watersheds: Chollas, SDR, Los Pen, and Tecolote. LR% schedules are available for Chollas for the entire watershed, SDR for the City of San Diego jurisdictional area only, Los Pen for the City of San Diego jurisdictional area only, and Tecolote for the entire watershed. The average % BMP implementation level per milestone year was calculated as the average LR% per milestone year divided by the average final LR% (i.e., final fecal coliform LR% target at FY31=21%).

Table 11. Average BMP implementation schedule

Fecal coliform % Load Reduction Target	FY19	FY24	FY29	FY31	Reference
Tecolote - City jurisdictional area	4.00%	9.00%	12.00%	17.90%	Table 4-1 of Mission Bay WMA WQIP
SDR - City jurisdictional area	5.20%	17.30%	23.90%	34.70%	Table 3-11 of SDR WMA WQIP
Chollas - Watershed total	5.00%	15.00%	26.00%	29.00%	Table 4-1 of San Diego Bay WMA WQIP
Los Pen - City jurisdictional area	0.30%	1.00%	1.40%	2.00%	Table 4-11 of Los Pen WMA WQIP
Average LR%	4.00%	11.00%	16.00%	21.00%	
Average % BMP implementation level	19% (4%/21%)	52% (11%/21%)	76% (16%/21%)	100% (21%/21%)	

- Potential project cost savings due to synergies
  - Developed for use in estimating BMP costs associated with the CBA ‘change schedule of compliance’ scenarios, as appropriate
  - An estimated 15% cost saving was identified for BMP construction costs. This cost savings is applicable for items that would not be duplicated if projects were bundled. For example, cost savings may occur in the mobilization/demobilization, traffic control, field orders and construction activities. Specifically, items such as demolition, asphalt pavement removal and replacement, and excavation would not have to be duplicated for water quality and flood control projects that are

bundled. This cost savings is based on review of historic construction costs for these items in the San Diego region.

- The following is a summary of the cost savings that are detailed in a Technical Memorandum prepared by Hoch Consulting on May 31, 2016 in relation to the Upper Chollas Watershed Master Plan (WMP; City of San Diego 2016b).
  - The Upper Chollas WMP prioritizes recommended water quality and flood control projects to help achieve optimal storm water benefits.
  - Synergies between water quality and flood control projects are identified, as bundled projects can lead to a reduction in overall construction costs.
  - Project cost savings due to synergies may include common items in construction bids. These items would not be duplicated if projects are bundled.
  - These costs savings occur in the mobilization/demobilization, SWPPP [stormwater pollution prevention plan] /WPCP [water pollution control program] preparation and execution, traffic control, field orders, and construction synergies. Specific examples include: demolition, asphalt pavement removal and replacement, and excavation that would not have to be duplicated.
  - Key assumptions: Based on review of historic construction costs for these items in the San Diego region, the maximum cost savings due to bundling projects is estimated at 15% of the water quality project cost, as is shown in Table 12.

Table 12. Potential Cost Savings due to Project Synergies

Synergy Bid Items	Cost Savings (% of Construction Cost)
Mobilization/Demobilization	2.00%
SWPPP/WPCP	2.00%
Traffic Control	2.00%
Field Orders	2.00%
Construction Synergy (e.g. demo, asphalt paving, excavation)	7.00%
Total	15.00%

6.0 INPUT DATA FOR CO-BENEFIT ANALYSES

BMP acreages and other pollutant load reduction estimates were calculated to support the CBA co-benefit analysis.

- BMP acreage estimates for all watersheds per CBA scenario
  - Only GI and GS BMP types for the WQIP watersheds in San Diego were requested for the co-benefit analysis.
  - BMP acres for all watersheds for all the CBA scenarios were estimated based on each CBA scenario cost and BMP acre per unit cost per BMP category.
  - Table 13 lists the watersheds that have an estimated LR% >10% and require more than NMNS BMPs. Note that the watersheds and CBA scenarios not shown have ≤ 10% LR. GI and GS implementation is not required if the estimated LR% ≤ 10%.

Table 13. Estimated GI and GS BMP acreage for the TMDL watersheds for CBA scenarios

Watershed Name	Scenario Name	LR%	BMP Cost ($M)	BMP acreage (acre)	
				GI	GS
San Luis Rey	2010 TMDL via WQIP	15.80%	127.81	0	0
	2012 REC criteria	13.87%	94.93	0	0
San Marcos	2010 TMDL via WQIP	11.53%	0.22	0	0

Watershed Name	Scenario Name	LR%	BMP Cost ($M)	BMP acreage (acre)	
				GI	GS
	2012 REC criteria	10.84%	0.17	0	0
SDG	2010 TMDL via WQIP	13.04%	23.93	0	0
	2012 REC criteria	11.59%	16.61	0	0
Los Pen	2010 TMDL via WQIP	17.76%	255.22	16.24	0
	2012 REC criteria	17.03%	241.39	11.81	0
Tecolote	2010 TMDL via WQIP	17.90%	30.97	3.16	0
	2012 REC criteria	17.20%	29.45	2.58	0
SDR	2010 TMDL via WQIP	30.80%	413.83	36.97	56.07
	2012 REC criteria	29.80%	395.77	36.97	50.04
	Create beach-specific water quality objectives (WQO) - SDR and Scripps only	20.60%	234.06	33.01	0
	Adjust wet-weather beach WQO - all watersheds	20.60%	234.06	33.01	0
Chollas	2010 TMDL via WQIP	28.75%	140.35	13.2	9.72
	2012 REC criteria	27.90%	131.44	13.2	7.13
	Adjust wet-weather beach WQO - all watersheds	19.30%	60.52	0	0

- Other pollutant reduction via BMPs - LR% and mass loads:
  - LR% for other pollutants: estimated LR%s were calculated for sediment, total metals (copper [Cu], lead [Pb], and zinc [Zn]), and nutrients (total nitrogen [TN], total phosphorus [TP]). The WQIP modeling results were used to develop LR% ratios between fecal coliform and the other pollutants for the WQIP watersheds (Los Pen, Tecolote, Scripps, Chollas, and SDR). For the non-WQIP watersheds, average ratios were developed based on the results from the WQIP watersheds (Table 14). The approach included the following:
    - LR%s are wet weather only
    - LR%s for other pollutants were estimated based on LR%s that were reported in each of the WQIPs for other pollutants.
    - For the non-WQIP watersheds, the average LR% for each pollutant from the WQIP watersheds was used.

Table 14. LR% ratios between fecal coliform and other pollutants

Watershed	Sediment to fecal coliform ratio	Total Cu to fecal coliform ratio	Total Pb to fecal coliform ratio	Total Zn to fecal coliform ratio	TN to fecal coliform ratio	TP to fecal coliform ratio	*Entero-coccus* to fecal coliform ratio	Total coliform to fecal coliform ratio
Los Pen -average of all the jurisdictions	0.96	1.13	0.94	1.23	0.85	0.78	1.04	0.97
Tecolote-City jurisdictional area	0.77	0.67	0.72	0.69	0.83	0.86	0.99	0.83
Scripps- City jurisdictional area	1.09	1	1.01	0.97	1.05	1.19	0.98	0.95
Chollas- City jurisdictional area	0.68	0.78	0.71	0.8	0.82	0.87	1.01	0.88
SDR- City jurisdictional area	0.75	0.68	0.67	0.76	0.85	0.82	0.86	0.94
Average of WQIP watersheds for OC and SD watersheds	0.85	0.85	0.81	0.89	0.88	0.9	0.98	0.91

- Mass LR estimates for other pollutants: mass LR (lbs) was estimated for other pollutants for two pilot watersheds (i.e., Chollas and Los Pen). These two watersheds were selected for the co-benefit analysis because they have another TMDL/regulatory driver (Chollas – metals TMDL; Los Pen – sediment TMDL). CBA scenario-specific LR% for other pollutants were calculated by applying the LR% ratios summarized in Table 15. CBA scenario-specific mass LRs were calculated by applying the LR% to the baseline load for each of the pilot watersheds.

Table 15. Co-benefit analysis input data: estimated mass LRs (lbs) for other pollutants for Los Pen and Chollas

watershed Name	Scenario Name	Total Sediment LR (lbs.)	Total Cu LR (lbs.)	Total Pb LR (lbs.)	Total Zn LR (lbs.)	Total N LR (lbs.)	Total P LR (lbs.)
Los Pen	2010 TMDL via WQIP	962,419	396	278	5,608	20,264	3,683
	2012 REC criteria	921,255	379	267	5,368	19,397	3,525
	Move compliance locations - DF 22	22,038	9	6	128	464	84
	Flow-based regulatory suspension	156,374	64	45	911	3,292	598
	Adjust wet-weather beach WQO - all watersheds	460,627	190	133	2,684	9,699	1,763
Chollas	2010 TMDL via WQIP	255,382	252	198	1,657	20,536	4,134
	2012 REC criteria	247,839	244	192	1,608	19,929	4,012
	Move compliance locations - DF 22	2,183	2	2	14	176	35
	Flow-based regulatory suspension	37,762	37	29	245	3,037	611
	Adjust wet-weather beach WQO - all watersheds	171,444	169	133	1,112	13,786	2,775

7.0 WATERSHED MODEL SUMMARY

This section summarizes background information on the watershed models that were used to generate the LRs and BMP costs for the CBA stormwater implementation scenarios, time-series *Enterococcus* concentrations to help estimate illness rates, and other input data discussed in this memorandum.

7.1 LSPC WATERSHED MODEL

LSPC is a watershed modeling system for simulating hydrology, sediment and pollutant generation, transformation, and transport on land, as well as fate and transport within streams (Shen et al. 2004; USEPA 2003; Tetra Tech and USEPA 2002). LSPC was used to develop the original 2010 Bacteria TMDLs and the models for several watersheds have been updated over time based on the collection of additional flow and water quality monitoring data, more detailed meteorological data, and refinements to the model configuration and key assumptions. The LSPC watershed modeling system includes Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating watershed hydrology, erosion, and water quality, as well as instream transport. A detailed discussion of HSPF-simulated processes and model parameters is available in the HSPF User's Manual

(Bicknell et al. 1997). The major components of watershed model development include: 1) watershed segmentation; 2) meteorology input dataset; and 3) land use representation.

Watershed segmentation refers to the subdivision of the entire model area into smaller, discrete subwatersheds and reaches for modeling and analysis. Model subdivision was primarily based on existing hydrologic boundaries and MS4 storm drain networks, and secondarily on topography and the locations of flow and water quality monitoring stations. Jurisdictional boundaries were also considered during model development. Segmentation of several watersheds in the San Diego region is provided in Figure 8 as an example.

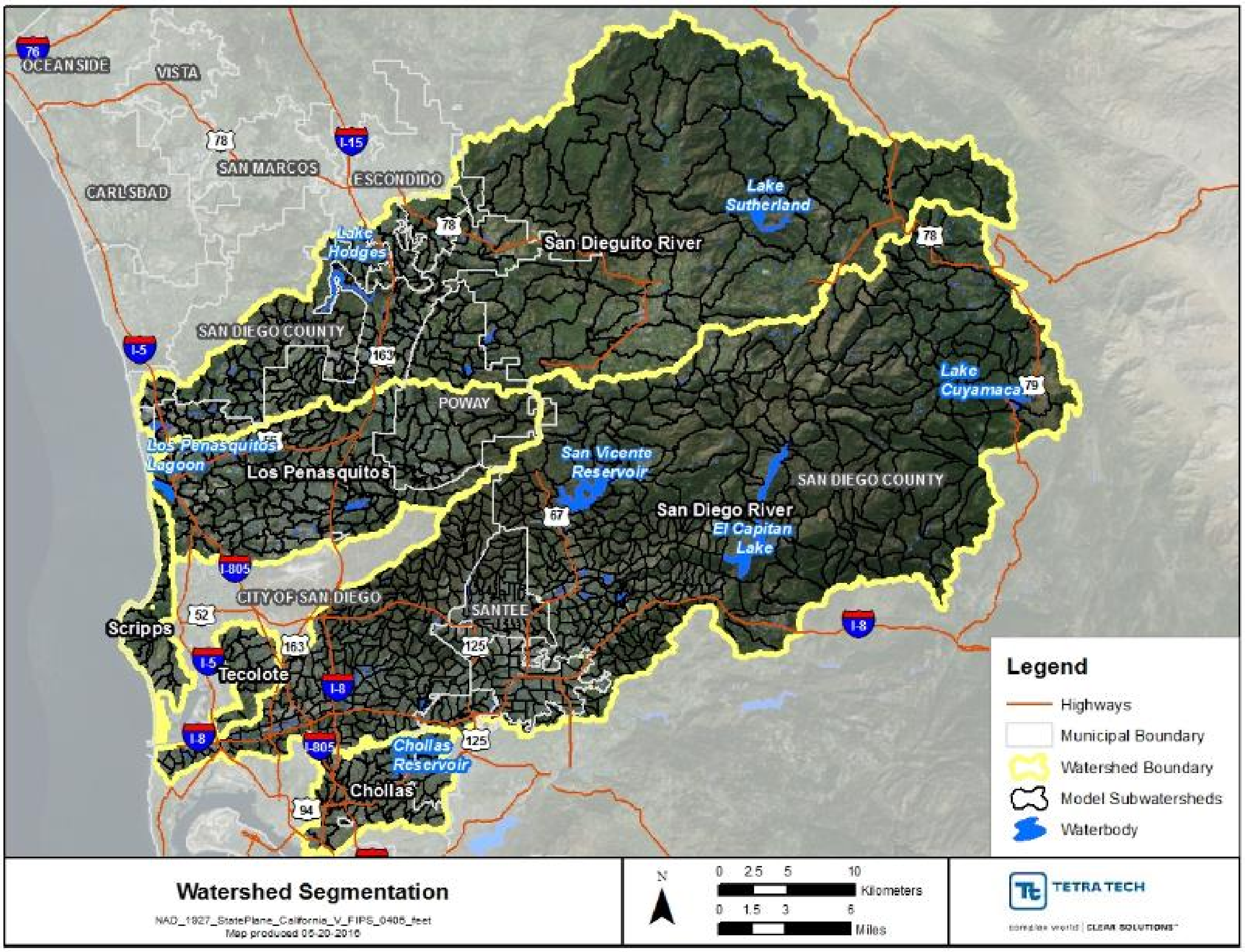

Figure 8. Example of watershed segmentation

Meteorological data are a critical component of the watershed model as successful hydrologic modeling depends on an accurate representation of the overall water balance. The two most important variables in the water balance are precipitation and potential evapotranspiration (PET). The primary source of precipitation data for watershed model development was the ALERT monitoring network (data provided by San Diego and Orange counties). In addition to available ALERT data, precipitation records from National Climactic Data Center (NCDC) monitoring stations were also compiled to provide a secondary source of data and provide a reference for any necessary data corrections or patching. Climatic variation throughout the region is largely determined by potential evapotranspiration zones, frequently referred to as ETo zones. Five ETo zones divide the San Diego and Orange County watersheds and spatially define the long-term trends in potential evapotranspiration (PET).

In a watershed model, land unit representation should be sensitive to the features of the landscape that most affect hydrology and pollutant transport, including land use (e.g. urban areas, agricultural areas, open space, etc.) and related impervious assumptions, hydrologic soil group (to help estimate runoff and infiltration), irrigation, and slope. The combination of land use, hydrologic soil group, and slope were used to define the hydrologic response units (HRUs) for watershed model development. Representation of these key landscape attributes allowed for the development of land use parameters that could be applied across the region, while still sufficiently capturing hydrologic and source loading variability at specific locations. Although the models account for the build-up and washoff of bacteria on land surfaces that may originate from a variety of sources, direct contributions from specific sources, such as transient encampments and sewage collection system impacts are not explicitly incorporated due to limited data availability. These sources are, however, implicitly included in the model representation through the calibration process and the resulting modeled concentrations reflect all sources that affect bacteria concentrations in the receiving waters.

7.2 WATERSHED MODEL CALIBRATION AND SIMULATION

The current watershed model configuration uses the latest available meteorological, soils, and land use data to characterize bacteria conditions at the outlet of each watershed (above the tidal prism, as discussed earlier in this memorandum) and at upstream locations. Model output generated using this setup was compared to available instream monitoring data to determine the predictive ability of the current models and help identify potential areas for improvement.

USGS flow gaging data were collected and inventoried to support hydrologic calibration. Accurate hydrologic calibration is critical to the simulation of water quality conditions. Hydrologic calibration followed the standard operating procedures that are described in the recently completed San Diego watershed model updates report (City of San Diego 2016). Daily, monthly, seasonal, and total modeled flow volumes were compared to observed data, and error statistics were calculated for the percent difference, along with the Nash-Sutcliffe coefficient of model fit efficiency (NSE) for daily average flows. An example time-series hydrologic calibration plot is presented in Figure 9 for the San Diego River USGS gage location near Santee, CA.

An inventory of bacteria water quality monitoring locations was also developed to support model development and calibration. These locations were used to compare model simulated instream bacteria concentrations to observed values. In addition to instream water quality, the City of San Diego conducted a storm drain characterization study in the winter of 2009–2010 that included characterizing bacteria loading from land use parcels within several urbanized watersheds (City of San Diego 2010a and b). These event mean concentration (EMC) data were used to calibrate land use bacteria loading rates. An example is presented in Figure 10 for *Enterococcus* (the x-axis lists monitoring station identifications [ID's], as well as the land use parcel type associated with each station). Also, an example instream calibration plot at the San Diego River mass loading station (MLS) at Fashion Valley is shown in Figure 11. In addition to these and other visual comparisons, a quantitative assessment comparing paired simulated and observed instream load R^2 values and the difference between simulated and observed load was done to assess the overall calibration. Similar to the criteria used to assess the hydrology calibration error statistics, metrics indicating acceptable calibration were developed for the quantitative bacteria calibration assessment. A watershed model that has been calibrated for both upland loading and instream water quality can be considered to be appropriately simulating pollutant loading and transport.

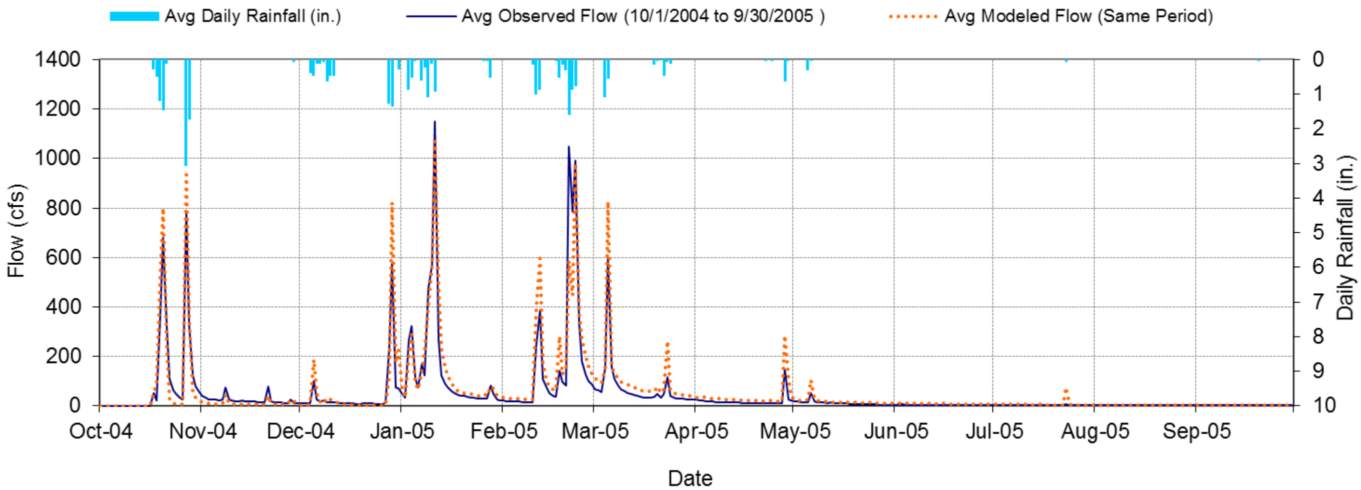

Figure 9. Example hydrologic (flow) calibration. Mean daily flow: Model Outlet 4050181 vs. USGS 11022480 San Diego R at Mast Rd near Santee CA

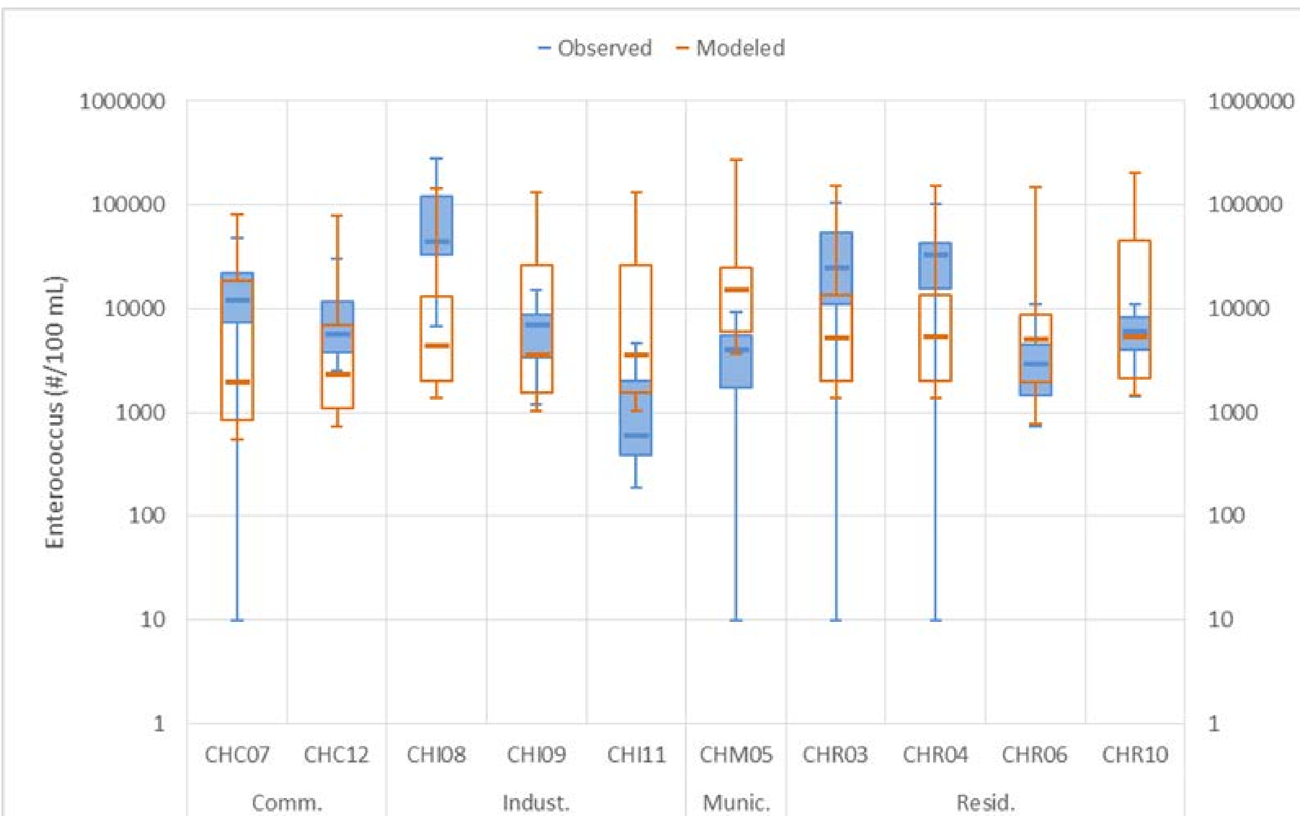

Figure 10. Example water quality comparison of simulated and observed land use based EMCs for *Enterococcus* (Comm = commercial; Indust = industrial; Munic = municipal; Resid = residential)

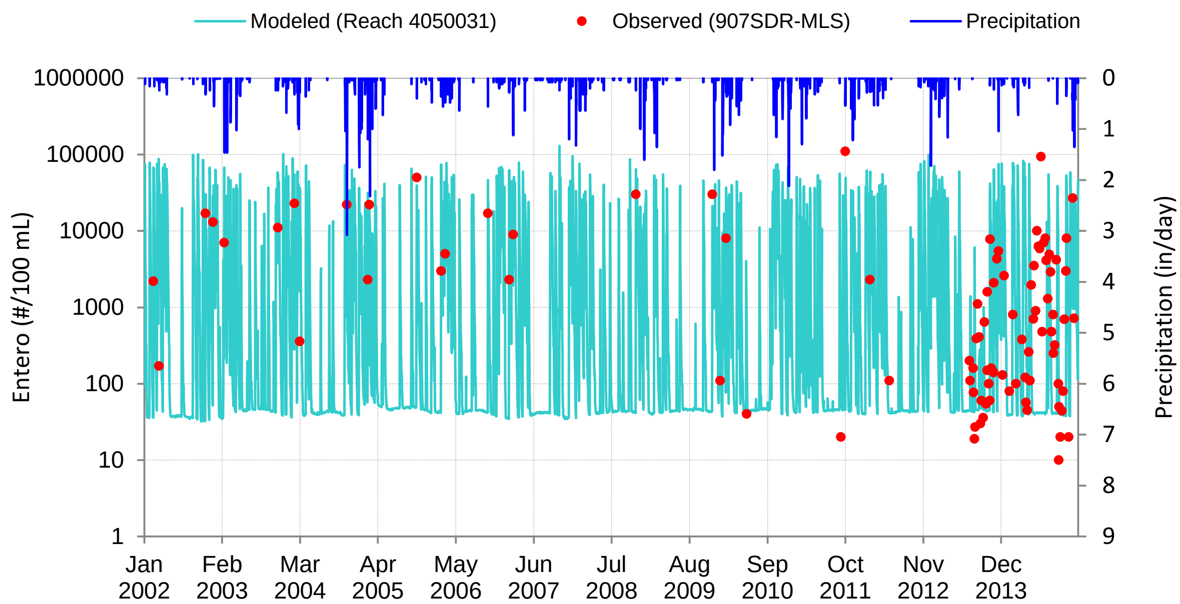

Figure 11. Example time-series water quality comparison of simulated and observed *Enterococcus* (#/100 mL) concentrations at the San Diego River MLS station

Sources of model uncertainty can be caused by the way a model was structurally configured (model segmentation, land use/cover representation, meteorological input data, etc.), model parameter calibration values, as well as the accuracy of the monitoring data used for calibration. Major structural components that tend to drive uncertainty include land use representation and meteorological data inputs. Model land use categories should properly capture the variety of land cover types without unnecessarily adding to model complexity. In a watershed model, the land use representation provides the foundation for characterizing hydrologic response and pollutant loading characteristics; therefore, care must be taken to select appropriate categories that capture those factors. Meteorological data serve as the forcing functions of the watershed model and thus are of critical importance. Whether the source input data are taken from point monitoring stations or gridded data derived from interpolation or radar/remote-sensed data, assignment of that data to a model domain always requires a simplification of true weather conditions, which can show significant variance over short distances. As a result, the model can never fully capture the true weather conditions resulting in some degree of model uncertainty. Model parameters used to "tune" a model are typically thought of as a means of not only capturing specific watershed characteristics (infiltration rate, subsurface storage depths, recession rates, pollutant build-up rates etc.), but also as a way to improve model performance given an implied level of uncertainty. Those parameters, themselves, have a built-in uncertainty as the modeler tries to generalize those characteristics for the associated modeling unit. Finally, the flow and water quality monitoring data used to calibrate/validate a model have uncertainty associated with those values. Flow data are typically generated from depth discharge relationships that imply some level of simplification and water quality data are subject to numerous factors that can cause uncertainty, including matching grab sample collection times with model simulation time steps and sample collection and lab processing steps. See City of San Diego (2016a) for further details on model uncertainties and calibration and validation results associated with the most recent model updates for several watersheds in the San Diego region.

7.3 MODELS USED FOR COMPLIANCE COST ANALYSIS

The CBA compliance cost analysis was based primarily on BMP implementation levels required to meet LR targets developed for the San Diego Region WQIPs (WQIP models) based on WY2003 (representative rainfall year). LR targets were estimated from LSPC watershed model simulated bacteria concentrations (consistent with the 2010 Bacteria TMDL methodology) that were linked to a SUSTAIN BMP model framework to determine BMP implementation levels required to meet those targets. This linked modeling system (WQIP model) and simulation results are described in detail in the San Diego Region WQIPs (City of San Diego et al. 2015a and b). The linked modeling system is available for the Los Pen, Scripps, Tecolote, SDR, and Chollas watersheds, which are referenced as the WQIP watersheds in this memorandum (Table 1). The WQIP models were developed to support the source loading analysis in the WQIP, in accordance with requirements in the 2013 MS4 National Pollution Discharge Elimination System (NPDES) Permit (Order R9-2013-0001, NPDES No. CAS0109266).

The CBA includes watersheds in San Diego and Orange Counties that were not explicitly modeled using this framework. These watersheds are referenced as non-WQIP watersheds in this memorandum (Table 1). The original 2010 Bacteria TMDL models were used to represent these watersheds. As part of the CBA analysis, LR targets were recalculated using WY2003 to provide a consistent framework. The 2010 Bacteria TMDL models were originally configured to run through calendar year 2002; therefore, the modeling time period was extended through 2013 by incorporating additional rainfall and ETo data as necessary. Orange County provided recent rainfall data collected from the Sulphur Creek rainfall gage (ETo Zone 4), except for the San Clemente watershed, which used data from the Palisades rainfall gage (ETo Zone 4).

The rationale for using the WQIP and 2010 Bacteria TMDL models for the cost analysis was to be consistent with the cost estimates developed as part of the WQIP BMP implementation scenarios (for the WQIP watersheds) and model availability/consistency with the TMDL LR%s (for the non-WQIP watersheds). The WQIPs included development of cost-effectiveness curves (CEC; also referred to as BMP cost curves or cost curves) that optimized the level of BMP implementation required to meet watershed LR targets. A watershed-specific CEC was not available for the non-WQIP watersheds. A composite CEC was developed to estimate costs for the non-WQIP watersheds for consistency, as discussed previously in this memorandum.

A summary of the model version used for each CBA purpose (LR, compliance cost, and time-series water quality simulation) is presented in Table 16.

7.4 MODELS FOR TIME-SERIES WATER QUALITY SIMULATION

The CBA included the generation of time-series water quality data as described in Section 2.1: daily and annual *Enterococcus* concentrations for the health risk/benefit analysis. *Enterococcus* concentrations were simulated directly by the watershed models to estimate the relative change in illness risk over time throughout the modeling period. Given the focus on Enterococcus to estimate illness risk based on the SHS QMRA, the most recent watershed models that were developed to support the San Diego Bacteria TMDL Reopener effort were used (City of San Diego 2016). These updated models (Bacteria TMDL Reopener Models) leverage more recent monitoring data, refined modeling assumptions, and other improvements. A major effort was made to include more recent instream bacteria water quality data, as well as upland stormwater monitoring data in model development and calibration, as detailed in the referenced modeling report.

As with the calculation of the scenario-specific LR targets, the Bacteria TMDL Reopener Models are only available for a subset of watersheds located in the San Diego Region, which include the Los Pen, Tecolote, SDR, SDG, Chollas, and Scripps watersheds. As a way to leverage the updated model calibration for the remaining watersheds, the 2010 Bacteria TMDL Models were updated with associated hydrology and bacteria loading parameters by mapping similar land uses to one another.

Refer to Table 16 for information on the model version used for each CBA purpose, as mentioned above.

Table 16. Model version used for each CBA purpose

	Watershed	Analysis	
		LR calculation and compliance cost estimate	*Enterococcus* concentration simulation
City of San Diego and San Diego County	Tecolote	●	◐
	Scripps	●	◐
	Chollas	●	◐
	Los Pen	●	◐
	SDR	●	◐
	San Luis Rey	○	◉
	San Marcos	○	◉
	SDG	○	◐
Orange County	San Juan	○	◉
	Laguna Beach	○	◉
	Aliso	○	◉
	Dana Point	○	◉
	San Clemente	○	◉

○ TMDL Model

● WQIP Model

◐ Bacteria TMDL Reopener Model

◉ TMDL Model with updated parameters based on the Bacteria TMDL Reopener Models

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APPENDIX A-1: CONCENTRATIONS AND DILUTION FACTORS

All daily concentration data is available for download at goo.gl/2Vz4K6.

Laguna Coastal Streams

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	93	45,790	194,459
	Storm-1	87	17,475	137,767
	Storm-2	90	6,005	126,136
	Storm-3	90	410	55,162
2012 REC Criteria	Storm-0	93	45,816	194,567
	Storm-1	87	17,484	137,844
	Storm-2	90	6,009	126,206
	Storm-3	90	410	55,192
Move Compliance Locations	Storm-0	94	46,118	195,853
	Storm-1	88	17,600	138,754
	Storm-2	90	6,048	127,040
	Storm-3	91	413	55,557
Flow-Based Suspensions	Storm-0	94	46,118	195,853
	Storm-1	88	17,600	138,754
	Storm-2	90	6,048	127,040
	Storm-3	91	413	55,557
Adjust All Beach WQO	Storm-0	94	46,066	195,631
	Storm-1	88	17,580	138,597
	Storm-2	90	6,042	126,896
	Storm-3	91	413	55,494

Aliso Creek

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	180	42,188	189,017
	Storm-1	74	22,204	124,274
	Storm-2	64	9,220	112,770
	Storm-3	63	3,559	66,962
2012 REC Criteria	Storm-0	181	42,299	189,516
	Storm-1	74	22,263	124,602
	Storm-2	64	9,244	113,068
	Storm-3	63	3,568	67,139
Move Compliance Locations	Storm-0	185	43,210	193,598
	Storm-1	76	22,743	127,286
	Storm-2	66	9,443	115,503
	Storm-3	65	3,645	68,585
Flow-Based Suspensions	Storm-0	185	43,210	193,598
	Storm-1	76	22,743	127,286
	Storm-2	66	9,443	115,503
	Storm-3	65	3,645	68,585
Adjust All Beach WQO	Storm-0	184	43,155	193,353
	Storm-1	76	22,714	127,124
	Storm-2	65	9,431	115,357
	Storm-3	65	3,641	68,498

Dana Point

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	92	38,779	262,237
	Storm-1	56	14,195	154,661
	Storm-2	88	5,605	122,213
	Storm-3	89	376	48,209
2012 REC Criteria	Storm-0	92	38,819	262,508
	Storm-1	57	14,210	154,821
	Storm-2	89	5,610	122,339
	Storm-3	89	376	48,259
Move Compliance Locations	Storm-0	93	39,452	266,791
	Storm-1	57	14,441	157,347
	Storm-2	90	5,702	124,335
	Storm-3	91	382	49,046
Flow-Based Suspensions	Storm-0	93	39,452	266,791
	Storm-1	57	14,441	157,347
	Storm-2	90	5,702	124,335
	Storm-3	91	382	49,046
Adjust All Beach WQO	Storm-0	93	39,377	266,282
	Storm-1	57	14,414	157,046
	Storm-2	90	5,691	124,097
	Storm-3	90	381	48,953

San Juan

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	1	4,566	22,110
	Storm-1	99	4,750	18,119
	Storm-2	40	1,878	10,027
	Storm-3	27	671	3,340
2012 REC Criteria	Storm-0	1	4,605	22,300
	Storm-1	100	4,791	18,275
	Storm-2	40	1,894	10,114
	Storm-3	27	677	3,368
Move Compliance Locations	Storm-0	1	4,613	22,339
	Storm-1	100	4,799	18,307
	Storm-2	40	1,897	10,131
	Storm-3	28	678	3,374
Flow-Based Suspensions	Storm-0	1	4,613	22,339
	Storm-1	100	4,799	18,307
	Storm-2	40	1,897	10,131
	Storm-3	28	678	3,374
Adjust All Beach WQO	Storm-0	1	4,613	22,339
	Storm-1	100	4,799	18,307
	Storm-2	40	1,897	10,131
	Storm-3	28	678	3,374

San Clemente

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	1,260	40,559	149,256
	Storm-1	83	22,073	124,415
	Storm-2	85	10,853	154,582
	Storm-3	91	2,943	109,287
2012 REC Criteria	Storm-0	1,262	40,618	149,472
	Storm-1	83	22,105	124,595
	Storm-2	86	10,869	154,806
	Storm-3	91	2,947	109,446
Move Compliance Locations	Storm-0	1,271	40,901	150,512
	Storm-1	84	22,259	125,462
	Storm-2	86	10,944	155,884
	Storm-3	91	2,967	110,207
Flow-Based Suspensions	Storm-0	1,271	40,901	150,512
	Storm-1	84	22,259	125,462
	Storm-2	86	10,944	155,884
	Storm-3	91	2,967	110,207
Adjust All Beach WQO	Storm-0	1,270	40,872	150,405
	Storm-1	84	22,243	125,373
	Storm-2	86	10,936	155,773
	Storm-3	91	2,965	110,129

San Luis Rey

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	104	13,829	49,324
	Storm-1	50	3,370	35,436
	Storm-2	45	258	13,445
	Storm-3	44	231	23,290
2012 REC Criteria	Storm-0	106	14,147	50,457
	Storm-1	51	3,448	36,250
	Storm-2	46	264	13,754
	Storm-3	45	236	23,825
Move Compliance Locations	Storm-0	123	16,425	58,582
	Storm-1	59	4,003	42,088
	Storm-2	54	306	15,968
	Storm-3	53	274	27,661
Flow-Based Suspensions	Storm-0	121	16,143	57,576
	Storm-1	58	3,934	41,364
	Storm-2	53	301	15,694
	Storm-3	52	269	27,186
Adjust All Beach WQO	Storm-0	123	16,381	58,426
	Storm-1	59	3,992	41,975
	Storm-2	54	305	15,926
	Storm-3	53	273	27,587

San Marcos

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	83	62,959	165,897
	Storm-1	81	22,152	162,958
	Storm-2	83	4,245	122,659
	Storm-3	83	1,297	125,196
2012 REC Criteria	Storm-0	83	63,453	167,199
	Storm-1	81	22,326	164,237
	Storm-2	83	4,278	123,621
	Storm-3	83	1,308	126,178
Move Compliance Locations	Storm-0	93	71,165	187,522
	Storm-1	91	25,040	184,200
	Storm-2	93	4,798	138,648
	Storm-3	94	1,466	141,516
Flow-Based Suspensions	Storm-0	93	71,165	187,522
	Storm-1	91	25,040	184,200
	Storm-2	93	4,798	138,648
	Storm-3	94	1,466	141,516
Adjust All Beach WQO	Storm-0	93	71,016	187,130
	Storm-1	91	24,988	183,815
	Storm-2	93	4,788	138,358
	Storm-3	93	1,463	141,219

San Dieguito

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	268	25,191	94,334
	Storm-1	71	14,022	75,998
	Storm-2	67	6,657	48,152
	Storm-3	62	3,288	40,005
2012 REC Criteria	Storm-0	272	25,612	95,913
	Storm-1	72	14,257	77,270
	Storm-2	68	6,769	48,957
	Storm-3	63	3,343	40,675
Move Compliance Locations	Storm-0	308	28,969	108,484
	Storm-1	81	16,126	87,398
	Storm-2	77	7,656	55,374
	Storm-3	71	3,781	46,006
Flow-Based Suspensions	Storm-0	304	28,609	107,134
	Storm-1	80	15,925	86,310
	Storm-2	76	7,561	54,685
	Storm-3	70	3,734	45,433
Adjust All Beach WQO	Storm-0	307	28,897	108,215
	Storm-1	81	16,086	87,181
	Storm-2	77	7,637	55,237
	Storm-3	71	3,772	45,892

Los Peñasquitos

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	1,343	20,705	79,887
	Storm-1	89	13,611	87,521
	Storm-2	56	6,487	60,935
	Storm-3	49	3,561	37,160
2012 REC Criteria	Storm-0	1,355	20,888	80,592
	Storm-1	90	13,731	88,294
	Storm-2	56	6,544	61,473
	Storm-3	49	3,593	37,489
Move Compliance Locations	Storm-0	1,626	25,074	96,743
	Storm-1	108	16,483	105,989
	Storm-2	67	7,856	73,792
	Storm-3	59	4,313	45,001
Flow-Based Suspensions	Storm-0	1,586	24,450	94,335
	Storm-1	106	16,073	103,351
	Storm-2	66	7,660	71,956
	Storm-3	58	4,205	43,881
Adjust All Beach WQO	Storm-0	1,494	23,035	88,877
	Storm-1	99	15,143	97,370
	Storm-2	62	7,217	67,792
	Storm-3	54	3,962	41,342

Scripps

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	57	40,928	144,920
	Storm-1	44	20,311	135,616
	Storm-2	44	4,574	92,348
	Storm-3	44	2,004	104,769
2012 REC Criteria	Storm-0	57	41,340	146,377
	Storm-1	45	20,515	136,980
	Storm-2	45	4,620	93,277
	Storm-3	44	2,024	105,823
Move Compliance Locations	Storm-0	63	45,684	161,760
	Storm-1	49	22,671	151,374
	Storm-2	49	5,106	103,079
	Storm-3	49	2,237	116,944
Flow-Based Suspensions	Storm-0	63	45,456	160,950
	Storm-1	49	22,557	150,617
	Storm-2	49	5,080	102,563
	Storm-3	49	2,225	116,358
Adjust All Beach WQO	Storm-0	61	44,404	157,226
	Storm-1	48	22,036	147,132
	Storm-2	48	4,962	100,190
	Storm-3	48	2,174	113,666

Tecolote

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	461	35,364	116,516
	Storm-1	91	19,112	106,621
	Storm-2	74	6,709	71,185
	Storm-3	74	6,093	88,635
2012 REC Criteria	Storm-0	465	35,671	117,527
	Storm-1	91	19,277	107,546
	Storm-2	75	6,767	71,802
	Storm-3	75	6,146	89,404
Move Compliance Locations	Storm-0	561	43,014	141,719
	Storm-1	110	23,245	129,684
	Storm-2	90	8,160	86,583
	Storm-3	90	7,411	107,807
Flow-Based Suspensions	Storm-0	556	42,667	140,577
	Storm-1	109	23,058	128,638
	Storm-2	89	8,094	85,885
	Storm-3	89	7,351	106,938
Adjust All Beach WQO	Storm-0	512	39,266	129,371
	Storm-1	82	6,765	98,414
	Storm-2	82	6,765	98,414
	Storm-3	82	6,765	98,414

San Diego River

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	1,879	23,521	78,430
	Storm-1	281	16,395	62,625
	Storm-2	142	10,085	40,605
	Storm-3	90	6,409	37,496
2012 REC Criteria	Storm-0	1,906	23,860	79,563
	Storm-1	285	16,631	63,530
	Storm-2	144	10,231	41,192
	Storm-3	91	6,502	38,038
Move Compliance Locations	Storm-0	2,711	33,935	113,157
	Storm-1	405	23,654	90,354
	Storm-2	204	14,551	58,584
	Storm-3	129	9,247	54,099
Flow-Based Suspensions	Storm-0	2,555	31,979	106,635
	Storm-1	382	22,291	85,147
	Storm-2	193	13,712	55,208
	Storm-3	122	8,714	50,981
Adjust All Beach WQO	Storm-0	2,156	26,984	89,980
	Storm-1	322	18,809	71,848
	Storm-2	163	11,571	46,585
	Storm-3	103	7,353	43,018

Chollas Creek

Scenario	Storm day	Low Value Concentration	Mean Value Concentration	High Value Concentration
2010 TMDL	Storm-0	275	27,304	92,051
	Storm-1	258	17,694	67,881
	Storm-2	32	6,866	77,080
	Storm-3	22	3,007	48,428
2012 REC Criteria	Storm-0	278	27,643	93,196
	Storm-1	261	17,914	68,725
	Storm-2	32	6,952	78,038
	Storm-3	22	3,044	49,030
Move Compliance Locations	Storm-0	385	38,227	128,875
	Storm-1	361	24,773	95,036
	Storm-2	44	9,613	107,915
	Storm-3	30	4,210	67,802
Flow-Based Suspensions	Storm-0	369	36,692	123,701
	Storm-1	346	23,778	91,220
	Storm-2	42	9,227	103,582
	Storm-3	29	4,041	65,079
Adjust All Beach WQO	Storm-0	311	30,922	104,249
	Storm-1	292	20,039	76,876
	Storm-2	36	7,776	87,294
	Storm-3	24	3,406	54,846

Recreation Dilution Factors

Watershed	Recreatior
San Luis Rey	117
San Marcos	557
San Dieguito	247
Los Pen	203
SDR	229
Tecolote	350
Chollas	265
Scripps	408
San Clemente	424
San Juan	51
Dana	345
Aliso	424
Laguna	428

Public Health Dilution Factors

Watershed	Public Hea
San Luis Rey	210
San Marcos	590
San Dieguito	485
Los Pen	690
SDR	1100
Tecolote	285
Chollas	1055
Scripps	935
San Clemente	960
San Juan	163
Dana	680
Aliso	885
Laguna	840

APPENDIX B: HUMAN SOURCES SCENARIOS TECHNICAL MEMO

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Technical Memorandum

Prepared for: County of San Diego, Department of Public Works, Watershed Protection Program

Project Title: Bacteria Total Maximum Daily Load (TMDL) – Human Sources Scenario for San Diego County and South Orange County Watersheds

Project No.: 551334 - Task Order 03

Technical Memorandum No. 1 – PUBLIC REVIEW DRAFT

Subject: Human Sources Scenario for San Diego County and South Orange County Watersheds

Date: July 21, 2017

To: Jo Ann Weber, Watershed Planning Program Manager, County of San Diego

From: Lisa Skutecki, Project Manager, Brown and Caldwell

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Limitations:

This document was prepared solely for the County of San Diego in accordance with professional standards at the time the services were performed and in accordance with the contract between the County of San Diego and Brown and Caldwell dated August 12, 2016. This document is governed by the specific scope of work authorized by the County of San Diego; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by the County of San Diego and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

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List of Abbreviations

Bacteria TMDL	*Revised Total Maximum Daily Loads (TMDLs) for Indicator Bacteria Project I – Twenty Beaches and Creeks in the San Diego Region (Including Tecolote Creek)*
CIPP	cured-in-place pipe
County of SD	County of San Diego, Department of Public Works, Watershed Protection Program
GIS	Geographic Information System
HF183	human-specific genetic marker HF183
OC	Orange County
County of Orange	Orange County Public Works Department, OC Environmental Resources
PACP	Pipeline Assessment Certification Program
PLSD	private lateral sewage discharge
RWQCB	California Regional Water Quality Control Board, San Diego Region
SANDAG	San Diego Association of Governments
SANGIS	San Diego Geographic Information Source
SCCWRP	Southern California Coastal Water Research Project
SD	San Diego County
SSO	sanitary sewer overflow
SWRCB	State Water Resources Control Board
TM	Technical Memorandum
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USGS	United States Geological Survey

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Section 1: Introduction

On February 10, 2010, the California Regional Water Quality Control Board, San Diego Region (RWQCB) adopted the *Revised Total Maximum Daily Loads (TMDLs) for Indicator Bacteria Project I – Twenty Beaches and Creeks in the San Diego Region (Including Tecolote Creek)* (Bacteria TMDL). The Bacteria TMDL lists impaired water bodies and provides concentration-based water quality targets. In response to the Bacteria TMDL, a cost-benefit analysis has been developed to investigate alternative pathways to compliance. One scenario of the cost-benefit analysis and the focus of this report is the targeting of human-sources of bacteria and viruses. The analysis presented in this Technical Memorandum (TM) describes the methodology to estimate load contributions and costs of load reduction strategies for human-sources of bacteria and viruses.

This study focuses specifically on load contributions from the following sources:

- Leaking sanitary sewer pipes (mains and laterals)
- Failing septic systems
- Sanitary sewer overflows (SSOs) and Private Lateral Sewage Discharges (PLSDs)
- Transient populations living near river banks

Other potential sources of human-source bacteria contribution, such as recreational vehicle discharges and illicit connections, are not covered in this analysis. The study area for the human sources scenario consists of the following watersheds listed in the Bacteria TMDL:

- San Diego County (SD):
  - Chollas Creek
  - Los Peñasquitos
    - Miramar Reservoir subarea
    - Poway subarea
  - San Diego River
  - San Dieguito River
  - San Luis Rey River
  - San Marcos (Cottonwood Creek drainage area)
  - Scripps
  - Tecolote
- South Orange County (OC):
  - Aliso Creek
  - Dana Point Coastal
  - Laguna Coastal
  - San Clemente Coastal
  - San Juan Creek
  - San Mateo Creek

The level of analysis in this report can be described as exploratory in nature. As described throughout the TM, several data gaps limit the ability to draw definitive conclusions about human-sources of bacteria and viruses from this analysis. The assumptions and limitations detailed in this TM should be considered when interpreting the results of this analysis.

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1.1 Project Objectives

The objectives of the human sources scenario analysis are to estimate load contributions from human sources of bacteria and viruses, identify possible load reduction strategies, and estimate the load reduction effectiveness and costs of the strategies based on available data. As discussed in subsequent sections, the human sources scenario prioritized sanitary sewer pipes and septic systems using a weighted criteria matrix to identify areas of high, medium, and low priority. The results for each watershed show costs of implementing load reduction strategies versus the estimated total load reduction.

These scenarios were not designed to represent the actual load reduction requirement or cost of projects needed to comply with any current and/or future regulations including the Bacteria TMDL, Waste Discharge Requirements (WDRs), or any other regulatory requirements. Costs are based on unit cost estimates applied to the amount of infrastructure data available at the time of this study. Actual strategies, projects, and costs needed to comply with any existing and/or future regulations may vary.

The results of the human sources scenario provide inputs to a quantitative microbial risk assessment, support the Bacteria TMDL cost-benefit analysis, and inform future studies.

Section 2: Overview of Methodology

This section provides an overview of the methodology used in the human sources scenario. Additional details on the data and assumptions used in the analysis are provided in subsequent sections. As illustrated in Figure 2-1, a methodology was developed using spatial and database analysis to prioritize human sources, estimate load contributions, and estimate effectiveness and cost of load reduction strategies.

To perform the analysis, a spreadsheet-based analytical model was developed to estimate bacteria and virus loading from the various human sources to the Bacteria TMDL watersheds. The model is analogous to a mass balance model where individual inputs of load contribution are combined and calibrated to a downstream point based on measured data. Copies of a human marker surrogate parameter (HF183) are used as the “mass” for the model. HF183 is an indicator of human fecal contamination and is assumed to correlate with bacteria and viruses from human sources. The model simulates loads over a single average wet weather day.

The first step in the analysis is to select the sources of human bacteria contribution for the model. As described above, sanitary sewer pipes (mains and laterals), septic systems, SSOs and PLSDs, and transient populations were selected for analysis.

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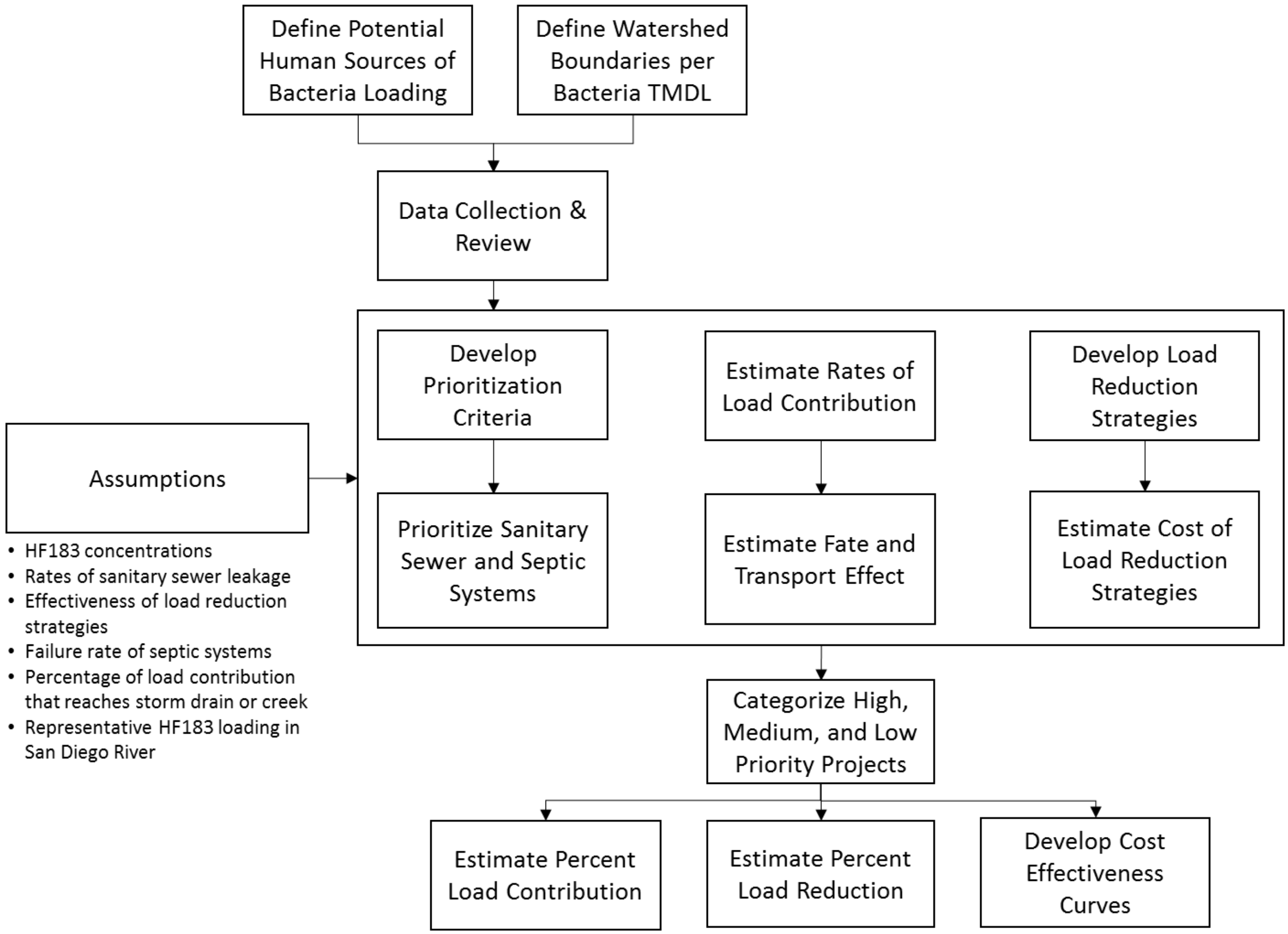

Figure 2-1. Human Sources Scenario Analysis Methodology

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While other sources, such as recreational vehicle dischargers and illicit connections, may be present, little to no data is available to estimate these potential sources throughout the study area. For simplicity, these sources have been excluded from the analysis. However, it is recommended that additional data be collected and analyzed to assess the significance of other human sources on overall watershed health.

As shown in Figure 2-2 and Figure 2-3, the Bacteria TMDL watershed boundaries served as the study area for the analysis. Tribal reservations are also depicted in Figure 2-2. Loading from sources within the contributing drainage areas to major reservoirs is assumed to reach the reservoir and be retained for a period longer than the survival time of the pathogen. As shown in the shaded areas in Figure 2-2 and Table 2-1, contributing drainage areas to San Vicente Reservoir, El Capitan Reservoir, Lake Hodges, Lake Sutherland, and Lake Henshaw were excluded from the analysis since the drainage to these water bodies is retained in the reservoirs and typically does not continue to the downstream areas.

Table 2-1. Summary of Reservoirs within the SD County Bacteria TMDL Watersheds

Reservoir	Watershed	Spills (Y/N)	Notes
Lake Henshaw	San Luis Rey	N	Drainage area excluded from study area.
Sutherland	San Dieguito	N	Drainage area excluded from study area.
Lake Hodges	San Dieguito	Y	Drainage area excluded from study area. Historically, Lake Hodges spilled intermittently and infrequently. With the construction of the Lake Hodges Pump Storage Project, there is now a much lower possibility of a spill. Any loading to the reservoir during a spill event is likely to be retained for a period longer than the survival time of the pathogen.
Miramar	Los Peñasquitos	N	Drainage area insignificant to study area.
San Vicente	San Diego River	N	Drainage area excluded from study area.
El Capitan	San Diego River	N	Drainage area excluded from study area.
Lake Jennings	San Diego River	N	Drainage area insignificant to study area.
Lake Murray	San Diego River	N	Drainage area insignificant to study area.

Available literature and data were reviewed to develop assumptions for the model. Section 3 and Table 5-1 discuss the data sources and assumptions in more detail.

A weighted prioritization matrix was then developed for use in the spatial analysis. This matrix assigned weighting and scoring for brackets of soil types, distance to a creek or storm drain, age of sanitary sewer pipe, and diameter of sanitary sewer pipe. The weighted scores were assigned to sanitary sewer pipes and septic system parcels for each criterion, then added to calculate the total score and priority of each segment of pipe and each septic system.

Concurrently, rates of contribution from each source were estimated, as described in Section 4. Once the sources were prioritized and total load contribution was estimated, effectiveness and costs for the load reduction strategies were estimated. The resulting output includes a percent breakdown of sources by watershed and cost estimates for each watershed. Results are summarized in Sections 5 and 7.

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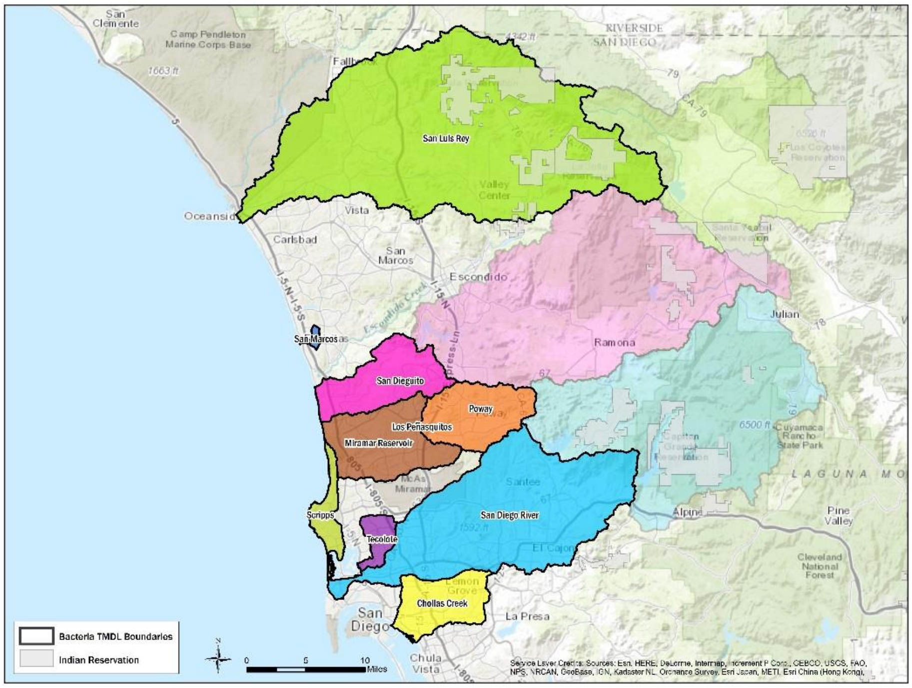

Figure 2-2. Map of SD Bacteria TMDL Watersheds

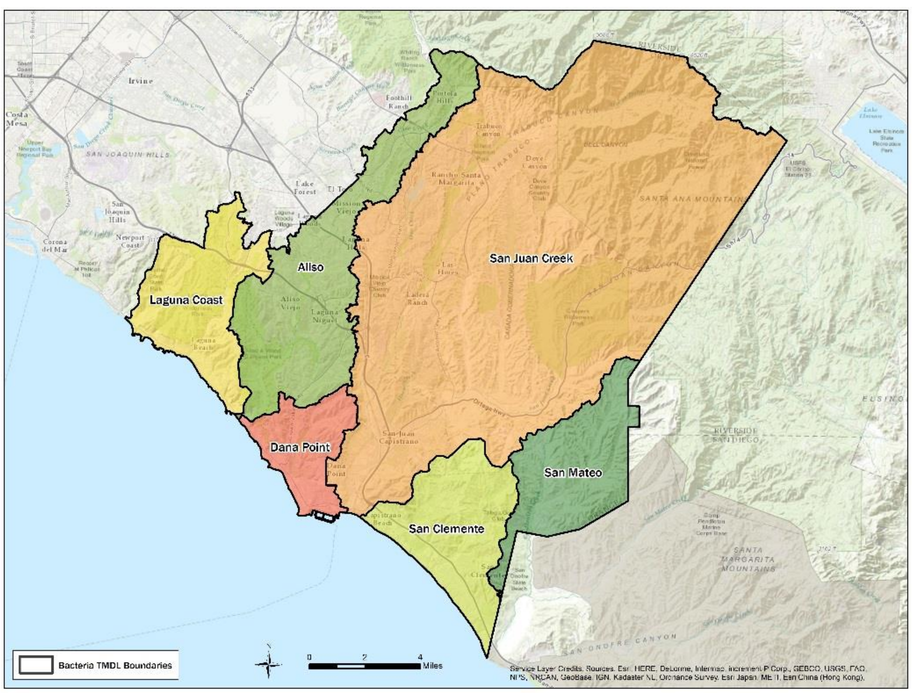

Figure 2-3. Map of OC Bacteria TMDL Watersheds

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Section 3: Summary of Available Data

Data provided by the County of San Diego, Department of Public Work, Watershed Protection Program (County of SD), Orange County Public Works Department, OC Environmental Resources (County of Orange), and from publicly available sources were compiled and used as the basis of the analysis. References for the available literature are listed in the references section of this TM. This section lists the data sources and provides summaries of available data used in the analysis.

3.1 Data Sources

A summary of available spatial and tabular data sources was prepared to compile the information used in developing the analysis. Table 3-1 presents the sources and types of data utilized in the analysis.

Table 3-1. Summary of Data Sources for the Human Sources Scenario Analysis

Data Layer	Type	Source	Notes
Population	Spatial	San Diego Association of Governments (SANDAG) and San Diego Geographic Information Source (SANGIS) using data provided by the United States Census Bureau and Orange County Public Works using data provided by the United States Census Bureau (TIGER)	2010 United States Census Bureau census tracts for San Diego County 2010 United States Census Bureau census tracts for Orange County used to identify risk from bacteria loads based on population density.
Soil Types	Spatial and PDF Report	SANDAG and United States Department of Agriculture (USDA) and Orange County Public Works using data provided by the US Department of Agricultural (USDA)	Soils layer based on USDA soil survey of the San Diego Area, published in 1973 Soil hydrologic groups as defined by the USDA soil survey for the Orange County Area (Hydrologic Classification Groups A through D, and W)
Surface Waters, Streams, and Storm Drains	Spatial	United States Geological Survey (USGS), SANDAG, County of San Diego and Orange County Public Works	Surface water features from National Hydrography Dataset. Storm drain data provided by SANDAG, County of San Diego, and Orange County Public Works
Sanitary Sewer Infrastructure (mains and laterals)	Spatial	County of San Diego, City of San Diego, Padre Dam Municipal Water District, City of Escondido and Orange County Public Works provided data from local cities and water agencies including: City of Laguna Beach (CLB), City of San Clemente (CSC), City of San Juan Capistrano (CSJC), El Toro Water District (ETWD), Irvine Ranch Water District (IRWD), Moulton Niguel Water District (MNWD), Santa Margarita Water District (SMWD), South Coast Water District (SCWD), and Trabuco Canyon Water District (TCWD)	Available sanitary sewer pipe data including inspection records data collected by Hirsch and Co. from 1998-2005
Septic Systems	Spatial	County of San Diego, Department of Public Works and Orange County Public Works	Provided by County of San Diego, Department of Public Works
SSO and PLSD Locations	Tabular	RWQCB	Category 1 SSOs from 2007 to 2016 and reported PLSDs from 2007
Unit Cost Estimates	Tabular	Brown and Caldwell Cost Estimating Group	Historic bid prices and historic project cost estimates

3.2 Spatial Data

A geographic information system (GIS) application, Esri ArcGIS, was used to analyze and prioritize sources of suspected bacteria load contributions. This section summarizes the spatial data layers used in the analysis.

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3.2.1 Population

Population data from SANGIS is based on the 2010 United States Census data. As discussed in Section 3.3, population data was used to estimate total transient populations for San Diego County and Orange County. Table 3-2 summarizes the total population by TMDL watershed. The compiled data layers are presented in Figure 3-1 and Figure 3-2.

Table 3-2. Summary of Available Population Data in Bacteria TMDL Watersheds

Watershed	Total Population
SAN DIEGO COUNTY	
Chollas Creek	433,068
Los Peñasquitos	377,333
Miramar Reservoir	*231,268*
Poway	*146,065*
San Diego River	620,439
San Dieguito	277,006
San Luis Rey	277,443
San Marcos	28,566
Scripps	87,710
Tecolote	112,490
Total	**2,214,055**
SOUTH ORANGE COUNTY	
Aliso Creek	256,857
Dana Point Coastal	77,840
Laguna Coastal	69,573
San Clemente Coastal	80,810
San Juan Creek	301,538
San Mateo Creek	26,491
Total	**813,109**

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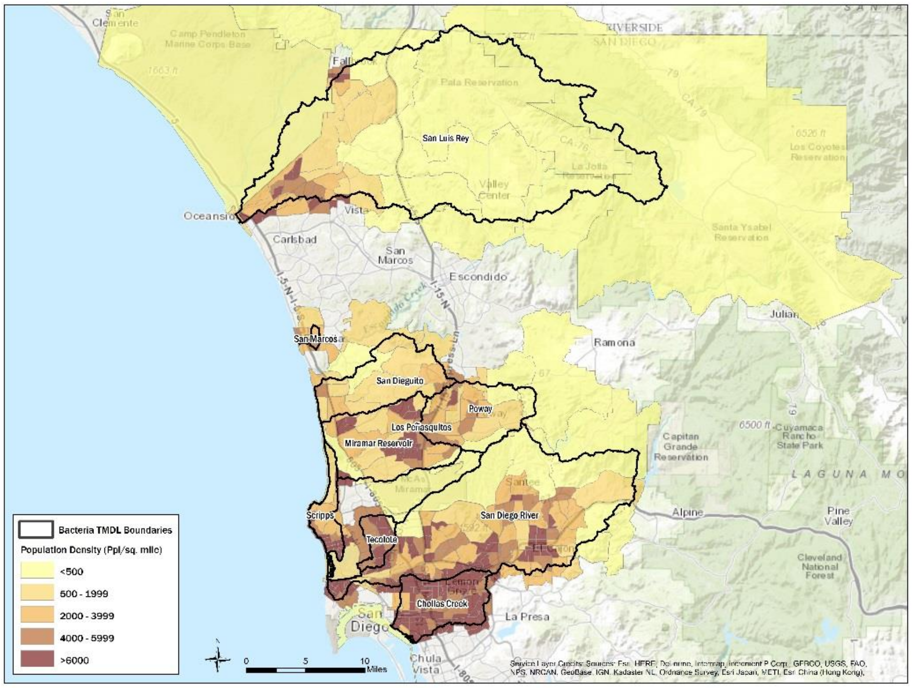

Figure 3-1. Map of Population Density in SD Bacteria TMDL Watersheds

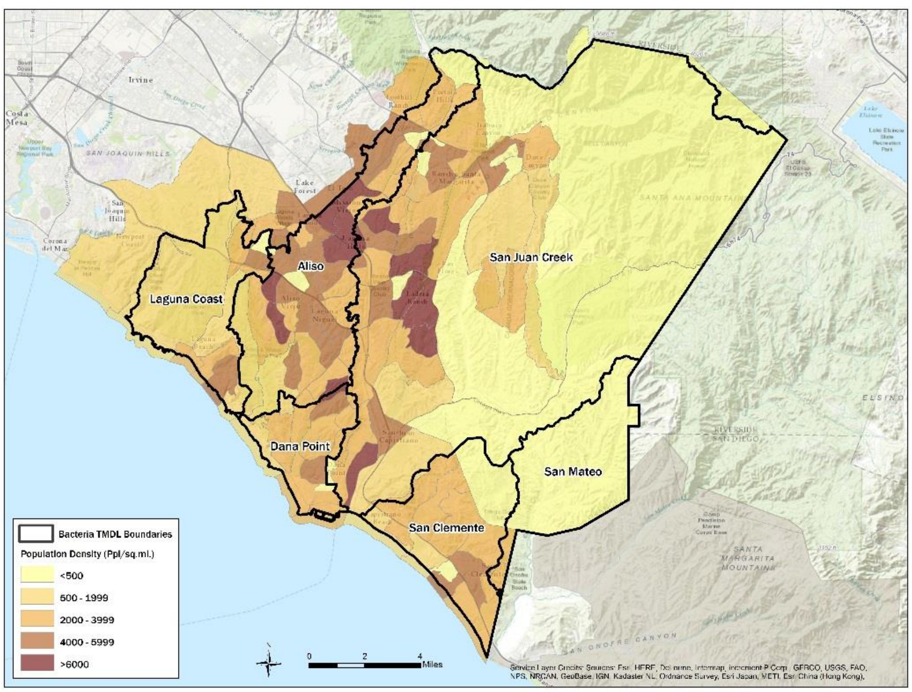

Figure 3-2. Map of Population Density in OC Bacteria TMDL Watersheds

3.2.2 Soil Types

Soils data from SANGIS and the County of Orange were based on the USDA soil survey of the San Diego area, published in 1973. These data were used to identify bacteria load contribution potential from sanitary sewer pipe leakage and failing septic system effluent migrating through soils and reaching surface waters. The variable permeability of soils would impact the ability of bacteria to reach surface waters, with higher permeability soils contributing a larger percentage of bacteria than lower permeability soils. Soil types were categorized into areas of low to high permeability, using hydrologic soil groups as defined in Table 3-3.

Table 3-3. Prioritization of Hydrologic Soil Groups (USDA 1973) in Bacteria TMDL Watersheds

Hydrologic Soil Group	Description	Prioritization Category
A	Soils have high infiltration rate when thoroughly wetted; chiefly deep, well-drained to excessively well-drained sand, gravel, or both. Rate of water transmission is high; thus, runoff potential is low.	3 - High
B	Soils have moderate infiltration rate when thoroughly wetted; chiefly soils that are moderately deep to deep, moderately well-drained to well-drained, and moderately coarse textured. Rate of water transmission is moderate.	2 - Medium
C	Soils have slow infiltration rate when thoroughly wetted; chiefly soils that have a layer impeding downward movement of water, or moderately fine to fine textured soils that have a slow infiltration rate. Rate of water transmission is low.	1 - Low
D	Soils have a very slow infiltration rate when thoroughly wetted; chiefly clays that have a high shrink-swell potential, soils that have a high permanent water table, soils that have a claypan or clay layer at or near the surface, or soils that are shallow over nearly impervious material. Rate of water transmission is very low.	1 - Low

The categorized data layers are presented in Figure 3-3 and Figure 3-4. Type A (high infiltration) type soils are generally found within the river channels of each watershed and Type C (low infiltration) type soils are found along topographic highs.

Several important limitations should be noted for the dataset. USDA maps describe soils from 0 to 60 inches below ground surface. Some map units do not provide the complete 0 to 60 inches, especially when:

- The area was never mapped (only 95 percent of the United States is mapped)
- Bedrock is encountered shallower than 60 inches
- In urban areas or rock outcrop (no soil present)

The soil data used in the analysis references to conditions in the San Diego area in 1969 and Orange County in 1978. The dataset does not account for land disturbances or development since the time of the survey (USDA 1973), nor does this analysis.

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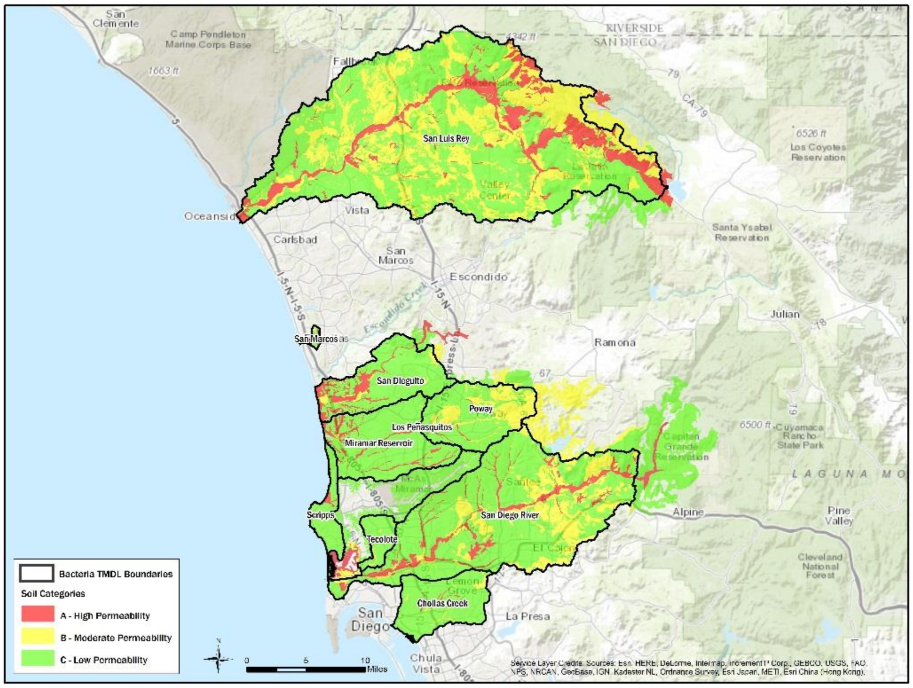

Figure 3-3. Map of Soil Types in SD Bacteria TMDL Watersheds

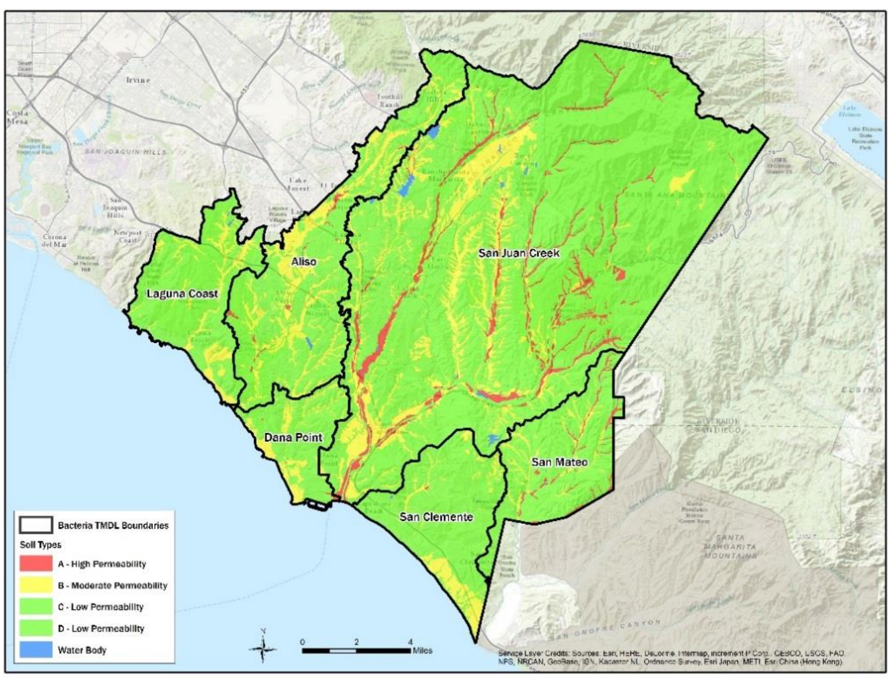

Figure 3-4. Map of Soil Types in OC Bacteria TMDL Watersheds

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3.2.3 Surface Waters, Streams, and Storm Drains

Available surface water, stream, and storm drain data were compiled from USGS, SANDAG, County of SD, and Orange County. These data were used to determine proximity of surface waters, streams, and storm drains to sanitary sewer pipes and septic systems, and identify bacteria load contribution potential. The compiled data layers are presented in Figure 3-5 and Figure 3-6.

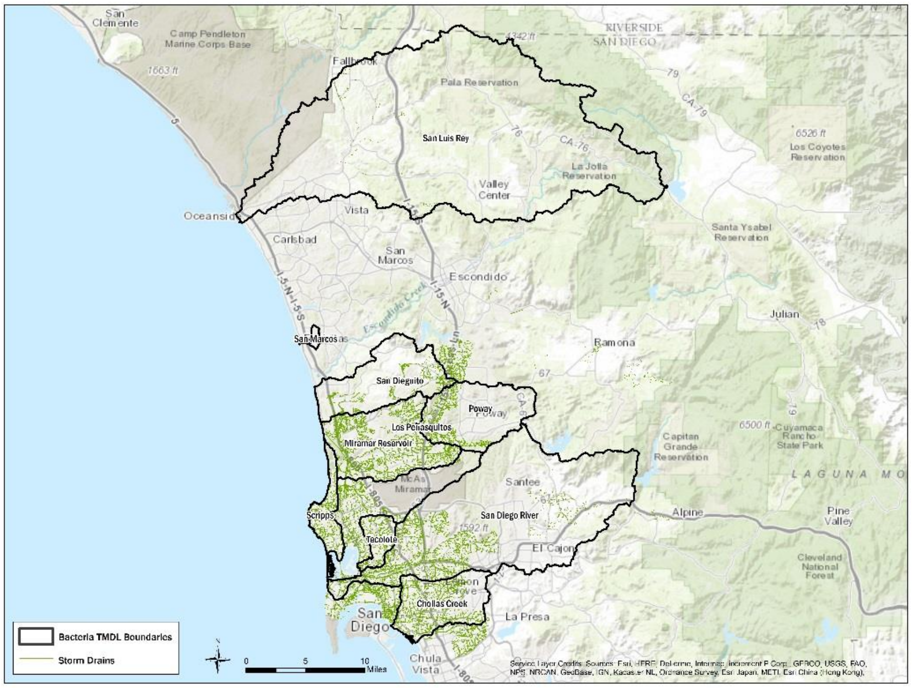

Figure 3-5. Map of Available Storm Drain Data in SD Bacteria TMDL Watersheds

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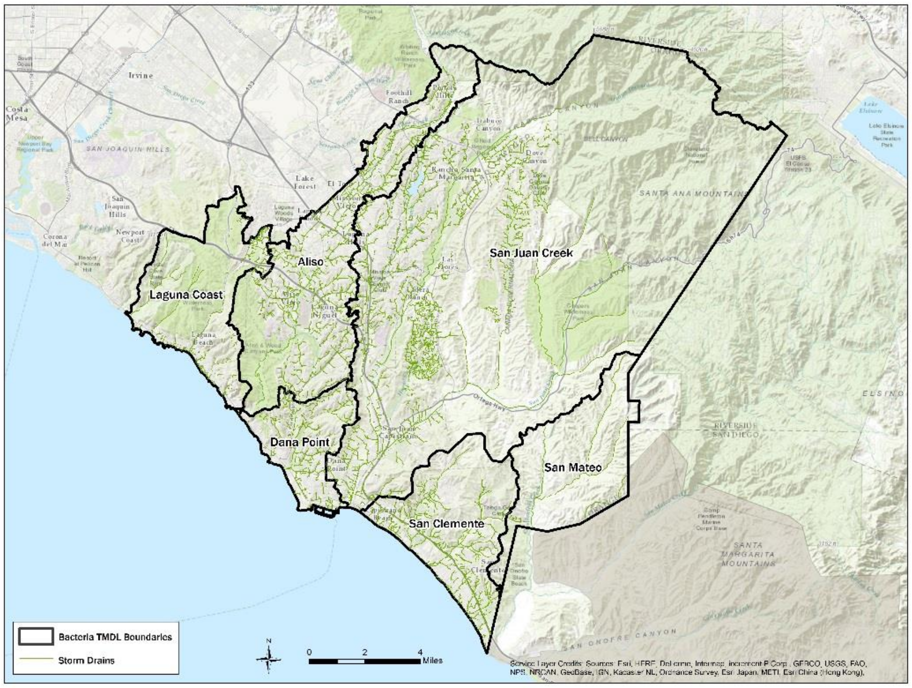

Figure 3-6. Map of Available Storm Drain Data in OC Bacteria TMDL Watersheds

3.2.4 Sanitary Sewer Pipes

Special Note: It must be noted that the load and cost estimates developed for this analysis are intended to be exploratory in nature and should not be interpreted as accurate leakage volumes from sanitary sewer pipes throughout the study area. Additionally, these scenarios were not designed to represent the actual load reduction requirement or cost of projects needed to comply with any current and/or future regulations including the Bacteria TMDL, Waste Discharge Requirements (WDRs), or any other regulatory requirements. Estimates of exfiltration from sanitary sewer pipes developed in this analysis do not account for varying conditions of water level and/or pressure in pipes during wet weather or other effects of infiltration and inflow.

Accurately estimating the amount of exfiltration from sanitary sewer pipes throughout the study area would require extensive data collection, testing, and modeling under a variety of conditions, pipe material types, and diameters (Heinrich, 2007). For the purposes of this high-level, exploratory analysis, a simplified method was developed to roughly estimate exfiltration.

This method relies on the measured exfiltration rates from the 2005 Orange County Sanitation District study as discussed in Section 3.4 (Brown and Caldwell, 2005). In that study, exfiltration was measured at six 6-inch and 8-inch diameter vitrified clay pipes (VCP) at areas of known defects under half-full sewage levels. This may diverge significantly from actual sewage systems as most are constructed of a variety of pipe materials, diameters, and have differing hydraulic conditions. The pipe data compiled for this analysis consists of approximately 48% VCP, 44% PVC, and 8% other and diameters of 2 to 108 inches. Note, this GIS data may not accurately reflect current conditions of the sewer collection systems for all local agencies.

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An average exfiltration rate of 0.35 gallons per day per defect per inch diameter was calculated. Although the margin of error is unknown, it was assumed that this exfiltration rate can be applied to the study area (South Orange County and San Diego County) for the purposes of this exploratory analysis (Heinrich, 2007). The next step was to apply this average exfiltration rate to the total number of defects estimated from available GIS and inspection data within the study area, as described below.

To the extent readily available, sanitary sewer pipe GIS data were compiled from local sewer utilities within the study area. As illustrated in Figure 3-7 through 3-10, the available sanitary sewer pipe data does not cover all sewered areas throughout the study area. For the San Marcos and San Luis Rey watersheds, sanitary sewer load estimates were extrapolated from the Scripps watershed by proportion of total watershed area. A defect frequency (number of defects that can contribute to exfiltration per feet of pipe) was estimated using inspection records of sanitary sewer pipes in San Diego County from 1998-2005 performed by Hirsch & Co. This database consists of data acquired from multiple projects of varying pipe conditions and types. This inspection database was queried by Pipeline Assessment Certification Program (PACP) codes and compared to the total length of inspected pipe to calculate an initial defect frequency. The initial defect frequency was then multiplied by an average replacement and rehabilitation rate of 45 miles per year to calculate the number of repaired defects and the subsequent adjusted defect frequency. It should be noted that since rehabilitation and replacement programs typically target high priority pipes, this method may overestimate the frequency of defects. It was assumed that for every 10 defects repaired, 1 new defect was generated, though this assumption is based on best professional judgement and should be validated during future study. The revised defect frequency was calculated as the average of adjusted defect frequencies over the course of 113 years (from 2005-present then over 100 years). This revised defect frequency was then multiplied by the total length of pipe in the available GIS data to estimate total number of system defects, then multiplied by the average exfiltration rate per defect to estimate the total daily volume of leaked sewage. As mentioned above, the 2005 OCSD study measured exfiltration from half full pipes. Therefore, this methodology does not account for changes in pipe sewage level or effects of infiltration and inflow during wet weather.

Updated defect frequency data was requested, but not available at the time of this study. It is recommended that any future refinement of this analysis include the most up-to-date defect frequency data from local agencies.

Table 3-4 summarizes the total length of sanitary sewer pipe in the Bacteria TMDL watersheds. The compiled data layers are presented in Figure 3-7 through Figure 3-10. Sanitary sewer pipe diameter and age data was also used as factors in the weighted prioritization matrix.

Table 3-4. Summary of Available Sanitary Sewer Pipe Data in Bacteria TMDL Watersheds

Watershed	Total Length of Mains (miles)	Total Length of Laterals (miles)
SAN DIEGO COUNTY		
Chollas Creek	475	674
Los Peñasquitos	617	737
Miramar Reservoir	*481*	*572*
Poway	*137*	*165*
San Diego River	883	689
San Dieguito	127	99
San Luis Rey[1]	NA	NA
San Marcos[1]	NA	NA

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Table 3-4. Summary of Available Sanitary Sewer Pipe Data in Bacteria TMDL Watersheds		
Watershed	Total Length of Mains (miles)	Total Length of Laterals (miles)
Scripps	211	265
Tecolote	146	210
Total	2,459	2,674
SOUTH ORANGE COUNTY		
Aliso Creek	414	55
Dana Point Coastal	178	9
Laguna Coastal	121	1
San Clemente Coastal	192	4
San Juan Creek	391	59
San Mateo Creek	1	-
Total	1,297	127

1. *Sanitary sewer pipe data was unavailable for San Marcos and San Luis Rey. Load contributions from sewer mains and sewer laterals were estimated for San Marcos and San Luis Rey based on extrapolating the results for Scripps watershed using percentage of watershed areas.*

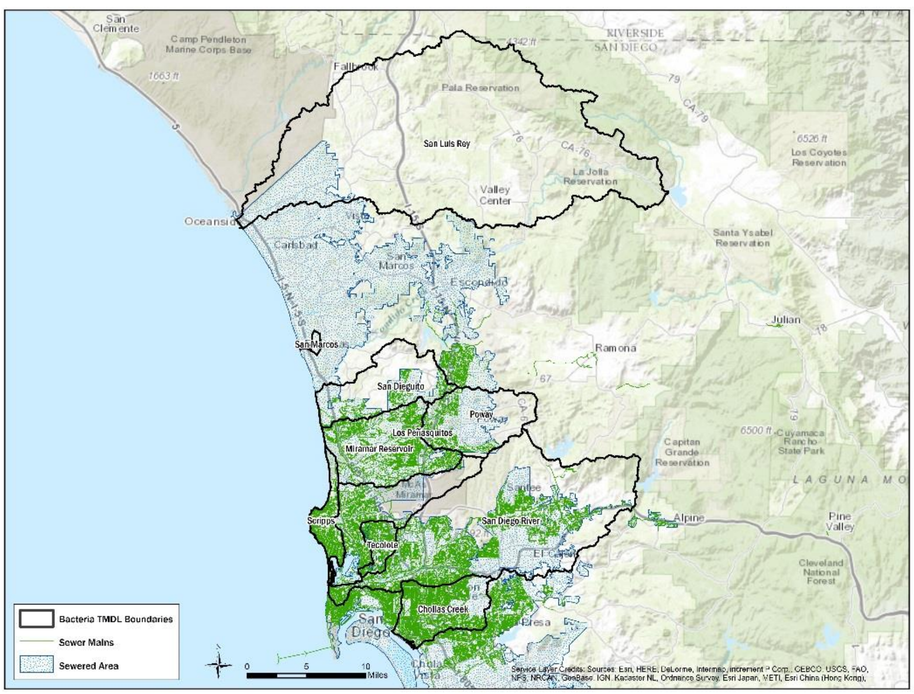

Figure 3-7. Map of Available Sanitary Sewer Mains Data in SD Bacteria TMDL Watersheds

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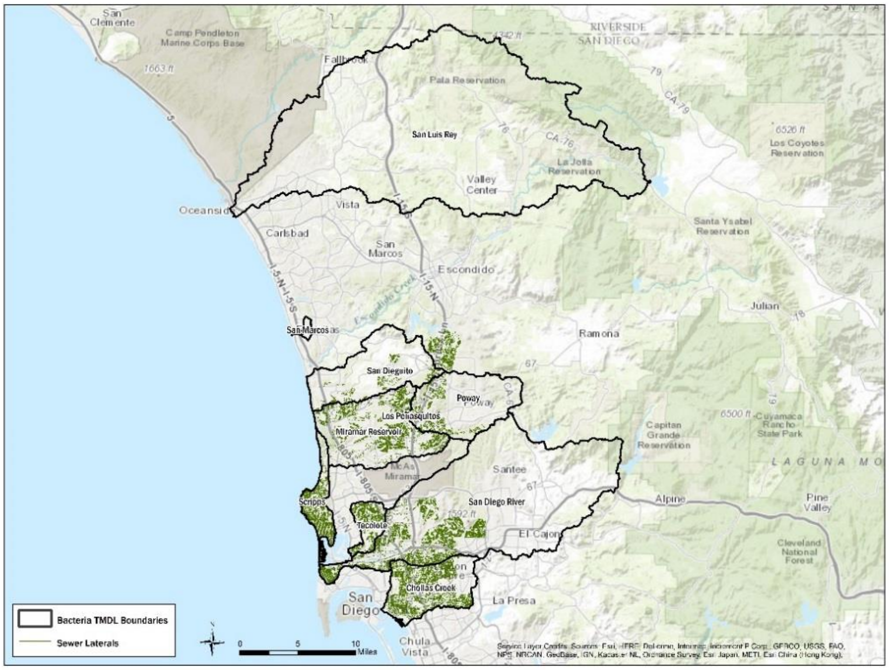

Figure 3-8. Map of Available Sanitary Sewer Laterals Data in SD Bacteria TMDL Watersheds

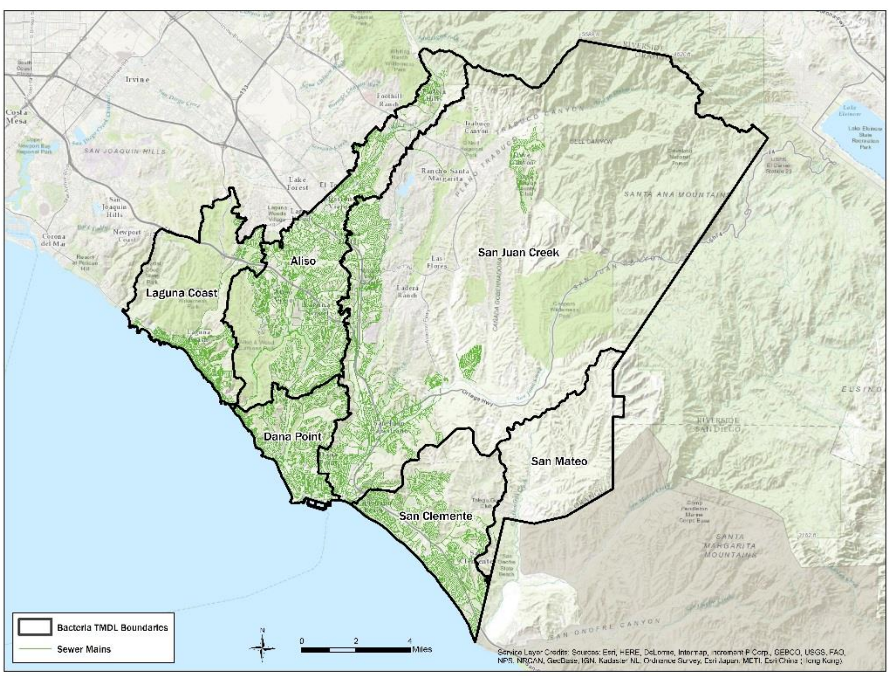

Figure 3-9. Map of Available Sanitary Sewer Mains Data in OC Bacteria TMDL Watersheds

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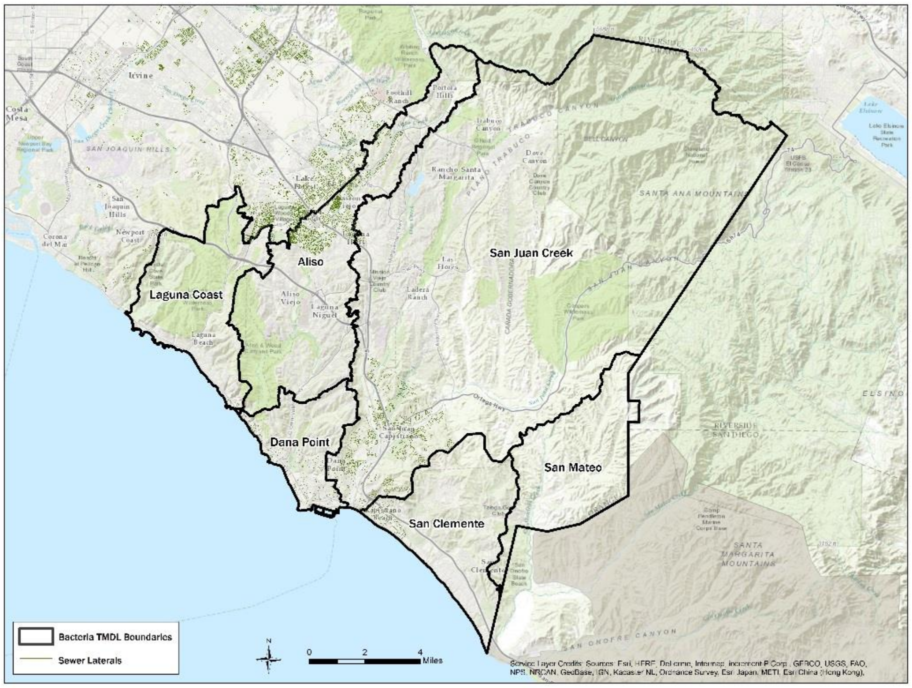

Figure 3-10. Map of Available Sanitary Sewer Laterals Data in OC Bacteria TMDL Watersheds

3.2.5 Septic Systems

Available septic system data were compiled from the County of SD and Orange County. The data layer contains the parcels served by septic systems, but does not identify the size or age of the system itself. The estimated bacteria contribution and planning-level replacement cost estimates were based on this data layer. Table 3-5 summarizes the number of parcels with septic systems. The compiled data layer is presented in Figure 3-11 and Figure 3-12.

Based on discussions with the County of San Diego, Department of Environmental Health, only a small fraction of septic systems fail in a manner that allows for completely untreated sewage to enter the environment. Predominantly, septic systems begin to fail gradually and will still provide a level of treatment. If the failure is more extensive, the owner typically becomes aware of the failure (through odor, backup, etc.) and fixes the system.

Table 3-5. Summary of Available Septic System Data in Bacteria TMDL Watersheds

Watershed	Number of Parcels on Septic Systems
SAN DIEGO COUNTY	
Los Peñasquitos (Poway)	35
San Diego River	11,418
San Dieguito	4,498
San Luis Rey	9,250

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Table 3-5. Summary of Available Septic System Data in Bacteria TMDL Watersheds	
Watershed	Number of Parcels on Septic Systems
Total	25,201
SOUTH ORANGE COUNTY	
Aliso Creek	4
Dana Point Coastal	8
Laguna Coastal	15
San Clemente Coastal	-
San Juan Creek	814
San Mateo Creek	1
Total	842

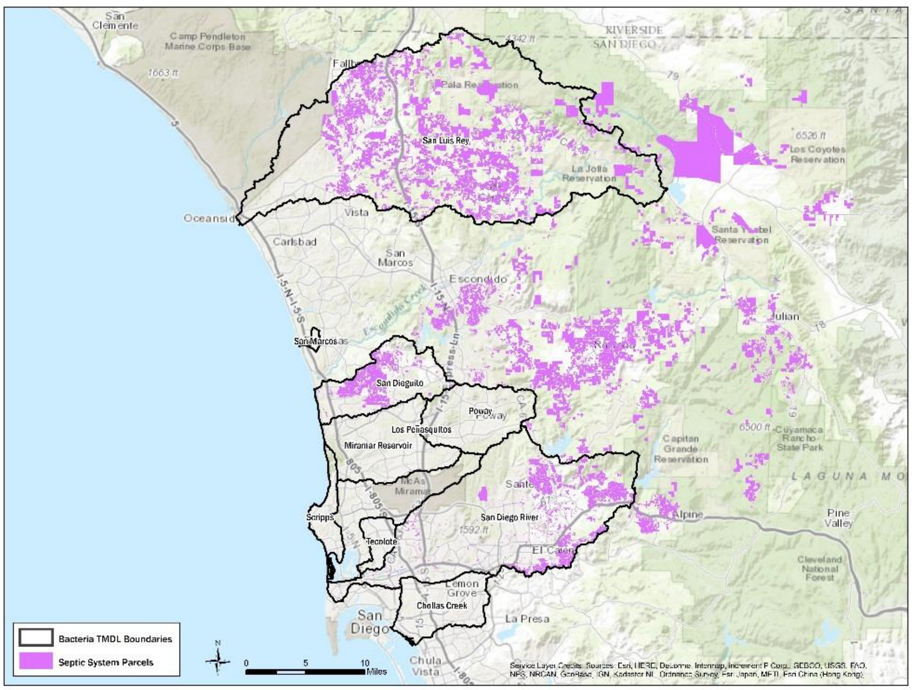

Figure 3-11. Map of Available Septic System Data in SD Bacteria TMDL Watersheds

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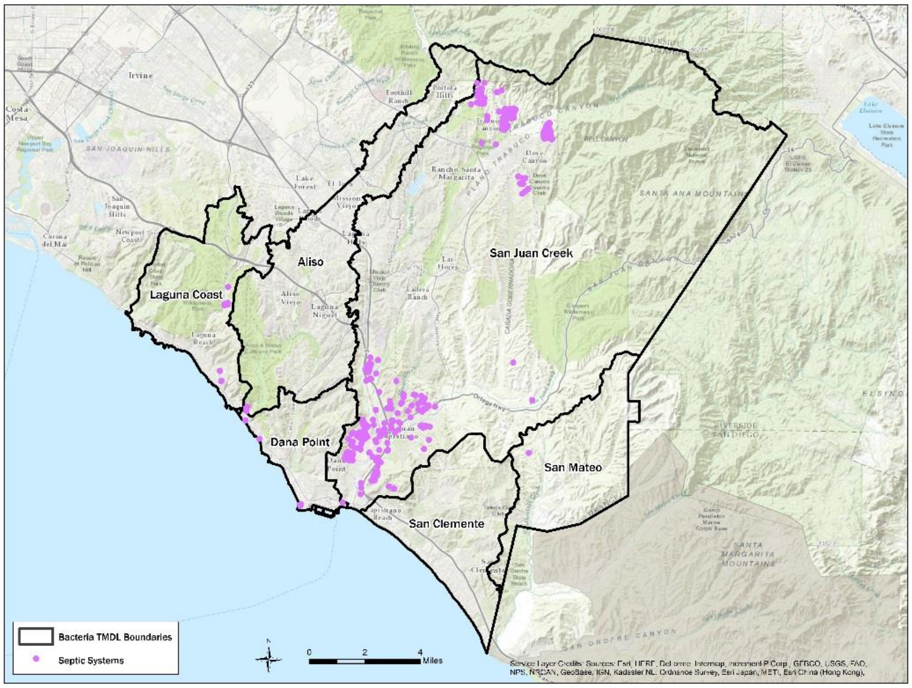

Figure 3-12. Map of Available Septic System Data in Bacteria TMDL Watersheds

3.2.6 Sanitary Sewer Overflows

Available information for SSOs and PLSDs were compiled from the RWQCB San Diego Region database. Only Category 1 SSOs were included in this assessment since these are reported to have reached surface waters. PLSDs are voluntarily reported and, therefore, may not represent all loading from private sewer laterals. Category 1 SSOs are defined as:

> "Discharges of untreated or partially treated wastewater of any volume resulting from an enrollees sanitary sewer system failure or flow condition that:
>
> - Reach surface water and/or reach a drainage channel tributary to a surface water; or
> - Reach a municipal separate storm sewer system and are not fully captured and returned to the sanitary sewer system or not otherwise captured and disposed of properly. Any volume of wastewater not recovered from the municipal separate storm sewer system is considered to have reached surface water unless the storm drain system discharges to a dedicated storm water or ground water infiltration basin (e.g., infiltration pit, percolation pond)."
>
> *(State Water Resources Control Board [SWRCB] 2016)*

SSOs and PLSDs can be caused by a variety of factors including (USEPA 1996):

- Excess infiltration and inflow into sanitary sewer pipes
- Inadequate capacity of sanitary sewer pipes, pump stations, and appurtenances
- Broken, cracked, or blocked sanitary sewer pipes

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- Root intrusion into sanitary sewer pipes
- Fats, oils, and grease buildup

Spill volumes were averaged across multiple years and, therefore, the effects of SSOs and PLSDs on total load contribution appear to be small. However, it should be noted that these events may occur instantaneously and sporadically causing very significant spikes to bacterial loading. The results of this analysis should not be used to assess the impacts of SSO and PLSDs on overall watershed health.

Based on the available data, average annual spill volumes for Category 1 SSOs and reported PLSDs were summarized, as presented in Table 3-6. The compiled data layer is presented in Figure 3-13 and Figure 3-14.

Table 3-6. Summary of Category 1 SSO and PLSD Spill Volumes in Bacteria TMDL Watersheds

Watershed	SSOs – Average Annual Spill Volume Reaching Water-body from 2007-2016 (Gallons/Year)	PLSDs - Annual Spill Volume Reaching Waterbody from 2007 (Gallons/Year)
SAN DIEGO COUNTY		
Chollas Creek	3,249	568
Los Peñasquitos	9,774	1,852
Miramar Reservoir	1,994	*1,852*
Poway	7,780	-
San Diego River	15,000	2,654
San Dieguito	71,751	71
San Luis Rey	38,902	4,000
San Marcos	4,900	-
Scripps	1,430	231
Tecolote	282	328
Total	145,287	9,704
SOUTH ORANGE COUNTY		
Aliso Creek	2,934	NA
Dana Point Coastal	2,235	
Laguna Coastal	89,344	
San Clemente Coastal	2,514	
San Juan Creek	93,334	
San Mateo Creek	10,010	
Total	200,371	

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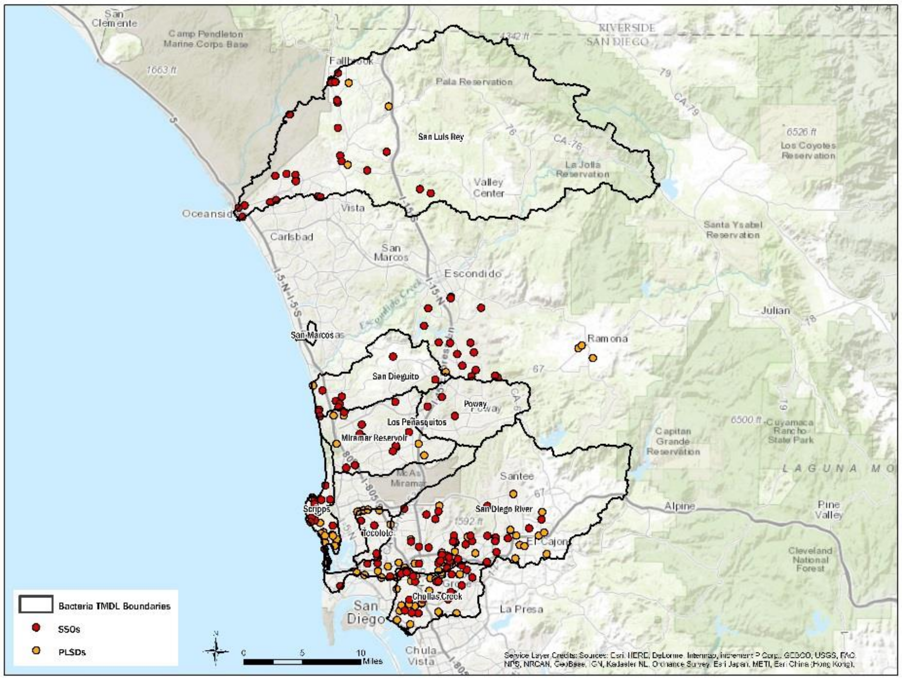

Figure 3-13. Map of Category 1 SSOs and PLSDs in SD Bacteria TMDL Watersheds

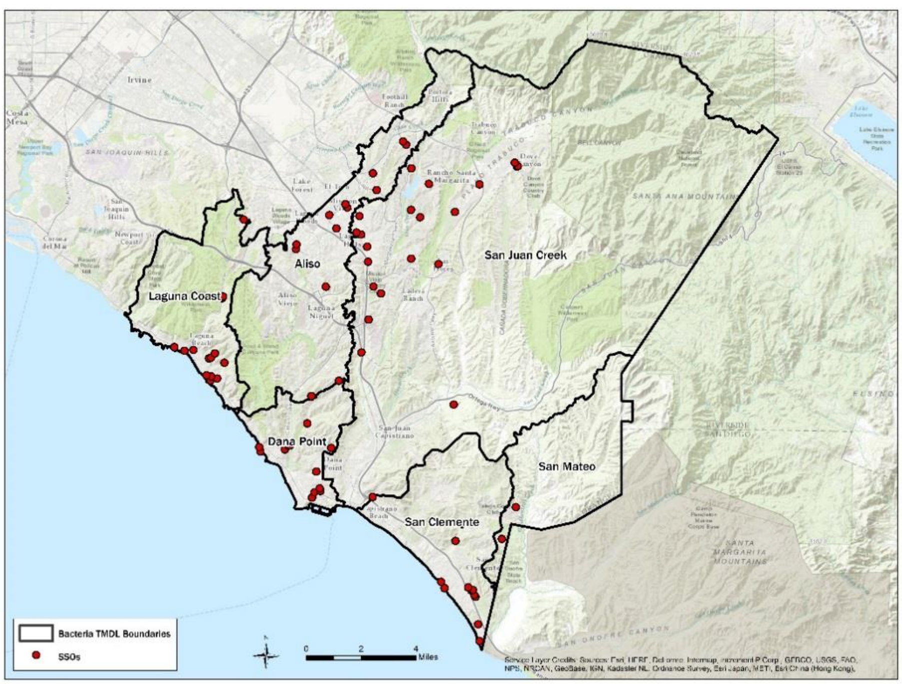

Figure 3-14. Map of Category 1 SSOs in OC Bacteria TMDL Watersheds

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3.3 Transient Populations

Transient populations were estimated by the Regional Task Force on the Homeless in the *2016 Point-In-Time County for San Diego County* (Regional Task Force on the Homeless 2016) and by Focus Strategies in the *2015 Orange County Homeless Count & Survey Report* (Schatz, 2015). The San Diego report included a count of total observed transient populations by census tract; however, it did not differentiate between populations living along river banks or creek corridors. The Orange County report provided total counts of the unsheltered population, but did not provide counts by census tract. An estimated total transient population of 300 individuals live along the San Diego River (personal communication between Todd Snyder (County of SD) and Rob Hutsel (San Diego River Park Foundation), 2017). The proportion of transient population living along the river versus the total estimated population within the San Diego River watershed estimate was extrapolated to the other watersheds. The resulting estimates of transient populations living along river banks or creek corridors is presented in Table 3-7.

It should be noted that the use of human marker HF183 as a surrogate parameter for pathogenic bacteria and viruses is most effective for a large sample size of population, such as that in a sewer collection system. If the population size is large enough, the proportion of people on any given day that are infected with a pathogen relatively predictable. Therefore, in these cases, HF183 (which is present in most individuals) can be assumed to be a reasonable surrogate for human pathogens and, thus, in raw wastewater, the reduction of HF183 can be assumed to represent a reduction of pathogens. The population sample size for transient population is much lower and, therefore, the ability to use HF183 as a surrogate for pathogens is tenuous since illness rates among a smaller population size is less predictable than a larger sample set of the population (personal communication between Jeff Soller and Tony Hancock, 2017).

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Table 3-7. Estimated Transient Populations in Bacteria TMDL Watersheds		
Watershed	Estimated Transient Population Count from Point-in-Time Census Tracts	Estimated Transient Count Living Near Riverbank (extrapolated from San Diego River Park Foundation count)
SAN DIEGO COUNTY		
Chollas Creek	1130	385
Los Peñasquitos	70	25
Poway	*16*	*6*
Miramar Reservoir	*54*	*19*
San Diego River	882	300
San Dieguito	144	49
San Luis Rey	257	88
San Marcos	41	14
Scripps	105	36
Tecolote	188	64
Total	2,817	961
SOUTH ORANGE COUNTY		
Aliso Creek	176	60
Dana Point Coastal	53	18
Laguna Coastal	48	16
San Clemente Coastal	55	19
San Juan Creek	207	70
San Mateo Creek	18	6
Total	558	190

3.4 Previous Studies

In 2016, wet weather samples were collected on the San Diego River and major tributaries and analyzed for the presence of HF183 (a genetic human waste marker) and human pathogens. This was a supplemental source tracking study to the Surfer Health Study (Schiff 2016). The study collected wet weather samples from 13 sites during a single storm event within the San Diego River. The samples were analyzed to identify human fecal markers and human-specific pathogens. The human marker, HF183, was detected at every monitoring site, suggesting that human-source bacteria loading may be prevalent throughout the watershed. The monitoring points are presented in Figure 3-15.

Since 2013, Southern California Coastal Water Research Project (SCCWRP) has collected and analyzed HF183 grab samples from the outfalls of Aliso Creek and San Juan Creek watershed as part of the Bight '13 Regional Monitoring program during dry and wet weather. The wet weather data were used to calibrate the human sources model for the South Orange County watersheds.

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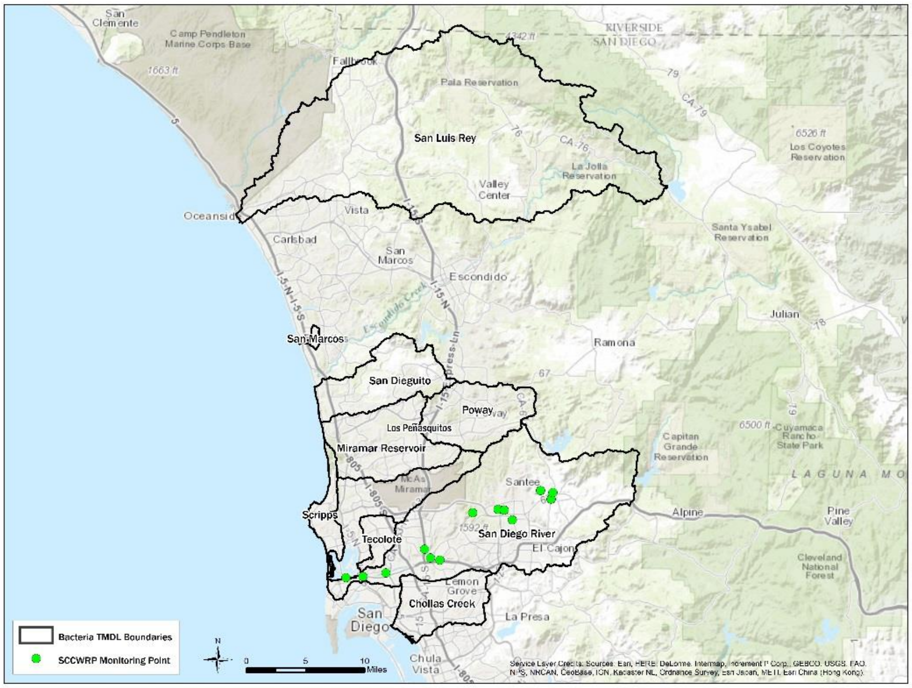

Figure 3-15. Map of Water Quality Monitoring Points from SCCWRP's Surfer Health Study

A 2009 study by the University of California, Santa Barbara, and the City of Santa Barbara looked at the human-specific *Bacteroides* marker as a potential indication of anthropogenic bacteria loading to storm drains and receiving water bodies. Similar to SCCWRP's results, human waste markers were found throughout the system. The study lists in-situ growth, direct contamination through illicit cross connections, and indirect contamination from nearby sanitary sewer lines as potential sources (Sercu, 2009).

Brown and Caldwell prepared a *Status Report on the Development of a Reporting Methodology for Subsurface Discharges of Sewage* for Orange County Sanitation District in 2005. The objective of the report was to develop a field methodology for accurately and defensibly estimating possible leakage from gravity sanitary sewer pipes. Testing was performed using a device called the Exfiltrometer, developed by the University of California, Irvine. The results of the testing showed a range of measurements from an infiltration rate of 26 liters per hour to an exfiltration rate of 0.92 liters per hour. The results concluded that there was no clear correlation between the type of defect of the pipe and resulting rate of exfiltration. It was noted that the soil type in which the sanitary sewer segment was located played a factor in determining the rate of exfiltration. The project did not assess the potential rate of contaminant/pathogen transport from sanitary sewer pipes to storm drains.

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Section 4: Prioritization

The data described in Section 2 was used to prioritize sanitary sewer pipes and septic systems and estimate bacteria load contributions. This section describes the prioritization methodology and presents the results of the data analysis.

4.1 Prioritization Methodology

A weighted numeric risk analysis methodology was applied to the available data to rank sanitary sewer pipes and septic systems within the watersheds with respect to their relative bacteria loading potential. Each criterion was assigned a weight and score based on the data values. The assigned weight percentages are assumed based on best engineering judgement to reflect the relative importance of each criterion. Weight percentages may be revised during future analysis to reflect updated information and data. The rationale behind each criterion is as follows:

- Distance from stream/storm drain: the closer a stream or storm drain is to a source; the more probable bacteria and/or viruses will survive and mobilize to the receiving waters. For example, if a sewer pipe is within 50 feet of a creek it is more likely the load will reach the creek that is the sewer pipe is 1 mile away, if all other factors are equal.
- Soil types: highly permeable soils are more likely to convey loads through the ground to receiving waters. For example, leaking sewer pipes in gravelly sands will mobilize more rapidly that in clay layers.
- Sanitary sewer pipe diameter: smaller diameter pipes are less likely to be inspected and maintained than large trunk sewers. Also, larger sewer pipes are typically constructed to a higher level of structural strength than smaller pipes.
- Sanitary sewer pipe age: older pipes are more likely to contain defects than newer pipes due to advances in pipe material, construction technique, and degradation over time.

Table 4-1 presents the prioritization criteria matrix. Table 4-2 describes the weighted prioritization categories.

Table 4-1. Prioritization Criteria Matrix

Criteria	Weight Septic	Weight Sewer	Values	Score
Distance from Stream/Storm Drain	50%	35%	< 100 ft.	3
			100-500 ft.	2
			>500 ft.	1
Soil Types[1]	50%	15%	High Permeability	3
			Moderate Permeability	2
			Low Permeability	1
Sanitary Sewer Pipe Diameter	NA	15%	0 – 15 inch	3
			16 – 24 inch	2
			>24 inch	1
Sanitary Sewer Pipe Age	NA	35%	>40 years	3
			21-40 years	2
			≤20 years	1

1. Soil types were categorized by hydrologic group, based on the 1973 USDA Soil Survey of the San Diego Area (Table 11, Part II of the survey).

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Table 4-2. Categories of Prioritization		
Weighted Score	Prioritization Category	Description
>2.5	High	Potential "hot spot." High priority for further investigation
2.1-2.5	Medium	Medium priority for further investigation
≤2	Low	Low priority for further investigation

4.2 Results

Total mileage of sanitary sewer mains and laterals, along with maps of the prioritized pipes, are presented in Table 4-3, Table 4-4, Figure 4-1, and Figure 4-3 below. The prioritized septic systems parcels are summarized in Table 4-5 and Figure 4-5 below.

Table 4-3. Prioritized Sanitary Sewer Mains in Bacteria TMDL Watersheds				
Watershed	High Priority (miles)	Medium Priority (miles)	Low Priority (miles)	Total Length (miles)
SAN DIEGO COUNTY				
Chollas Creek	91	144	240	475
Los Peñasquitos	89	245	283	617
Miramar Reservoir	*82*	*187*	*212*	*481*
Poway	*8*	*58*	*71*	*137*
San Diego River	177	293	412	883
San Dieguito	14	34	78	127
San Luis Rey[1]	NA	NA	NA	NA
San Marcos[1]	NA	NA	NA	NA
Scripps	43	70	97	211
Tecolote	42	61	43	146
Total	458	848	1,153	2,459
SOUTH ORANGE COUNTY				
Aliso Creek	35	190	189	414
Dana Point Coastal	14	76	87	178
Laguna Coastal	2	61	57	121
San Clemente Coastal	27	91	74	192
San Juan Creek	85	142	164	391
San Mateo Creek	-	-	1	1
Total	164	561	572	1,297

1. *Sanitary sewer pipe data was unavailable for San Marcos and San Luis Rey. Load contributions from sewer mains and sewer laterals were estimated for San Marcos and San Luis Rey based on extrapolating the results for Scripps watershed using percentage of watershed areas.*

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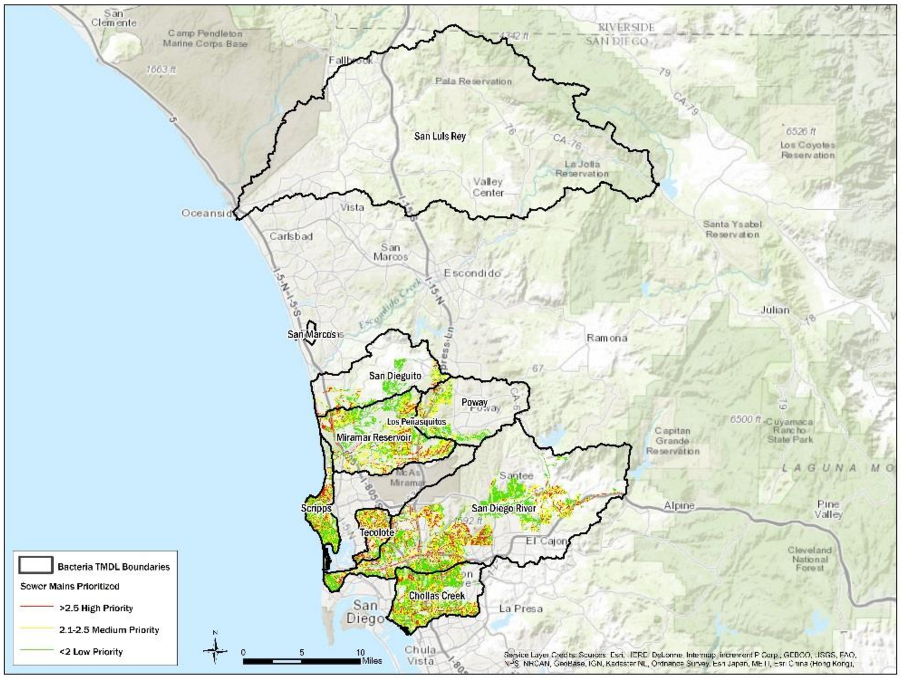

Figure 4-1. Map of Prioritized Sanitary Sewer Mains in SD Bacteria TMDL Watersheds

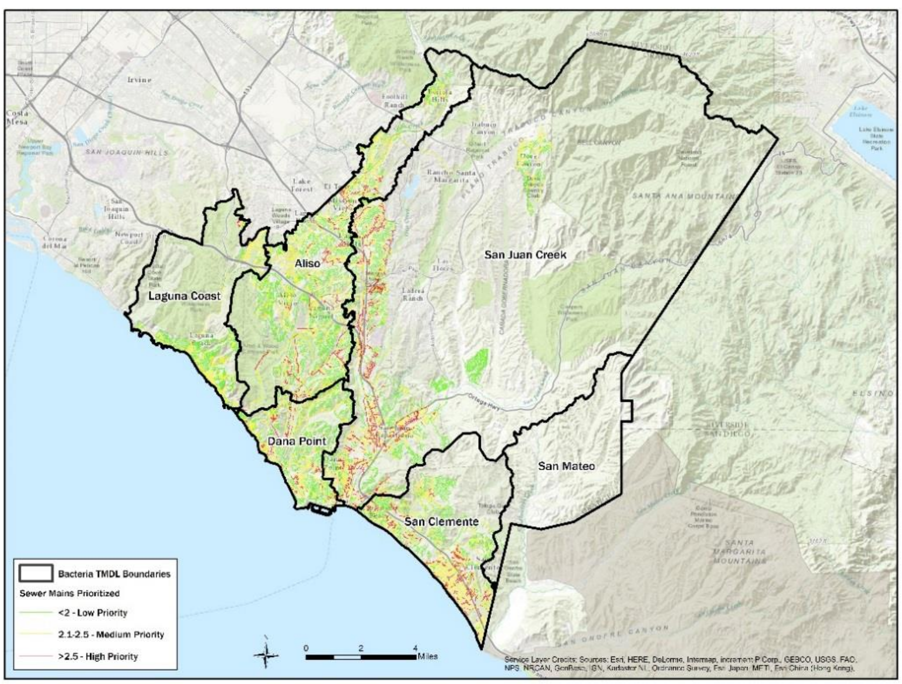

Figure 4-2. Map of Prioritized Sanitary Sewer Mains in OC Bacteria TMDL Watersheds

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Table 4-4. Prioritized Sanitary Sewer Laterals in Bacteria TMDL Watersheds

Watershed	High Priority (miles)	Medium Priority (miles)	Low Priority (miles)	Total Length (miles)
SAN DIEGO COUNTY				
Chollas Creek	3	118	552	674
Los Peñasquitos	13	181	544	737
Miramar Reservoir	*13*	*132*	*427*	*572*
Poway	-	*49*	*116*	*165*
San Diego River	14	147	528	689
San Dieguito	3	15	81	99
San Luis Rey[1]	NA	NA	NA	NA
San Marcos[1]	NA	NA	NA	NA
Scripps	6	64	194	265
Tecolote	-	47	162	210
Total	39	573	2,062	2,674
SOUTH ORANGE COUNTY				
Aliso Creek	4	26	25	55
Dana Point Coastal	-	3	6	9
Laguna Coastal	-	-	1	1
San Clemente Coastal	-	2	2	4
San Juan Creek	17	26	16	59
San Mateo Creek	-	-	-	-
Total	21	57	50	127

1. *Sanitary sewer pipe data was unavailable for San Marcos and San Luis Rey. Load contributions from sewer mains and sewer laterals were estimated for San Marcos and San Luis Rey based on extrapolating the results for Scripps watershed using percentage of watershed areas.*

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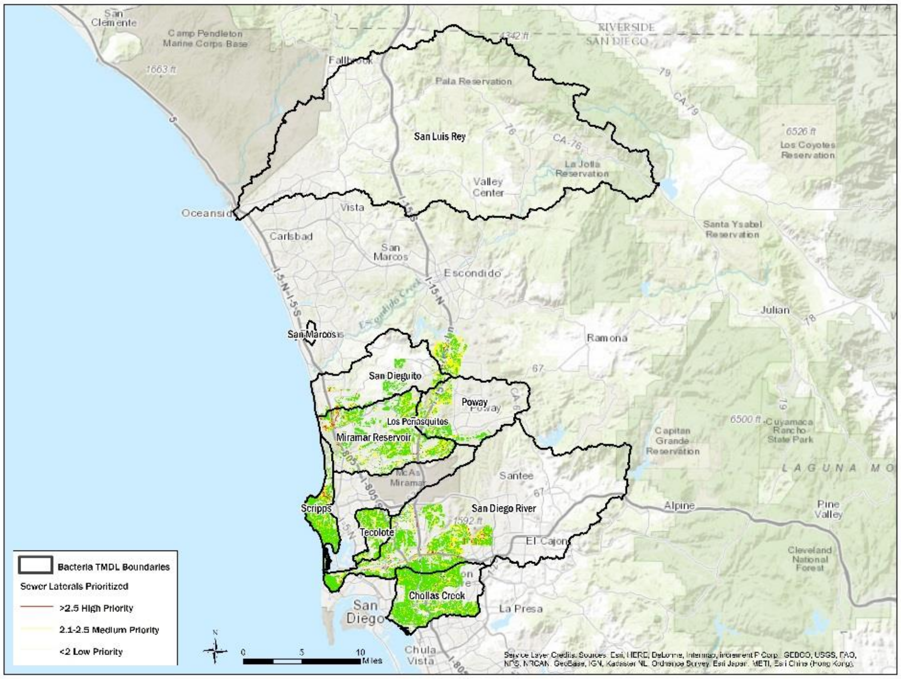

Figure 4-3. Map of Prioritized Sanitary Sewer Laterals in SD Bacteria TMDL Watersheds

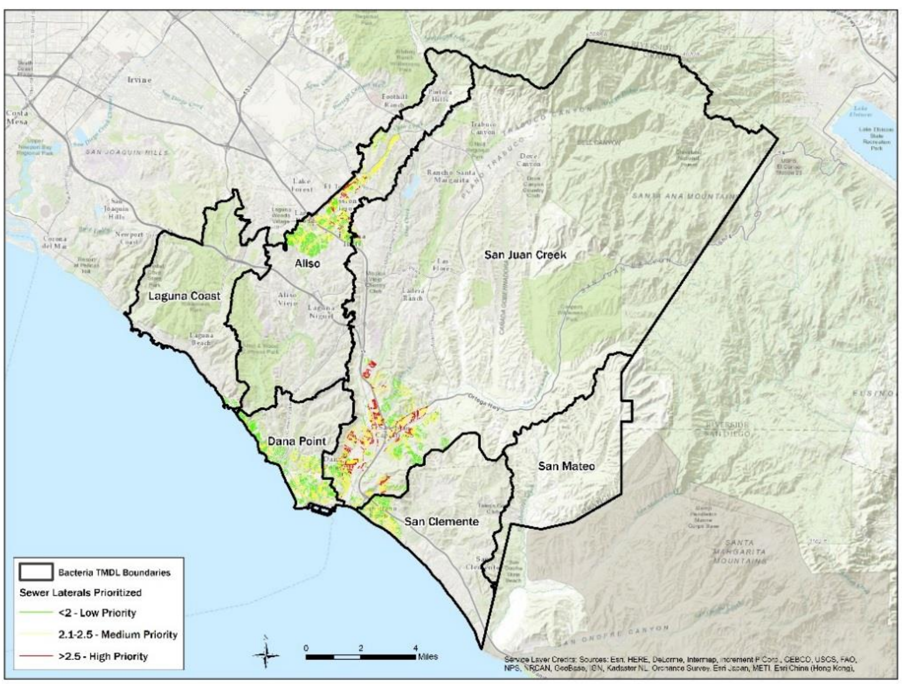

Figure 4-4. Map of Prioritized Sanitary Sewer Laterals in OC Bacteria TMDL Watersheds

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Table 4-5. Prioritized Septic Systems		
Watershed	Priority	Number of Parcels
SAN DIEGO COUNTY		
Los Peñasquitos (Poway)	High	2
	Medium	13
	Low	20
San Diego River	High	108
	Medium	450
	Low	10,860
San Dieguito	High	45
	Medium	204
	Low	4,249
San Luis Rey	High	115
	Medium	806
	Low	8,329
SOUTH ORANGE COUNTY		
Aliso Creek	High	-
	Medium	-
	Low	4
Dana Point Coastal	High	-
	Medium	1
	Low	7
Laguna Coastal	High	-
	Medium	-
	Low	15
San Clemente Coastal	High	-
	Medium	-
	Low	-
San Juan Creek	High	-
	Medium	36
	Low	778
San Mateo Creek	High	-
	Medium	-
	Low	1

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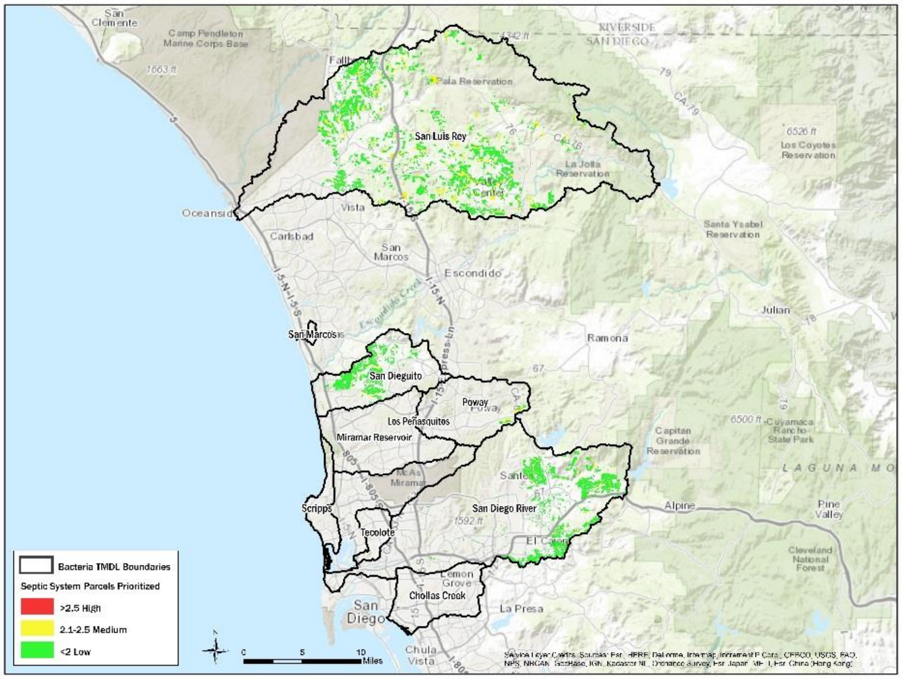

Figure 4-5. Map of Prioritized Septic System Parcels in Bacteria TMDL Watersheds

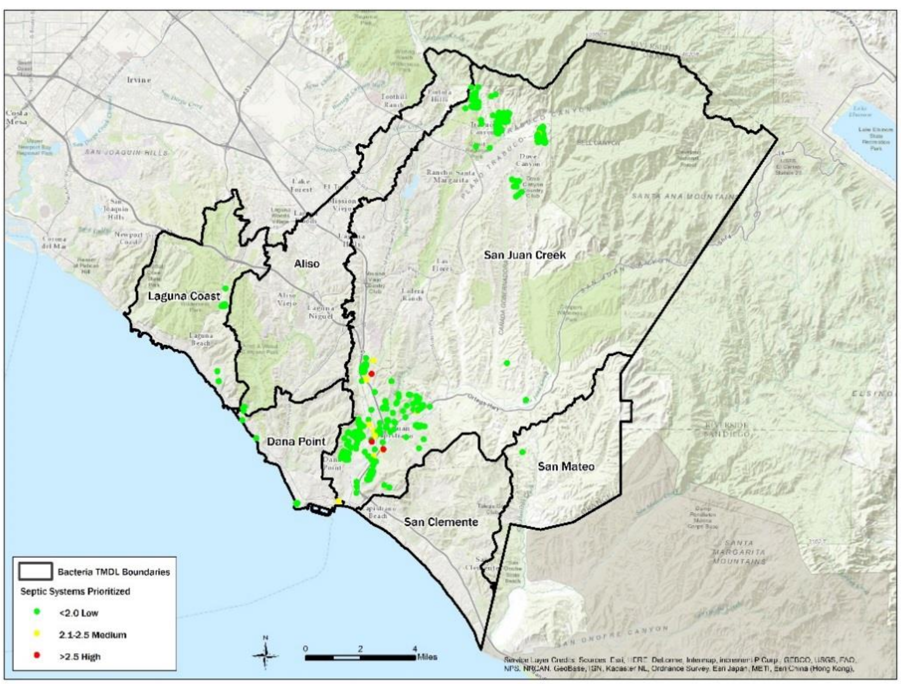

Figure 4-6. Map of Prioritized Septic System Parcels in Bacteria TMDL Watersheds

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Section 5: Load Contributions

This section presents a discussion on estimated human-source bacteria loading contributions.

5.1 Load Contribution Estimates

Determining accurate estimates of bacteria load contribution from human sources and load reduction from projects requires extensive modeling and a substantial dataset. While previous studies have shown that measuring exfiltration of sanitary sewer systems is feasible, there is limited local data showing potential transport of bacteria loading from sanitary sewer or septic systems to storm drains or receiving waters.

Due to the scarcity of data, several assumptions were made to develop very preliminary estimates of bacteria loading from leaking sanitary sewer pipes and failing septic systems and bacteria load reduction from strategies. Table 5-1 presents the assumptions that were made for the quantitative estimates of load contributions and reductions.

The relative importance of specific sources of sewage entering the watershed during wet weather conditions are unknown at this time but could originate from a combination of failing septic systems, transient encampments along the river, leaking private sewer laterals, main lines of the wastewater collection system, or other illegal discharges (e.g., illegal dumping from recreational vehicles).

Because the relative importance of different potential sources of human sewage during wet weather cannot be reliably quantified at this time, the estimates developed for the human sources scenarios are considered exploratory in nature due to limited data and should be further refined to guide future management decisions.

Table 5-1. Load Contribution Assumptions

Item	Assumed Value	Reference
Concentration of HF183 in raw sewage (sewer pipes and septic)	10^7 Copies per 100 milliliters	Point Loma Wastewater Treatment Plant influent[2]
Rate of leakage – Existing sanitary sewer pipes[1]	0.35 gallons/inch-diameter/defect/day	Brown and Caldwell 2005. Average exfiltration rate measured from 6 pipe defects in Orange County.
Frequency of Critical Pipe Defects	SD County: 1 defect per 10,019 feet of sanitary sewer pipe Orange County: 1 defect per 16,542 feet of sanitary sewer pipe	Inspection of City of San Diego sanitary sewer pipes from 1998-2005 performed by Hirsch & Co. Accounts for ongoing rehabilitation and replacement of pipes at a rate of 45 miles per year averaged over 100 years.
Rate of Leakage – Post-cured-in-place pipe (CIPP) sanitary sewer pipes	0 gallons/inch-diameter/mile length/day	Leakage from properly rehabbed pipe is expected to be significantly less than before repair and is assumed at zero for the purposes of this analysis.
Loading from Category 1 SSOs – Sanitary Sewer pipes	See Table 3-6.	SWRCB, 2016
Failure rate of septic systems	0.7 percent of total systems during course of a year. Estimates 1/3 of failed systems fail in mode than can contribute untreated sewage to environment.	CSU Chico, 2003 County of San Diego, Department of Environmental Health
Rate of untreated septic discharge – Failed septic systems	153 gallons per day per system. Estimates 1/10 of flow from system exits untreated.	Brown and Caldwell, 2005 County of San Diego, Department of Environmental Health

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Table 5-1. Load Contribution Assumptions

Item	Assumed Value		Reference
Rate of untreated septic discharge – New septic system	0 gallons per day per system		Properly operating septic systems are assumed to remove 100% of HF183.
Percentage of load contribution that reaches storm drain or creek (fate and transport factor)[1]	SD County: High Priority – 95% Medium Priority – 55% Low Priority – 20%	Orange County: High Priority – 95% Medium Priority – 55% Low Priority – 25%	Assumption factor to account for attenuation of bacteria in soil and interception/retention within watershed. Values were adjusted to calibrate with San Diego River monitoring results at Fashion Valley (Schiff, 2016) and OC Bight study data.
Proportion of transient population defecating directly into the water[1]	SD County: 25%	Orange County: 13%	Assumption based on best professional judgement. This assumption results in an estimated population of 15 out of 300 individuals per day defecating into the river for the San Diego River watershed. Additional data is needed to refine assumption. Effects of changing this value are discussed in Section 8.
Number of days feces accumulates, without HF183 decay	1 day		Email correspondence from Ken Schiff (SCCWRP) (personal communication, 2016)
Grams per person per day wet weight fecal mass	126 grams		Rose, 2015
Copies of HF183 per gram fecal material	3.8x10^8 copies		Layton, 2013
Proportion of people who carry HF183 marker	70%		Email correspondence from Ken Schiff (SCCWRP) (personal communication, 2016)
Average Daily Wet Weather HF183 Load (total copies of HF183 per wet weather day)	SD County: 2.97E+12	Orange County: 3.48E+11	SD: San Diego River monitoring results at Fashion Valley (Schiff, 2016). OC: Unpublished data from Bight '13 Regional Monitoring program. Samples at Aliso Creek sample site.

1. Sensitivity Parameter. See sensitivity analysis in Section 8

2. Samples collected between Dec and Feb 2016, SCCWRP unpublished data (Schiff 2016)

Based on these assumptions, percentage of bacteria load contributions were estimated for each watershed for the prioritized sanitary sewer pipes and septic systems. The estimates are summarized below in Table 5-2.

Table 5-2. Estimated Daily Load Contributions (copies HF183/day)

Watershed	Septic Systems	SSOs	PLSDs	Sewer Mains	Sewer Laterals	Transient Population	TOTAL
SAN DIEGO COUNTY							
Chollas Creek	0.00E+00	3.37E+09	5.89E+08	1.58E+11	9.44E+10	3.22E+12	**3.48E+12**
Los Peñasquitos	1.77E+08	1.01E+10	1.92E+09	2.11E+11	9.95E+10	2.03E+11	**5.26E+11**
Miramar Reservoir	*0.00E+00*	*2.07E+09*	*1.92E+09*	*1.73E+11*	*7.83E+10*	*1.56E+11*	***4.11E+11***
Poway	*1.77E+08*	*8.07E+09*	*0.00E+00*	*3.84E+10*	*2.12E+10*	*4.66E+10*	***1.14E+11***
San Diego River	3.42E+10	1.56E+10	2.75E+09	3.15E+11	9.57E+10	2.51E+12	**2.98E+12**

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Table 5-2. Estimated Daily Load Contributions (copies HF183/day)

Watershed	Septic Systems	SSOs	PLSDs	Sewer Mains	Sewer Laterals	Transient Population	TOTAL
San Dieguito	1.36E+10	7.44E+10	7.36E+07	3.06E+10	7.72E+09	4.11E+11	**5.37E+11**
San Luis Rey[1]	3.01E+10	4.03E+10	4.15E+09	1.35E+11	7.05E+10	7.34E+11	**1.01E+12**
San Marcos[1]	0.00E+00	5.08E+09	0.00E+00	8.14E+09	4.26E+09	1.19E+11	**1.36E+11**
Scripps	0.00E+00	1.48E+09	2.40E+08	6.86E+10	3.59E+10	3.00E+11	**4.07E+11**
Tecolote	0.00E+00	2.93E+08	3.40E+08	5.99E+10	2.83E+10	5.36E+11	**6.25E+11**
SOUTH ORANGE COUNTY							
Aliso Creek	1.36E+07	3.04E+09	0.00E+00	7.91E+10	5.23E+09	2.61E+11	**3.48E+11**
Dana Point Coastal	3.12E+07	2.32E+09	0.00E+00	2.94E+10	8.19E+08	7.91E+10	**3.02E+11**
Laguna Coastal	5.08E+07	9.27E+10	0.00E+00	1.89E+10	6.11E+07	7.07E+10	**1.82E+11**
San Clemente Coastal	0.00E+00	2.61E+09	0.00E+00	3.45E+10	4.10E+08	8.21E+10	**1.20E+11**
San Juan Creek	2.90E+09	9.68E+10	0.00E+00	9.73E+10	5.95E+09	3.06E+11	**5.09E+11**
San Mateo Creek	3.39E+06	1.04E+10	0.00E+00	8.68E+07	0.00E+00	2.69E+10	**3.74E+10**

LOW CONFIDENCE ON INDIVIDUAL SOURCE ALLOCATION.
NOT RECOMMENDED FOR IMPLEMENTATION ACTIONS.
LOW CONFIDENCE ON INDIVIDUAL SOURCE ALLOCATION.
NOT RECOMMENDED FOR IMPLEMENTATION ACTIONS.

1. *Sanitary sewer pipe data was unavailable for San Marcos and San Luis Rey. Load contributions from sewer mains and sewer laterals were estimated for San Marcos and San Luis Rey based on extrapolating the results for Scripps watershed using percentage of watershed areas.*

Section 6: Load Reduction Strategies

Strategies to reduce the bacteria loading from various sources were developed, and the cost-effectiveness of each strategy was analyzed to provide inputs to the cost-benefit analysis. The load reduction strategies considered for this analysis consisted of CIPP rehabilitation, replacement of septic systems, replacement of sanitary sewer laterals, and re-housing of transient populations. These strategies were selected to provide a generalized basis for the cost/benefit analysis, and was not an exhaustive review of all feasible options. The costs presented also do not reflect any costs associated with the investigation and identification effort to confirm the source. Alternative load reduction strategies may be more effective in specific conditions and regions and should be considered during subsequent phases of study.

6.1 Load Reduction Effectiveness

Complete reduction of all bacteria loading from all human sources is likely not feasible. However, if fully implemented, these load reduction strategies are expected to significantly reduce bacteria loading from the selected human sources by orders of magnitude. Therefore, as a simplification for this planning-level analysis, a complete reduction of loading was assumed for each unit of load reduction implemented. It should also be noted that rehabilitation of all sanitary sewer pipes and septic systems within a short timeframe is also not likely feasible. Therefore, the percent load contributions shown in Table 7-4 also represent the percent load reduction across various levels of implementation assuming each load reduction strategy is fully effective.

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6.2 CIPP Rehabilitation

CIPP rehabilitation is a trenchless rehabilitation technology that utilizes a thermosetting resin and a flexible carrier tube to create a pipe within a pipe. The flexible carrier tube may be constructed of various materials but falls into two main categories—reinforced and non-reinforced. Non-reinforced carrier tubes may be made from felt material and provide no additional strength to the pipe system, but do form well to changes in shape and size. Reinforced carrier tubes provide additional strength to the host pipe and typically have thinner walls than the non-reinforced carrier tubes (under the same design conditions). Once the resin/carrier tube system is inserted into the host pipe, the thermosetting reaction is initiated by a heat source (typically, hot water or steam). This heat source is applied until the resin is cured or "cooked" (up to a maximum cure time of 24 hours), creating a new, seamless pipe. See Figure 6-1 for a representation of the CIPP installation process.

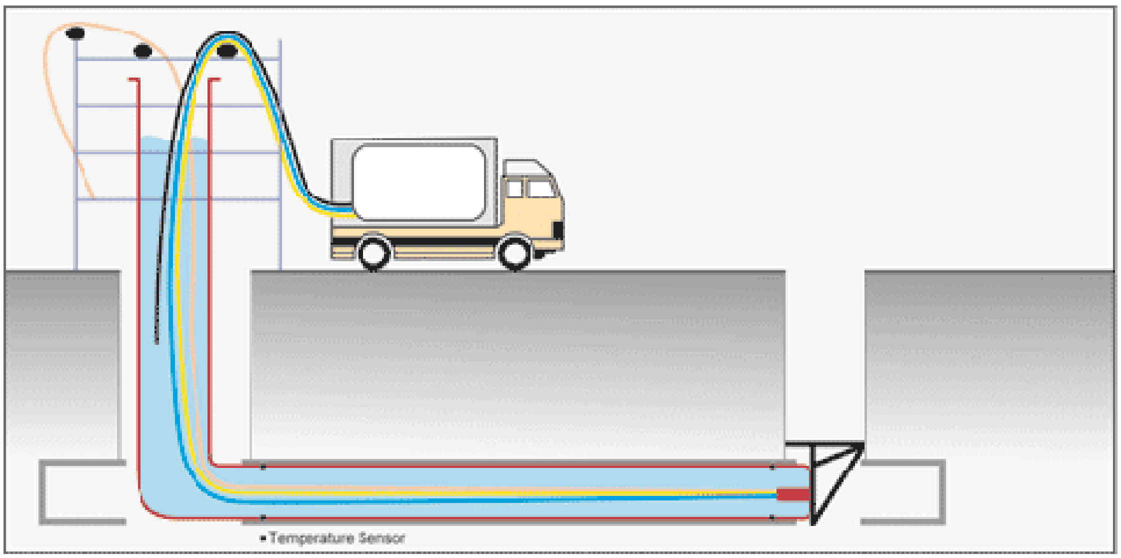

Figure 6-1. Typical CIPP Installation

(Brown and Caldwell 2012)

While CIPP requires minimal excavation, and reduces the risks associated with open cut replacement, it has the potential to temporarily impact the local community. Certain resin types, mainly polyester and vinyl ester, contain styrene that is vaporized during the cure process and can result in a styrene odor (non-toxic) in the vicinity of the construction zone. This odor can be unpleasant to residents living in close proximity to the work area, but can be mitigated. Non-styrenated resins are also available at a higher cost. Odor control options may be incorporated into design specifications to limit potential odor issues.

CIPP rehabilitation may reduce SSO frequencies caused by excess infiltration and inflow, cracked pipes, and poor hydraulic performance.

6.3 Septic System Replacement

While rehabilitation of existing septic systems may be feasible, full replacement of the systems was assumed for this study. Due to scarcity of data on individual septic systems, this analysis assumed an average sized septic system for each parcel. An example of a typical septic system is shown in Figure 6-2. Detailed design of septic systems is subject to local conditions, but consist of the following typical components:

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- Distribution piping:
  - Typically, approximately 4-inch Schedule 40 polyvinyl chloride
  - Connects home to septic tank
- Septic tank:
  - Typically, 1,000 to 1,500 gallons
  - Typically reinforced concrete, fiberglass, or polyethylene
- Drainfield: consists of trenches containing perforated pipe surrounded by rock and covered with mesh and dirt
- Distribution box (Optional): promotes even distribution of effluent to the drainfield

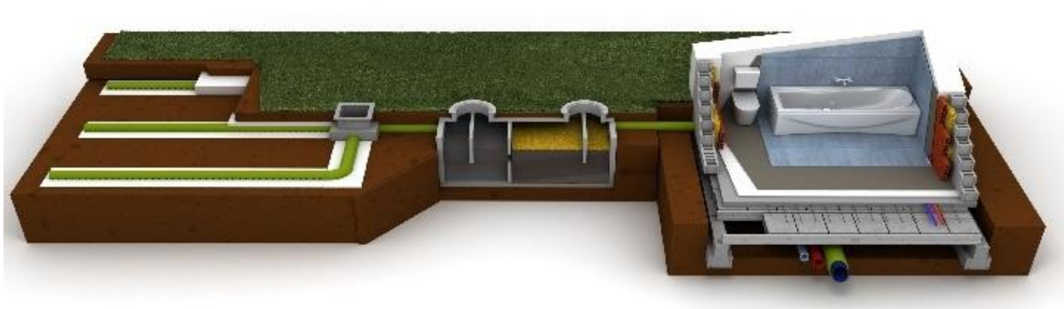

Figure 6-2. Typical Septic System Layout

(DEH 2017)

6.4 Transient Population

Load reduction strategies targeting the transient population require a complex social, economic, and political analysis beyond the scope of this study. For the purposes of this analysis, housing of transient populations was selected as the load reduction strategy and served as the basis to estimate the costs and effectiveness of load reduction. Based on a review of available literature, the cost of housing cost in the middle of the range of estimates was estimated at $14,280 per person (San Diego County Grand Jury, 2010). This cost does not include social, administrative, or other costs for agencies coordinating the additional services.

As discussed in Section 3.3, the use of HF183 as a surrogate parameter for pathogens may not be statistically valid for the transient population source. Therefore, load reductions of HF183 from housing of transient populations may not translate to load reduction of pathogens.

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Section 7: Cost Effectiveness

This section discusses the development of unit costs for implementation of the bacteria load reduction strategies and presents a summary of planning-level implementation cost estimates and cost effectiveness.

7.1 Unit Cost Development and Assumptions

Special Note: The cost estimates for the Human Sources scenarios are conceptual estimates to be used for exploratory purposes only. They are intended to be incremental; subtracting out estimated existing average annual budgets for routine sewer main pipe rehabilitation and replacement. These scenarios were not designed to represent the actual load reduction requirement or cost of projects needed to comply with any current and/or future regulations including the Bacteria TMDL, Waste Discharge Requirements (WDRs), or any other regulatory requirements. Costs are based on unit cost estimates applied to the amount of infrastructure data available at the time of this study. Actual strategies, projects, and costs needed to comply with any existing and/or future regulations may vary.

In accordance with the Association for the Advancement of Cost Engineering International criteria, this is a Class 5 estimate. A Class 5 estimate is defined as a Conceptual Level or Project Viability Estimate. Typically, engineering is from 0 to 2 percent complete. Expected accuracy for Class 5 estimates typically ranges from -50 to +100 percent, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. In unusual circumstances, ranges could exceed those shown.

The costs were developed with the assumption the work will be competitively bid between a minimum of four bidders and that the work will occur in San Diego County.

This estimate was prepared using historic bid prices and historic project construction cost estimates from 2014-2016. The unit costs include all labor, materials, equipment, and subcontractors as well as contractor markups, sales tax, bonds and insurance, and 20 to 30 percent contingency. The costs do not include escalation to midpoint of construction, financing costs, costs associated with the presence of hazardous materials, or permitting costs beyond those normally needed for this type of work.

Unit cost estimates for CIPP rehabilitation, sanitary sewer lateral replacement, and septic system replacement are provided in Table 7-1, Table 7-2, and Table 7-3, respectively.

Table 7-1. Estimated Unit Costs for CIPP Rehabilitation in San Diego County

Nominal Pipe Size Range	Cost, Sanitary Sewer CIPP with Bypass Pumping ($/LF/inch-diameter)
<8- to 10-inch	$5.50
12- to 14-inch	$9.00
15- to 36-inch	$9.50
38- to 72-inch	$11.50
74- to >96-inch	$14.50

Notes:

1. *Included in the cost estimates: bypass pumping, traffic control, contractor markups, bonds, insurance, sales tax, and contingency (20-30%)*
2. *Not included in the cost estimates: escalation to midpoint of construction, financing, hazardous materials, and permitting beyond normal*
3. *Cost estimates were prepared using historic bid prices and historic project cost estimates*

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Table 7-2. Estimated Sanitary Sewer Lateral Replacement Costs in San Diego County	
Item	**Cost**
Replacement of Sanitary Sewer Lateral from Main Line Connection to End of Public Right-Of-Way	$7,000 per lateral

Notes:

1. *Cost estimates were prepared using historic bid prices and historic project cost estimates*

Table 7-3. Estimated Septic Tank Replacement Costs in San Diego County	
Item	**Cost**
1,500-gallon tank, drainfield, and pipe from house to tank	$10,000 per system

Notes:

1. *Included in the cost estimates: restoration allowance, contractor markups, bonds, insurance, sales tax, and contingency (20-30%)*
2. *Not included in the cost estimates: escalation to midpoint of construction, financing, hazardous materials, and permitting beyond normal*
3. *Cost estimates were prepared using historic bid prices and historic project cost estimates*

7.2 Summary of Planning-Level Cost Estimates and Cost Effectiveness

Unit implementation costs were applied to the prioritized sanitary sewer pipes and septic systems as discussed in Section 3.2. Estimated percent load reduction and cost estimates for load reduction strategies by source, priority, and watershed are presented in Table 7-4.

As noted in the table, a 100% load reduction is a theoretical value based on the parameters of this limited, exploratory study. This provides an upper value if all high, medium, and low load reduction strategies were implemented and assumed to work efficiently. Actual load reduction rates will vary and are subject to further evaluation.

Table 7-4. Estimated Percent Load Reduction and Cost Estimate for Load Reduction Strategies

Watershed	Load Contribution Source	Estimate Cumulative Cost by Priority[1]			Estimated Cumulative Percent Load Reduction[2]		
		H	H+M	H+M+L	H	H+M	H+M+L
Chollas Creek	Septic Systems	$-	$-	$-	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	0%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$623,510	$2,616,232	$3,997,909	2%	4%	5%
	Sewer Laterals	$46,078	$1,937,029	$11,254,441	0%	3%	3%
	Transient Population	$5,491,699	$5,491,699	$5,491,699	93%	93%	93%
	TOTAL	**$6,161,287**	**$10,044,960**	**$20,744,049**	**94%**	**99%**	**100%**
Los Peñasquitos		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$140	$1,050	$2,450	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	2%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$850,972	$3,241,527	$5,512,467	12%	32%	40%

LOW CONFIDENCE ON INDIVIDUAL SOURCE ALLOCATION.
NOT RECOMMENDED FOR IMPLEMENTATION ACTIONS.

LOW CONFIDENCE ON INDIVIDUAL SOURCE ALLOCATION.
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Table 7-4. Estimated Percent Load Reduction and Cost Estimate for Load Reduction Strategies

Watershed	Load Contribution Source	Estimate Cumulative Cost by Priority[1]			Estimated Cumulative Percent Load Reduction[2]		
	Sewer Laterals	$191,399	$2,891,366	$10,917,720	1%	17%	19%
	Transient Population	$345,383	$345,383	$345,383	39%	39%	39%
	TOTAL	$1,387,894	$6,479,326	$16,778,019	52%	88%	100%
Miramar Reservoir		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$-	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	1%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$788,353	$2,679,539	$4,555,744	15%	34%	42%
	Sewer Laterals	$190,291	$2,133,966	$8,390,101	1%	17%	19%
	Transient Population	$265,896	$265,896	$265,896	38%	38%	38%
	TOTAL	$1,244,540	$5,079,401	$13,211,740	53%	89%	100%
Poway		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$140	$1,050	$2,450	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	7%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$62,619	$561,988	$956,723	5%	25%	34%
	Sewer Laterals	$1,108	$757,400	$2,527,619	0%	16%	19%
	Transient Population	$79,487	$79,487	$79,487	41%	41%	41%
	TOTAL	$143,354	$1,399,925	$3,566,279	45%	82%	100%
San Diego River		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$7,560	$39,060	$799,260	0%	0%	1%
	SSOs	$-	$-	$-	0%	0%	1%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$1,426,270	$4,950,267	$8,936,834	4%	9%	11%
	Sewer Laterals	$190,513	$2,363,246	$10,709,928	0%	0%	0%
	Transient Population	$4,284,000	$4,284,000	$4,284,000	87%	87%	87%
	TOTAL	$5,908,343	$11,636,574	$24,730,022	92%	96%	100%

LOW CONFIDENCE ON INDIVIDUAL SOURCE ALLOCATION.
NOT RECOMMENDED FOR IMPLEMENTATION ACTIONS.
LOW CONFIDENCE ON INDIVIDUAL SOURCE ALLOCATION.
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Table 7-4. Estimated Percent Load Reduction and Cost Estimate for Load Reduction Strategies

Watershed	Load Contribution Source	Estimate Cumulative Cost by Priority[1]			Estimated Cumulative Percent Load Reduction[2]		
San Dieguito		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$3,150	$17,430	$314,860	0%	0%	3%
	SSOs	$-	$-	$-	0%	0%	14%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$94,935	$280,238	$618,578	2%	4%	6%
	Sewer Laterals	$41,425	$268,269	$1,480,020	0%	1%	1%
	Transient Population	$700,283	$700,283	$700,283	76%	76%	76%
	TOTAL	**$839,794**	**$1,266,220**	**$3,113,740**	**78%**	**81%**	**100%**
San Luis Rey[3]		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$8,050	$64,470	$647,500	0%	1%	4%
	SSOs	$-	$-	$-	0%	0%	5%
	PLSDs	$-	$-	$-	0%	0%	1%
	Sewer Mains	$1,107,296	$3,308,515	$5,582,183	0%	0%	0%
	Sewer Laterals	$173,477	$2,237,372	$8,701,229	0%	0%	0%
	Transient Population	$1,251,691	$1,251,691	$1,251,691	91%	91%	91%
	TOTAL	**$2,540,514**	**$6,862,048**	**$16,182,603**	**91%**	**92%**	**100%**
San Marcos[3]		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$-	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	4%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$66,924	$199,964	$337,383	2%	5%	6%
	Sewer Laterals	$10,485	$135,225	$525,896	0%	3%	3%
	Transient Population	$201,995	$201,995	$201,995	87%	87%	87%
	TOTAL	**$279,404**	**$537,184**	**$1,065,274**	**90%**	**95%**	**100%**
Scripps		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$-	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	0%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$271,805	$919,906	$1,422,699	7%	14%	17%
	Sewer Laterals	$88,389	$1,139,976	$4,433,413	0%	8%	9%
	Transient Population	$511,932	$511,932	$511,932	74%	74%	74%
	TOTAL	**$872,126**	**$2,571,814**	**$6,368,044**	**81%**	**96%**	**100%**

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Table 7-4. Estimated Percent Load Reduction and Cost Estimate for Load Reduction Strategies							
Watershed	Load Contribution Source	Estimate Cumulative Cost by Priority[1]			Estimated Cumulative Percent Load Reduction[2]		
Tecolote		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$-	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	0%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$412,147	$807,640	$1,116,394	5%	9%	10%
	Sewer Laterals	$8,418	$707,556	$3,133,273	0%	4%	5%
	Transient Population	$913,543	$913,543	$913,543	86%	86%	86%
	TOTAL	**$1,334,108**	**$2,428,739**	**$5,163,210**	**91%**	**99%**	**100%**
Aliso Creek		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$93	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	1%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$463,180	$3,399,372	$5,918,135	4%	17%	23%
	Sewer Laterals	$134,245	$990,003	$1,706,863	0%	1%	2%
	Transient Population	$855,505	$855,505	$855,505	75%	75%	75%
	TOTAL	**$1,452,930**	**$5,244,880**	**$8,480,597**	**79%**	**93%**	**100%**
Dana Point Coastal		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$23	$187	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	2%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$173,101	$997,590	$1,842,874	5%	19%	26%
	Sewer Laterals	$-	$676,764	$1,777,530	0%	0%	1%
	Transient Population	$259,259	$259,259	$259,259	71%	71%	71%
	TOTAL	**$432,360**	**$1,933,636**	**$3,879,850**	**76%**	**90%**	**100%**
Laguna Coastal		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$350	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	51%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$16,515	$748,188	$1,373,876	0%	7%	10%
	Sewer Laterals	$222	$9,083	$89,054	0%	0%	0%
	Transient Population	$231,725	$231,725	$231,725	39%	39%	39%
	TOTAL	**$248,461**	**$988,995**	**$1,695,005**	**39%**	**46%**	**100%**

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Table 7-4. Estimated Percent Load Reduction and Cost Estimate for Load Reduction Strategies

Watershed	Load Contribution Source	Estimate Cumulative Cost by Priority[1]			Estimated Cumulative Percent Load Reduction[2]		
San Clemente Coastal		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$-	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	2%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$255,314	$1,166,413	$2,031,780	8%	23%	29%
	Sewer Laterals	$-	$401,849	$858,194	0%	0%	0%
	Transient Population	$269,151	$269,151	$269,151	69%	69%	69%
	TOTAL	**$524,465**	**$1,837,414**	**$3,159,126**	**76%**	**92%**	**100%**
San Juan Creek		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$840	$18,993	0%	0%	1%
	SSOs	$-	$-	$-	0%	0%	19%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$1,559,432	$3,839,910	$5,305,301	8%	15%	19%
	Sewer Laterals	$656,605	$1,853,735	$2,707,720	1%	1%	1%
	Transient Population	$1,004,323	$1,004,323	$1,004,323	60%	60%	60%
	TOTAL	**$3,220,359**	**$6,698,808**	**$9,036,338**	**69%**	**77%**	**100%**
San Mateo Creek		H	H+M	H+M+L	H	H+M	H+M+L
	Septic Systems	$-	$-	$23	0%	0%	0%
	SSOs	$-	$-	$-	0%	0%	28%
	PLSDs	$-	$-	$-	0%	0%	0%
	Sewer Mains	$-	$-	$9,199	0%	0%	0%
	Sewer Laterals	$-	$-	$-	0%	0%	0%
	Transient Population	$88,233	$88,233	$88,233	72%	72%	72%
	TOTAL	**$88,233**	**$88,233**	**$97,455**	**72%**	**72%**	**100%**

LOW CONFIDENCE ON INDIVIDUAL SOURCE ALLOCATION.
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1. *H = High Priority; M = Medium Priority; L = Low Priority.*
2. *A 100% load reduction is a theoretical value based on the parameters of this limited, exploratory study. This provides an upper value if all high, medium, and low load reduction strategies were implemented and assumed to work efficiently. Actual load reduction rates will vary and are subject to further evaluation.*
3. *Sanitary sewer pipe data was unavailable for San Marcos and San Luis Rey. Load contributions from sewer mains and sewer laterals were estimated for San Marcos and San Luis Rey based on extrapolating the results for Scripps watershed using percentage of watershed areas.*

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Section 8: Illustration of Sensitivity and Error

Sources of error within this analysis originate from a lack of available data and inherent to the methodology of an exploratory analysis. As previously noted in Table 5-1, several assumptions require additional data to be refined. Thus, the results from this exploratory analysis may not accurately reflect existing conditions and should be interpreted with an understanding that additional data collection and further refinement may produce conclusions that vary from the results presented in this TM.

As noted in Section 7.1, expected accuracy for Class 5 cost estimates typically ranges from -50 to +100 percent. Therefore, the cost estimates shown in this report could vary substantially.

Additionally, the sample results for HF183 used to calibrate the model have inherent variability associated with the analytical method used. For example, the San Diego River monitoring result at Fashion Valley was reported at a concentration of 554 copies of HF183 per 100 milliliters (Schiff, 2016). The poisson confidence intervals from the laboratory assay can provide a range of concentration from 370 copies of HF183 per 100 milliliters (5% confidence interval) to 762 copies of HF183 per 100 milliliters (95% confidence interval).

The following three assumptions have a highly sensitive effect on the model results:

- Proportion of transient population assumed to be defecating directly into the water within 1 day of wet weather event
- Percentage of load contribution that reaches storm drain or creek (fate and transport factor)
- Rate of leakage – existing sanitary sewer pipes

As shown in Table 8-1, an example of the sensitivity of these assumptions and a demonstration of the changes to the modeled results by changing the values of the assumptions is presented. This example should not be interpreted as providing an accurate range of possible conditions, but rather as an illustration of the variability inherent to this analysis.

As the proportion of transient population defecating directly into the water and sewer leakage rates are changed, the fate and transport factors are adjusted to calibrate the model to measure values.

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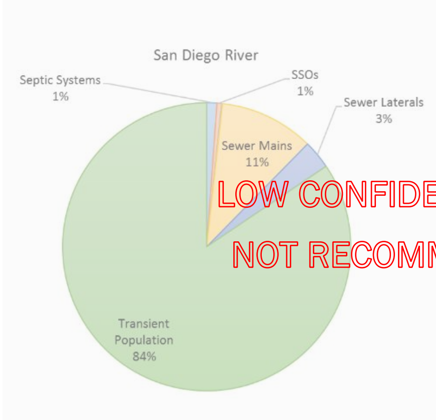
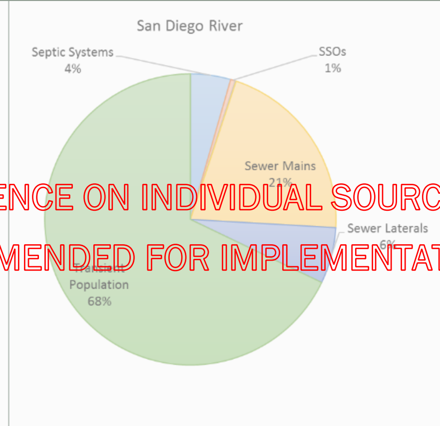
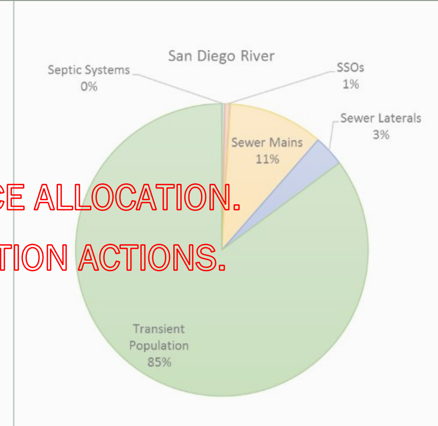
Table 8-1. Example of Sensitivity of Assumptions Used in the Human Sources Scenario Analysis

	Scenario 1 – Baseline Model	Scenario 2 – Lower Proportion of Transient Population Defecating in River	Scenario 3 – Higher Leakage Rate from Sanitary Sewer Pipes
Sensitivity Parameter Value			
• Rate of leakage – Existing sanitary sewer pipes	0.35 gallons/inch-diameter/defect/day	0.35 gallons/inch-diameter/defect/day	0.72 gallons/inch-diameter/defect/day
• Proportion of transient population defecating directly into the water	25%	20%	25%
• Percentage of load contribution that reaches storm drain or creek (fate and transport factor) (used to calibrate results to observed data point)	High – 95% Medium – 55% Low – 20%	High – 100% Medium – 95% Low – 85%	High – 50% Medium – 30% Low – 5%
Resulting Load Contribution Pie Chart			
Overall Effect on Load Contribution	Assumed Baseline	Decreased load contribution from transient populations. Increased proportion of load from other sources.	Doubling unit sewer leakage rate does not significantly affect modeled results.

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Section 9: Conclusions and Limitations

The human sources scenario analysis discussed in this TM provides insight into bacteria loading from human sources. As discussed in Section 8, the results of this exploratory analysis may not accurately reflect existing conditions due to data limitations. Additional data collection and analysis would result in a more accurate understanding of existing conditions. As additional data is collected, the methodology presented in this TM can be revisited to develop a more refined and accurate model. Development of a robust monitoring program would improve understanding of watershed and infrastructure conditions within the County and inform optimal use of funds to implement the most effective load reduction strategies.

Special Note: This exploratory analysis suggests that transient populations are a major source of human pathogen loading to the watersheds. However, the San Diego River Source Study indicated a wide distribution of human pathogens across the San Diego River watershed and did not only reflect the areas of transient encampments (Schiff, 2016). The relative importance of specific sources of sewage entering the watershed during wet weather conditions are unknown at this time but could originate from a combination of failing septic systems, transient encampments along the river, leaking private sewer laterals, main lines of the wastewater collection system, or other illegal discharges (e.g., illegal dumping from recreational vehicles).

Because the relative importance of different potential sources of human sewage during wet weather cannot be reliably quantified at this time, the estimates developed for the human sources scenarios are considered exploratory in nature due to limited data and should be further refined to guide future management decisions. It is worth noting that alternative load reduction strategies may be identified as new analyses are performed. Additional cost-savings and efficiencies may also be possible by evaluating optimal load reduction strategies on a subwatershed basis.

As discussed in Section 8, three parameters have a highly sensitive impact on the model and require additional data collection to develop a better understanding of watershed conditions.

- Proportion of transient population assumed to be defecating directly into the water
- Percentage of load contribution that reaches storm drain or creek (fate and transport factor)
- Rate of leakage – existing sanitary sewer pipes

Other parameters not fully understood at the time of this study include, but are not limited to:

- Septic system effectiveness for removing human-source bacteria and pathogens
- Fate and transport mechanisms of human-source bacteria and pathogens in infrastructure, septic systems, groundwater, and various soil types
- Rate of accumulation and mobilization of human-source bacteria and pathogens during dry weather and wet weather of varying intensities
- Seasonal effects on accumulation and mobilization of human-source bacteria and pathogens
- Elevations of the storm drain and sanitary systems (consistent data not available)
- Effects of groundwater levels and quality on septic systems and sanitary sewer collection systems
- Runoff volume and peak flow calculations were not performed as part of this study
- The impact of reclaimed irrigation water which may produce positive HF183 signal
- The correlation between HF183 to pathogen loading for the transient population source

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APPENDIX C: STREAM SCENARIOS TECHNICAL MEMO

Final

San Diego County Department of Public Works

Restoration Approaches for Bacteria TMDL Cost Benefit Analysis

Prepared for
San Diego County Department of Public Works

June 8, 2017

Final

San Diego County Department of Public Works

Restoration Approaches for Bacteria TMDL Cost Benefit Analysis

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Executive Summary

The County of San Diego is part of a multi-agency, governmental and stakeholder steering committee that is conducting an environmental cost-benefit analysis for the San Diego Bacteria Total Maximum Daily Load (Bacteria TMDL). The cost-benefit-analysis includes the assessment of the anticipated bacteria load reductions that are feasible from different types of best management practices (BMPs) and the associated costs and co-benefits. Environmental Science Associates, Inc. (ESA) has been contracted to develop the input data for the cost-benefit-analysis for stream and riparian habitat restoration implementation in watersheds within San Diego and Orange Counties under the Bacteria TMDL, or also referred to as the restoration approach.

This report presents the results of a multi-step analysis of restoration scenarios. A feasibility review was first conducted for numerous approaches to stream and riparian habitat restoration for applicability to conditions and opportunities in the watersheds under the Bacteria TMDL. As restoration approaches, these techniques focus on restoring natural stream and riparian habitat function through reducing channelization, restoring natural sediment transport processes, and restoring native vegetation. These techniques can improve water quality including removal of bacteria by increasing residence time and infiltration opportunities. The outcome of this review was the selection of restoration approaches for both stream (within the stream channel or "in-stream") and riparian habitat (wetlands with inlet control or "off-line" wetlands) restoration. The selected approaches were then used to develop the "model" restoration types to determine potential bacteria reductions for infiltration and retention mechanisms using a continuous hydrological simulation of over 40 years of rainfall data.

Restoration scenarios were then developed to provide "book ends" to these restoration approaches as shown on **Figure ES-1**. Scenario 1 focuses on in-stream restoration within feasible stream segments on public lands consisting of modifying the channel dimensions to improve channel stability and biological habitat. The feasible stream segments were identified through a GIS analysis of segments within public parcels including those that have concrete side walls and maintenance easement in more urbanized watersheds. Scenario 2 adds to these in-stream restoration projects with off-line wetland sites that have sufficient retention time to provide measurable bacteria load reductions. Thus Scenario 2 provides greater opportunity for bacteria load reductions with increased costs for off-line wetlands. For Scenario 2 the maximum reduction was calculated with the goal of achieving the fecal indicator bacteria (FIB) load reduction targets of the current Water Quality Improvement Plans (WQIPs) for the applicable watersheds (see Section 11 for list of referenced WQIPs). Enterococcus was used as the FIB for this assessment.

The analysis of Scenario 1 that focuses on in-stream restoration achieves FIB reduction rates of 0.2% to 1.6% which reflect the number of feasible stream restoration opportunities and the hydraulic characteristics of the watershed. The bacteria load reduction rates are based on the infiltration that occurs in the expanded channel bottom and slope. The higher infiltration rates for in-stream restoration scenarios were achieved in watersheds that have less urbanization and generally flatter and longer storm hydrographs. Infiltration rates also depend on favorable hydrogeological conditions. A general assumption of favorable conditions was assumed.

SOURCE: ESA, 2017

County of San Diego - Watershed Protection

Figure ES-1
Restoration Approach Scenarios - "Bookends"

Table ES-1 provides the total costs for Scenario 1 that ranged from $6-$275M per watershed, and reflect the range in the number of feasible sites and FIB load reduction targets. The cost per acre of watershed that drains to the restoration projects varied from $1,700 to $4,700/acre. The higher cost per acre is generally associated with more urbanized watersheds. The cost of the implementation of stream restoration projects needs to also consider the multi-benefits that are achieved from these projects that include improving the benthic macro-invertebrate habitat and subsequently the potential for enhanced fish habitat. These projects often include recreational benefits to the community in new trails and educational opportunities. Additional co-benefits include reductions of other constituents that include nutrients, sediment, metals and pesticides in storm flows. Load reductions for these other constituents are also achieved at similar rates.

The analysis of the other "book end" under Scenario 2, included both the implementation of the in-stream restoration and also off-line riparian wetlands restoration. For off-line wetlands, both infiltration and removal by wetland type mechanism from retention were estimated. Several watersheds had limitations on the availability of feasible wetland sites and associated drainage area due to greater urbanization and/or available public lands. The results of the analysis of Scenario 2 indicated three of the eleven watersheds under the Bacteria TMDL did not attain the enterococcus load reduction targets in the WQIPs using 50% wetland removal efficiency.

The rates of removal efficiencies vary with the flow controlled through the wetland. An analysis of literature values and actual reported efficiencies for natural treatment systems implemented in Orange County indicate a wide range of efficiencies. A range of removal efficiencies for wetlands under Scenario 2 were analyzed as part of the sensitivity analysis. As shown in **Table ES-1**, this analysis indicated that the number of available sites is the constraint in most of the watersheds to attain a higher overall reduction (see results for 10% and 20% overall reduction goals). The number of watersheds that did not meet the WQIP reduction targets remained at three watersheds for 50% up to 70% efficiencies (four watersheds at 40%) when the number of sites is varied to either attain the target or is constrained by the number of available sites. As efficiency is increased from 40-70%, the number of needed sites and costs decrease, but these costs are within the 25% contingency. When the number of sites is held constant and the wetland efficiency is modified, more watersheds do not meet the WQIP targets at 40%, but the number of watersheds that do not meet the target remains unchanged at three for 50% to 70% efficiency.

The costs to achieve the enterococcus FIB load reduction targets per the WQIPS under Scenario 2 range from $3-545M and $2,200 to $6,500/acre of drainage area for just the off-line wetland projects using 50% removal efficiency. This significant range in costs for off-line wetlands restoration projects is due to the range in feasible sites needed to attain WQIP levels of reduction and the characteristic of the watershed. The range in total costs also reflects watersheds that do not reach these targets as noted (a low total cost may reflect a limited number of feasible sites). Scenario 2 includes the implementation of in-stream projects that further increase these estimated costs. These additional costs may be reduced to achieved comparable load reduction by emphasizing off-line approaches where feasible. In addition, cost saving may occur if these are implemented as integrated restoration projects. Additionally, co-benefits for the implementation of restoration approaches include reductions of other constituents that include nutrients, sediment, metals and pesticides in storm flows. These co-benefits are quantified and presented in this report.

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TABLE ES-1
SUMMARY OF RESTORATION APPROACH SCENARIOS RESULTS - FIB REDUCTIONS AND COSTS

Watershed	Baseline Wet Weather Enterococcus Load (colonies/year)	Scenario 1 (In-stream)			Scenario 2 (instream+wetland) 10% goal			Scenario 2 (instream+wetland) 20% goal			Scenario 2 (instream+wetland) Reduction Goal per WQIPs (50% wetland retention efficiency)					Scenario 2 (instream+wetland) Reduction Goal per WQIPs (40% wetland retention efficiency)[8]			Scenario 2 (instream+wetland) Reduction Goal per WQIPs (70% wetland retention efficiency)[8]		
		Load Reduction Rate[1]	Annual Enterococcus Reduction (colonies/yr.)[2]	Total Cost ($millions)[3]	Load Reduction Rate[4]	Annual Enterococcus Reduction (colonies/yr.)[2]	Total Cost ($millions)[5]	Load Reduction Rate[4]	Annual Enterococcus Reduction (colonies/yr.)[2]	Total Cost ($millions)[5]	Reduction Goal per WQIPs	Reduction Achieved[6]	Annual Enterococcus Reduction (colonies/yr.)[2]	Total Cost for Off-Line Wetlands Only ($millions)[7]	Total Cost ($millions)[5]	Load Reduction Rate[9]	Annual Enterococcus Reduction (colonies/yr.)[2]	Total Cost ($millions)[10]	Load Reduction Rate[9]	Annual Enterococcus Reduction (colonies/yr.)[2]	Total Cost ($millions)[10]
San Diego County Watersheds																					
San Diego River (Lower San Diego HA)	4.30E+15	1.0%	4.10E+13	$231	10%	4.40E+14	$341	20%	8.60E+14	$456	30.8%	30.9%	1.33E+15	$325	$556	28.4%	1.22E+15	$556	35.8%	1.54E+15	$556
Chollas Creek HSA	1.70E+15	0.2%	4.10E+12	$60	10%	1.80E+14	$101	20%	2.20E+14	$109	28.8%	14.2%	2.39E+14	$49	$109	12.9%	2.17E+14	$109	16.8%	2.83E+14	$109
San Dieguito River (Solana Beach HA)	6.80E+14	1.1%	7.50E+12	$48	10%	6.80E+13	$73	20%	1.40E+14	$103	13.0%	14.7%	9.97E+13	$35	$83	13.5%	9.17E+13	$83	17.0%	1.16E+14	$83
Los Peñasquitos (Miramar HA)	2.90E+15	0.6%	1.80E+13	$198	10%	2.90E+14	$342	20%	5.80E+14	$497	17.8%	17.8%	5.17E+14	$240	$438	16.3%	4.71E+14	$438	21.0%	6.09E+14	$438
Tecolote Creek HA	8.40E+14	0.3%	2.20E+12	$18	10%	6.70E+13	$30	20%	6.70E+13	$30	18.0%	8.9%	7.43E+13	$12	$30	8.0%	6.69E+13	$30	10.7%	8.92E+13	$30
San Luis Rey River (Lower San Luis Rey HA)	3.60E+15	0.3%	1.00E+13	$275	10%	3.70E+14	$660	20%	5.10E+14	$820	15.8%	15.9%	5.72E+14	$545	$820	14.3%	5.14E+14	$820	19.1%	6.88E+14	$820
Orange County Watershed																					
Laguna Hills HAS/ San Joaquin Hills HSA	2.50E+14	0.3%	6.90E+11	$33	10%	2.50E+13	$59	20%	3.00E+13	$65	2.5%	2.7%	6.61E+12	$6	$39	2.4%	6.03E+12	$39	3.2%	7.77E+12	$39
Aliso Creek HSA	1.30E+15	1.6%	2.10E+13	$66	10%	1.30E+14	$112	20%	1.80E+14	$130	5.8%	5.8%	7.67E+13	$20	$86	5.3%	7.09E+13	$86	6.7%	8.85E+13	$86
Dana Point HSA	2.80E+14	1.2%	3.50E+12	$6	10%	2.00E+13	$12	20%	2.00E+13	$12	2.5%	4.4%	1.25E+13	$3	$9	4.1%	1.17E+13	$91	5.0%	1.41E+13	$91
Lower San Juan HSA	2.60E+14	0.3%	6.60E+11	$192	10%	2.60E+13	$346	20%	3.10E+13	$378	17.6%	13.2%	3.41E+13	$186	$378	12.0%	3.10E+13	$378	15.5%	4.02E+13	$378
San Clemente HA	4.80E+14	0.2%	1.10E+12	$21	10%	4.40E+13	$41	20%	4.40E+13	$41	3.2%	4.3%	2.07E+13	$9	$30	3.9%	1.88E+13	$30	5.1%	2.45E+13	$30

1 Percent infiltration by stream restoration as a total of total wet weather flows
2 Annual enterococcus load reductions - load reduction rate multiplied by the base average annual load - ***shaded cell*** indicate load reduction target NOT achieved
3 Total feasibility level cost for stream restoration projects - includes planning, permits, CEQA, design, implementation, contingency (25%) and maintenance
4 Load reduction goal held at 10% and 20% for all watersheds to assess sensitivity of the number of feasible restoration sites -***shaded cell*** indicate load reduction target NOT achieved
5 Total feasibility level cost for both off-site wetlands and in-stream projects needed to reach reduction goal or up to the number of available feasible sites
6 Total reduction achieved from both in-stream and off-line wetlands up to the number of feasible sites or WQIP reduction target for enterococcus
7 Total feasibility level costs shown are for off-line wetlands sites only - as the wetlands sites provide a significant portion of the reductions achieved, total costs with the in-stream sites shown in the next column may be reduced if the portion of the reduction achieved by the in-stream sites is addressed using wetland sites. Scenario 2 using all the feasible in-stream sites first and then using available off-line wetlands to achieve the target reduction.
8 As part of the uncertainty analysis, the wetland retention mechanism enterococcus reduction efficiency rate was modified from 50% to 40% and 70% while maintaining the same number of feasible wetland sites at the numbers determined for the 50% reduction efficiency. This will change the overall removal rate achieved but the not the total costs as the number of sites remain the same.
9 The total rates of reduction include the in-stream projects and the number of wetland projects determined for a wetland efficiency rate of 50% but then using a different wetland reduction rate on those same number of projects. Decreasing the efficiency rate to below the 50% (to 40%) will reduce the overall reduction rate. Conversely, increasing the efficiency rate to above 50% (to 70%) for the same number of projects will increase the overall efficiency rate.
10 Total costs include both the in-stream and wetland projects - these total costs are the same for the 50% efficiency scenario as the total number of projects remains the same for this uncertainty analysis.

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1 Introduction

The County of San Diego is part of a multi-agency, governmental and stakeholder steering committee that is conducting an environmental cost-benefit analysis for the San Diego Bacteria Total Maximum Daily Load (TMDL). The Steering Committee is working with a consultant team to develop both input to, and the performance of, the cost-benefit analysis. A Technical Advisory Committee has also been assembled to conduct review of the analysis. As shown in **Figure 1**, *Cost-Benefit Analysis Diagram*, inputs to the analysis require data on the change in bacteria concentrations resulting from the implementation of best management practices (BMPs), and the associated costs and ancillary benefits of these BMPs. The bacteria reductions are then used as input to the risk-based modeling of human health risk based on epidemiology studies. Reductions of health risk are then compared to BMP costs and other benefits provided to develop cost-benefit analysis outcomes. One of the BMP types that have been requested for cost-benefit analysis is stream and riparian habitat restoration. The purpose of this report is to present the required input data to the cost-benefit analysis for stream and riparian habitat restoration implementation in watersheds within San Diego and Orange Counties under the Bacteria TMDL.

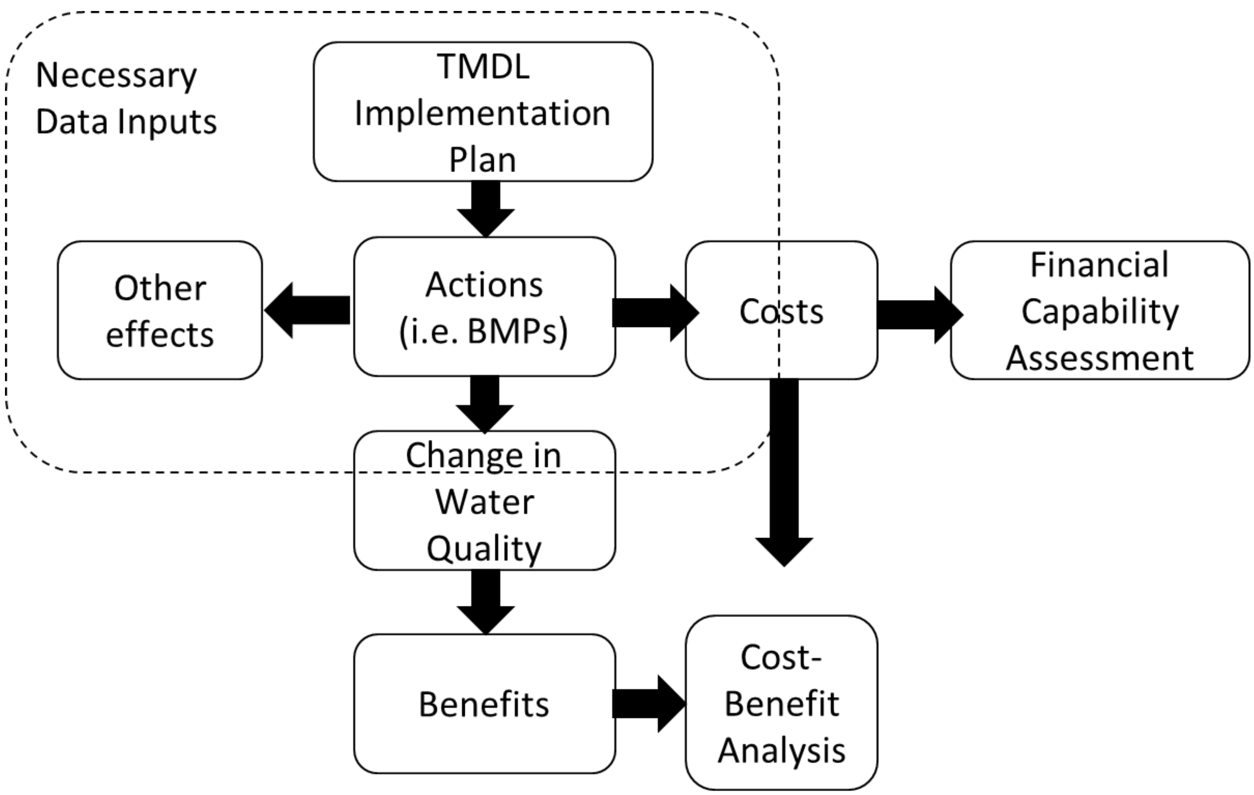


Figure 1
Cost-Benefit Analysis Diagram

ESA has completed a multi-step analysis to develop the required input data for the Bacteria TMDL Cost-Benefit Analysis for stream and riparian habitat restoration implementation. The analysis includes the following steps that are presented as individual sections of this report:

- **Literature Review** – A literature review was completed on over 200 studies regarding the removal efficiencies of bacteria in natural systems. In addition, removal efficiency data from natural treatment systems implemented in Orange County as analyzed. The results of the literature review and local data analysis were used to apply bacteria reduction factors to the restoration approaches that provided sufficient retention times to achieve measurable levels of bacteria removal. The literature review indicated that bacteria reductions are achievable when inflow and outflow is controlled into natural systems allowing from sufficient retention time. There is a paucity of data n bacteria removal efficiencies of stream restoration project under wet weather flows conditions.
- **Feasibility Review of Restoration Approaches** – A feasibility review was conducted for numerous approaches to stream and riparian habitat restoration for applicability to conditions and opportunities in the watersheds under the TMDL. As restoration approaches, these techniques focus on restoring natural stream and riparian habitat function through reducing channelization, thereby increasing residence time and infiltration opportunities, restoring natural sediment transport processes, and restoring native plants that can improve water quality including removal of bacteria. The outcome of this review was the selection of restoration approaches for both stream (within the stream channel or "in-stream") and riparian habitat (wetlands with inlet control or "off-line") restoration. The selected stream and riparian habitat restoration approaches were then used to develop the "model" restoration types following the GIS analysis in each watershed.
- **Mechanisms for Bacteria Reduction** – In order to determine potential bacteria reductions from restoration approaches, the applicable removal mechanisms were evaluated through modeling. This step included modeling the anticipated retention times for the selected stream channel (in-stream) and off-line wetland approaches compared to the required retention times to achieve a level of bacteria reduction based on literature values. It was determined that a measurable increase in retention time was not achievable from the in-stream restoration during storm flows (retention times increased by less than 30 minutes compared to several days needed to attain measurable removal efficiency of FIB in natural treatment systems – see more detailed discussion in Section 4) . The results also supported the use of one restoration approach to represent in-stream and one for off-line categories. This was based on the similar mechanisms and conditions within each of these categories (e.g. stream channel, side channel and channel alcove in-stream restoration approaches all have similar low retention times under storm flow conditions).
- **GIS Analysis of Restoration Opportunities** – A GIS analysis was completed for each of the watersheds under the Bacteria TMDL in both San Diego and Orange Counties to identify the restoration opportunities. The GIS analysis included identifying public parcels within or adjacent (to within ¼ mile) to streams and tributaries with the land use of open space, park or vacant land that are less than 15 percent slope and greater than one acre. This analysis was used for both defining the "model" restoration types for each watershed and later in identifying the potential number of feasible sites for both in-stream and off-line wetland restoration.
- **"Model" Restoration Approaches**– Based on the feasibility review of the restoration approaches, the bacteria mechanisms evaluation and the GIS analysis of potential restoration opportunities, "model" restoration types for both stream (within the stream channel or "in-stream") and riparian habitat (wetlands with inlet control or "off-line") were developed for

each watershed. For the in-stream “model”, the restored channel length, width and drainage area were determine based on review of feasible sites and analysis of channel stability. The area of the off-line wetlands was based on an assessment of feasible sites and associated drainage areas. The “model” restoration types developed for in-stream and off-site wetland restoration types for each watershed were then used to analyze the rates of infiltration for the in-stream model and for both infiltration and retention/filtration rates for the off-line wetland system. These rates provide a volume and area based rate that can be applied to the watershed analysis for bacteria load reductions.

- **Watershed Scenarios and Potential FIB Load Reduction -** The next step in the analysis applied the infiltration and retention rates, where applicable, for the in-stream and off-line “model” projects to a watershed scale. In order to “book end” the level of bacteria reduction that could be achieved by the restoration strategies, two scenarios were analyzed on a watershed scale. The first scenario (Scenario 1) includes implementing stream restoration within feasible stream segments that are on public lands. The number and length of feasible stream segments is based on the GIS analysis of public parcels that are within the portion of the watershed analyzed. The other side of the book end, Scenario 2, includes both in-stream restoration and off-line wetlands. The off-line wetlands are located along tributaries of the main stream channels in the larger watersheds and along both main stem and tributaries in the smaller watersheds. The watershed analysis for these two scenarios use the rates of infiltration and retention determined for the “model” restoration types and apply them to the number of feasible sites within each watershed to obtain the target enterococcus load reductions per the WQIPS total rates for each scenario and watershed. The compiled results are summarized for the two scenarios that book end the potential rates of bacteria load reduction for each watershed.

- **Co-Benefits Analysis –** In addition to reductions in FIB loading, the co-benefit of nutrients, metals and sediment load reduction for each scenario and watershed was determine and presented for input into the cost-benefit analysis. Co-benefits may include reduction of FIB loading in dry weather flows from infiltration and retention mechanisms during these lower flows. The quantification of reduction under dry weather flows was not determined as this assessment focuses on wet weather flows.

- **Cost Estimated for each Watershed –** Feasibility level cost estimates are presented for the two scenarios in each of the watersheds. The bacteria load reductions focusing on enterococcus for each scenario are presented with the estimated range in costs for input into the cost –benefit analysis.

- **Conclusions –** Overall conclusions are provided on the range of bacteria reductions and the cost estimates. The results of sensitivity analysis of input parameters are also summarized. Additional co-benefits provided by restoration approaches and implementation constraints are also discussed.

Each of these steps and subsequent results is discussed in more detail in the following sections.

2 Results of Literature Review

ESA conducted a review of more than 200 studies on fecal indicator bacteria (FIB) removal efficiencies in natural treatment systems. The results of the literature review are provided in Appendix A. Removal efficiencies of 50-70 percent of FIB concentrations were reported (see **Figure 2**, Data from Knox, et al., 2007) for engineered wetland systems that have controlled inflow between 1-1.5 cubic feet per second (cfs) per acre, and therefore achieved a retention time that allows for these higher removal efficiencies. As such, wetlands would likely be able to reduce FIB loading to downstream waters, as long as the flow to those wetlands does not exceed their "assimilative capacity" to reduce FIB abundance. The most directly applicable study suggests that FIB reductions in wetland systems might be expected to exceed 70 percent if their hydrologic load was kept to 1.0 cfs per acre or less (see Figure 2).

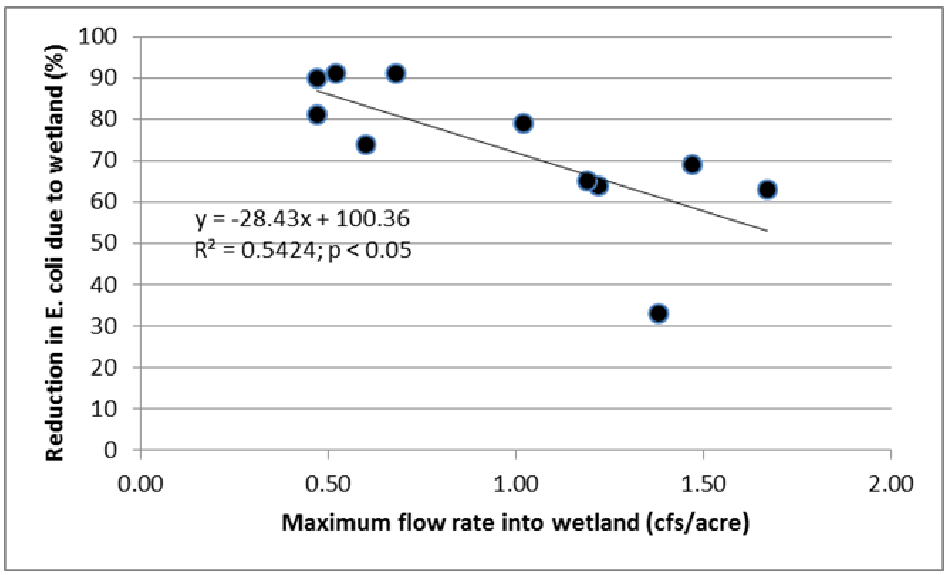


Figure 2
Relationship between Reductions in E. coli Abundance vs. Maximum Inflow Rate (cubic feet per second (cfs) per acre). Data from Knox et al. (2007)

Based on prior guidance, wetlands used for FIB reduction should include features such as a diversity of plant species, adequate space for exposure of sediments to sunlight, while also reducing the likelihood of sediments being re-suspended back into the water column by later flows. As such, controlled inflows and outflows are required to bring about the features required to optimize FIB reduction efficiencies.

Natural systems implemented as part of riparian habitat restoration are likely to have more limited inlet and outlet control that could increase retention times. For wetland systems connected to the stream channel, or "in-stream" wetlands, control of storm flows into the wetland would be limited unless engineered inlet controls such as weirs, culverts and/or separate channels are constructed. As this analysis focuses on restoration approaches that restore natural function and habitat, more natural restoration approaches are considered and analyzed compared to more engineered systems that have a primary function for pollutant reduction. More engineered pollutant removal BMPs have already been assessed through other watershed studies, modeling and plans (e.g. Water Quality Improvement Plans for each watershed). Lower removal efficiencies than the published data for engineered natural treatment systems would be expected for these off-line restoration approaches that have wetland mechanism due to the more limited controls on retention times in these more natural systems. As the selected removal efficiency may be a sensitive input parameter, a sensitivity analysis is conducted using a range of potential efficiencies as part of this assessment.

Published data on FIB removal efficiencies of in-channel systems, which may include channel expansion, branching, and floodplain benching, are very limited. For the small number of reported results on stream restorations, the data suggest low FIB reductions due to the limited increase in retention times during storm flows. Some reduction of bacteria may be expected in lower dry weather flows through mechanisms of filtration and settlement depending on flow, substrate and vegetative cover. This analysis is focused on the reduction of FIB in storm flows, and the resulting higher flow velocities and lower retention time would significantly reduce the effectiveness of in-channel mechanisms to reduce bacteria loads and concentrations. Increased infiltration where the appropriate geologic and hydrologic conditions exist can be a mechanism for pollutant reductions. This is further analyzed in the following steps.

2.1 Analysis of Local Treatment Wetland Data

Wetland flows and enterococcus concentrations have been measured in natural treatment systems (NTS) in Orange County. The Irvine Ranch Water District recorded enterococcus concentrations and flow measurements at the inflow and outflow locations for twelve NTS within Orange County. ESA obtained these data and analyzed this data set to determine removal efficiencies of these NTS loads. Using the enterococcus and flow measurements from these sites, the average percent reduction was calculated at each site. Five of the twelve sites had monitoring events where increases in enterococcus at the outlet were observed. In three of the twelve sites a negative average reduction rate was determined. The sites with negative overall reduction efficiency rates are evidence that in some cases the wetland can contribute bacteria to the storm flows. The sources of these increased bacteria loads may be from wildlife attracted to the wetland habitat created by the NTS.

The average reduction efficiency of the seven of twelve wetlands with an overall decrease in enterococcus concentrations is 88%. **Figure 3** presents the average reduction efficiency rates for each of the twelve NTS sites. The variability in bacteria reductions rates for these NTS was considered in conjunction with the literature review in the analysis presented in this report. A removal efficiency rate of 50% for enterococcus was selected to represent a reasonable average based on this local data set and the values obtained from the literature search summarized in the report. As the selected removal efficiency may be a sensitive input parameter, a sensitivity analysis is conducted using a range of potential efficiencies as part of this assessment.

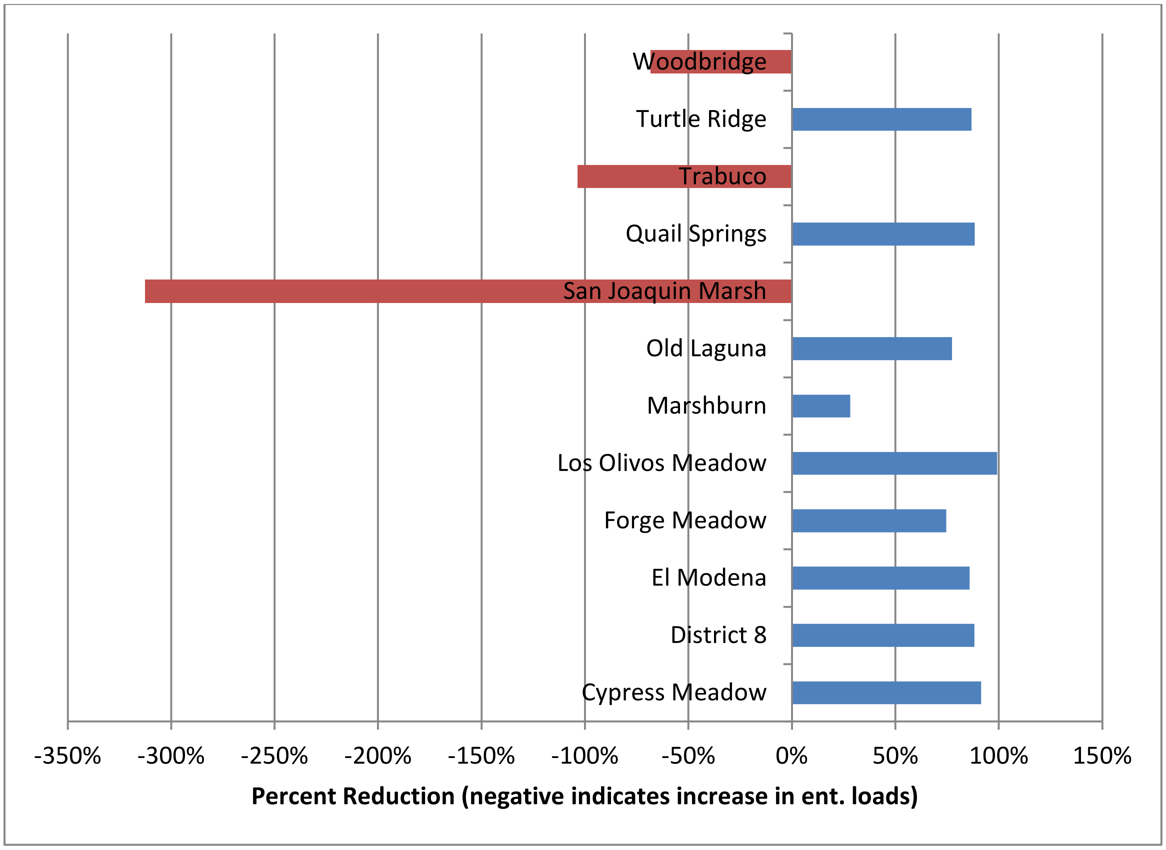
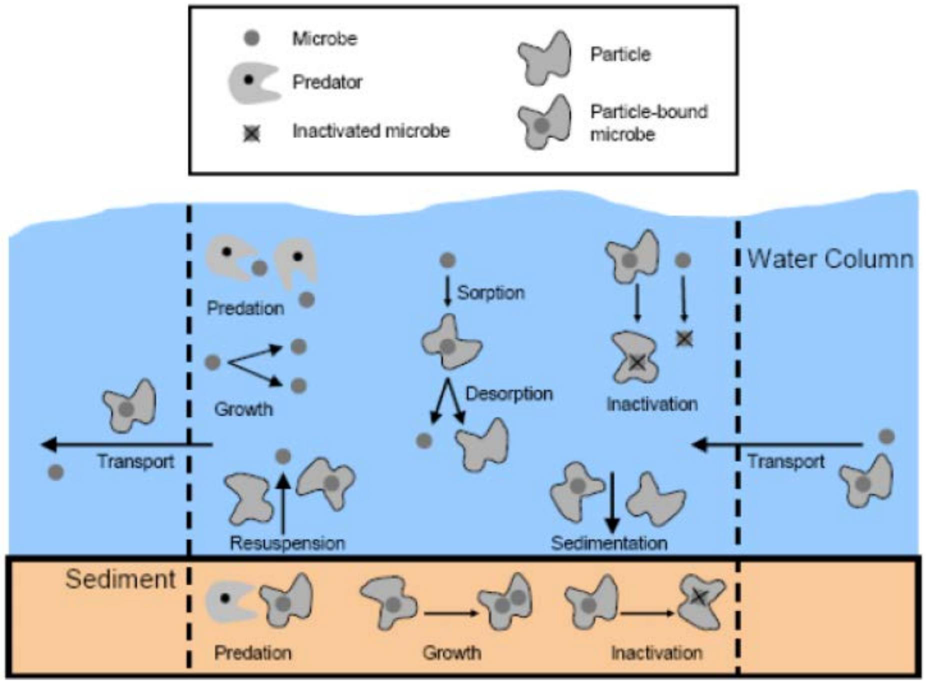


Figure 3
Average Percent Load Reduction from Orange County Natural Treatment Systems (NTS) Sites.

3 Feasibility Review of Restoration Approaches

Channel and riparian habitat restoration approaches can provide water quality improvements that may include reductions of FIB under conditions that result in the enhancement of pollutant removal mechanisms. These include physical, chemical, and biological mechanisms that are responsible for bacterial removal in natural waters. For example, restoration alternatives can enhance sedimentation and biofiltration of solids (resulting in reduction of bacteria that are attached to suspended solids) (see **Figure 4**). FIB removal mechanisms in natural systems include natural inactivation, predation, and filtration through plant and streambed contact (infiltration), sedimentation, sorption and chemical inactivation. While some processes remove bacteria from the water column, such as sedimentation, the FIB may continue to thrive in sediments and may be available for future resuspension (see **Figure 4**).



SOURCE: International Stormwater BMP Database, Pollutant Category Summary: FIB, December 2010

Figure 4
The Possible Fates of Fecal Indicator Bacteria in the Water Column and Sediments.

The use of restoration approaches for FIB reductions is challenging due to the variable nature of riparian ecosystems in terms of FIB sources, flowrates, soil types and land availability. As discussed in the literature review above, in-stream restoration approaches have limited pollutant reduction capacity due to very low retention times under storm flow conditions that can also remobilize sediment that contains FIB. However, channel and riparian habitat restoration do provide floodplain and other riparian benefits that enhance whole ecosystems. Therefore, it seems appropriate to consider the use of in-stream restoration as a way of benefitting the whole ecosystem, while also providing some removal of bacteria.

In-Line Stream Restoration Project – Increase Channel Capacity and Floodplain to Create More Stable System

Based on the feasibility review of restoration strategies for the San Diego region watersheds under the Bacteria TMDL, the restoration types under these strategies that will be carried forward and modeled are summarized in Appendix B. The two main restoration strategies include “in-stream” and “off-line” approaches. In-stream strategies are those that are implemented within the creek, e.g. channel restoration to widen artificially confined channels, or adjacent to the main channel, and serve as an extension of the main channel, e.g.

side channel restoration. Under these strategies, flow through these restorations is controlled by the dimension of the channel, channel roughness, base flow, and storm flow. In-stream strategies serve to restore the natural hydrology, biological and sediment transport functions. These strategies therefore are limited in their ability to retain and remove pollutants in storm flows through mechanisms that require sufficient retention times.

Off-line strategies are those that divert some flow out of the creek into an adjacent natural feature such as a wetland or distributary channel system. These off-line restoration systems mimic naturally disconnected tributaries where low flows seeped back into the main stem via wetlands similar to natural bio-retention cells. As these systems rely on infiltration and higher retention times to restore natural hydrology and also water quality benefit, flows into these systems need to be controlled and limited. These systems are most applicable in tributary canyon systems that have lower flows and can mimic historical canyon fluvial systems. As off-line systems, the flows to these restorations can be better managed while also providing ecosystem benefits. These off-line systems can also be located closer to storm sewer outfalls where potential sources of bacteria can be managed. These types of restoration approaches can also be implemented in phases to reduce temporary impacts.

Tributary Riparian Corridor and Wetlands

A consideration with either the in-stream or off-line restoration approaches is that likely feasible sites will be within sensitive habitat requiring mitigation for temporary disturbance that would be defined in the natural resource permits. In addition, maintenance of these sites will also require likely mitigation and restrictions on the type and timing of the maintenance. Continued water quality functions may be reduced with sedimentation and reduction in infiltration without periodic maintenance. These systems also attract wildlife that can be a source of FIB as indicated in the NTS data discussed above. Sediment and plants that can limit FIB in low storm flows can also be a source of FIB in bigger storm flows particularly with in-stream systems.

Based on this feasibility review, the in-stream restoration types that will be moved forward are channel restoration, side channel and side channel alcove. However, because all these restoration types have similar pollutant removal mechanisms, the restoration type modeled is the in-stream channel restoration. This is based on the limited retention times for in-stream restoration types as inlet and outlet controls are limited under these approaches for storm flows. The off-line restoration type that is moved forward into the model is the alluvial tributary wetlands restoration. As presented in Appendix B, invasive removal and replanting with native vegetation is an important restoration strategy and an element in all restoration projects. As this element does not provide for measurable change in retention times and limited change in infiltration, this strategy is not brought forward.

4 Mechanisms for Bacteria Removal

Because of the limited published data and monitoring results on the efficacy of creek and riparian habitat restoration to reduce FIB concentrations, modeling was conducted for both in-stream and off-line restoration strategies to determine what bacteria removal mechanisms were applicable that could then be compared with available published data on removal efficiencies. For example, the in-stream restoration strategy was modeled to determine the increase in retention time achieved when the channel was restored through increasing the channel width and allowing water to spread out across a wider bed. The increased retention time was then compared to published retention times that have been shown to provide a significant level of FIB removal. The mechanism of retention was modeled for the off-line strategy by simulating the process of alluvial fan flow dispersal into distributaries and wetlands. The mechanism of infiltration to reduce bacteria loading was also modeled for both the in-stream and off-line restoration strategies.

The results of this modeling indicated no measurable increase in retention time was achievable from the in-stream restoration for storm flows. The difference in retention times for the stream before and after restoration was minutes compared to the required 24-76 hours of retention time to achieve the bacteria reductions reported for engineered natural systems that have wetland type functions. For example, the increase in retention time for an event with an average flow of 40 cubic feet per second (cfs) and an in-stream channel expansion restoration length of 5000 feet is less than 5 minutes (from 18 to 22 minutes) and would not provide measurable FIB removal.

The modeling of removal mechanisms for in-stream restoration strategies indicated that infiltration may provide a mechanism for removal if hydro-geological conditions are favorable. These conditions include higher permeable materials in the stream bed and a groundwater table below these permeable materials. These conditions would allow for seepage of storm flows into the sub-soils to the groundwater (losing stream). If the groundwater is at the surface, infiltration will not occur (gaining stream). For the off-line tributary wetlands, retention times can be much longer as flow into these systems can be controlled and the project located where storm flows will be lower. Both infiltration and retention mechanisms are applicable for the off-line restoration strategy, and are modeled in the analysis in the next steps.

The results also supported the use of one restoration approach to represent in-stream and one for off-line categories. This was based on the similar mechanisms and conditions within each of these categories (e.g. stream channel, side channel and channel alcove in-stream restoration approaches all have similar low retention times under storm flow conditions).

5 GIS Analysis of Restoration Opportunities

Figures 5 and **6** present the watersheds in San Diego and Orange Counties, respectively that are under the Bacteria TMDL, and analyzed in this report. These watersheds are identified in the Bacteria TMDL Technical Report Appendix E, Maps of Impaired Watersheds (San Diego Regional Water Quality Control Board, February 2010). The Scripps and San Marcos watersheds were not included in this analysis due to their small watershed areas and limited opportunities for restoration scenarios on public lands. The GIS analysis for this report was conducted on these watersheds using data compiled from current parcel ownership information and boundaries (for interpretation of public versus private lands), current land use, water body (stream reaches and tributaries), channel right-of-way areas, and slope percentage shape files from *San Diego's Regional GIS Data Source, SanGIS/SANDAG GIS Data Warehouse and Orange County GIS Public Works Data Set.* For each of the watersheds shown on **Figures 5** and **6**, a GIS analysis was conducted to determine feasible reaches of streams and public parcels available for in-stream and off-line restoration projects.

As shown on **Figures 5** and **6**, only the portion of each watershed that contains the impaired waterbody and below a dam, where applicable, was analyzed. The location of dams and reservoirs was first assessed as these create hydrologic barriers that can also affect water quality conditions up- and downstream of these structures. Restoration projects above these structures will provide multi-benefits in these hydrologic units, however due to the effects of these structures on water quality, only the water quality benefits of restoration projects below these hydrologic barriers were analyzed. The GIS analysis then included compiling parcel data to identify public parcels within or adjacent to the main stems and tributaries hydraulically connected to the identified impaired waterbodies under the Bacteria TMDL. Public parcels within a ¼-mile of these main stems and tributaries were identified and then further filtered based on land use, parcel size and slope.

Public parcels with determined generalized land use categories of open space, vacant, park, or right of ways designated as protected areas, <15% slope, and at least 1 acre in area were selected for consideration. The feasible stream segments identified through this GIS analysis included those that have concrete side walls and maintenance easement in more urbanized watersheds. These selected public parcels were then further identified if the parcel is within a protected sensitive habitat based on designation through the National Wetlands Inventory, San Diego County Multiple Species Conservation Plan, and/or San Diego County Multiple Habitat Conservation Plan. This designation is important in assessing the feasibility of parcels and the requirements of protection and mitigation when working in these areas. The parcel inventory was expanded in more urbanized watersheds where public parcels are limited to include designated channel right-of-ways (public easement).

The results of the GIS analysis of public parcels are presented on the maps of each watershed in Appendix C for both San Diego and Orange Counties. The maps identify the parcels that meet the criteria listed above. The results of the GIS public parcel analysis were then used to identify the feasible stream segments for in-stream channel restoration, and feasible sites for off-line tributary wetland projects. Minimum stream segment length or area needed for off-line wetlands varied by "model" project for each watershed. The "model" in-stream and off-line projects were based on the conditions and drainage area for an actual feasible site within each watershed using the results of the GIS analysis. The number of feasible in-stream and off-line sites were then compiled for each watershed depending the stream segment and wetland area needed per model project, and used in the watershed bacteria load reduction analysis. Further discussion of the specific project attributes is presented in the discussions in the following sections.

6 "Model" Restoration Approaches

The purpose of the modeling of the restoration strategies was to establish "model" restoration strategies that are feasible for each watershed, and can be used to develop estimated bacteria load reduction that can be achieved through these restoration approaches. The "model" strategies are used first to estimate the volume of historical storm flows that can be either retained and/or infiltrated resulting in a measurable bacteria load reduction. These "model" restoration strategies or projects are then applied to the watershed scale to estimate reductions that can be achieved across the watershed based on the number of feasible sites, size of the overall drainage area and reduction targets.

This section first presents the restoration strategies modeled based on the results of the feasibility review. These include an in-stream and off-line restoration strategy that represents the types of restorations under these overall strategies. The strategy description includes the input parameters and assumptions used for the modeling. Following the strategy description is a summary of the modeling methods.

6.1 Analyzed Restoration Types

6.1.1 In-Stream Restoration

The analyzed in-stream restoration strategies involve widening and deepening confined reaches of a stream channel to mimic historical and natural sizes, thereby increasing infiltration and retention time. Widening stream channels is a common practice in confined channels to reduce shear stress and erosion on the channel sides. A wider channel reduces flow velocity and allows for more sediment deposition, and storm flow infiltration. Additionally, with a wider channel, residence time over a reach is increased. However, as discussed under the analysis of removal mechanisms in Section 4, these retention times are minimal under storm flow conditions, and are not sufficient to result in measurable FIB reductions when compared to required retention times for FIB removal in engineered natural systems (minutes compared to 1-3 days).

However, increasing the wetted perimeter of the channel by increasing channel size would allow for additional infiltration and removal of bacteria under favorable hydro-geologic conditions. Therefore, the analysis for in-stream restoration types is based on infiltration and the percent increase that occurs when the channel is widened and deepened with restoration. **Figure 7** shows cross section widening and how it increases the cross sectional area to allow for more infiltration.

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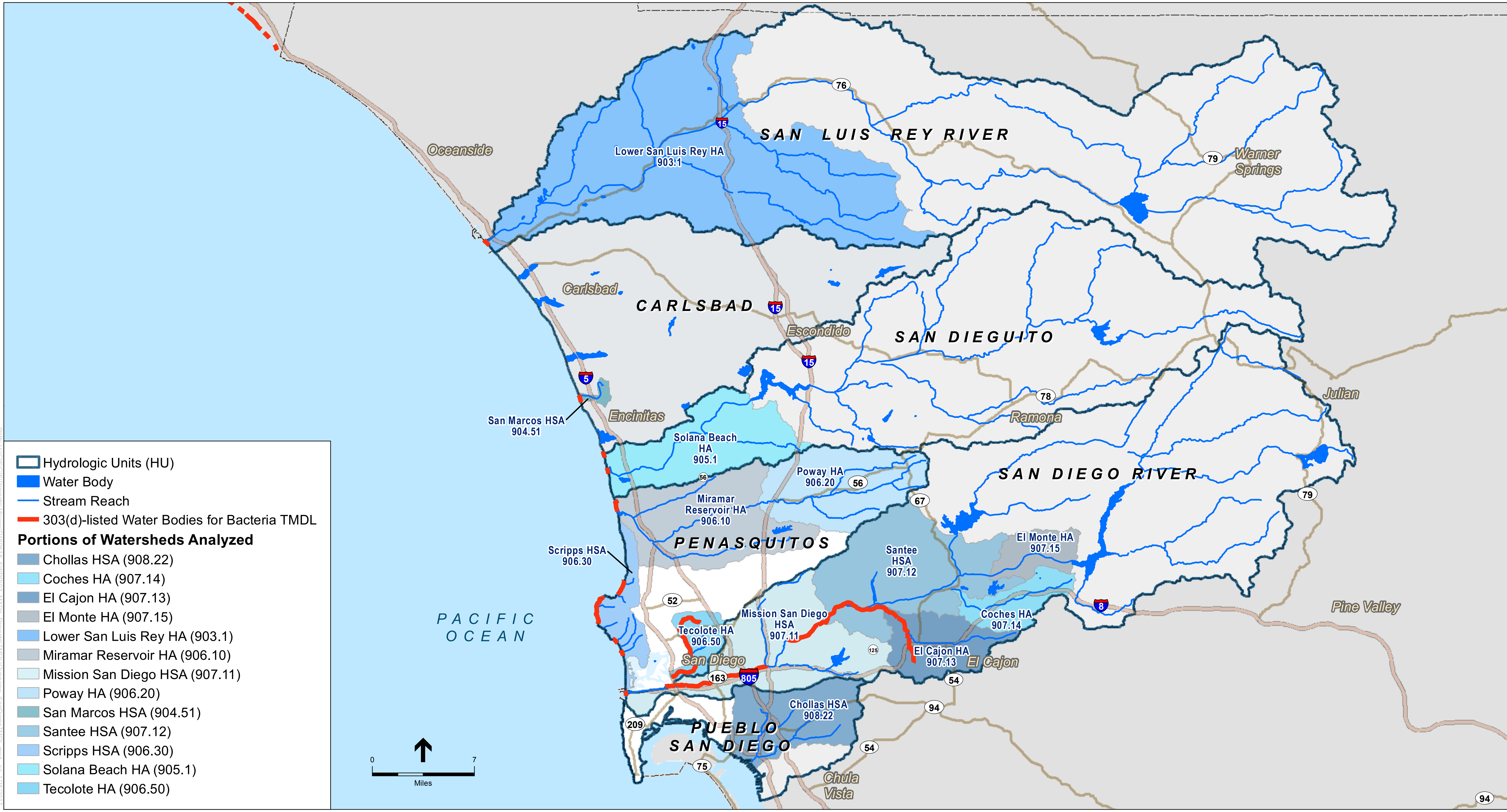


SOURCE: ESRI; State of California; SanGIS; NHD

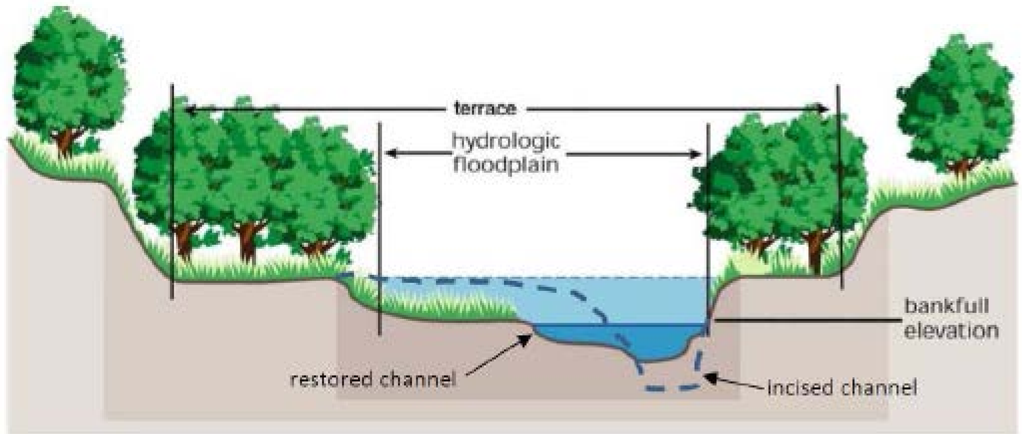
Figure 5
San Diego Region Watersheds under the Bacteria TMDL

SOURCE: ESRI; State of California; SanGIS; NHD

San ie o Bacteria BA

Figure 6

South Orange County Region Watersheds under the Bacteria TMDL



SOURCE: Adapted From Stream Habitat Restoration Guidelines, Washington State Aquatic Habitat Guidelines Program, 2012, Page AB-15

Figure 7
In-stream Channel Restoration Strategy using Cross-Section Widening

The feasible stream segments identified through the GIS analysis of segments within public parcels included those that have concrete side walls and maintenance easement in more urbanized watersheds. The segments that have concrete sidewalls in Chollas and Tecolote Creeks were further analyzed with regard to having sufficient area to flatten out the side slopes to accommodate the flood flows after the concrete is replaced with a natural vegetated slope. This analysis indicated that sufficient area was not available in most cases on both sides of the channel. Therefore, for these segments, it was generally assumed that only one side of the concrete channel was removed and replaced with a more gently vegetated slope. The infiltration rates for these segments accounted for the removal of one side of the concrete channel slope, and are reflected in the overall watershed infiltration rates.

6.1.2 Off-line Restoration

The off-line restoration strategies mimic natural processes where water is diverted from a channel and retained off-line for longer periods. For example, prior to human modifications such as channelization, many tributaries didn’t directly connect to main stem creeks, but instead dissipated flow across alluvial fans and through seasonal wetlands (sometimes referred to as ‘sausals’ or willow wetlands) (Beller et. al., 2011). Small to moderate flows dissipated into depressions on the alluvial fan and percolated to groundwater or seeped downslope before joining the creek as interflow, while larger flows were able to reach the main stem via distributary channels or sheet flow. The tributary approach modeled in this study involves creating a series of distributary channels that draw low flows off the main tributary and into depressions where percolation and evaporation can take place. This approach is illustrated on **Figure 8**. The distributary splits would require some form of stable hydraulic control such as a boulder or gabion weir structure that is designed so that low flows could pass into distributary channels while higher flows would mostly remain in the main tributary and flow to the main stem creek, or pass through the depressions with a faster residence time.

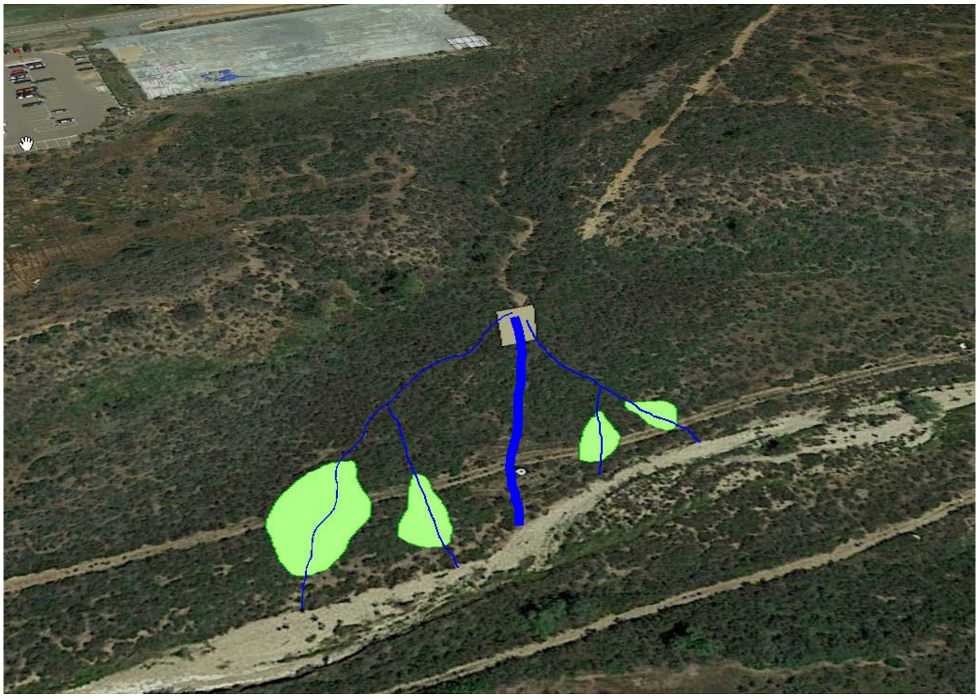


Figure 8
Schematic of Off-line Tributary Wetland: Low flows are diverted by hydraulic structure (tan box) into distributary channels and onto wetlands (green)

6.2 Modeling Methods

6.2.1 In-Stream "Model" Restoration Project Methods

An in-stream channel restoration "model" project was designed for each watershed under the Bacteria TMDL. To determine the bacteria removal in the restored channel, a model was created to calculate increased infiltration, resulting in increased bacteria removal. The "model" projects are located on a stream reach identified in the GIS parcel analysis as being potentially feasible for a project site (Section 5.0), and were designed to be representative of each watershed. The dimensions of the restored channel were determined by the relationship between drainage area and channel geometry as describe in Dunne and Leopold, 1978. Streamstats, a USGS web application was used to delineate a watershed that drains to an available parcel and identify land use coverage of the drainage area. This information was used to develop a concept-level watershed hydrologic model using the San Diego Hydrology Model, which in turn produced a 35 plus year time series of discharge based on rainfall data from the nearest ALERT station. The modeling process for the in-stream "model" projects incorporates the inputs presented in **Table 1**.

TABLE 1
IN-STREAM "MODEL" RESTORATION PROJECT INPUTS

Watershed	Total Acreage of Watershed	"Modeled" Stream Segment Length (ft.)	"Modeled" Drainage Area (ac)	Cross-sectional area increase (ft^2)	Cross section width increase (ft.)
San Diego County Watersheds					
San Diego River (Lower San Diego HA)	77,205	1,500	1,000	15	6
Chollas Creek HSA	21,490	1,400	1,088	20	10
San Dieguito River (Solana Beach HA)	28,725	1,000	1,536	19	15
Los Peñasquitos (Miramar HA)	60,421	1,000	768	16	9
Tecolote Creek HA	6,257	1,400	1,344	20	10
San Luis Rey River (Lower San Luis Rey HA)	119,662	1,000	1,088	20	10
Orange County Watersheds					
Laguna Hills HSA/ San Joaquin Hills HSA	8,935	1,500	768	14	8
Aliso Creek HSA	22,861	1,500	1,024	15	5
Dana Point HSA	5,759	1,500	640	14	5
Lower San Juan HSA	113,299	1,500	704	10	5
San Clemente HA	12,029	1,500	640	8	5

The following are key assumptions used in the development of the In-Stream Model:

- Manning's n of channels = 0.04.
- Depth to groundwater = 5ft: the stream is initially assumed to be perched above the groundwater table year-round, and able to infiltrate bed losses. Note that during the wet season, the streams and rivers are likely not receiving rivers and therefore this assumption produces an overassumption of infiltration.
- Daily evaporation rates generated by SDHM3.0
- Soil infiltration rate of 6 inches/day
- Interpolated infiltration determined from polynomial regression relating infiltration to discharge.

The flow depths and wetted perimeters for both existing and restored channels were calculated from the flow time series using Manning's Equation. An empirical relationship between infiltration and discharge was developed and used to determine infiltration at every time step of the model. The percentage of infiltration to total discharge was compared between the existing and restored channel and is reported as percent increase in Section 7.0.

6.2.2 Off-line Tributary Wetland "Model" Restoration Methods

The off-line wetland restoration "model" project infiltration was calculated in a similar way, with a continuous model developed by the team in MATLAB. The low flows were assumed to infiltrate in the wetlands at a rate of 1 inch per day. The "model" wetland project was set up as a simple box model allowing 1 foot of inundation from tributaries. From there the water was either evaporated or percolated. If water entered the wetland when it was at full capacity, the flow passed through the wetland with longer retention time (up to 1.5 cfs). The size of the wetland area for each "model project" was determined based on feasibility- the more developed watersheds with less acreage availability used smaller wetland sizes. **Table 2** presents the tributary wetland "model" restoration project modeling inputs.

TABLE 2
OFF-LINE TRIBUTARY WETLANDS "MODEL" RESTORATION INPUTS

Watershed	Total Acreage of Watershed	"Modeled" Drainage Area (ac)	Wetland area (acres per 1000 acres of drainage area)
San Diego County Watersheds			
San Diego River (Lower San Diego HA)	77,205	1,000	4
Chollas Creek HSA	21,490	1,088	2
San Dieguito River (Solana Beach HA)	28,725	1,536	4
Los Peñasquitos (Miramar HA)	60,421	768	4
Tecolote Creek HA	6,257	1,344	2
San Luis Rey River (Lower San Luis Rey HA)	119,662	1,088	4
Orange County Watersheds			
Laguna Hills HSA/San Joaquin Hills HSA	8,935	768	2
Aliso Creek HSA	22,861	1,024	2
Dana Point HSA	5,759	640	2
Lower San Juan HSA	113,299	704	2
San Clemente HA	12,029	640	2

The wetland area shown in the last column in Table 2 per 1000 acres of drainage area is largely based on the availability of feasible public parcels identified through the GIS parcel analysis, and the size of the watershed. If there are a sufficient number of feasible public parcels that could accommodate a 4-acre tributary wetland and an additional six acres for channel grading to bring storm flows to the wetlands and for habitat mitigation, then these larger off-line wetlands are used. If sufficient parcels of this size are not available, then a smaller 2-acre off-line wetland is used. The 2-acre scenario is used in smaller and highly developed watersheds that generally contain smaller parcels of feasible public spaces for the implementation of these restoration projects. For the smaller 2-acre off-line wetlands, and additional three acres was estimated for channel grading and habitat mitigation. These total acreages are used in the cost estimating presented later in this report.

The wetland enterococcus reduction efficiency rate for the retention mechanism was determined from the analysis of published studies and data from local natural treatment systems as presented in Section 2. Wetland FIB reduction rates have a wide range and depend on the flow rates and FIB concentrations. A reduction efficiency rate of 50% was selected. A sensitivity analysis using reductions rates ranging from 40-70% was completed and summarized in Section 10.

The load reduction for dry weather flows in in-stream and off-line systems occur through the same processes as in wet-weather flows: infiltration and retention. Dry weather flows are not analyzed in this analysis as the focus was on wet weather flows. Non storm water dry weather flows are prohibited in MS4 discharges under the current Permit. Non storm flow management measures are defined in the WQIPs in each of the watersheds.

Additional assumptions that were used in the off-line wetlands modeling are as follows:

- Alluvial fan settings are subject to geomorphic dynamism: channels and depressions may require some structural measures and/or periodic maintenance to maintain the channel alignment and flow split required to provide infiltration and bacteria treatment, and to prevent sedimentation of depressions.
- Stream flow into a wetland instantaneously spreads over the area of the wetland
- Soil infiltration rate of 1 inch per day assumed.
- Wetland FIB reduction efficiency = 50% (based on the results of the literature review and data from local natural treatment systems). Also tested for sensitivity with 40%, 60%, and 70% efficiency (See Section 10).

7 Watershed Scenarios and Potential FIB Load Reduction

The next step in the analysis is applying the infiltration and retention rates, where applicable, for the in-stream and off-line “model” projects to a watershed scale to determine the potential bacteria reductions from restoration strategies. In order to “book end” the level of bacteria reduction that could be achieved by the restoration strategies, two scenarios were analyzed on a watershed scale. The first scenario includes implementing stream restoration within feasible stream segments that are on public lands. The number and length of feasible stream segments is based on the GIS analysis of public parcels or channel right of ways that are within the stream segments.

The other end of the “book end”, Scenario 2, includes both in-stream restoration and off-line wetlands. The off-line wetlands are located along tributaries of the main stream channels in the larger watersheds and along both main stem and tributaries in the smaller watersheds. Scenario 2 first applies the in-stream restoration approach on a watershed scale to provide bacteria reduction through infiltration. Scenario 2 then uses off-line wetland approaches up to the number of feasible sites that achieve a combined (in-stream and off-line approach) FIB reduction (enterococcus used for the FIB analysis) on a watershed scale that meets the target wet weather reductions provided in the applicable WQIPs.

The watershed analysis for these two scenarios use the rates of infiltration and retention determined for the “model” restoration types and apply them to the number of feasible sites within each watershed to obtain the total rates and subsequent bacteria reductions for each scenario and watershed. The results of this watershed analysis are summarized in this section.

7.1 Scenario 1: Watershed Analysis - In-Stream Restoration

Table 3 presents the results of the watershed analysis for Scenario 1 that uses in-stream restoration strategies within feasible stream segments on public lands or channel right of ways. Table 3 presents the total number of “model” in-stream restoration projects for each watershed based on the GIS analysis. The total acreage of the watershed that drains to the “model” projects is based on the total number of feasible projects and the drainage area associated with the “model” project listed in Table 1. In some watersheds, the total area that drains to feasible sites is greater than the total watershed area, and in that case, the size of the watershed is the limiting factor of the number of feasible sites. Table 3 shows the total area draining to restored areas.

Using the infiltration rates determined for the “model” in-stream projects to the total number of feasible projects in the watershed, the total rate of infiltration on a volume basis ranges from 0.2 to 1.6%.These infiltration rates assume favorable hydro-geologic conditions as discussed (assumes “losing stream” conditions). Infiltration is assumed to have 100% bacteria removal efficiency; therefore, the rate of bacteria load reduction is equal to the estimated infiltration rates shown in Table 3. These rates are comparable to the rates determined for stream restoration project rates of 0.3 – 2.5% in the San Diego River Watershed Management Area (WMA) Water Quality Improvement Plan (County of San Diego, March 2016).

The estimated annual reduction in bacteria load per watershed is then estimated using the baseline annual total enterococcus bacteria wet weather loads. The baseline wet weather loads are calculated from the modeled enterococcus concentrations and flows developed for the Water Quality Improvement Plans, and are consistent with the other cost benefit analyses. The baseline loads are determined using the mean wet weather concentrations and total average annual wet weather flow over the period of 2010-2016. Wet weather is defined for this total wet weather loading as 0.2 inches or greater of rainfall over a 24-hour period plus the next three days if rainfall continues, consistent with the TMDL and San Diego WQIPs. These estimates include the loads for the allowable exceedance days, because the hydrology model to determine the infiltration rates is a continuous simulation model. The greater load estimated by including these days is likely off-set by the assumed favorable hydro-geologic conditions for the infiltration rates. The total enterococcus bacteria load reduction achieved by the in-stream Scenario 1 is presented in the final column of Table 3 and is the infiltration rate multiplied by the baseline total enterococcus bacteria load wet weather loads.

TABLE 3
SCENARIO 1: IN-STREAM RESTORATION ESTIMATED BACTERIA LOAD REDUCTIONS BY WATERSHED

Watershed	Number of Feasible Stream Segments in Watershed [1]	Total Acreage Draining to Restored Areas (acres)[2]	Area Draining to Restored Area/ Total Area in Watershed[3]	Percent Infiltrated by Stream Restoration (% of total storm flow)[4]	Baseline Annual Enterococcus Bacteria Wet weather Loads (colonies/yr.)[5]	Annual Enterococcus Load Reduction (colonies)[6]
San Diego County Watersheds						
San Diego River (Lower San Diego HA)	77	77,205	1.0	1.0%	4.3E+15	4.1E+13
Chollas Creek HSA	17	18,496	0.9	0.2%	1.7E+15	4.1E+12
San Dieguito River (Solana Beach HA)	19	28,725	1.0	1.1%	6.8E+14	7.5E+12
Los Peñasquitos (Miramar HA)	79	60,421	1.0	0.6%	2.9E+15	1.8E+13
Tecolote Creek HA	5	6,257	1.0	0.3%	8.4E+14	2.2E+12
San Luis Rey River (Lower San Luis Rey HA)	110	119,662	1.0	0.3%	3.6E+15	1.0E+13
Orange County Watersheds						
Laguna Hills HSA/ San Joaquin Hills HSA	11	8,448	0.9	0.3%	2.5E+14	6.9E+11
Aliso Creek HSA	22	22,528	1.0	1.6%	1.3E+15	2.1E+13
Dana Point HSA	2	1,280	0.2	1.2%	2.8E+14	3.5E+12
Lower San Juan HSA	64	45,056	0.4	0.3%	2.6E+14	6.6E+11
San Clemente HA	7	4,480	0.4	0.2%	4.8E+14	1.1E+12

1 These are stream segments identified through the GIS parcel analysis that are located within public lands and are of sufficient length that corresponds to the "model" stream restoration per Table 1.
2 This is the total drainage area for all feasible stream restorations consistent with the "model" case studies per Table 1.
3 Total acreage from column 3 divided by the total area of the portion of the watershed analyzed as shown on Figures 5 and 6.
4 This is the percent of infiltration from all the feasible model stream restoration projects based on the continuous hydrology modeling of historical rain events for the total drainage areas associated with the number restoration sites listed in column 2. This % infiltration is area and volume based and represents the infiltration rates for the historical storm flows.
5 Baseline average annual Enterococcus load wet weather.
6 Enterococcus load reduction determined using the infiltration rate in column 5 multiplied by the baseline enterococcus wet weather loads. The baseline load is determined using the mean wet weather concentrations and total average annual wet weather flow over the years 2010-2016 from the modeled flow and enterocuccus concentrations used in the WQIPs.

7.2 Scenario 2: In-Stream and Off-line Tributary Wetland Restoration Approches

Scenario 2 includes both in-stream restoration and off-line wetlands. The off-line wetlands are located along tributaries of the main stream channels in the larger watersheds and along both main stem and tributaries in the smaller watersheds. Scenario 2 first applies the in-stream restoration approach on a watershed scale to provide bacteria reduction through infiltration. The removal rate for enterococcus for the infiltration mechanism is 100%. **Table 4** presents the results of the bacteria reduction analysis for Scenario 2. Table 4 first provides the total number of feasible in-stream restoration projects for each watershed based on the GIS analysis that corresponds to the same number used for Scenario 1. The percent total infiltration as a percent of volume of wet weather flows is shown in Table 4 for the in-stream restoration. The removal efficiency of infiltration (100%) is the same as the Scenario 1 instream infiltration efficiency. Therefore, the total bacteria load reduction rate for the overall in-stream sites is equal to the overall infiltration rate for the feasible in-stream sites within the portion of the watershed analyzed.

TABLE 4
SCENARIO 2: IN-STREAM AND OFF-LINE WETLAND RESTORATION LOAD REDUCTION BY WATERSHED – PERCENT LOAD REDUCTION WITH ENTEROCOCCUS REDUCTION GOALS PER WQIPS AND 50% WETLAND RETENTION REMOVAL EFFICIENCY

Watershed	Number of In-Stream Restoration Projects	Rate of Total Infiltration for In-Stream Projects (%)	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of Wetland Projects to Achieve WQIPs Reduction Targets	Reduction Achieved	Reduction Goal per WQIPs	Annual Enterococcal Reduction (colonies/yr.)
San Diego County Watersheds								
San Diego River (Lower San Diego HA)	77	1.0%	17.6%	13.6%	65	30.9%	30.8%	1.33E+15
Chollas Creek HSA	17	0.2%	7.5%	6.5%	17	14.2%*	28.8%	2.39E+14*
San Dieguito River (Solana Beach HA)	19	1.1%	7.7%	5.9%	7	14.7%	13.0%	9.97E+13
Los Peñasquitos (Miramar HA)	79	0.6%	9.3%	7.9%	48	17.8%	17.8%	5.17E+14
Tecolote Creek HA	5	0.3%	4.2%	4.4%	4	8.9%*	18.0%	7.43E+13*
San Luis Rey River (Lower San Luis Rey HA)	110	0.3%	7.6%	8.0%	109	15.9%	15.8%	5.72E+14
Orange County Watershed								
Laguna Hills HSA/ San Joaquin Hills HSA	11	0.3%	1.2%	1.2%	2	2.7%	2.5%	6.61E+12
Aliso Creek HSA	22	1.6%	2.0%	2.2%	7	5.8%	5.7%	7.67E+13
Dana Point HSA	2	1.2%	1.8%	1.4%	1	4.4%	2.5%	1.25E+13
Lower San Juan HSA	64	0.3%	7.0%	5.9%	64	13.2%*	17.6%	3.41E+13*
San Clemente HA	7	0.2%	2.1%	2.0%	3	4.3%	3.2%	2.07E+13

* Enterococcus reduction targets per the WQIPs were not attained

Scenario 2 then uses the feasible off-line wetland sites in order to reach the enterococcus load reduction targets presented in the applicable WQIPs (listed in column 8 of Table 4). Table 4 presents the overall watershed infiltration and retention rates for the feasible off-site wetland sites that when combined with the instream sites, reach the WQIP targets. Using the selected reduction efficiency rate of 50% for the wetland retention mechanism, Table 4 then presents the retention rate multiplied by the reduction efficiency (column 5). The combined reduction rate is then determined (column 6) by combining the overall watershed infiltration rate for the in-stream feasible sites with the infiltration and retention efficiency rates for the off-site wetland feasible sites. The number of off-site wetland sites shown in Table 4 represents the number of feasible sites to attain the enterococcus load reduction from the WQIPs (column 8) or the total feasible sites (number of sites is limiting factor and reduction target not achieved).

The maximum enterococcus reduction rate and annual load reduction achieved for Scenario 2 are shown in Table 4. The baseline annual enterococcus loads that were also used for Scenario 1 were multiplied by the total reduction rates for Scenario 2 to obtain the annual anticipated enterococcus load reduction. The level of bacteria reduction achieved in each watershed using a combined in-stream and off-line wetland restoration approach is constrained by the rates of infiltration and retention based on the "model" sites, the number of feasible sites and watershed drainage area. As noted in Table 4, three of the twelve watersheds do not attain the enterococcus load reduction goal due to the limited number of feasible sites and associated drainage area. These watersheds are generally more urbanized and have a limited number of public parcels within and along the stream segments.

8 Co-Benefits of Restoration Projects

In addition to enterococcus bacteria load reductions; co-benefits of implementing these restoration projects include ancillary metals, nutrients and sediment load reductions. An analysis of these co-benefit constituent load reductions is provided in Appendix D.

The baseline loads for San Diego County are average annual wet weather loads from 2007-2015. The Chollas nutrient loads are from the North Fork of Chollas Creek only, as no nutrient monitoring data were available for the South Fork. The Chollas metal loads are presented as dissolved loads, if available, for comparison with the TMDLs. Sediment, reported as total suspended solids (TSS) values were only available for the Los Peñasquitos (Miramar HA) watershed and Chollas HSA watershed. Loads for Orange County watersheds were calculated by multiplying average concentrations for wet weather events in a given year by that year's annual flow. The annual loads were averaged over five years (2010-2011 to 2015-2016) for each nutrient and metal. No additional data was available for the Dana Point watershed.

Based on literature values, specific reduction efficiencies for wetlands were used to estimate potential load reductions for nutrients, metals and sediments (see Appendix D). These specific reduction efficiencies were for the retention mechanism for wetlands was added to the wetland infiltration rate (with removal efficiency of 100%) to get the total constituent reduction rates. This method is similar to enterococcus reduction calculations except with reduction efficiencies specific to the metal, nutrient or TSS. The efficiency of fecal coliform removal from retention in a wetland was estimated as 50%. The estimated annual load reductions for nutrients, metals and sediment are provided in Appendix D and provide a basis for quantifying co-benefits.

The reduction of enterococcus and other FIB loading during dry weather flows from stream and wetland restoration projects provides an additional co-benefit. During dry weather flows, flow rates are lower and rates of FIB removal from infiltration and retention mechanism will be higher for stream restoration projects. Data from Upper Sulfur Creek and Narco Channel Restoration projects located in Orange County indicate a FIB reduction rates ranging from 40-80%. Wetland FIB reduction rates can be expected to range from 40-70% depending on the flow rates and FIB concentrations. Dry weather flows were not analyzed in this analysis as the focus was on wet weather flows. Non storm water dry weather flows are prohibited in MS4 discharges under the current Permit. Non storm flow management measures are defined in the WQIPs in each of the watersheds.

9 Cost Estimates

The required inputs to the cost benefit analysis include the feasibility level costs for the two restoration scenarios that achieve the estimated bacteria load reductions for each watershed. Feasibility cost estimates are high level cost estimates used for planning purposes and generally have a 25% contingency added to the estimated total costs. The estimated costs for restoration scenarios were developed using a feasibility level cost estimated for each “model” project. The unit “model” cost are then multiplied by the number of feasible sites used in the estimates for the bacteria load reductions presented in the previous section. Unit costs include planning, engineering design, CEQA, permitting, implementation and maintenance. The costs for the off-line tributary wetlands model project include the cost for likely habitat mitigation due to temporary disturbance of protected habitat. Based on the GIS parcel analysis, most of the public parcels that would be used for these restoration projects are within designated protected habitat areas. The costs for mitigation were incorporated into the feasibility level costing by increasing the acreage of the tributary wetlands to double the area modeled for bacteria reduction. Acreage was also added for grading to implement the conveyance channels to the tributary wetlands. As the sites were all located on public parcels, no costs for land purchases were included.

Table 5 presents the “model” stream project dimensions, excavated cross sectional area, cut volumes and estimated feasibility level <u>unit</u> costs. The cost for the in-stream stream restoration “model” project is based on planning, design and implementation costs from comparable stream restoration projects completed in California. The unit prices reflect the differences in excavated volumes and the length of the model project.

TABLE 5
SUMMARY OF IN-STREAM STREAM QUANTITIES AND FEASIBILITY LEVEL UNIT COSTS

Watershed	Length of "Model" Stream Segment (ft.)	Added cross sectional width (ft.)	Added cross sectional area (sq. ft.)	Total Cut volume (cu.yd.)	Price per linear foot of project	Cost per project
San Diego County Watersheds						
San Diego River (Lower San Diego HA)	1,500	6	15	850	$2,000	$3.0M
Chollas Creek HSA	1,400	10	20	1,050	$2,500	$3.5M
San Dieguito River (Solana Beach HA)	1,000	15	19	700	$2,500	$2.5M
Los Peñasquitos (Miramar HA)	1,000	9	16	600	$2,500	$2.5M
Tecolote HA	1,400	10	20	1,050	$2,500	$3.5M
San Luis Rey River (Lower San Luis Rey HA)	1,000	10	20	750	$2,500	$2.5M
Orange County Watersheds						
Laguna Hills HSA/ San Joaquin Hills HSA	1,500	8	14	800	$2,000	$3.0M
Aliso Creek HSA	1,500	5	15	800	$2,000	$3.0M
Dana Point HSA	1,500	5	14	800	$2,000	$3.0M
Lower San Juan HSA	1,500	5	10	500	$2,000	$3.0M
San Clemente HA	1,500	5	8	400	$2,000	$3.0M

Table 6 presents the total estimated feasibility level costs for Scenario 1 that includes implementing stream restoration at the feasible sites using the in-stream stream restoration "model" project as a basis. The total costs for Scenario 1 for each watershed are calculated using the unit costs for the in-stream model project and the number of feasible sites from the GIS and watershed analyses. The overall infiltration rates achieved which equates to the FIB load reduction rates for each watershed is also shown on Table 6. The total costs and overall infiltration rates are a dependent on the total number of feasible stream segments in each watershed. In order to assess the variability of these total costs, Table 6 also provides the cost per acre of drainage area that is captured in each watershed. The unit cost per acre of drainage area varies from $1,700 to $4,700/acre with an average of $3,300/acre.

TABLE 6
SCENARIO 1 – SUMMARY OF FEASIBILITY LEVEL TOTAL COSTS

Watershed	Feasibility Level Unit Cost	Number of Feasible Sites	Total Cost	Estimated FIB Load Reduction Rate	Cost per Acre of Watershed Draining to Restoration sites
San Diego County Watersheds					
San Diego River (Lower San Diego HA)	$3M	77	$231M	1.0%	$3,000
Chollas Creek HSA	$3.5M	17	$60M	0.2%	$3,200
San Dieguito River (Solana Beach HA)	$2.5M	19	$48M	1.1%	$1,700
Los Peñasquitos (Miramar HA)	$2.5M	79	$198M	0.6%	$3,300
Tecolote Creek HA	$3.5M	5	$18M	0.3%	$2,900
San Luis Rey River (Lower San Luis Rey HA)	$2.5M	110	$275M	0.3%	$2,300
Orange County Watersheds					
Laguna Hills HSA/ San Joaquin Hills HSA	$3M	11	$33M	0.3%	$3,900
Aliso Creek HSA	$3M	22	$66M	1.6%	$2,900
Dana Point HSA	$3M	2	$6M	1.2%	$4,700
Lower San Juan HSA	$3M	64	$192M	0.3%	$4,300
San Clemente HA	$3M	7	$21M	0.2%	$4,700

Table 7 presents the estimated feasibility level costs for Scenario 2 that include the implementation of both the in-stream restoration and off-line tributary wetland "model" projects at feasible sites to achieve the enterococcus load reduction target in the WQIPs. The estimated feasibility level costs for the off-line wetland restoration is based on planning, design, permitting and implementation costs from comparable wetland and riparian habitat restoration projects completed in California. These costs include a contingency of 25%, a mobilization/ insurance/bonding cost of 8% and operations and maintenance cost of 20% of total planning and construction costs. The unit prices reflect the differences in the areas required for the wetland bioretention areas, area for additional grading and channels, and habitat mitigation to address temporary impacts to sensitive habitat. Due to the much lower reduction rates achieved by the in-stream restoration project, these costs are shown separately.

TABLE 7
SCENARIO 2: SUMMARY OF FEASIBILITY LEVEL COSTS

Watershed	Area of off-line Tributary Wetlands (ac)	Area needed for off-line Tributary Wetlands (ac)[1]	Feasibility Level Unit Cost (millions)	Number of Feasible Sites w/ 50% reduction	Feasibility Level Costs for FIB Reduction with 50% removal Efficiency (off-line only) (millions)	Number of Instream Restoration Projects	Feasibility Level Unit Cost for In-Stream Projects (millions)	Additional Feasibility Level Costs for In-stream Stream Projects (millions)
San Diego County Watersheds								
San Diego River (Lower San Diego HA)	4	10	$5.0	65	$325	77	$3.0	$231
Chollas Creek HSA	2	5	$2.9	17	$49	17	$3.5	$60
San Dieguito River (Solana Beach HA)	4	10	$5.0	7	$35	19	$2.5	$48
Los Peñasquitos (Miramar HA)	4	10	$5.0	48	$240	79	$2.5	$198
Tecolote HA	2	5	$2.9	4	$12	5	$3.5	$18
San Luis Rey River (Lower San Luis Rey HA)	4	10	$5.0	109	$545	110	$2.5	$275
Orange County Watersheds								
Laguna Hills HSA/San Joaquin Hills HSA	2	5	$2.9	2	$6	11	$3.0	$33
Aliso Creek HSA	2	5	$2.9	7	$20	22	$3.0	$66
Dana Point HSA	2	5	$2.9	1	$3	2	$3.0	$6
Lower San Juan HSA	2	5	$2.9	64	$186	64	$3.0	$192
San Clemente HA	2	5	$2.9	3	$9	7	$3.0	$21

10 Sensitivity Analysis

Uncertainties in the modeling parameters used to develop the FIB load reductions and costs have been acknowledged in the results discussion, and include the FIB reduction efficiency rate for the retention mechanism for the off-site wetlands. The analysis described in Section 7 uses 50% for the FIB reduction efficiency rate. As discussed in Section 2, the efficiency of wetlands to reduce bacteria loads based on literature and local natural treatment system data will vary based on incoming loads, wetland design and flows scenarios. Section 10.1 present the results of the sensitivity analysis of this parameter on the overall enterococcus load reduction achieved and associated costs by varying the reduction rates from 40 to 70%. Additional uncertainty analysis is presented in Appendix E of the wetland reduction efficiencies by assessing the effect on the overall FIB load reduction achieved when maintaining the number of projects required to achieve reduction goals at 50% wetland removal efficiency and varying the wetland reduction efficiency.

An additional input parameter that was assessed was the number of feasible sites. The number of feasible sites is based on the GIS analysis. The results of the overall reduction analysis indicated that this was a limiting parameter for some watershed and warranted further sensitivity analysis. Section 10.2 presents a discussion of the results of the sensitivity analysis for the number of feasible sites by varying the overall reduction goals to set percentages of 10 and 20% for a fixed wetland removal efficiency rate. The results of this additional analysis is provided in Appendix E. By setting the same overall reduction goals for all the watersheds, the sensitivity of the limitation on feasible sites can be better determined. These additional analyses were conducted to review potential scenarios and associated costs.

10.1 Sensitivity Analysis of Wetland Reduction Efficiency

Based on literature review, it is known that the rates of wetland FIB removal efficiency range significantly. In order to test the sensitivity of the wetland reduction efficiency, further analysis was conducted with the low range 40% removal efficiency to 60% and 70% removal efficiency. The results of this analysis are summarized in Tables 8 and 9. The number of feasible wetlands sites needed to achieve the enterococcus load reduction targets per the WQIPs is reduced as shown on Table 8. For example, the number of needed sites to attain the WQIP reduction targets for Lower San Diego River HA reduces from 71 for an efficiency of 40% to 56 sites for an efficiency of 70%. This represents a 20% reduction in needed feasible sites to reach the target reduction. The San Diego River WMA represents a larger watershed with a comparatively greater FIB reduction target. In comparison, the number of feasible sites needed for smaller watersheds with lower FIB reduction target that includes Aliso Creek HSA, decreases from 8 to 6 sites when the removal efficiencies increase from 40 to 70%. This represents a decrease of 25%. However, due to the limitation on the number of feasible wetland sites, the watersheds that are not able to achieve the WQIP FIB reduction targets at 50% efficiency (Lower San Juan HA, Tecolote Creek HA and Chollas Creek HSA), still do not achieve the reduction goals at 60% or 70%. At 40% removal efficiency, San Luis Rey also falls short of the reduction goal.

As shown in Table 9 and graphically in Figures 9 and 10, the increase in FIB reduction efficiency for wetlands results in a reduction in the total costs for just the wetlands sites corresponding to a reduction in the number of sites needed. For the San Diego River WMA, the cost reduction is from $355M to $280M, or a reduction of 20%, which is within the contingency of 25%. Similarly, the total implementation cost for the smaller watershed of the Aliso Creek HSA, decreases from $23M to $17M when the removal efficiencies increase from 40 to 70%. This represents a decrease of approximately 25%, which is also within the contingent of 25%. A contingency of 25% was used for the total implementation costs for all watersheds for consistency in comparison purposes. The costs for the watersheds that are not able to achieve the WQIP FIB reduction targets at 50%, 60% or 70% efficiency (Lower San Juan HA, Tecolote Creek HA and Chollas Creek HSA), do not vary as the total feasible sites used (full amount) remain the same for all the efficiency ranges.

Also shown on Figures 9 and 10 are the total costs for the implementation of the stream restoration projects that are included in Scenario 2. As these are implemented for the total number of feasible segments and rely on infiltration for FIB reduction, no changes in total costs are realized under Scenario 2 with the varying of the wetland reduction efficiencies.

TABLE 8
RESULTS OF SENSITIVITY ANALYSIS - OFF-LINE WETLAND RESTORATION LOAD REDUCTION BY WATERSHED FOR 40%, 60% AND 70% WETLAND REMOVAL EFFICIENCY (RETENTION)

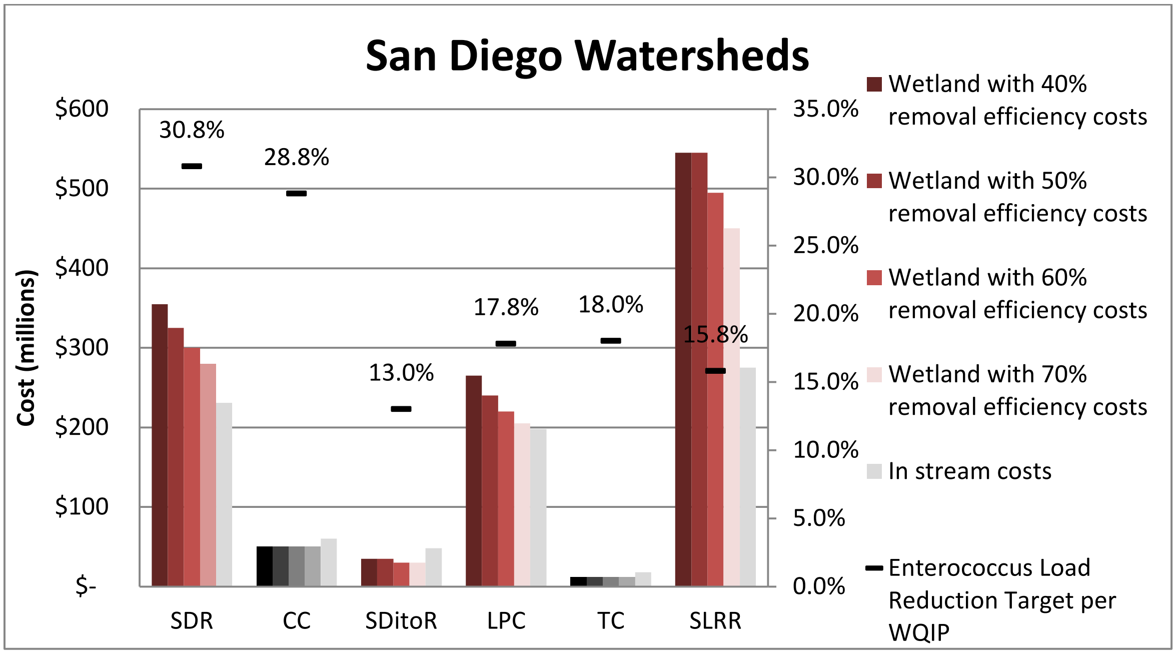
Watershed	40% removal efficiency for wetland retention				60% removal efficiency for wetland retention				70% removal efficiency for wetland retention			
	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of wetland projects to achieve MS4 reductions	Annual Enterococcal Reduction (colonies/yr.)	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of wetland projects to achieve MS4 reductions	Annual Enterococcal Reduction (colonies/yr.)	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of wetland projects to achieve MS4 reductions	Annual Enterococcal Reduction (colonies/yr.)
San Diego County Watersheds												
San Diego River (Lower San Diego HA)	19.2%	10.7%	71	1.33E+15	16.3%	13.6%	60	1.3E+15	15.2%	14.8%	56	1.3E+15
Chollas Creek HSA	7.5%	5.2%	17*	2.17E+14	7.5%	7.8%	17*	2.6E+14	7.5%	9.1%	17*	2.8E+14
San Dieguito River (Solana Beach HA)	7.7%	4.7%	7	9.17E+13	6.6%	6.1%	6	9.3E+13	6.6%	7.1%	6	1.0E+14
Los Peñasquitos (Miramar HA)	10.3%	7.0%	53	5.19E+14	8.5%	8.7%	44	5.2E+14	8.0%	9.4%	41	5.2E+14
Tecolote Creek HA	4.2%	3.5%	4*	6.69E+13	4.2%	5.3%	4*	8.2E+13	4.2%	6.2%	4*	8.9E+13
San Luis Rey River (Lower San Luis Rey HA)	7.6%	6.4%	109*	5.14E+14	6.9%	8.7%	99	5.7E+14	6.3%	9.2%	90	5.7E+14
Orange County Watersheds												
Laguna Hills HSA/ San Joaquin Hills HSA	1.8%	1.4%	3	8.69E+12	1.2%	1.4%	2	6.6E+12	1.2%	1.7%	2	7.8E+12
Aliso Creek HSA	2.3%	2.0%	8	7.80E+13	2.0%	2.7%	7	7.7E+13	1.7%	2.7%	6	7.9E+13
Dana Point HSA	1.8%	1.1%	1	1.17E+13	1.8%	1.7%	1	1.3E+13	1.8%	2.0%	1	1.4E+13
Lower San Juan HSA	7.0%	4.7%	64*	3.10E+13	7.0%	7.1%	64*	3.4E+13	7.0%	8.3%	64*	4.0E+13
San Clemente HA	2.1%	1.6%	3	1.88E+13	1.4%	1.6%	2	2.1E+13	1.4%	1.8%	2	1.7E+13

* Does not attain target enterococcus reduction goal per the WQIPs

TABLE 9
RESULTS OF SENSITIVITY ANALYSIS - SUMMARY OF FEASIBILITY LEVEL UNIT COSTS FOR 40%, 60% AND 70% WETLAND REMOVAL EFFICIENCIES (RETENTION)

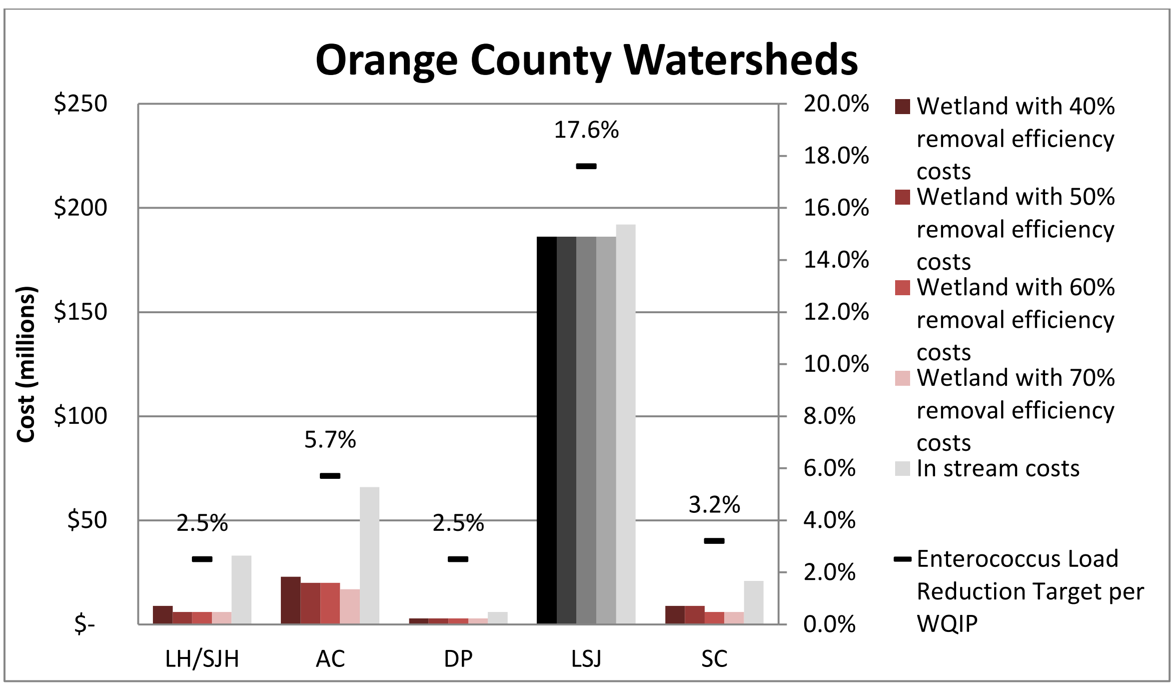
Watershed	Area of off-line Tributary Wetlands (acres)	Area needed for off-line Tributary Wetlands (ac)[1]	Feasibility Level Unit Cost	Number of Feasible Sites with 40% reduction	Number of Feasible Sites w/ 60% reduction	Number of Feasible Sites w/ 70% reduction	Feasibility Level Costs for FIB Reduction with 40% removal Efficiency (off-line only) (millions)	Feasibility Level Costs for FIB Reduction with 60% removal Efficiency (off-line only) (millions)	Feasibility Level Costs for FIB Reduction with 70% removal Efficiency (off-line only) (millions)	Additional Feasibility Level Costs for In-stream Stream Projects
San Diego County Watersheds										
San Diego River (Lower San Diego HA)	4	10	$5.0	71	60	56	$355	$300	$280	$231
Chollas Creek HSA	2	5	$2.9	17	17	17	**$49***	**$49***	**$49***	$60
San Dieguito River (Solana Beach HA)	4	10	$5.0	7	6	6	$35	$30	$30	$48
Los Peñasquitos (Miramar HA)	4	10	$5.0	53	44	41	$265	$220	$205	$198
Tecolote HA	2	5	$2.9	4	4	4	$12*	$12*	$12*	$18
San Luis Rey River (Lower San Luis Rey HA)	4	10	$5.0	109	99	90	**$545***	$495	$450	$275
Orange County Watersheds										
Laguna Hills HSA/San Joaquin Hills HSA	2	5	$2.9	3	2	2	$9	$6	$6	$33
Aliso Creek HSA	2	5	$2.9	8	7	6	$23	$20	$17	$66
Dana Point HSA	2	5	$2.9	1	1	1	$3	$3	$ 3	$6
Lower San Juan HSA	2	5	$2.9	64	64	64	**$186***	**$186***	**$186***	$192
San Clemente HA	2	5	$2.9	3	2	2	$9	$6	$6	$21

* Does not attain target enterococcus reduction goal per the WQIPs



SDR = San Diego River, CC = Chollas Creek, SditoR = San Dieguito River, LPC = Los Penasquitos Creek, TC = Tecolote Creek, SLRR = San Luis Rey River.
Note: Wetland costs are just for the wetland construction, they do not include instream costs.

Figure 9: Results of Sensitivity Analysis - San Diego County Watersheds Cost Comparison



LH/SJH = Laguna Hills/San Juan Hills, AC = Aliso Creek, DP = Dana Point, LSJ = Lower San Juan, SC = San Clemente
Note: Wetland costs are just for the wetland construction, they do not include instream costs.

Figure 10: Results of Sensitivity Analysis - Orange County Watersheds Cost Comparison

10.2 Sensitivity Analysis of the Number of Feasible Sites

Section 7 describes the process to determine the number of wetlands required to achieve the WQIP load reduction goals using 50% wetland removal efficiency. The number of feasible sites may vary greatly between watersheds as it depends on the number and characteristics of the available public parcels that were assessed in the GIS analysis presented in Section 5. The results of the overall reduction analysis indicated that the number of feasible sites was a limiting parameter for some watershed and warranted further sensitivity analysis. To further analyze the sensitivity of this input parameter on the overall analyses, an additional sensitivity analysis was conducted. Table 10 presents the results of this sensitivity analysis on the number of feasible sites by varying the overall reduction goals to set percentages of 10 and 20% for a wetland removal efficiency rate of 50%. By setting the same overall reduction goals for all the watersheds, the sensitivity of the limitation on feasible sites can be better determined.

The results of this additional analysis indicate the same smaller urbanized watersheds (Tecolote Creek HA and Chollas Creek HSA) that did not attain the WQIP enterococcus reduction target do not meet the 10% and 20% reduction goals. In addition, the Dana Point HAS does not attain the 10% reduction goals. Lower San Juan HA does meet the 10% target, but not the 20% target. At the 20% reduction target, eight of the eleven watersheds do not meet enterococcus reduction target. The number of feasible sites is a limitation to achieving bacteria reduction goals. Based on the sensitivity analysis, as the reduction target is increased from 10 to 20%, the number of watersheds that are not able to achieve the reduction target increases from 3 to 8 of the eleven watersheds. Appendix E provides a summary of these results that includes the estimated total implementation costs.

An additional analysis was conducted to determine the variability in total reduction with a fixed number of projects. Using the number of projects determined necessary to meet the reduction goals from the WQIPs with a 50% wetland reduction efficiency, the total reduction rate was then determined by varying the wetland removal efficiency to 40% and 70%. These results are presented in Figures 11 and 12. The results indicate that when the number of sites is held constant at a removal efficiency of 50%, more watersheds do not meet the WQIP targets at 40%, but the number of watersheds that do not meet the target remains unchanged at three for 50% to 70% efficiency. Additional results are shown in Appendix E.

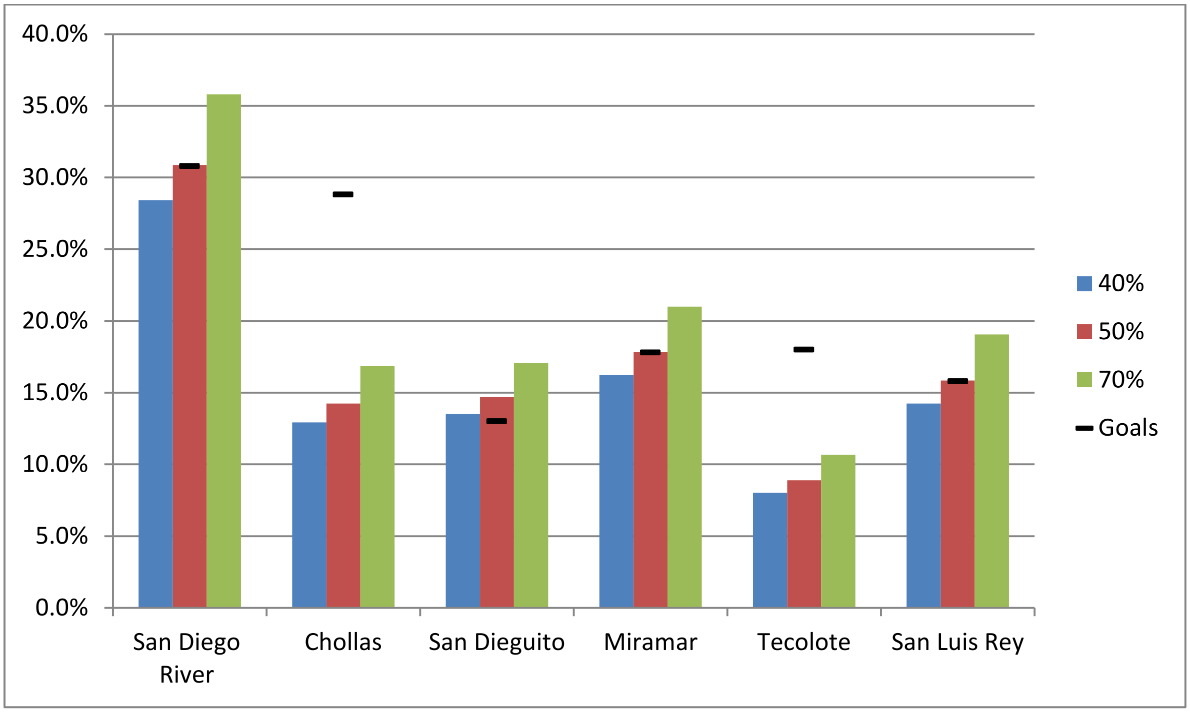


Figure 11: Results of Sensitivity Analysis for Varying Wetland Removal Efficiency and Holding Site Number Constant - San Diego County Watersheds

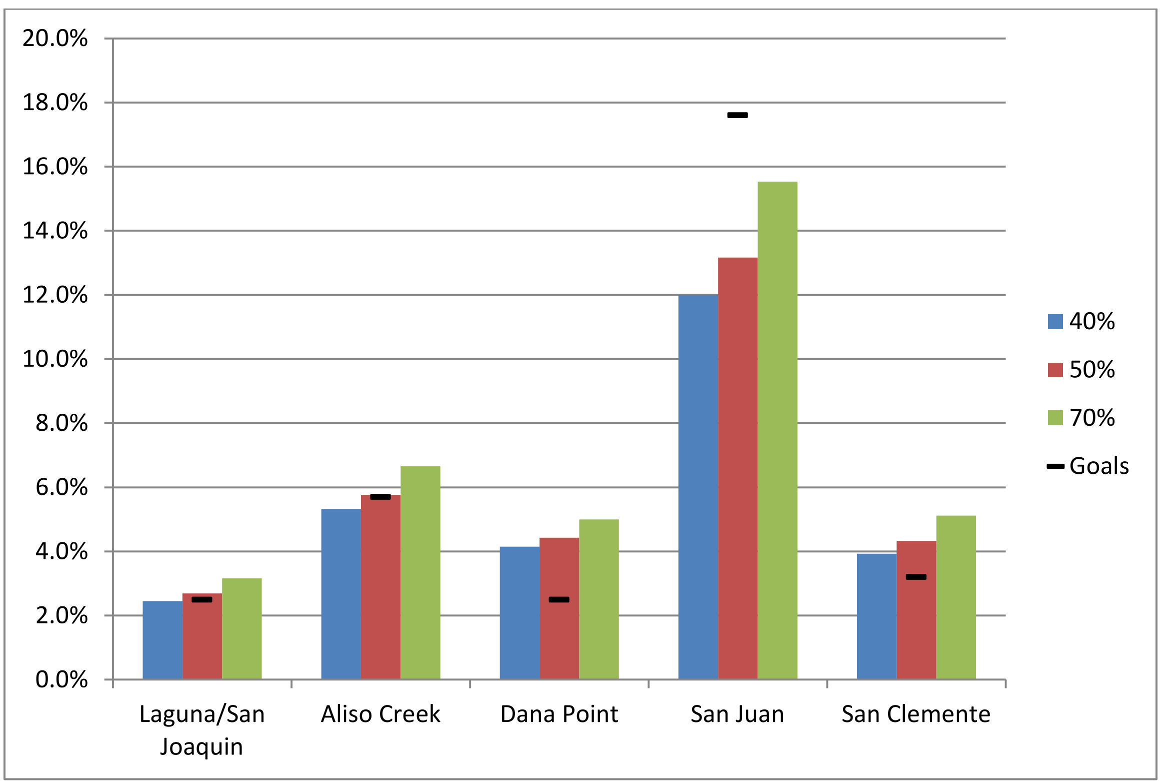


Figure 12: Results of Sensitivity Analysis for Varying Wetland Removal Efficiency and Holding Site Number Constant -Orange County Watersheds

Table 10

Results of Sensitivity analysis - Scenario 2: In-Stream and Off-line Wetland Restoration Load Reduction by Watershed – 10 and 20% Reduction targets for all watersheds

Watershed	Number of Feasible Stream Segments in Watershed	Percent Infiltrated by "Model" Stream Restoration Site (% of total storm flow)†	Rate of Infiltration for "Model" Off-Line Wetland Site†	Rate of Retention for Off-Line "Model" Wetland site Multiplied by Removal Efficiency†	Number of wetland projects to achieve 10% FIB load reduction	Number of wetland projects to achieve to 20% FIB load reduction	10% Annual Enterococcus Reduction#	20% Annual Enterococcus Reduction#
San Diego County Watersheds								
San Diego River (Lower San Diego HA)	77	1.0%	21%	15%	22	45	4.4E+14	8.6E+14
Chollas Creek HSA	17	0.3%	9%	8%	14	17	1.8E+14	2.2E+14*
San Dieguito River (Solana Beach HA)	19	1.1%	21%	16%	5	11	6.8E+13	1.4E+14
Los Peñasquitos (Miramar HA)	79	0.6%	15%	13%	29	60	2.9E+14	5.8E+14
Tecolote HA	5	0.3%	5%	5%	4	4	6.7E+13*	6.7E+13*
San Luis Rey River (Lower San Luis Rey HA)	110	0.3%	8%	8%	77	109	3.7E+14	5.1E+14*
Orange County Watersheds								
Laguna Hills HSA/ San Joaquin Hills HAS	11	0.3%	7%	7%	9	11	2.5.E+13	3.0E+13*
Aliso Creek HSA	22	1.6%	6%	7%	16	22	1.3.E+14	1.8E+14*
Dana Point HSA	2	5.6%	16%	13%	2	2	2.0.E+13*	2.0E+13*
Lower San Juan HSA	64	0.6%	18%	15%	53	64	2.6.E+13	3.1E+13*
San Clemente HA	7	0.6%	13%	12%	7	7	4.4.E+13*	4.2E+13*

* The feasible FIB reduction rates are below the target rates in these watersheds. Feasible FIB reduction rates: Tecolote HA (9%), Chollas HSA (14%), Lower San Luis Rey HA (%16), Laguna/San Joaquin (14%), Aliso Creek (15%), Dana Point (8%), San Juan (13%), San Clemente (10%).

† These rates of retention and infiltration represent the unit "model" rates for the in-stream and off-line wetland and not the rate for the total feasible number of sites. These unit "model" rates apply to both the 10% and 20% analysis.

The reductions represent either the 10 or 20% targeted reduction or up to the feasible reduction of the baseline enterococcus loads. The baseline load is determined using the mean wet weather concentrations and total average annual wet weather flow over the years 2010-2016 from the modeled flow and enterococcus concentrations used in the WQIPs.

11 Conclusion

The analysis presented in this report assessed two scenarios (Scenario 1 and Scenario 2) for the restoration approach to achieve reductions in FIB loading to the streams and rivers in the watersheds under the Bacteria TMDL. The two scenarios provided “book ends” for the cost benefit analysis under the restoration approach. The results of the bacteria load reduction analysis for the two scenarios of the restoration approach indicated that in-stream stream restoration under Scenario 1 achieves FIB reduction rates of 0.2% to 1.6% which reflect the number of feasible stream restoration opportunities and the hydraulic characteristics of the watershed. Scenario 1 does not achieve the FIB load reduction targets in the WQIPs and therefore does not provide a complete compliance solution. Steam restoration may be part of an overall watershed management strategy which are defined in the WQIPs.

The bacteria load reduction rates are based on the infiltration that occurs in the expanded channel bottom and slope. The higher infiltration rates for in-stream restoration scenarios were achieved in watersheds that have less urbanization and generally flatter and longer storm hydrographs that allows for longer periods of flow and infiltration over the expanded creek channel. Infiltration rates also depend on favorable hydrogeological conditions. A general assumption of favorable conditions was assumed.

The most favorable sites for this restoration approach are public parcels that extend on both sides of the channel along tributaries of the main stems that have smaller drainage areas, and that are not heavily urbanized since these attributes allow for longer flow durations that promote greater infiltration. Stream segments that are verified through geotechnical investigations to be predominantly losing streams (groundwater table is not above or at the channel depth) will also be favorable for this approach. This condition may also vary seasonally as the wet weather season may change a stream to a losing to a gaining stream that is not favorable for infiltration.

The constraint of available stream segments of sufficient length within public parcels may limit the implementation of stream restoration projects in more urbanized watersheds (e.g. Tecolote) and larger watersheds (e.g. San Luis Rey) that have limited public parcels in the lower watershed where the water quality benefit is the greatest. For the more urbanize watersheds, stream segments with concrete sidewalls were included along with segments that were within a designated maintenance easement but not identifies as public property.

Reduction of FIB within the in-stream channel from retention was not included based on the literature review and the analysis of the increased retention time achieved by stream restoration. This analysis indicated a minimal increase, in the order of several minutes compared to wetland type systems that require 24-72 hours of retention time to achieve measurable reductions in FIB.

Total Costs for Scenario 1 ranged from $6-$275M per watershed that reflect the range in the number of feasible sites. The cost per acre of watershed that drains to the restoration projects varied from $1,700 to $4,700/acre. The higher cost per acre was generally associated with more urbanized watersheds. The variability of conceptual costs for Scenario 1 between watersheds is due to the number of feasible stream segments where these projects can be implemented and the watershed characteristics that affect the "model" project with regard to the amount of excavation and grading required to achieve a stable channel cross section. The required dimensions for the available expanded channel cross section are controlled by the drainage area and existing channel characteristics. These will vary between watersheds and within a watershed. The "model" projects were based on actual feasible sites to provide a more representative model for each watershed. This analysis is a high level planning evaluation that does not account for variability within a watershed that would require a site specific analysis of each feasible restoration site.

The cost of the implementation of stream restoration projects needs to also consider the multi-benefits that are achieved from these projects that include improving the benthic macro-invertebrate habitat and subsequently the potential for enhanced fish habitat. These projects often include recreational benefits to the community in new trails and educational opportunities. These additional benefits need to be considered in the overall cost-benefit analysis. These benefits are less easily quantifiable, and are not assessed in this report. Additional co-benefits include reductions of other constituents that include nutrients, sediment, metals and pesticides in storm flows. Load reductions for these other constituents are achieved at similar rates for Scenario 1 through infiltration that is assumed to have 100% removal efficient.

Pollutant removal would also be expected to increase measurably in dry weather flows under restored stream conditions. These conditions include increased residence time from an expanded stream cross section, improved plant structure, and improved pollutant adsorption from improved vegetation and sediment characteristics. Removal rates of nutrients could be expected to increase to 50-70% in dry weather flows where the established vegetation, sediment type and residence time are favorable.

The assessment of the other book end under Scenario 2 included both the implementation of the in-stream restoration and also off-line riparian wetlands restoration. The addition of off-line wetland restoration for this scenario was developed to increase the bacteria reduction rates through wetland type mechanisms to achieve the enterococcus load reduction targets of the WQIPs. These mechanisms include natural inactivation, predation, filtration, infiltration, sedimentation, sorption and chemical inactivation. These mechanisms require retention times of 1-2 days to achieve rates greater than 40 percent removal.

This off-line riparian habitat restoration includes an off-line wetland system that receives controlled flows from smaller tributaries. These systems have the characteristics of natural canyon alluvial fan systems that existed in many watersheds prior to extensive urbanization. To increase FIB removal, these off-line systems were assumed to have both inlet and outlet controls to maintain low flows and longer retention times. These systems would then by-pass larger flows that would not be subject to the same pollutant reduction mechanisms. The size of the off-line tributary wetland system varies based on the evaluation of the feasible public parcel sites and the characteristics of the watershed.

Several watersheds had limitations on the availability of feasible wetland sites and associated drainage area due to greater urbanization and/or available public lands. The results of the analysis of Scenario 2 indicated three of the eleven watersheds under the Bacteria TMDL did not attain the enterococcus load reduction targets in the WQIPs using 50% removal efficiency for wetland retention mechanism.

To further assess the sensitivity of the number of available feasible off-line wetland sites, an analysis was conducted to assess achieving 10% and 20% FIB load reduction for all the watersheds. The results of this analysis indicated the same smaller urbanized watersheds (Tecolote Creek HA and Chollas Creek HSA) that did not attain the WQIP enterococcus reduction target do not meet the 10% and 20% reduction goals. For the 10% overall reduction, three of the eleven watersheds do not attain this target. The number of watersheds that are not able to achieve the 20% reduction target increases from 3 to 8 of the eleven watersheds.

The rates of removal efficiencies vary based on flow through the wetland controlled by inlet and outlet structures. An analysis of literature values and actual reported efficiencies for natural treatment systems implemented in Orange County indicate a wide range of efficiencies. Removal efficiencies of 40%, 50%, 60%, and 70% for the retention mechanism in the off-line wetlands under Scenario 2 were analyzed to assess the sensitivity of this parameter with regard to achieving the WQIP load reduction targets in each watershed, the number of projects needed and total costs. The results of this sensitivity analysis indicated the number of watersheds that did not meet the reduction targets remained at three. The increase in removal efficiencies reduces the number of sites needed and totals costs. The difference in total costs from 40 to 70% reduction efficiencies were within the level of contingency of 25% used for the overall cost estimates.

The costs to achieve the enterococcus FIB load reduction targets per the WQIPS under Scenario 2 range from $3-545M and $2,200 to $6,500/acre of drainage area for just the off-line wetland projects using 50% retention efficiency. This significant range in costs for off-line wetlands restoration projects is due to the range in feasible sites needed to attain these levels of reduction and the characteristic of the watershed. The range in total costs also reflects watersheds that do not reach these targets as noted (a low total cost may reflect a limited number of feasible sites).

Scenario 2 includes the implementation of the in-stream projects which will further increase these estimated costs. Due to the lower rates for FIB reduction achieved by the in-stream restoration projects, these additional costs may be reduced to achieved comparable load reduction by emphasizing off-line approaches where feasible. In addition, cost saving may occur if these are implemented as integrated restoration projects. Additionally, co-benefits for the implementation of restoration approaches include reductions of other constituents that include nutrients, sediment, metals and pesticides in storm flows.

As the sensitivity of the rates of reduction achieve by the off-line wetlands restoration depends greatly on the number of sites implemented, the issue of the feasibility of these sites warrant further assessment. Most of the public sites that were assessed are also identified as protected habitat areas. To address this issue in this high level assessment, the estimated costs include costs for likely habitat mitigation and more extensive environmental assessment and permitting. Implementing these projects in protected areas would need to consider restricted construction schedule to address bird nesting season restrictions and other requirements for these protected areas. These projects would likely need to be implemented in phases to address potential impacts to sensitive species.

Operations and maintenance of these facilities will also have similar challenges in addressing potential temporary impacts and restrictions on when these activities are allowed. The cost estimates include a 20 percent of total cost operations and maintenance estimate.

Comments on the draft report received from the Steering Committee (SC) and the Technical Advisory Committee (TAC) on the draft report are incorporated into this final report. Responses to comments are discussed in Appendix F.

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Appendix E, Maps of Impaired Watersheds, Revised Total Maximum Daily Loads for Indicator Bacteria, Project I – Twenty Beaches and Creeks in the San Diego Region (Including Tecolote Creek), San Diego Regional Water Quality Control Board, updated July 25, 2010.

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Technical Report, Revised Total Maximum Daily Loads for Indicator Bacteria, Project I – Twenty Beaches and Creeks in the San Diego Region (Including Tecolote Creek) Appendix E, Maps of Impaired Watersheds, San Diego Regional Water Quality Control Board, updated July 25, 2010.

Appendix A
Literature Review

APPENDIX A
LITERATURE REVIEW

Introduction

Contamination of recreational waters by sewage or runoff containing pathogenic organisms such as bacteria or viruses can lead to increased swimmer illness (e.g., Given et al. 2006). San Diego County has determined that a holistic approach to reducing pathogen loads to coastal waters requires the compilation, analysis and interpretation or existing data sets and reports on the relative effectiveness of various best management practices (BMPs) for reducing Fecal Indicator Bacteria (FIB) concentrations and loads to receiving waters. Proposed and potential bacteria load reductions would then be one of the inputs to a risk-based modeling of human health risk based on epidemiology studies. Reductions of health risk would then be compared to BMP costs to develop cost-benefit analysis outcomes for issues associated with FIB. This section of the report focuses on one of the BMP types suggested for cost-benefit analysis, the restoration of wetlands in the watershed and flood plains of various creeks in San Diego County.

Summary of Literature

The use of natural or constructed wetlands has been previously suggested as a valuable strategy to reduce pathogen loads to receiving waters, including loads of FIB (e.g., Dorsey et al. 2010). As an example, a report conducted for the Texas Commission on Environmental Quality (TCEQ) found that natural and/or constructed wetlands reduced FIB concentrations (outflows compared to inflows) by an average of 88 percent (Rifai 2006). The summary report for TCEQ compiled results from 32 studies, and found that 29 of them (91 percent) showed evidence of reductions in concentrations of FIB, when comparing outflows to inflows.

In 2010, the Water Environment Research Federation (WERF) summarized results from over 140 reports that dealt with the ability of various BMP techniques to reduce FIB concentrations. The 140 reports were those that comprised the International Stormwater BMP database, which is compiled and maintained by WERF. Although not all of the 140 reports were used for further analysis, there was enough data to compare different BMP treatment options as far as their ability to reduce concentrations of fecal coliform bacteria. Grassy swales and dry retention systems were reduced concentrations of fecal coliform bacteria (comparing inflows to outflow) in 67 and 73 percent of studies, respectively (WERF 2010). Wet ponds were found to reduce concentrations of fecal coliform bacteria in all studies examined. However, the authors found that the reduction in the concentrations of fecal coliform bacteria was greater in wet ponds than in the typical grassy swale or dry retention basin.

In addition to the summary reports by Rifai (2006) and WERF (2010) a number of other studies have been conducted that examined the ability of natural and/or artificial wetlands to reduce the quantities of FIB. These include results from studies in California (Knox et al. 2007), California and Pennsylvania (Bastian and Hammer 1993), Ohio (Uldrich et al. 2004) and Alabama (Hammer et al. 1993). Outside the

US, researchers have examined the ability of wetland systems to reduce FIB concentrations in studies conducted in Canada (Bastian and Hammer 1993), Czechoslovakia (Vymazal, 1993) and Spain (Reinoso et al. 2008).

The results of a review of relevant scientific literature are shown in Table 1 – which summarizes findings related to reductions in the concentrations of various FIB. Based on a review of references, it appears that the studies whose results are summarized in Table 1 do not include reports that were previously included in the datasets compiled by Rifai (2006) or WERF (2010).

Table 1 - Summary of findings of studies on reductions in removal of FIB by various wetland treatment systems.

Constituent	Removal efficiency	Type of system	Location	Comments	Reference
Total coliform bacteria	99.8	Bulrush wetland	Santee, California	WWTP effluent - winter	Bastian and Hammer (1993)
Total coliform bacteria	99.6	Bulrush wetland	Santee, California	WWTP effluent - summer	Bastian and Hammer (1993)
Fecal coliform bacteria	79.1	Bulrush wetland	Arcata, California	WWTP effluent - winter	Bastian and Hammer (1993)
Fecal coliform bacteria	95.6	Bulrush wetland	Arcata, California	WWTP effluent - summer	Bastian and Hammer (1993)
Fecal coliform bacteria	99.6	Cattails and grassses	Iselin, Pennsylvania	WWTP effluent - winter	Bastian and Hammer (1993)
Fecal coliform bacteria	99.9	Cattails and grassses	Iselin, Pennsylvania	WWTP effluent - summer	Bastian and Hammer (1993)
Fecal coliform bacteria	99.7	Cattails	Listowell, Ontario	WWTP effluent - winter	Bastian and Hammer (1993)
Fecal coliform bacteria	99.8	Cattails	Listowell, Ontario	WWTP effluent - summer	Bastian and Hammer (1993)
Total coliform bacteria	99.9	Reed (Phragmites) bed	Prague, Czechoslovakia	WWTP effluent	Vymazal (1993)
Fecal coliform bacteria	99.9	Reed (Phragmites) bed	Prague, Czechoslovakia	WWTP effluent	Vymazal (1993)
Enterobacteria	99.9	Reed (Phragmites) bed	Prague, Czechoslovakia	WWTP effluent	Vymazal (1993)
Fecal coliform bacteria	99.4	Various emergent vegetation	Dekalb County, Alabama	Effluent from swine farms	Hammer et al. (1993)
Fecal streptococci bacteria	98.4	Various emergent vegetation	Dekalb County, Alabama	Effluent from swine farms	Hammer et al. (1993)
Total coliform bacteria	84.8	Pond	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
Total coliform bacteria	36.1	Surface flow wetland	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
Total coliform bacteria	69.3	Sub-surface flow wetland	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
Fecal streptococci bacteria	89.6	Pond	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
Fecal streptococci bacteria	62.0	Surface flow wetland	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
Fecal streptococci bacteria	54.7	Sub-surface flow wetland	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
E. coli bacteria	96.8	Pond	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
E. coli bacteria	37.6	Surface flow wetland	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
E. coli bacteria	74.0	Sub-surface flow wetland	Cubillas de los Oteros, Spain	WWTP effluent	Reinoso et al. (2008)
Total coliform bacteria	91.0	Wetland 1	Columbus, Ohio	Ambient from river - October 2000	Uldrich et al. (2004)
Total coliform bacteria	45.0	Wetland 1	Columbus, Ohio	Ambient from river - March 2001	Uldrich et al. (2004)
Total coliform bacteria	89.0	Wetland 1	Columbus, Ohio	Ambient from River - April 2001	Uldrich et al. (2004)
Total coliform bacteria	89.0	Wetland 1	Columbus, Ohio	Ambient from River - May 2001	Uldrich et al. (2004)
Total coliform bacteria	90.0	Wetland 1	Columbus, Ohio	Ambient from River - June 2001	Uldrich et al. (2004)
Total coliform bacteria	73.0	Wetland 2	Columbus, Ohio	Ambient from river - October 2000	Uldrich et al. (2004)
Total coliform bacteria	61.0	Wetland 2	Columbus, Ohio	Ambient from river - March 2001	Uldrich et al. (2004)
Total coliform bacteria	47.0	Wetland 2	Columbus, Ohio	Ambient from River - April 2001	Uldrich et al. (2004)
Total coliform bacteria	86.0	Wetland 2	Columbus, Ohio	Ambient from River - May 2001	Uldrich et al. (2004)
Total coliform bacteria	94.0	Wetland 2	Columbus, Ohio	Ambient from River - June 2001	Uldrich et al. (2004)
E. coli bacteria	73.0	Wetland	Yuba County, California	Runoff from pastureland	Kate et al. (2007)

Table 1 includes multiple results from single reports if multiple data sets were collected during discrete sampling events. For example, Bastian and Hammer (1993) and Uldrich et al. (2004) specifically tested removal efficiencies at different times of the year, and so each season's performance is entered separately. Uldrich et al. (2004) not only tested removal efficiencies at different times of the year, they also tested two separate wetland systems. The work done by Reinoso et al. (2008) listed results from both three stormwater BMP types (ponds, surface flow wetlands and sub-surface flow wetlands) and three pathogen indicators (total coliform bacteria, fecal streptococci bacteria and E. coli bacteria) with the results from all nine treatment type – pathogen combinations listed separately.

Twenty of the results shown in Table 1 come from studies conducted using partially treated sewage as the inflows for studies, while two came from discharges from a swine farm. Ten of the studies were conducted by passing water from a river (with elevated abundance of FIB) through various wetland configurations (Uldrich et al. 2004) while one of them was conducted by directing runoff from pastureland in northern California into a treatment wetland (Knox et al. 2007). Of all the studies shown in Table 1, only one of them included measurements of flow (Knox et al. 2007). The results of studies summarized in Rifai (2006) and WERF (2010) are only shown as changes in concentrations of FIB, not loads.

The arithmetic mean of the reductions in concentrations in FIB for all results shown in Table 1 is 82.2, a value very close to the grand mean value of 88 percent found for the 32 studies summarized by Rifai (2006). The report by WERF (2010) summarized the percentage of studies that showed benefits (i.e., reductions in FIB abundance) by various BMP types, but did not calculate average reductions in removal efficiencies.

When broken down into the categories of inflows from sewage or swine farms, the arithmetic mean of the reductions in the concentrations of various FIB was 85.3 percent. For those results using either river inflows or runoff from pastureland, the arithmetic mean of the reductions in the concentrations of various FIB was 76.2 percent. As such, it appears that the results summarized in Table 1 are very similar to the results previously found by Rifai (2006) for all BMP types, and that there does not appear to be a substantial difference in the FIB removal efficiencies of wetland systems when comparing inflows from sewage or swine farm discharges, as opposed to reductions based on inflows from pastureland or ambient water from nearby rivers.

In the report "Water Quality Improvement Plan – Sand Diego River Watershed" (TetraTech 2015) a list of reductions in FIB is given (Table 3E-3) for four locations: Forester Creek, Woodglen Vista Creek, Las Colinas Channel, and Alvarado Channel Restoration. The information included in the report appears to be estimates based on model scenarios, which are dependent upon the validity of numerous assumptions related to growth and "decay" of bacterial populations, rather than actual data. On average, however, it was expected that a variety of implemented stream enhancement and restoration projects would be able to reduce FIB loads by an average of 67 percent.

The importance of loads vs. concentrations

The utilization of constructed wetlands to treat stormwater and wastewater has been proposed for decades, and a significant amount of data exists to quantify their ability to reduce impacts of various pollutants. The reference book "Constructed Wetlands for Water Quality Improvement" edited by Gerald A. Moshiri (1993) includes 68 chapters that summarize results from well over 200 individual assessments of the ability of wetlands to reduce pollutant loads. In terms of the abundance of data, the majority of studies cited in Moshiri (1993) were focused on documentation of reductions in loads of the nutrients nitrogen and phosphorous, along with total suspended solids. Of the 68 studies included in Moshiri (1993) only three of them included results sufficient to quantify removal efficiencies for FIB or other pathogens. Of those three, none of them included detailed information on how removal efficiencies could be affected by loading rates. In contrast, one chapter alone in that reference book (Knight et al. 1993) included information on the removal efficiencies of nitrogen, phosphorous and/or total suspended solids from 84 assessments.

In a more recent review, using data in the International Stormwater Management Best Management Practices (BMP) Database (WERF 2010) over 140 studies were found where the ability of wetlands to reduce FIB or other pathogens was studied. However, this survey of effectiveness of wetlands to reduce FIB only included data on concentrations, not loads. In a similar review of 32 studies on wetlands and FIB reductions, the data were presented in terms of reductions in the concentrations of FIB, without information related to actual loads of FIB.

The much greater data set on wetlands and nutrients includes studies that examined the removal of various forms of nutrients as a function of loading rates. For example, the removal efficiency of nitrate plus nitrite (NOx) via wetland systems can be expressed (Mitsch et al. 2001) as:

$$y=-0.45*\text{Log}(x) + 1.23$$

Where:

Y = expected nutrient removal efficiency for nitrate plus nitrite (NOx),

0.45 = derived value from the empirical relationship,

Log = base 10 log value,

X = area-normalized nitrogen load, in units of grams NOx per square meter per year, and

1.23 = derived value from the empirical relationship.

For the broader category of TN, which includes both inorganic and organic forms of nitrogen, Richardson and Nichols (1985) determined that the removal efficiency of TN via wetland systems can be expressed as:

$$Y =-14.479*\text{LN}(X) + 107.71$$

Where:

Y = expected nutrient removal efficiency for TN,

14.479 = derived value from the empirical relationship,

LN = natural log,

X = area-normalized nitrogen load, in units of grams TN per square meter per year, and

107.71 = derived value from the empirical relationship.

For Total Phosphorous (TP) Richardson and Nichols (1985) determined that the removal efficiency of TP via wetland systems can be expressed as:

$$Y = -15.507*\text{LN}(X) + 87.399$$

Where:

Y = expected nutrient removal efficiency for Total Phosphorous (TP),

-15.507 = derived value from the empirical relationship,

LN = natural log,

X = area-normalized nitrogen load, in units of grams TP per square meter per year, and

87.399 = derived value from the empirical relationship.

For the three constituents listed above (NOx, TN and TP) the equations comparing removal efficiencies to area-normalized loading rates are inverse (negative slope) and exponential (either log or natural log coefficients). These results illustrate that the efficiency of removal of nutrients is greatest under conditions when the load of nutrients per acre of wetland is lowest, and as the load increases, whether due to increased flow, increased concentrations, or a combination of flows and concentrations, the efficiency of pollutant removal decreases in an exponential manner. These results indicate that for FIB, it would likely be true as well that there would be an expected inverse and non-linear relationship between removal rates and loading rates.

In a study conducted in Yuba County, Knox et al. (2007) measured both flows and concentrations of the FIB of *E. coli* above and below a flow-through wetland that received runoff from an irrigated pasture at the Sierra Foothill Research and Extension Center. During the duration of the experiement, cattle were excluded from the wetland itself, and flows across the pasture were controlled through the use of an irrigation system. A wetland at the downstream end of the pasture was modified for the collection of data on both flows and E. coli concentrations at points just above, and just below the wetland itself.

Results from the study are summarized in Table 2.

Table 2 - Summary of findings of studies on reductions in removal of E. coli bacteria in Knox et al. (2007).

Max flow rate into wetland	Total flows		Flow reduction	Reduction in E. coli due to wetland
	Into wetland	Out of wetland		
(cfs / acre)	(cu ft / acre)		(percent)	(percent)
1.38	21,800	19,250	12	33
0.52	14,200	11,900	16	91
1.02	16,300	14,700	10	79
1.22	29,900	26,200	12	64
0.60	17,200	16,350	5	74
1.67	37,800	34,800	8	63
0.47	18,450	17,200	7	81
1.19	19,200	14,700	23	65
0.68	10,450	8,700	17	91
1.47	20,700	16,800	19	69
0.47	8,900	7,400	17	90
Mean	**19,536**	**17,091**	**13**	**73**

The mean reduction in E. coli concentrations shown in Table 2 is 73 percent, similar to the 88 percent average percent reduction for FIB shown by Rifai (2006) or the average of 82 percent for studies summarized in Table 1. On average, FIB reductions via wetland systems might be expected to fall in the range of 70 to 80 percent would be a reasonable expectation.

The results shown in Table 2 can be analyzed to look for patterns between inflow rates and reduction efficiency. For example, Figure 1 illustrates the relationship between the reduction in *E. coli* abundance and the maximum inflow rate, while Figure 2 illustrates the relationship between the reduction in *E. coli* abundance and the reduction in flows into and then out of the wetland system.

Figure 1 – Relationship between reductions in E. coli abundance vs. maximum inflow rate (cfs per acre). Data from Knox et al. (2007).

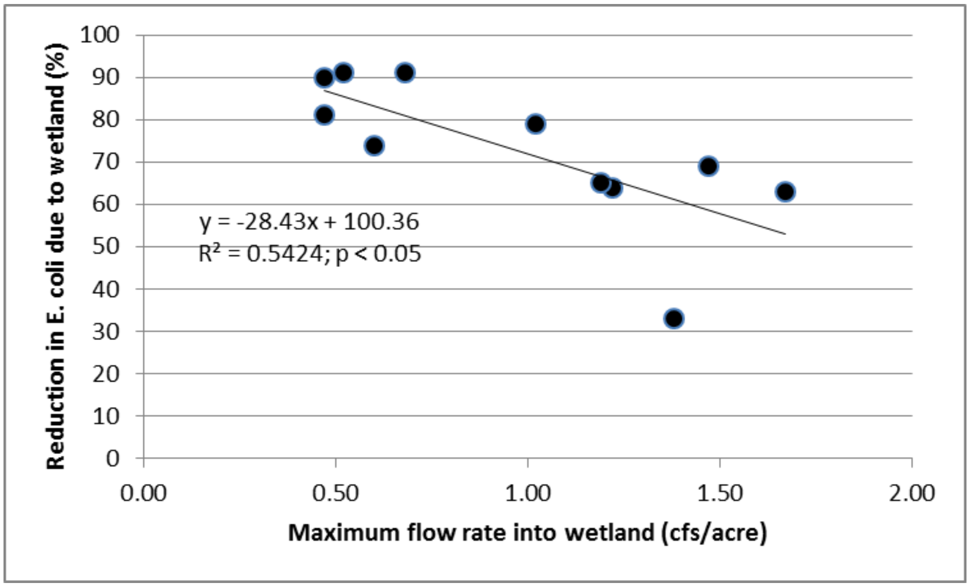
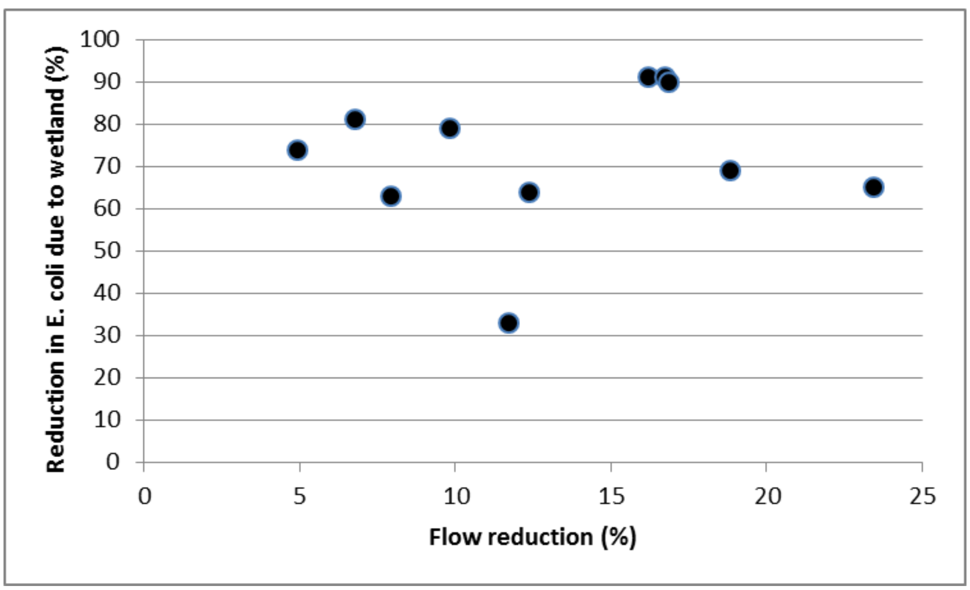


Figure 2 – Relationship between reductions in E. coli abundance vs. percent reduction in volume in the wetland system studied. Data from Knox et al. (2007).



Results shown in Figure 1 show that as in NOx, TN and TP, there appears to be an inverse relationship between area-normalized hydrologic loads and the efficiency of removal of FIB in the wetland system studied by Knox et al. (2007). Roughly speaking, should hydrologic loads equal 1 cfs per acre, then the removal of FIB would be approximately 72 percent. If hydrologic loads were maximized at 0.5 cfs per acre, the expected removal efficiencies would increase to 86 percent. Using these results, a two-fold increase in wetland area would be required to reduce hydrologic loads from 1 cfs per acre down to 0.5

cfs per acre, but the removal efficiency would only increase by 19 percent; the difference between 72 percent efficiency (at 1 cfs per acre) to 86 percent efficiency (at 0.5 cfs per acre).

Table 2 shows that even the lowest FIB removal efficiency shown in Table 2 (33 percent) is higher than the greatest reduction in flow (23 percent) documented. Combined with the data shown in Figure 2, the results indicate that FIB removal processes are not associated with the reduction in flow alone – the removal of FIB occurs at levels in excess of the amount of flow reduction created by the wetland.

Mechanisms of actions for wetlands as a stormwater BMP, and implications for design

As summarized by WERF (2010) the reduction in BIF abundance in wetlands can occur via many different pathways, including:

1) Die-off or inactivation due to a variety of environmental factors, such as exposure to sunlight, water temperature, and exposure to air. Factors that allow for growth of bacterial populations, such as the amount of particulate material present in the water column, can reduce the rate of decline in the population, or actually provide the nutrients and/or organic carbon required for continued population growth.
2) Predation of FIB by other microorganisms protozoa and other eukaryotic (nucleus containing) organisms can reduce bacterial populations.
3) Filtration and/or sedimentation of suspended solids (and reducing the likelihood of future resuspension) can help to reduce the abundance of FIB that are associated with or bound to particulates in the water column.

In a study conducted in the Los Angeles area, it was also found that exposure of sediments to sunlight was a major reason why tidal wetlands appeared to cycle between being net sinks for FIB during daylight hours and net sources at night (Dorsey et al. 2010). However, that study looked at tidal waters entering and leaving a wetland along the perimeter of the wetland, rather than examining the ability of a wetland to treat water introduced into the wetland at a set location.

In his review of the effectiveness of wetlands for water treatment, Moshiri (1993) stresses that wetland processes include more than uptake of nutrients into above-ground biomass. In particular, microbial activities can help to reduce nutrient availability via processes such as denitrification and that the microbial biomass and sediments can be more important sinks for organic matter and nutrients than the more visible plants that comprise the wetland ecosystem. A monitoring and management program that tracks wetland functions via more than percent coverage of plant species alone might be useful to determine that the wetlands are continuing to provide the services expected of them after their creation or protection.

Conclusions

A review of more than 200 studies on FIB removal with wetland systems suggests that removal efficiencies of 70 to 80 percent would not be unexpected. As such, wetlands would likely be able to improve FIB abundance in downstream waters, as long as the flow to those wetlands does not exceed

Richardson, C.J. and D.S. Nichols. 1985. Ecological analysis of wastewater management criteria in wetland ecosystems. Pp. 351-391. In: Ecological considerations in wetlands treatment of municipal wastewaters. Van Nostrand Reinhold Company, NY.

Rifai, H. 2006. Study on the Effectiveness of BMPs to Control Bacteria Loads. Report for Texas Commission on Environmental Quality, Austin, Texas. 20 pp.

Uldrich, E., Phipps, R., Hinds, T., and E. Burns Jr. 2005. Selective reduction of coliforms in constructed wetlands. Summary Report to the Olentangy River Wetland Research Park. 7 pp.

Vymazal, J. 1993. Constructed wetlands for wastewater treatment in Czechoslovakia. Pp. 255-260. In: G. Moshiri (ed.). Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, FL.

TetraTechj. 2015. Water Quality Improvement Plan – San Diego River Watershed. Appendix 3.

WERF. 2010. International Stormwater Best Management Practices (BMP) Database - Pollutant Category Summary: Fecal Indicator Bacteria. Report prepared for Water Environmental Research Federation by Wright Water Engineers, Inc. and Geosyntec Consultant. 35 pp.

their “assimilative capacity” to reduce FIB abundance. The most directly applicable study found suggests that FIB reductions in wetland systems might be expected to exceed 70 percent if their hydrologic load was kept to 1.0 cfs per acre or less. A two-fold increase in acreage – resulting in a hydrologic load of 0.5 cfs per acre would only increase FIB removal rates by 19 percent – at a potential cost (in terms of acreage of wetlands required) of perhaps 30-50 percent.

Based on prior guidance, wetlands used for FIB reduction should include features such as a diversity of plant species, adequate space for exposure of sediments to sunlight, while also reducing the likelihood of sediments being resuspended back into the water column by later flows. As such, controlled inflows and outflows might be required to bring about the features required to optimize FIB reduction efficiencies.

Literature Cited

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Given, S., Pendleton, L.H., Boehm, A.B., 2006. Regional public health cost estimates of contaminated coastal waters: a case study of gastroenteritis at southern California beaches. Environmental Science and Technology 40: 4851-4858.

Hammer, D., Pullin, B., McCaskey, T., Eason, J., and V. Payne. 1993. Treating livestock wastewaters with constructed wetlands. Pp. 343-348. In: G. Moshiri (ed.). Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, FL.

Knox A., Tate, K., Dahlgren, R., and E. Atwill. 2007. Management reduces E. coli in irrigated pasture runoff. California Agriculture 61: 159-165.

Mitsch, W.J., J.W. Day, W. Gilliam, P. Groffman, D. Hey, G. Randall and N. Wang. 2001. Reducing Nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to counter a persistent ecological problem. BioScience. 51: 373-388.

Moshiri, G. 1993. Constructed Wetlands for Water Quality Improvement. Lewis Publishers, Boca Raton, FL.632 pp.

Reinoso, R., Torresa, L., and E. Becaresb. 2008. Efficiency of natural systems for removal of bacteria and pathogenic parasites from wastewater. Science of the Total Environment 395: 80-86.

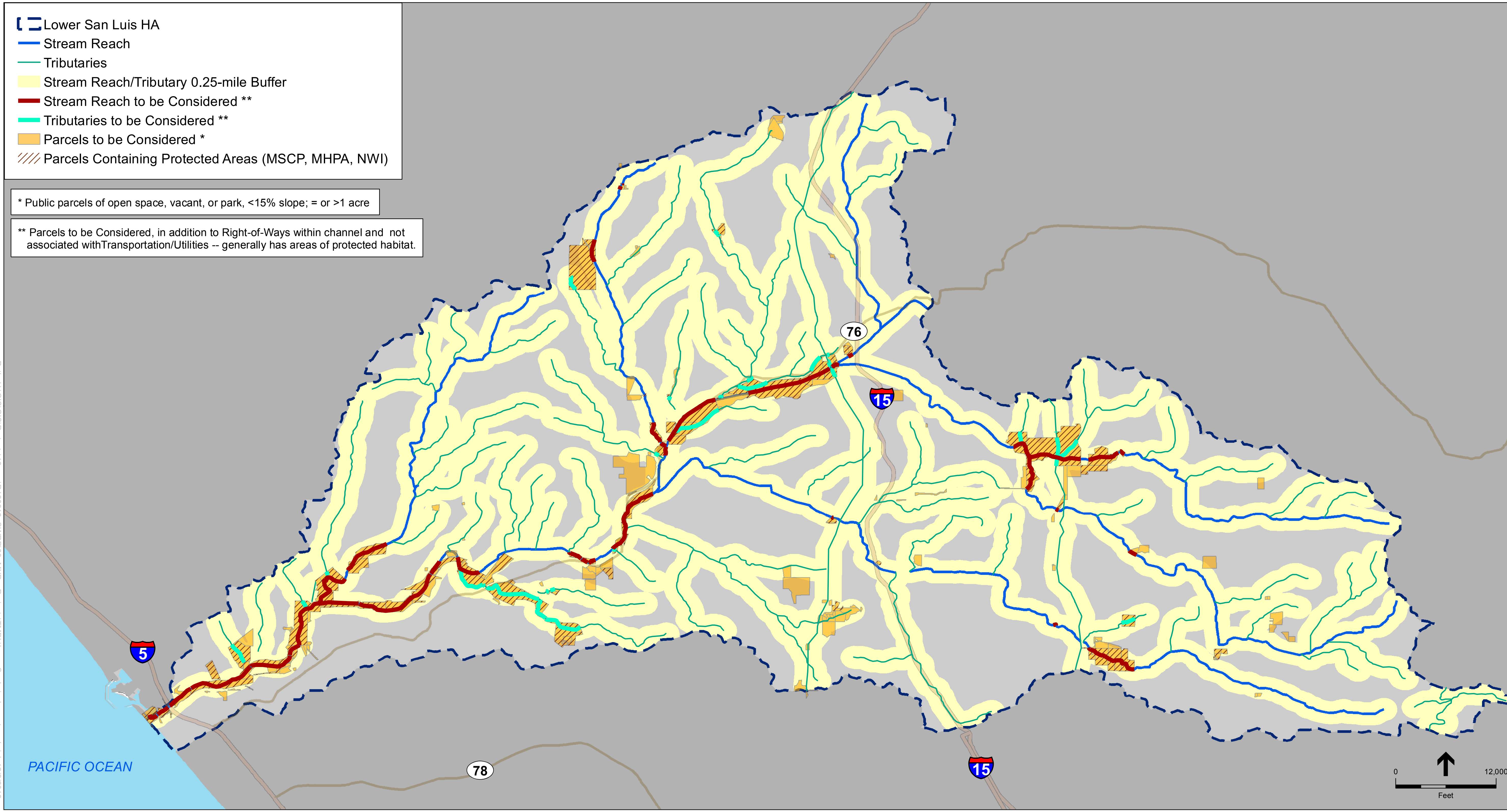
Appendix B
Restoration Type
Feasibility Review Summary

APPENDIX B: Restoration Type Feasibility Review Summary

Restoration Strategy	Restoration Type	Feasibility Review	Carried Forward
"In-Stream"	Channel Restoration – restore channel stability and functions	- Enhances geomorphic and habitat functions and values - Inflow and Outflow difficult to control - Retention time limited - Infiltration can be mechanism for load reduction if losing stream	- This restoration type is carried forward
	Side Channel	- Enhances geomorphic and habitat functions and values - Flow can be controlled during small events but not larger ones. - Channels that resemble bioswales are potentially sources of FIB - Infiltration can be mechanism for load reduction if soil types and groundwater levels are favorable	- Use of these restoration features are common and has benefits - Restoration type carried forward – similar removal mechanism to channel restoration
	Side Channel Alcove	- Straight forward construction, lower cost, may utilize geomorphic features, large flows controlled through bypass. - Maintenance and site access required for sediment removal and may be difficult if wetlands are present - May be a source of FIB in some flow events - Infiltration can be mechanism for load reduction if soil types and groundwater levels are favorable	- Long low gradient side channels with outlet control should be considered further. - Removal enhanced if supports wetland vegetation - Restoration type carried forward – similar removal mechanism to channel restoration
	Wetland Bench	- Easy to site and construct at low cost, can reduce channel and bank erosion and benefit the ecosystem - Resuspension of FIB could occur.	- Not a standalone approach to FIB removal
	Invasive Removal and Replanting with Native Vegetation	- Low impact, easy to site, low cost, benefits ecosystem and does not require additional area. - Resuspension of FIB occurs at varying flowrates, stream shading may protect from natural ultra violet disinfection.	- Not a standalone approach to FIB removal. - All the above restoration types include this element
"Off-line"	Alluvial fan tributary wetlands	- Mimics naturally disconnected tributaries where low flows seeped to main stem via wetlands, moves treatment closer to sources, results in more manageable flow rates, and ecosystem benefits - Would need access for O&M and may act as FIB source	- Merits further investigation as a standalone option for FIB treatment.

Appendix C

Results of GIS Parcel Analysis for Feasible Restoration Site for San Diego and Orange Counties Watershed Management Areas under the Bacteria TMDL



Source: SanGIS; NHD; ESRI; NWI

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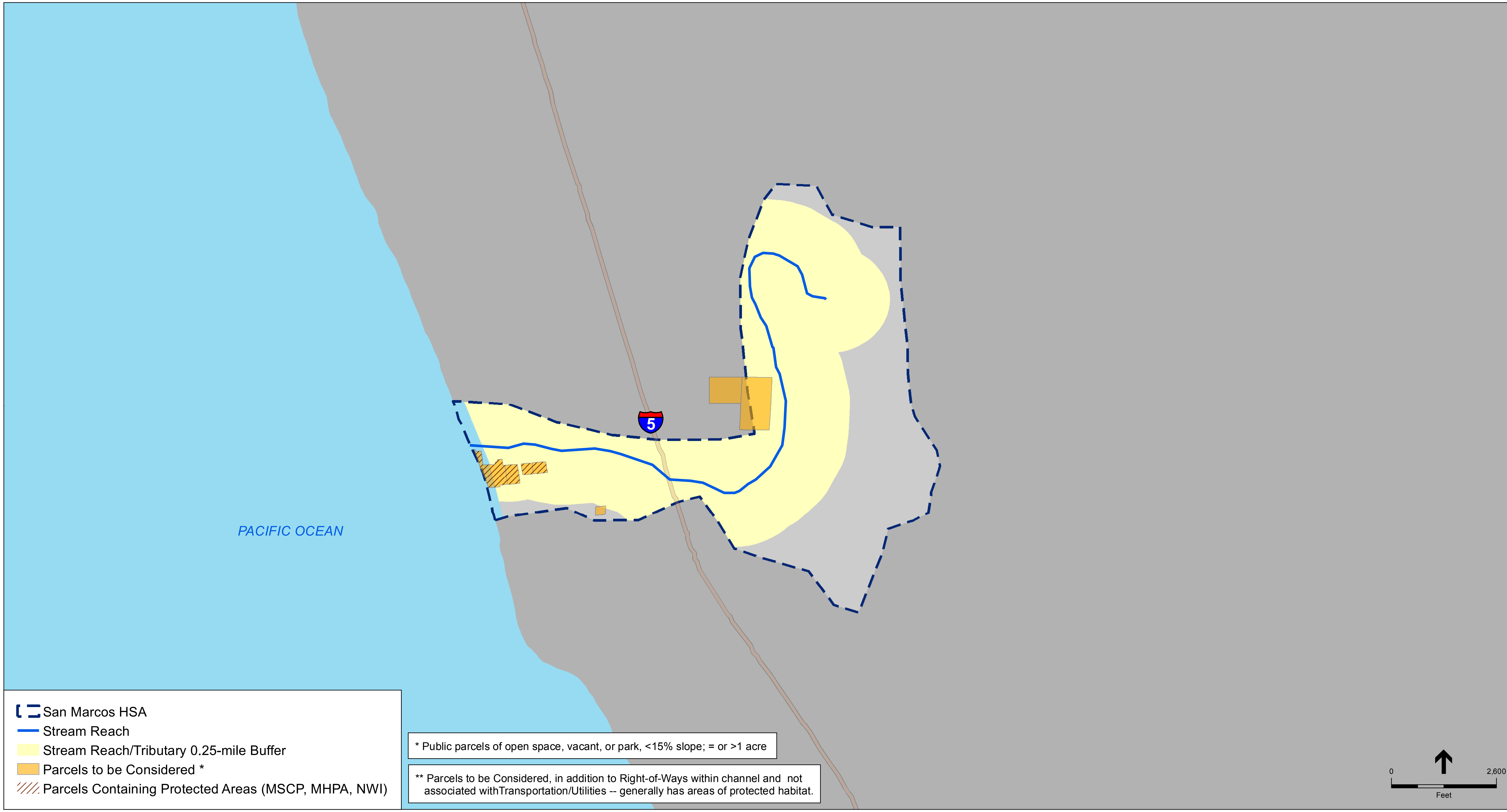
Appendix C-1

San Diego County Watershed Management Areas - Lower San Luis Rey HA



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Source: SanGIS; NHD; ESRI; NWI

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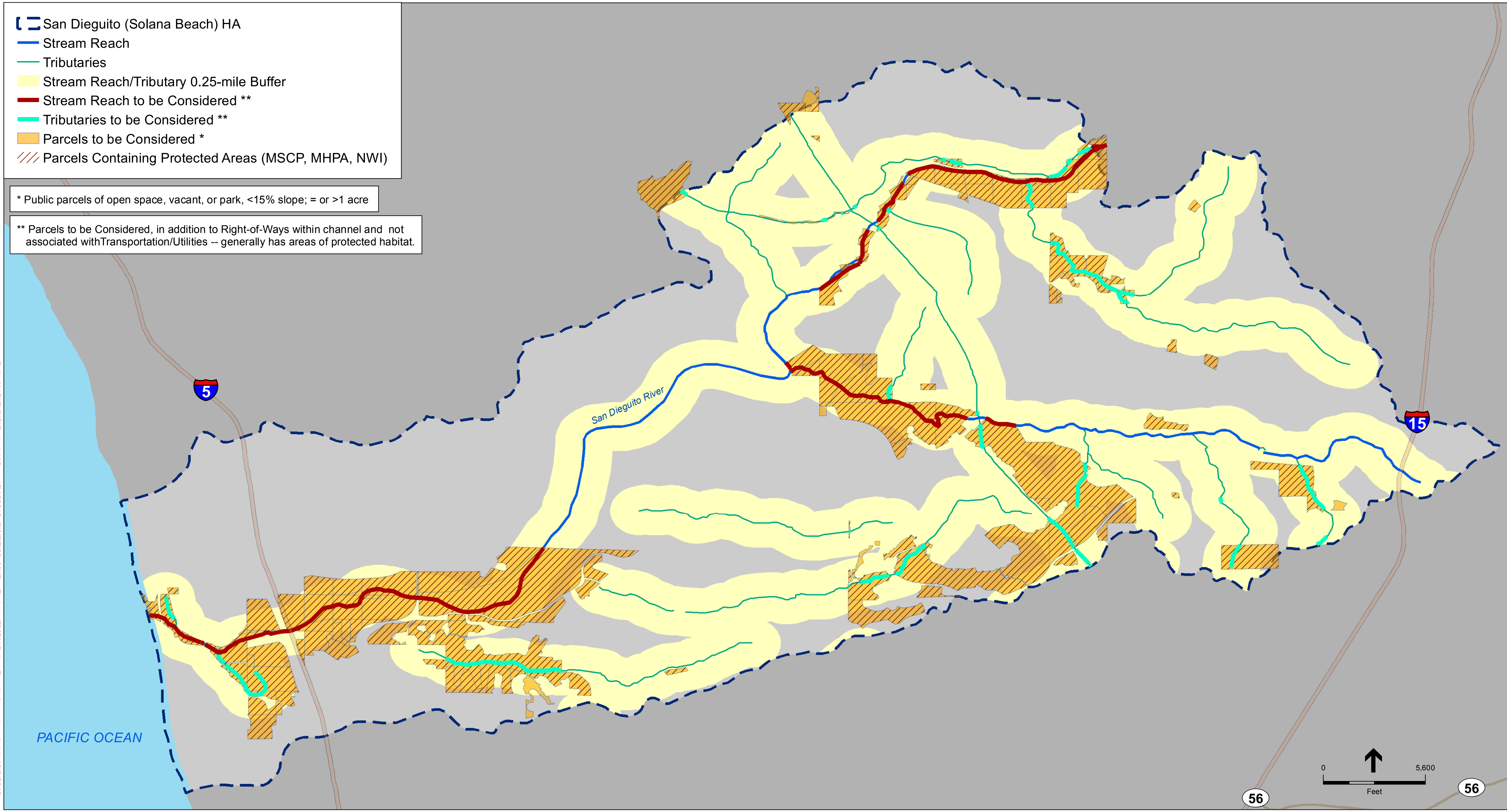
Appendix C-2

San Diego County Watershed Management Areas - San Marcos HSA



Source: SanGIS; NHD; ESRI; NWI

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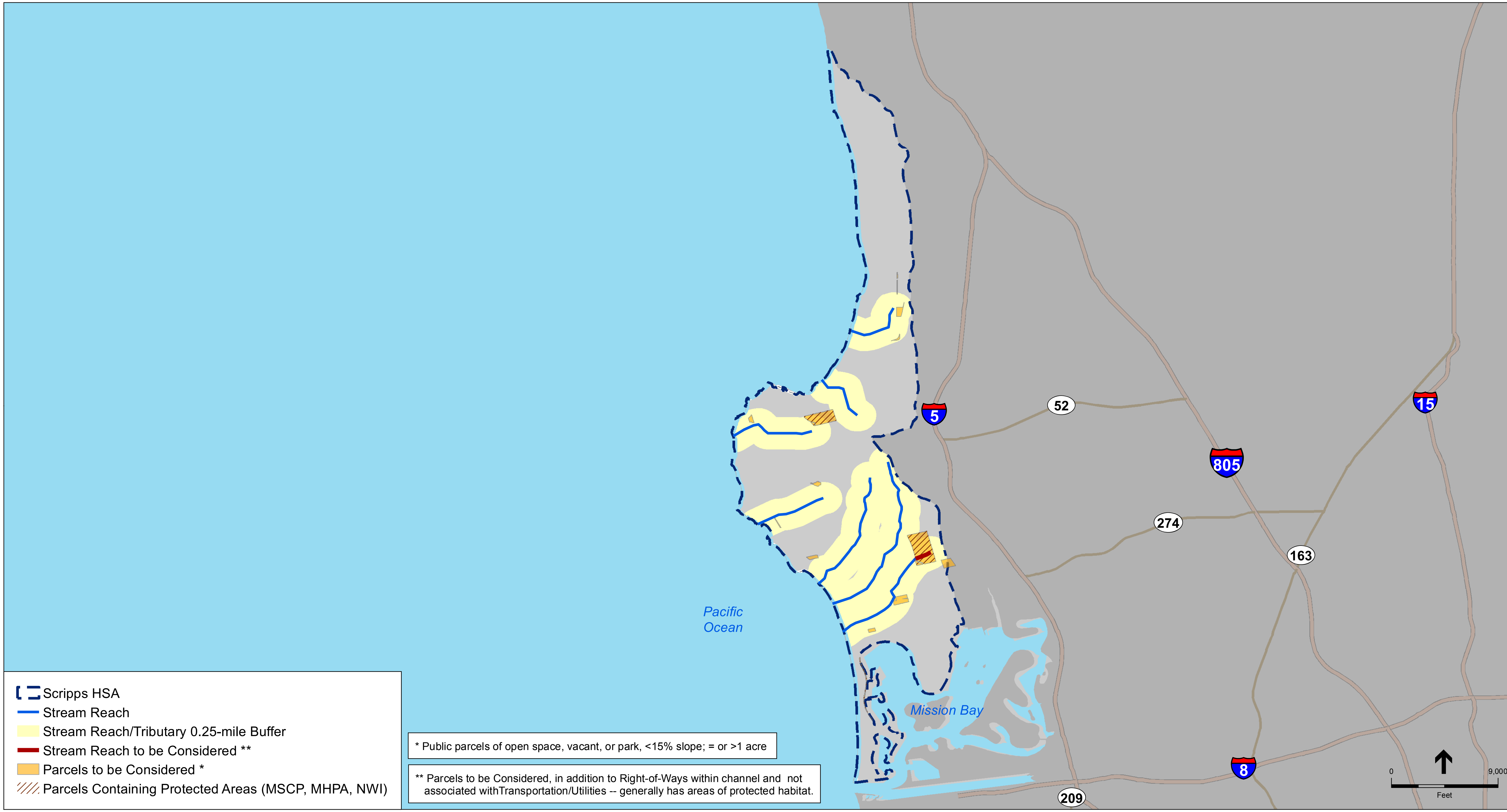
Appendix C-3

San Diego County Watershed Management Areas - San Dieguito (Solana Beach) HA



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Source: SanGIS; NHD; ESRI; NWI

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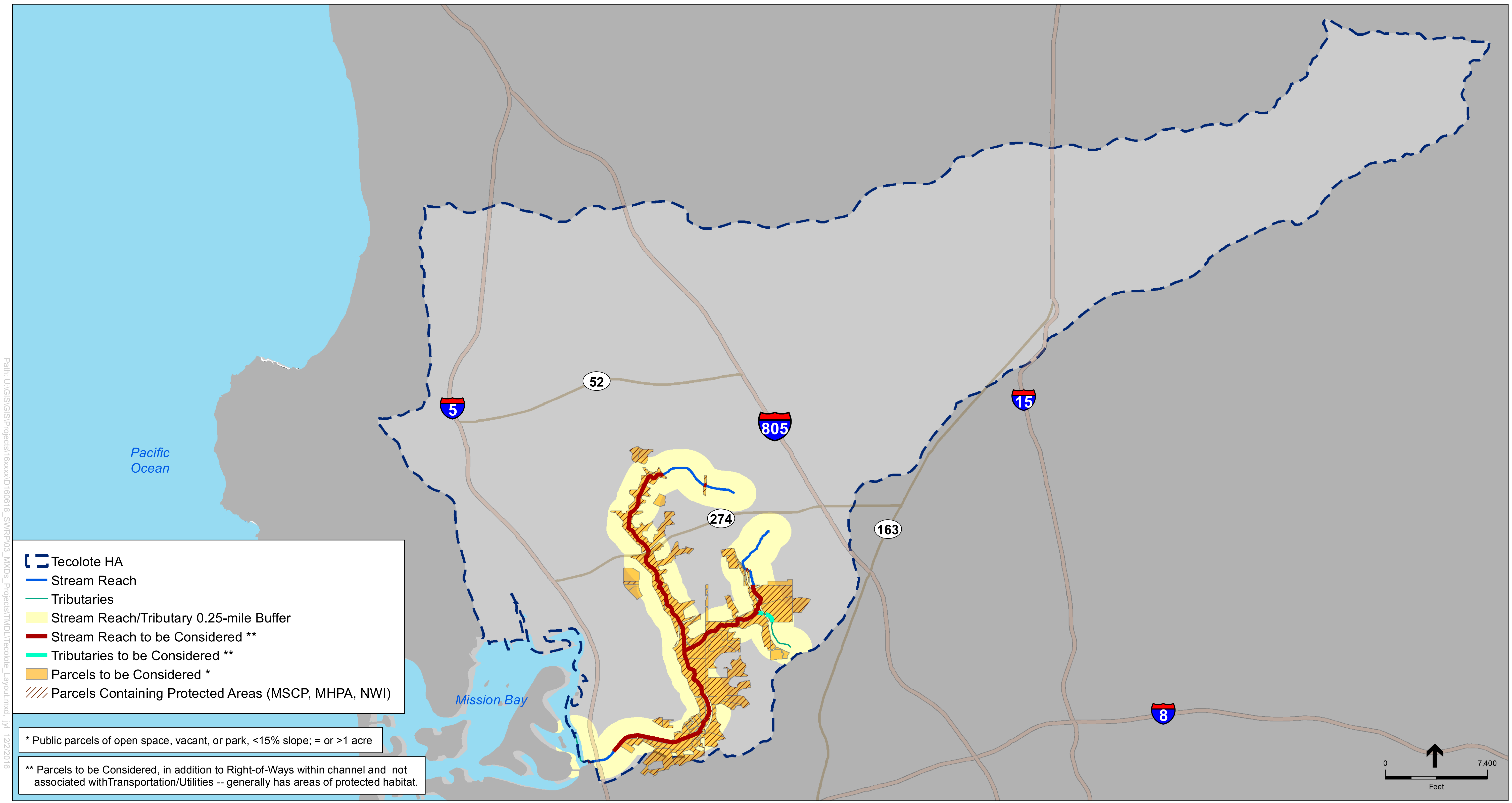
Appendix C-4

San Diego County Watershed Management Areas - Scripps HSA



Source: SanGIS; NHD; ESRI; NWI

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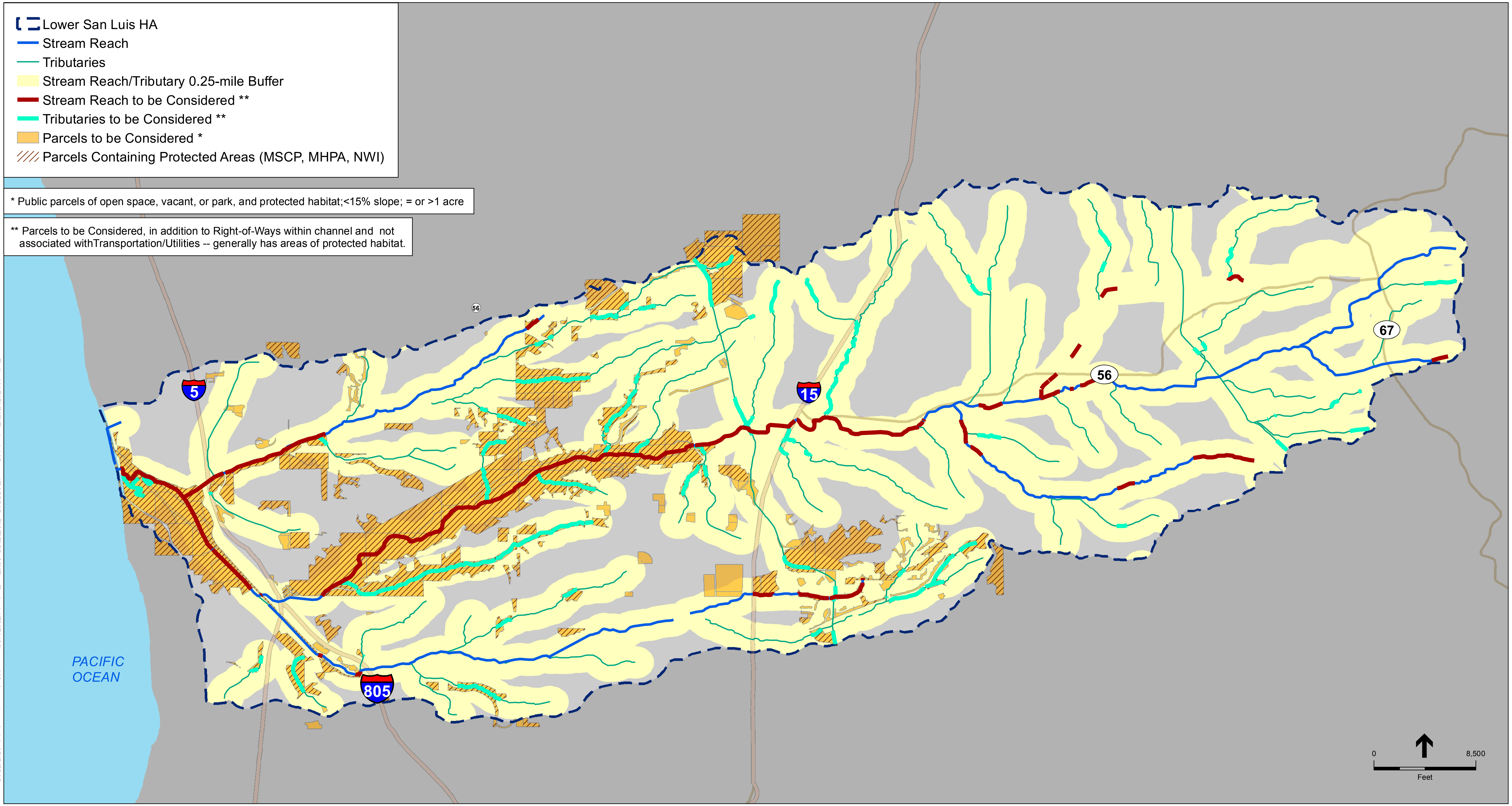
Appendix C-5

San Diego County Watershed Management Areas - Tecolote HA



Source: SanGIS; NHD; ESRI; NWI

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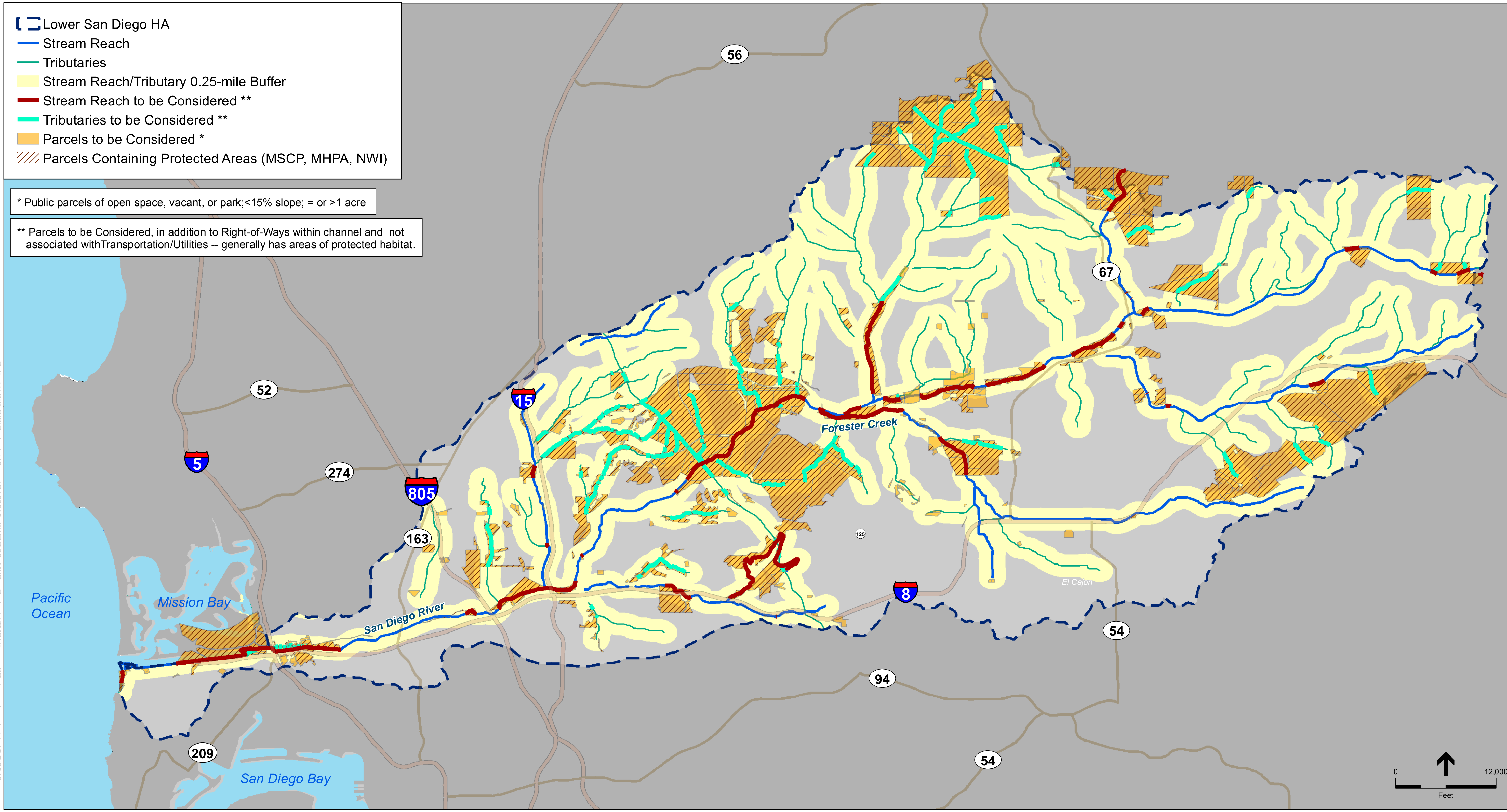
Appendix C-6

San Diego County Watershed Management Areas - Miramar HA



Source: SanGIS; NHD; ESRI; NWI

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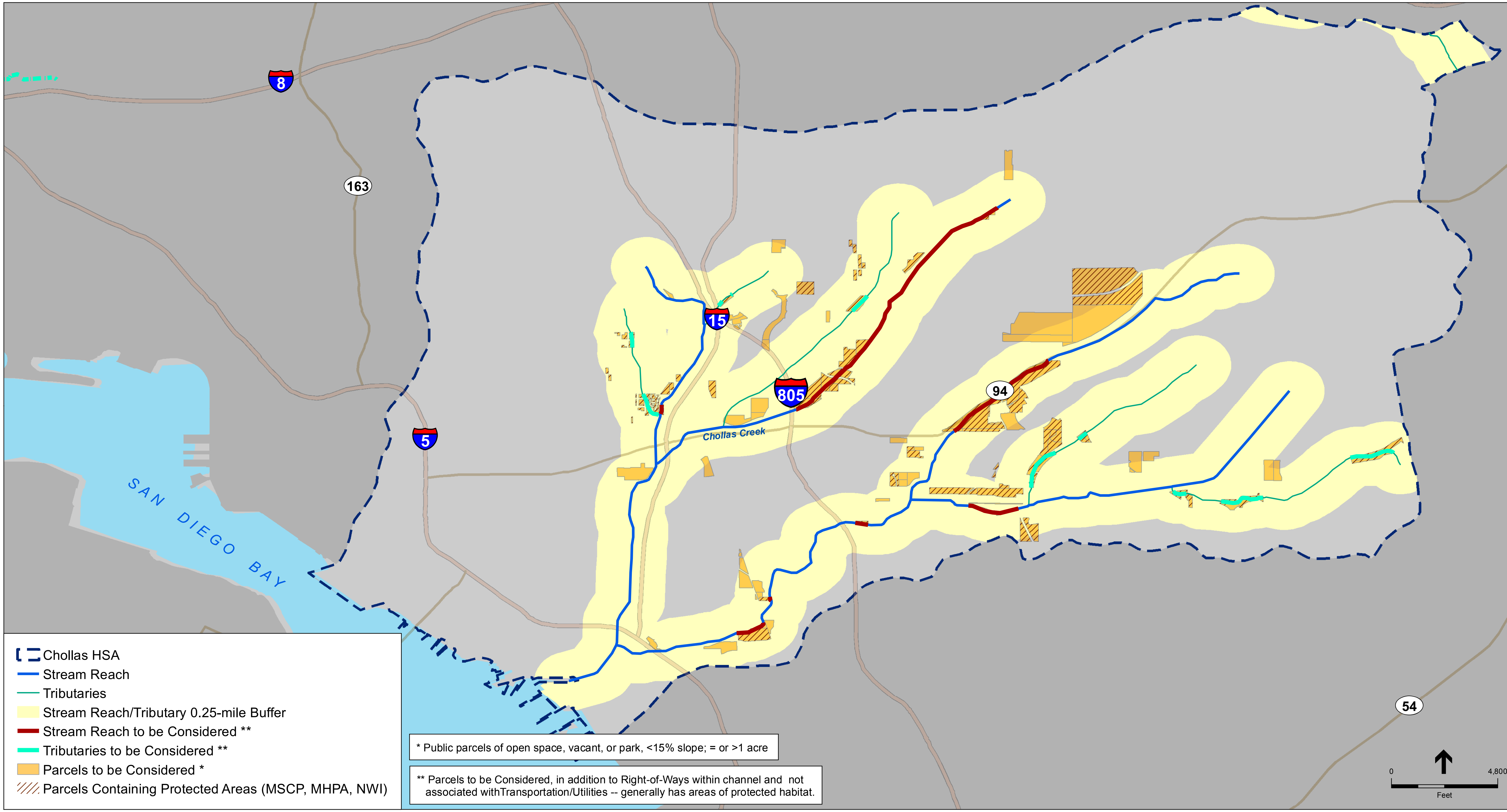
Appendix C-7

San Diego County Watershed Management Areas - Lower San Diego HA



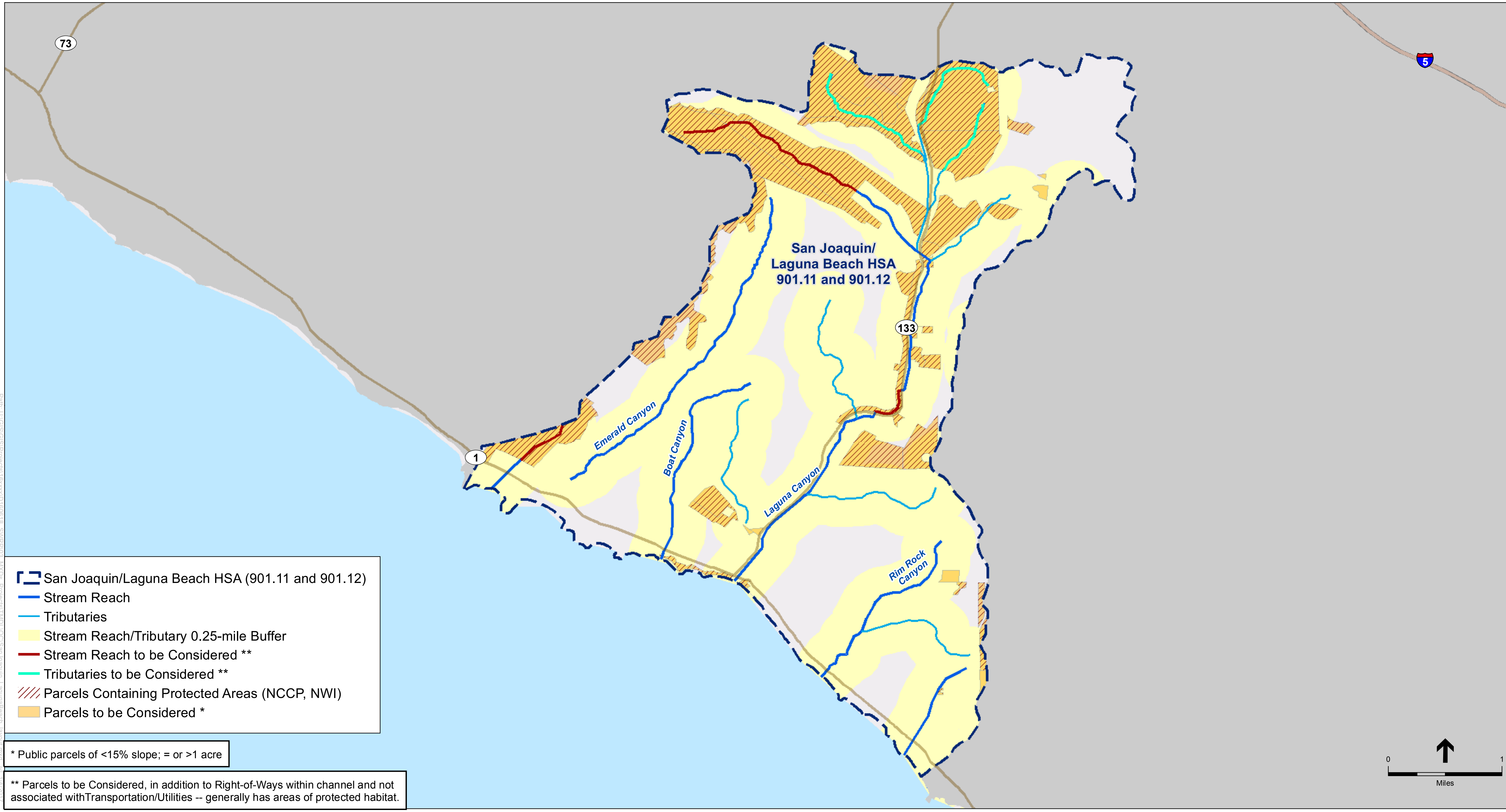
Source: SanGIS; NHD; ESRI; NWI

SWRP . 160618

Appendix C-8

San Diego County Watershed Management Areas - Chollas HSA

Path: U:\GIS\GIS\Projects\16xxxx\D160618_SWRP\03_MXDs_Projects\TMDL\Chollas_Layout.mxd, jyl 12/2/2016

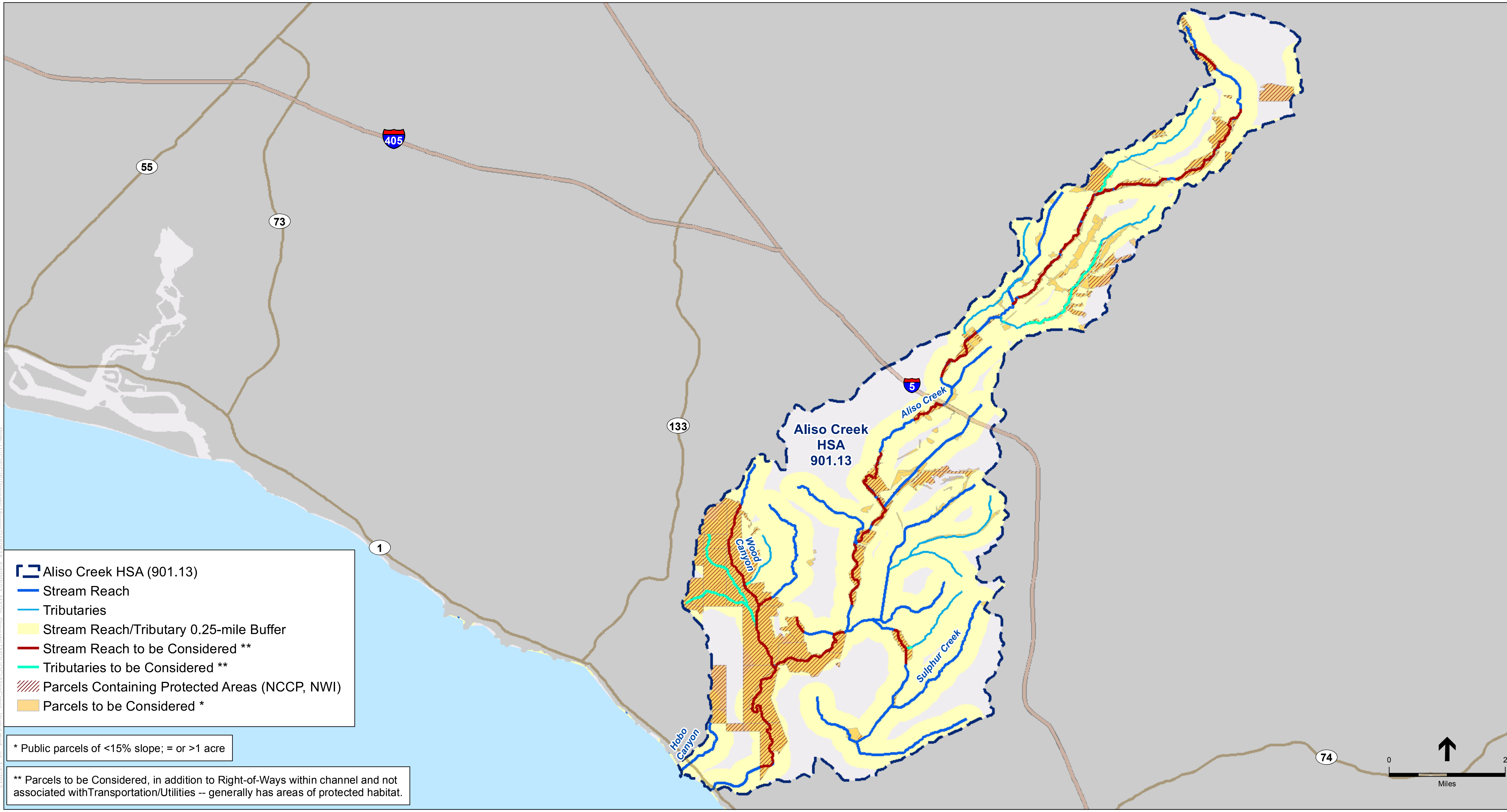


SOURCE: ESRI; State of California; County of Orange; NHD

SWRP. 160618

Appendix C-9

Results of GIS Parcel Analysis for Feasible Restoration Sites - San Joaquin/Laguna Beach HSA

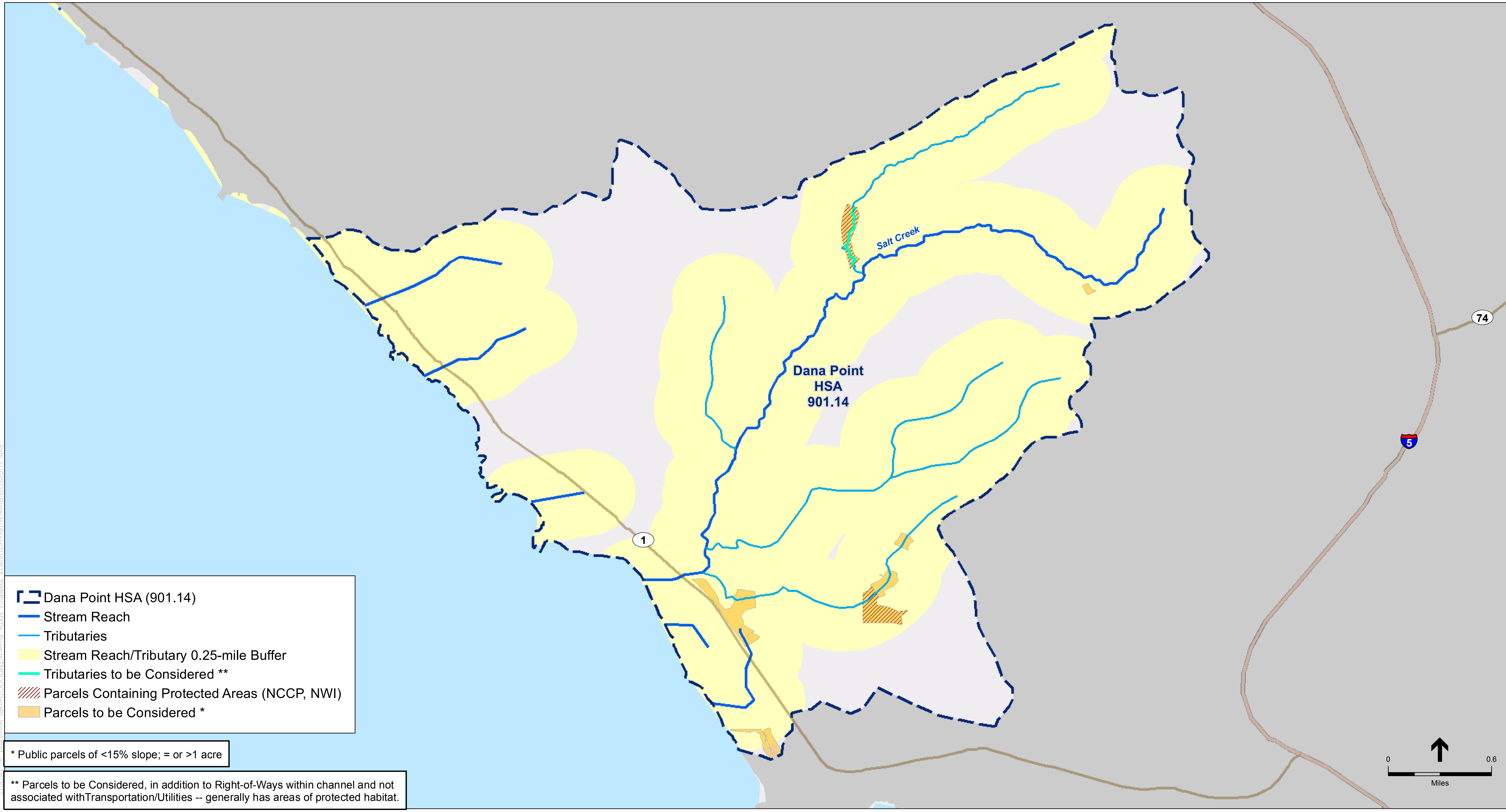


SOURCE: ESRI; State of California; County of Orange; NHD

SWRP.. 160618

Appendix C-10

Results of GIS Parcel Analysis for Feasible Restoration Sites - Aliso Creek HSA

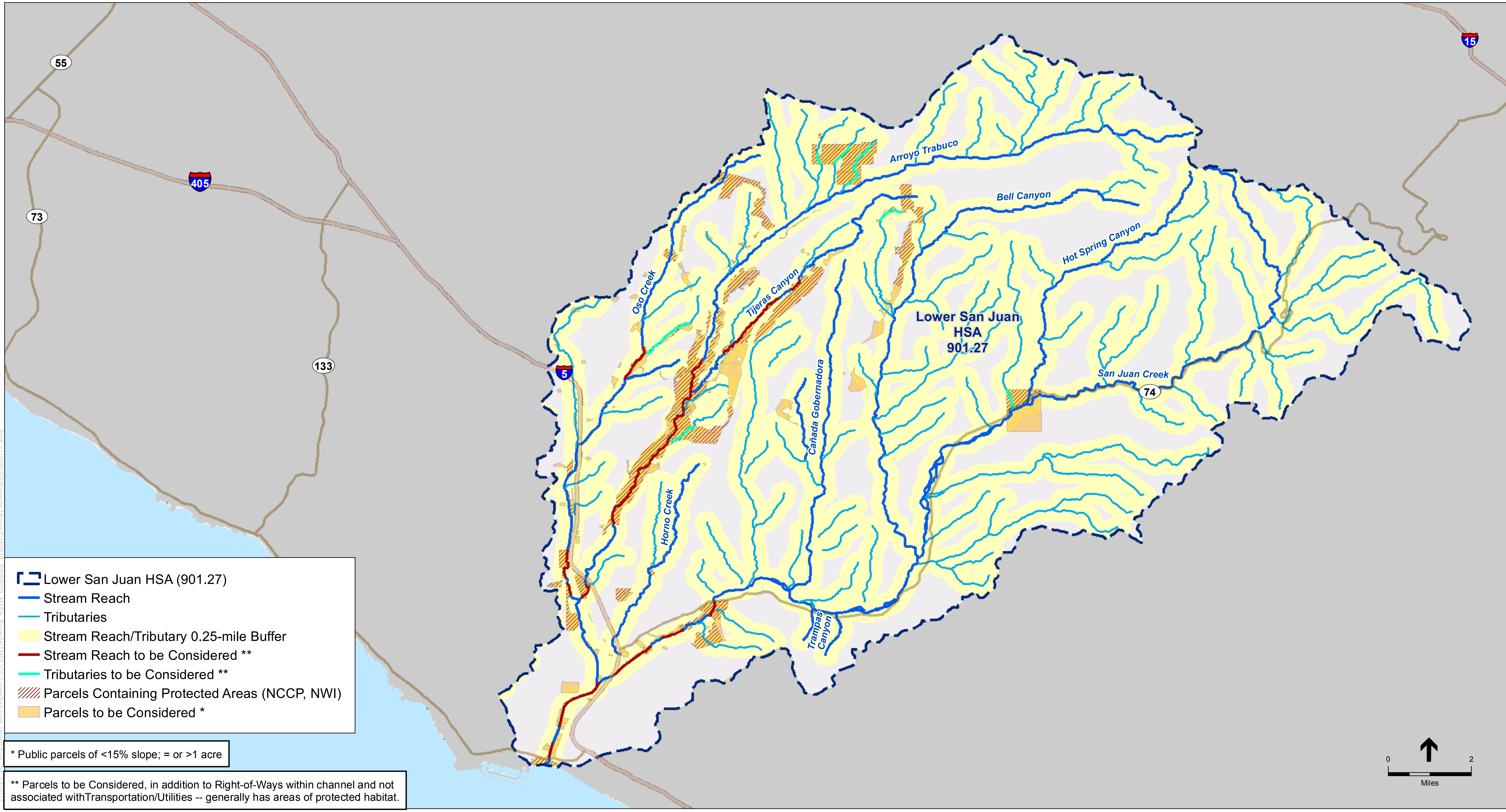


SOURCE: ESRI; State of California; County of Orange; NHD

SWRP.. 160618

Appendix C-11

Results of GIS Parcel Analysis for Feasible Restoration Sites - Dana Point HSA

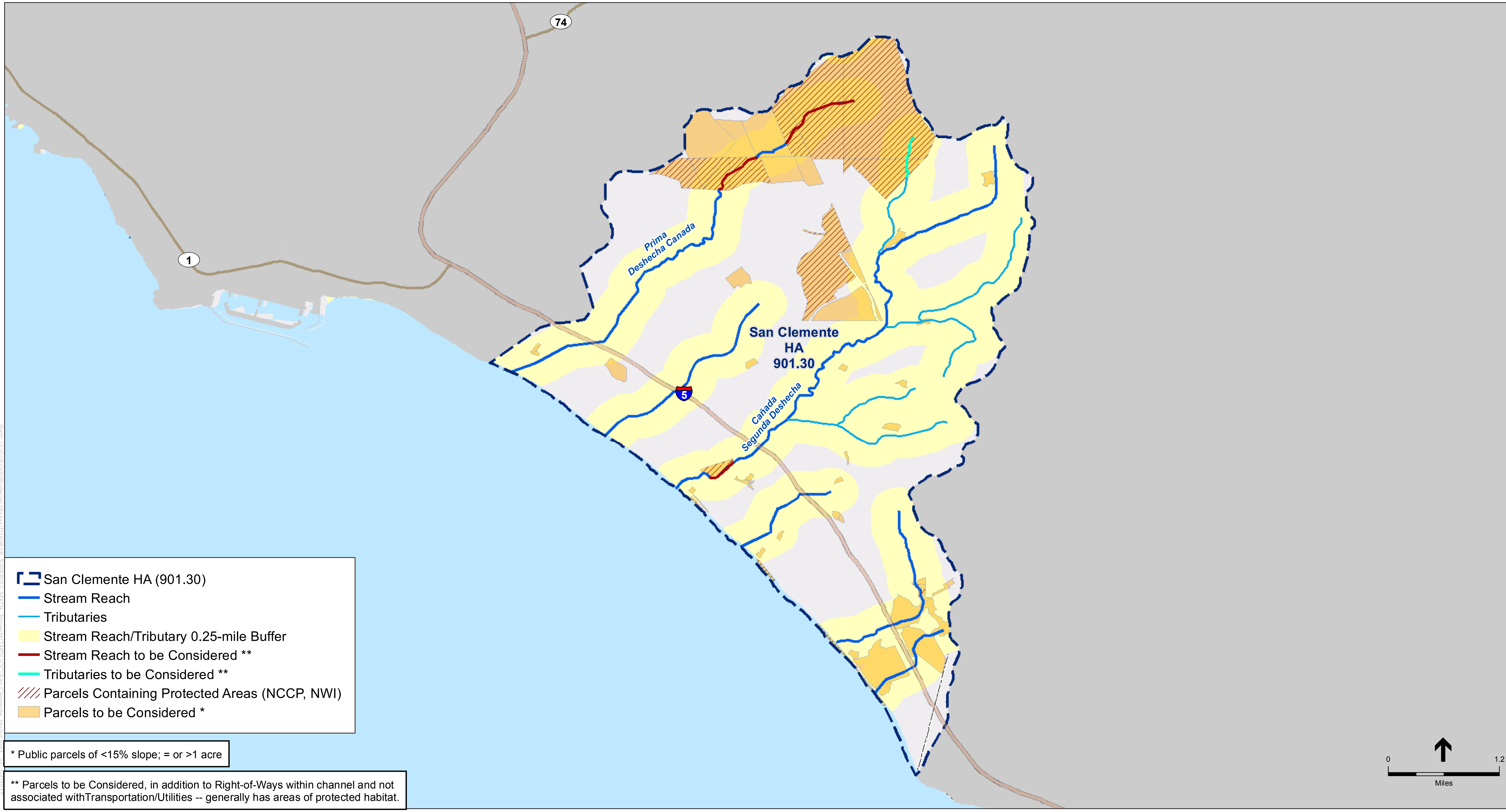


SOURCE: ESRI; State of California; County of Orange; NHD

SWRP.. 160618

Appendix C-12

Results of GIS Parcel Analysis for Feasible Restoration Sites - Lower San Juan HSA



SOURCE: ESRI; State of California; County of Orange; NHD

SWRP.. 160618

Appendix C-13

Results of GIS Parcel Analysis for Feasible Restoration Sites - San Clemente HA

Appendix D

Results of Fecal Coliform Reduction Analysis and Co-Benefits

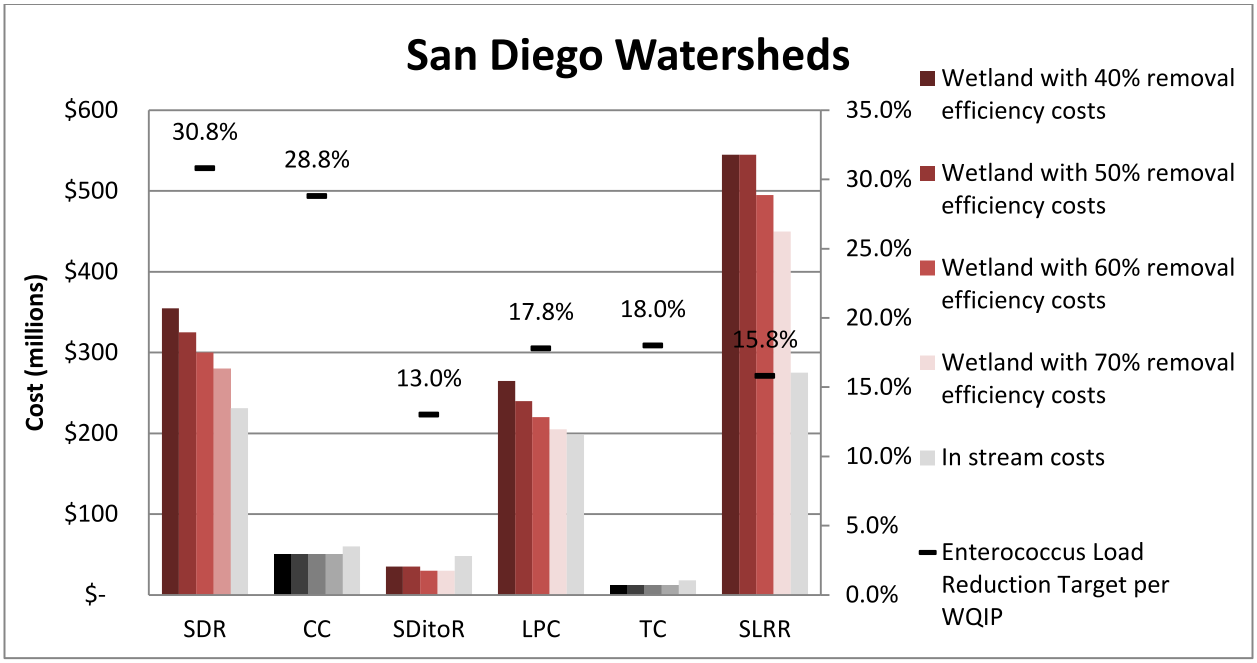
TABLE D-1 SAN DIEGO COUNTY CO-BENEFITS

	Annual Load Reduction lbs/yr	Reduction efficiency of nutrient	San Diego River			Chollas			San Dieguito			Miramar			Tecolote			San Luis Rey		
			Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)
Nutrients	Nitrate As N	47%	14307.2	114.4	4286.3	10507.1	22.2	1449.7	3825.6	15.8	521.4	17469.5	65.6	2988.9	4053.1	9.1	348.2	83903.5	232.8	12881.2
	Nitrite As N	47%	1033.3	8.3	309.6	789.2	1.7	108.9	973.6	4.0	132.7	3016.6	11.3	1.9	684.6	1.5	58.8	2972.8	8.2	456.4
	Total Kjeldahl Nitrogen	11%	44977.5	359.7	9447.2	32660.8	69.0	2956.1	16276.3	67.0	1518.4	52874.0	198.4	22.5	11005.4	24.6	590.4	53165.9	147.5	5066.2
	Total N	28%	60279.5	482.1	15256.3	43953.4	92.8	4981.2	21074.8	86.8	2401.8	73201.4	274.7	38.8	15206.8	34.0	1051.7	140022.7	388.6	17263.0
	Nitrate As N	36%	7740.0	61.9	2105.5	3373.9	7.1	416.2	2881.0	11.9	354.5	13674.7	51.3	7.9	2027.3	4.5	154.1	22168.3	61.5	3006.2
Metals	Total Suspended Solids	44%	49.5	0.4	14.5	22.7	0.0	3.0	2.0	0.0	0.3	38.4	0.1	0.0	7.3	0.0	0.6	16.4	0.0	2.4
	Chlorpyrifos	44%	177.7	1.4	52.0	27.4	0.1	3.7	35.1	0.1	4.7	193.1	0.7	0.1	33.0	0.1	2.8	78.9	0.2	11.8
	Diazinon	44%	5.4	0.0	1.6	3.8	0.0	0.5	0.8	0.0	0.1	6.4	0.0	0.0	1.1	0.0	0.1	4.9	0.0	0.7
	Malathion	44%	33.0	0.3	9.6	43.1	0.1	5.8	4.1	0.0	0.6	105.5	0.4	0.1	13.9	0.0	1.2	40.5	0.1	6.0
	Total Antimony	28%	253.8	2.0	64.2	150.7	0.3	17.1	15.1	0.1	1.7	675.9	2.5	0.4	113.2	0.3	7.8	363.9	1.0	44.9
	Total Arsenic	44%	125.2	1.0	36.6	15.4	0.0	2.1	1.4	0.0	0.2	202.2	0.8	0.1	57.8	0.1	4.8	30.6	0.1	4.6
	Total Chromium	44%	100.3	0.8	29.3	77.9	0.2	10.5	66.1	0.3	8.8	155.8	0.6	0.1	30.8	0.1	2.6	110.4	0.3	16.5
	Total Copper	44%	48.8	0.4	14.3	5.6	0.0	0.8	11.9	0.0	1.6	19.4	0.1	0.0	4.6	0.0	0.4	22.2	0.1	3.3
	Total Lead	38%	1047.6	8.4	290.4	850.3	1.8	107.2	43.8	0.2	5.5	2770.9	10.4	1.6	423.3	0.9	33.0	358.4	1.0	49.8
Other	TSS	55%				1.5E+06	3.2E+03	2.2E+05				3.6E+06	1.3E+04	2.5E+03						
	Fecal Coliform	40%	4.3E+15	3.4E+13	1.2E+15	1.7E+15	3.5E+12	2.2E+14	6.8E+14	2.8E+12	8.7E+13	2.9E+15	1.1E+13	1.7E+12	8.4E+14	1.9E+12	6.7E+13	3.6E+15	1.0E+13	5.1E+14

TABLE D-2 ORANGE COUNTY CO-BENEFITS

	Annual Load Reduction lbs/yr	Reduction efficiency of nutrient	Laguna/ San Joaquin			Aliso Creek			Dana Point			San Juan			San Clemente		
			Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)	Baseline Load (lb/yr)	Reduction from In-stream (Scenario 1)	Reduction In-stream and wetland (Scenario 2)
Nutrients	Nitrate As NO3	47%	755.9	0.4	18.0	100257.1	496.5	4560.6				156568.6	158.2	19804.0	82848.3	29.3	3325.6
	Total Kjeldahl Nitrogen	11%	866.3	0.4	13.2	44224.0	219.0	1299.0				68667.2	69.4	5728.4	26561.4	9.4	684.0
	Total Phosphorus	36%	377.5	0.2	8.0	3087.8	15.3	125.1				5723.4	5.8	648.1	1833.3	0.6	65.5
Metals	Total Arsenic	44%	838.1	0.4	19.4	165.7	0.8	7.3				223009.7	225.4	27469.2	33810.2	12.0	1319.7
	Total Cadmium	44%	91.5	0.0	2.1	86.6	0.4	3.8				27517.4	27.8	3389.5	163500.4	57.9	6382.1
	Total Chromium	44%	4517.5	2.2	104.5	82.8	0.4	3.7				183500.4	185.4	22602.6	59524.8	21.1	2323.5
	Total Copper	28%	9880.6	4.8	191.0	413.5	2.0	15.3				586325.6	592.5	61052.5	269275.8	95.4	8796.9
	Total Lead	44%	3172.0	1.5	73.4	59.7	0.3	2.6				100145.8	101.2	12335.4	29242.4	10.4	1141.4
	Total Nickel	44%	3873.4	1.9	89.6	481.7	2.4	21.3				342295.5	345.9	42162.2	1007506.9	356.8	39327.1
	Total Selenium	44%	195.4	0.1	4.5	49.6	0.2	2.2				79093.4	79.9	9742.3	48811.5	17.3	1905.3
	Total Zinc	38%	40304.1	19.5	872.4	1291.1	6.4	53.5				2626770.1	2654.5	303973.6	1704401.0	603.7	62284.5
Other	TSS	55%	1.1E+05	5.2E+01	2.8E+03	3.0E+06	1.5E+04	1.5E+05				9.9E+06	1.0E+04	1.3E+06	1.5E+06	5.4E+02	6.6E+04
	Fecal Coliform	50%	2.5E+14	1.2E+11	6.0E+12	1.3E+15	6.6E+12	6.2E+13	2.8E+14	3.9E+11	9.4E+12	2.6E+14	2.6E+11	3.4E+13	4.8E+14	1.7E+11	2.0E+13

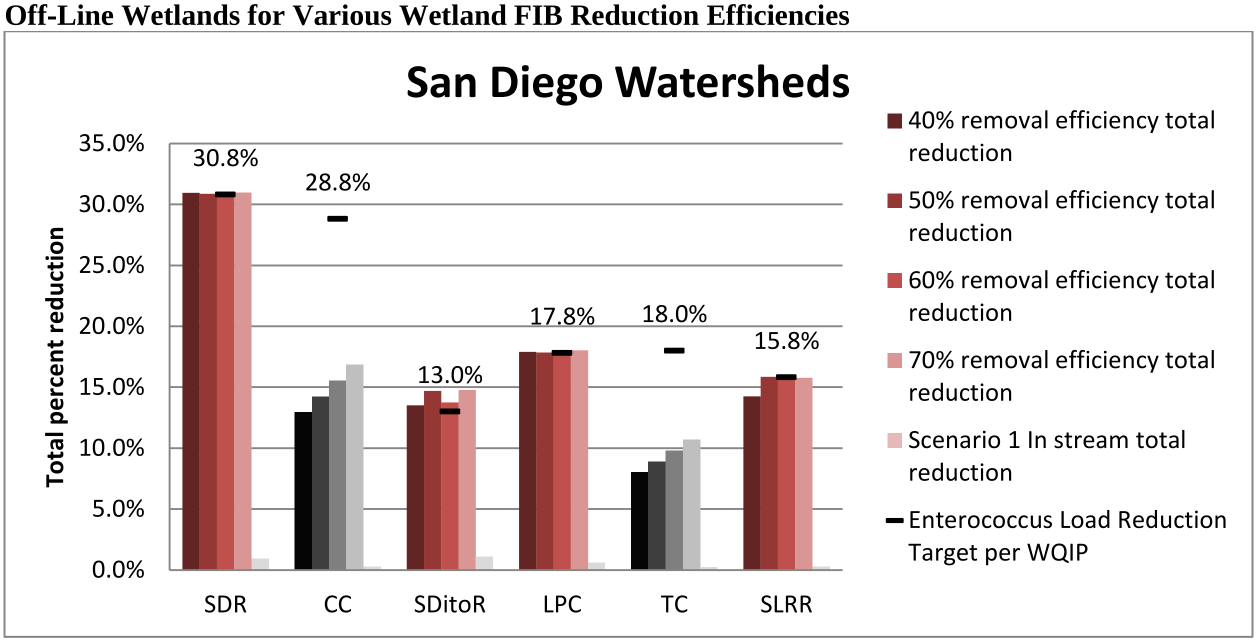
Appendix E
Additional Results of Sensitivity Analysis



SDR = San Diego River, CC = Chollas Creek, SditoR = San Dieguito River, LPC = Los Penasquitos Creek, TC = Tecolote Creek, SLRR = San Luis Rey River.

Note: Wetland costs are just for the wetland construction, they do not include instream costs.

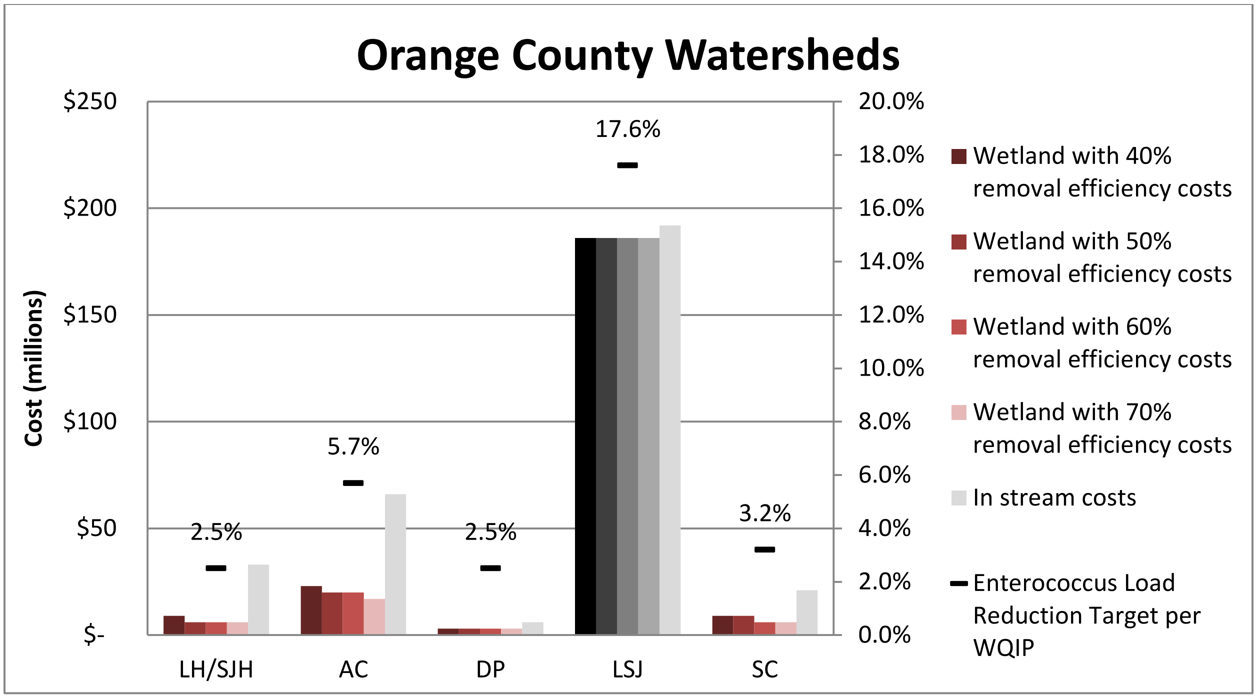
Figure E-1. Results of Sensitivity Analysis for San Diego County Watersheds on Total Costs for Off-Line Wetlands for Various Wetland FIB Reduction Efficiencies



SDR = San Diego River, CC = Chollas Creek, SditoR = San Dieguito River, LPC = Los Penasquitos Creek, TC = Tecolote Creek, SLRR = San Luis Rey River.

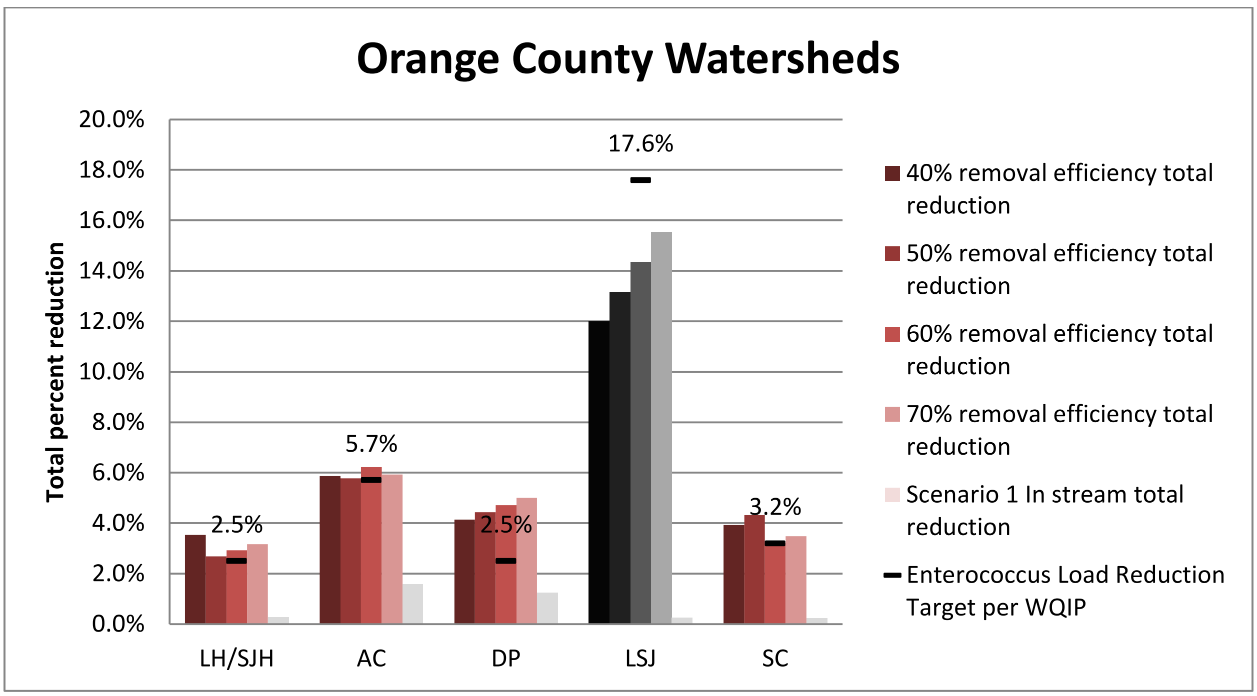
Note: Reduction rates for scenario 2 include implementation of instream and wetland projects to achieve goal.

Figure E-2. Results of Sensitivity Analysis for San Diego County Watersheds on FIB Reduction Rates for Various Off-Line Wetlands FIB Removal Efficiencies



LH/SJH = Laguna Hills/San Juan Hills, AC = Aliso Creek, DP = Dana Point, LSJ = Lower San Juan, SC = San Clemente
Note: Wetland costs are just for the wetland construction, they do not include instream costs.

Figure E-3. Results of Sensitivity Analysis for Orange County Watersheds on Total Costs for Off-Line Wetlands for Various Wetland FIB Reduction Efficiencies



LH/SJH = Laguna Hills/San Juan Hills, AC = Aliso Creek, DP = Dana Point, LSJ = Lower San Juan, SC = San Clemente
Note: Reduction rates for scenario 2 include implementation of instream and wetland projects to achieve goal.

Figure E-4. Results of Sensitivity Analysis for Orange County Watersheds on FIB Reduction Rates for Various Off-Line Wetlands FIB Removal Efficiencies

Table E-1

Summary of Enterococcus Load Reduction and Costs Uncertainty Analysis for Restoration Scenario 2 (Number of Wetland Sites Held Constant and Wetland Reduction Efficiencies Varied)

Watershed	Number of Wetland Projects***	Target Reductions per WQIPs	Low* % Reduction**	Low* Total Annual Load Reduction (#colonies/yr.)	Medium* % Reduction**	Medium* Total Annual Load Reduction (#colonies/yr.)	High* % Reduction**	High* Total Annual Load Reduction (#colonies/yr.)
San Diego Watersheds								
San Diego River (Lower San Diego HA)	65	30.8%	28.4%	1.22E+15	30.9%	1.33E+15	35.8%	1.54E+15
Chollas Creek HSA	17	28.8%	12.9%	2.17E+14	14.2%	2.39E+14	16.8%	2.83E+14
San Dieguito River (Solana Beach HA)	7	13.0%	13.5%	9.17E+13	14.7%	9.97E+13	17.0%	1.16E+14
Los Peñasquitos (Miramar HA)	48	17.8%	16.3%	4.71E+14	17.8%	5.17E+14	21.0%	6.09E+14
Tecolote Creek HA	4	18.0%	8.0%	6.69E+13	8.9%	7.43E+13	10.7%	8.92E+13
San Luis Rey River (Lower San Luis Rey HA)	109	15.8%	14.3%	5.14E+14	15.9%	5.72E+14	19.1%	6.88E+14
Orange County Watersheds								
Laguna Hills HSA/ San Joaquin Hills HSA	2	2.50%	2.4%	6.03E+12	2.7%	6.61E+12	3.2%	7.77E+12
Aliso Creek HSA	7	5.70%	5.3%	7.09E+13	5.8%	7.67E+13	6.7%	8.85E+13
Dana Point HSA	1	2.50%	4.1%	1.17E+13	4.4%	1.25E+13	5.0%	1.41E+13
Lower San Juan HSA	64	17.60%	12.0%	3.10E+13	13.2%	3.41E+13	15.5%	4.02E+13
San Clemente HA	3	3.20%	3.9%	1.88E+13	4.3%	2.07E+13	5.1%	2.45E+13

* Uncertainty analysis based on potential range of reduction efficiency for retention mechanism of wetland systems from literature values and local data (40%-70%) – Low= 40%, Medium =50%, High = 70% removal efficiency
** Enterococcus rate of reduction that includes both infiltration and retention mechanism from wetland systems
*** Number of projects determined using 50% removal efficiency to achieve the MS4 requirements if possible.
Shaded cells indicate WQIP target reduction NOT achieved

SOURCE: ESA, 2017.

Table E-2

Sensitivity Analysis Results - Total Costs for 10 and 20% Reductions Across All Watersheds for a Wetland Reduction Efficiency of 50%

	Scenario 1: Instream Restoration			Scenario 2: Off-line Wetlands and Instream Restoration						
Watershed	Number of Stream Segments in Watershed	Price Per Instream Project (millions)	Scenario 1: Price for Instream Projects (millions)	Number of wetland projects to achieve 10% reduction	Number of wetland projects to achieve 20% reduction	Price per Wetland Project (millions)	Total price for wetland projects to achieve 10% reduction (millions)	Total price for wetland projects to achieve 20% reduction (millions)	Total Price for Scenario 2 to achieve 10% scenario (millions)	Total Price for Scenario 2 to achieve 20% scenario (millions)
San Diego County Watersheds										
San Diego River (Lower San Diego HA)	77	$3.0	$231	22	45	$5	$110	$225	$341	$ 456
Chollas Creek HSA	17	$3.5	$60.	14	17	$2.9	$41	$49	$101	$109*
San Dieguito River (Solana Beach HA)	19	$2.5	$48	5	11	$5	$25	$55	$73	$103
Los Peñasquitos (Miramar HA)	79	$2.5	$198	29	60	$5	$145	$300	$342	$497
Tecolote HA	5	$3.5	$18	4	4	$2.9	$12	$12	$30*	$30*
San Luis Rey River (Lower San Luis Rey HA)	110	$2.5	$275	77	109	$5	$385	$545	$660	$820*
Orange County Watersheds										
Laguna Hills HSA/San Joaquin Hills HAS	11	$3.0	$33	9	11	$2.9	$26	$32	$59	$65*
Aliso Creek HSA	22	$3.0	$66	16	22	$2.9	$46	$64	$112	$130*
Dana Point HSA	2	$3.0	$6	2	2	$2.9	$6	$6	$12*	$12*
Lower San Juan HSA	64	$3.0	$192	53	64	$2.9	$154	$186	$346	$378*
San Clemente HA	7	$3.0	$21	7	7	$2.9	$20	$20	$41*	$41*

* The feasible FIB reduction rates are below the target rates in these watersheds. Feasible FIB reduction rates: Tecolote HA (9%), Chollas HSA (14%), Lower San Luis Rey HA (%16), Laguna/San Joaquin (14%), Aliso Creek (15%), Dana Point (8%), San Juan (13%), San Clemente (10%). Note: The enterococcus reduction efficiency of wetlands under the retention mechanism is assumed at 50% based on the Literature Review (Appendix A). The total enterococcus bacteria load reduction achieved by the Scenario 2 for the 10 and 20 percent (if feasible) reduction rates is presented in the main report. Table E-2 shows the costs associated with these reduction levels.

Appendix F

Memo: Updates to Restoration Approach Bacteria TMDL CBA

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memorandum

date May 2, 2017 (revised June 8, 2017)

to Jo Ann Weber (County of San Diego, Watershed Protection), Chad Praul (Environmental Incentives)

cc

from David Pohl PhD, PE, Ellen Buckley, EIT, Andy Collison, PhD

subject Updates to Restoration Approach Bacteria TMDL CBA

This technical memorandum provides a summary of the additional and updated analyses that respond to the comments received from the Steering Committee (SC) and the Technical Advisory Committee (TAC) on technical report entitled *San Diego Bacteria Total Maximum Daily Loads (TMDL) Cost Benefit Analysis (CBA) Inputs for Stream and Riparian Habitat Restoration San Diego and Orange Counties* (Restoration Inputs Report) dated March 2017. Specific responses to comments from the San Diego Regional Water Quality Control Board (SDRWQCB) on the Restoration Inputs Report are included as an attached to this memorandum (Attachment 2). The edits and additional and updated analyses will be incorporated in to an updated Restoration Inputs Report. The following discussions are organized by the key areas of the comments received.

Updated Costs for In-Stream and Off-Line Wetlands Restoration

Comments received from the SC and TAC included the use of a contingency of 50% and mitigation costs. The contingency use in the Restoration Inputs Report is consistent with Feasibility Level cost estimates. Because it was noted that the other options did not indicate the use of a contingency, the cost were adjusted for a lower contingency of 25%. In addition, several target reduction rates needed adjustment to be consistent with the updated enterococcus load reduction requirements developed for the Water Quality Improvement Plans (WQIPs). Table 1 presents the updated reductions for the Scenario 2 that uses the enterococcus load reductions per the WQIPs. This update revises the number of watersheds that achieve the compliance target to 8 of the 11 watersheds under Scenario 2 (off-line wetlands). The removal efficiency assumed for this scenario for wetland retention is 50%. Table 2 presents the revised costs for Scenarios 1 and 2 based on the reduced contingency rate for both Scenarios 1 and 2, and the updated compliance rates for Scenario 2.

TABLE 1
SCENARIO 2: IN-STREAM AND OFF-LINE WETLAND RESTORATION LOAD REDUCTION BY WATERSHED – PERCENT LOAD REDUCTION WITH ENTEROCOCCUS REDUCTION GOALS PER WQIPS AND 50% WETLAND RETENTION REMOVAL EFFICIENCY

Watershed	Number of In-Stream Restoration Projects	Rate of Total Infiltration for In-Stream Projects (%)	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of Wetland Projects to Achieve WQIPs Reduction Targets	Reduction Achieved	Reduction Goal per WQIPs	Annual Enterococcal Reduction (colonies/yr.)
San Diego County Watersheds								
San Diego River (Lower San Diego HA)	77	1.0%	17.6%	13.6%	65	30.9%	30.8%	1.33E+15
Chollas Creek HSA	17	0.2%	7.5%	6.5%	17	14.2%*	28.8%	2.39E+14*
San Dieguito River (Solana Beach HA)	19	1.1%	7.7%	5.9%	7	14.7%	13.0%	9.97E+13
Los Peñasquitos (Miramar HA)	79	0.6%	9.3%	7.9%	48	17.8%	17.8%	5.17E+14
Tecolote Creek HA	5	0.3%	4.2%	4.4%	4	8.9%*	18.0%	7.43E+13*
San Luis Rey River (Lower San Luis Rey HA)	110	0.3%	7.6%	8.0%	109	15.9%	15.8%	5.72E+14
Orange County Watershed								
Laguna Hills HSA/ San Joaquin Hills HSA	11	0.3%	1.2%	1.2%	2	2.7%	2.5%	6.61E+12
Aliso Creek HSA	22	1.6%	2.0%	2.2%	7	5.8%	5.7%	7.67E+13
Dana Point HSA	2	1.2%	1.8%	1.4%	1	4.4%	2.5%	1.25E+13
Lower San Juan HSA	64	0.3%	7.0%	5.9%	64	13.2%*	17.6%	3.41E+13*
San Clemente HA	7	0.2%	2.1%	2.0%	3	4.3%	3.2%	2.07E+13

* Enterococcus reduction targets per the WQIPs were not attained

TABLE 2

SUMMARY OF FEASIBILITY LEVEL COSTS

Watershed	Feasibility Level Unit Cost	Number of Feasible Sites	Total Cost	Estimated FIB Load Reduction Rate	Cost per Acre of Watershed Draining to Restoration sites
San Diego County Watersheds					
San Diego River (Lower San Diego HA)	$3M	77	$231M	1.0%	$3,000
Chollas Creek HSA	$3.5M	17	$60M	0.2%	$3,200
San Dieguito River (Solana Beach HA)	$2.5M	19	$48M	1.1%	$1,700
Los Peñasquitos (Miramar HA)	$2.5M	79	$198M	0.6%	$3,300
Tecolote Creek HA	$3.5M	5	$18M	0.3%	$2,900
San Luis Rey River (Lower San Luis Rey HA)	$2.5M	110	$275M	0.3%	$2,300
Orange County Watersheds					
Laguna Hills HSA/ San Joaquin Hills HSA	$3M	11	$33M	0.3%	$3,900
Aliso Creek HSA	$3M	22	$66M	1.6%	$2,900
Dana Point HSA	$3M	2	$6M	1.2%	$4,700
Lower San Juan HSA	$3M	64	$192M	0.3%	$4,300
San Clemente HA	$3M	7	$21M	0.2%	$4,700

Wetland Scenario Bacteria Reduction Efficiencies Sensitivity

Comments received from the TAC included a request to consider the use of more engineered inlet and outlet structures that would increase retention times and improve bacteria removal efficiencies closer to the literature values for engineered wetland systems. Per the literature that was reviewed, engineered natural treatment systems (NTS) can achieve removal efficiencies between 50-70% when the inflow is controlled to 1.5 cubic feet per second (cfs) or lower. The lower range was used in the off-site wetland scenarios based on the assumption that these sites would have a greater focus on restoration and have fewer engineered controls. Engineered controls include concrete weirs, culverts and riser pipes to control inlet and outlet flow.

In order to address this comment, an additional analysis was conducted for the off-site wetlands scenario (Scenario 2) that analyzed the sensitivity of varying the wetland retention enterococcus removal efficiencies closer to the range of the literature values for engineered NTS. This sensitivity analysis included determining the total load reductions and costs for enterococcus removal efficiencies of 40%, 50% and 60%. The results of this analysis are shown on Figures 1 and 3. Figures 1 and 3 compare the costs to achieve the required reductions percentage using the 40%, 50% and 60% reduction efficiency rates. Attachment 1 includes a summary of the costs that were used to develop these figures. Figures 2 and 4 show total reduction rates for Scenario 2 (at 50%, 60%, and 70% wetland reduction efficiencies). The bars in grayscale indicate that the reduction requirement was not achieved.

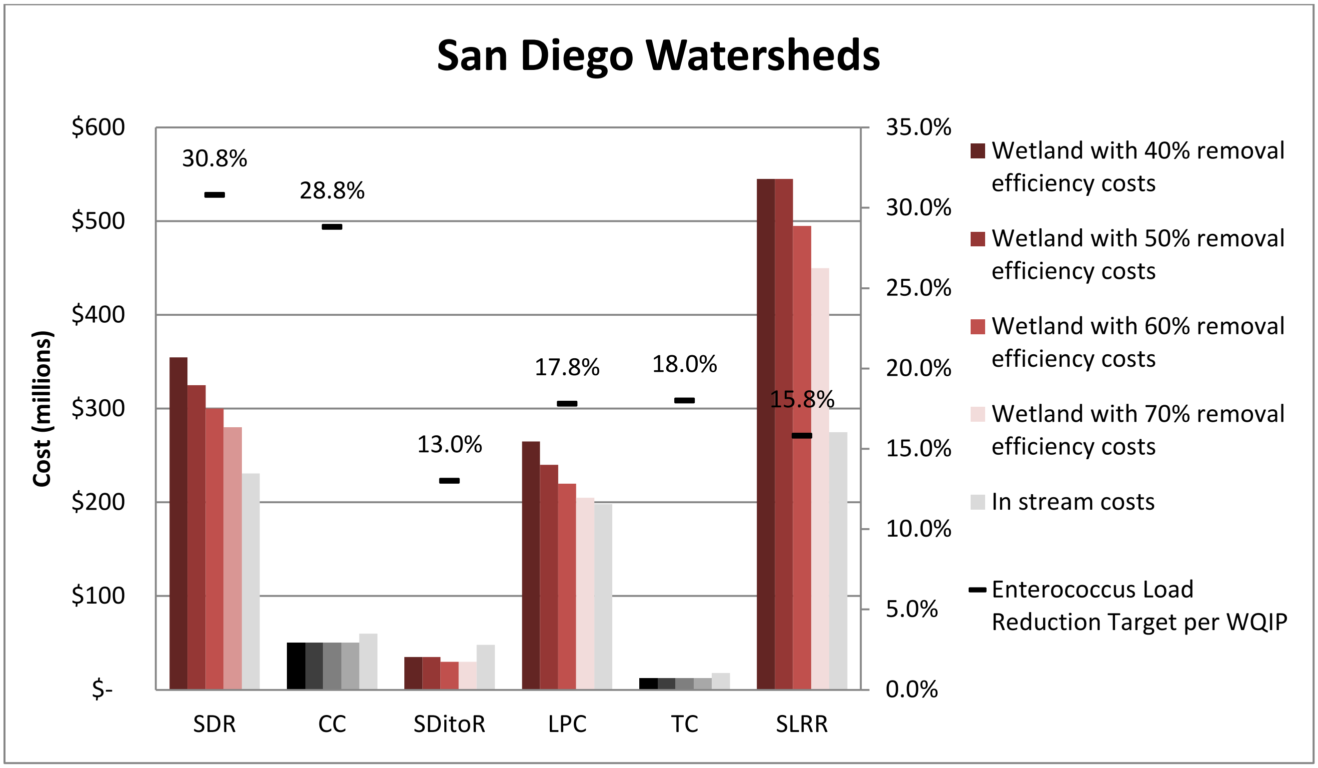

Figure 1.San Diego County Wetlands Cost Comparison

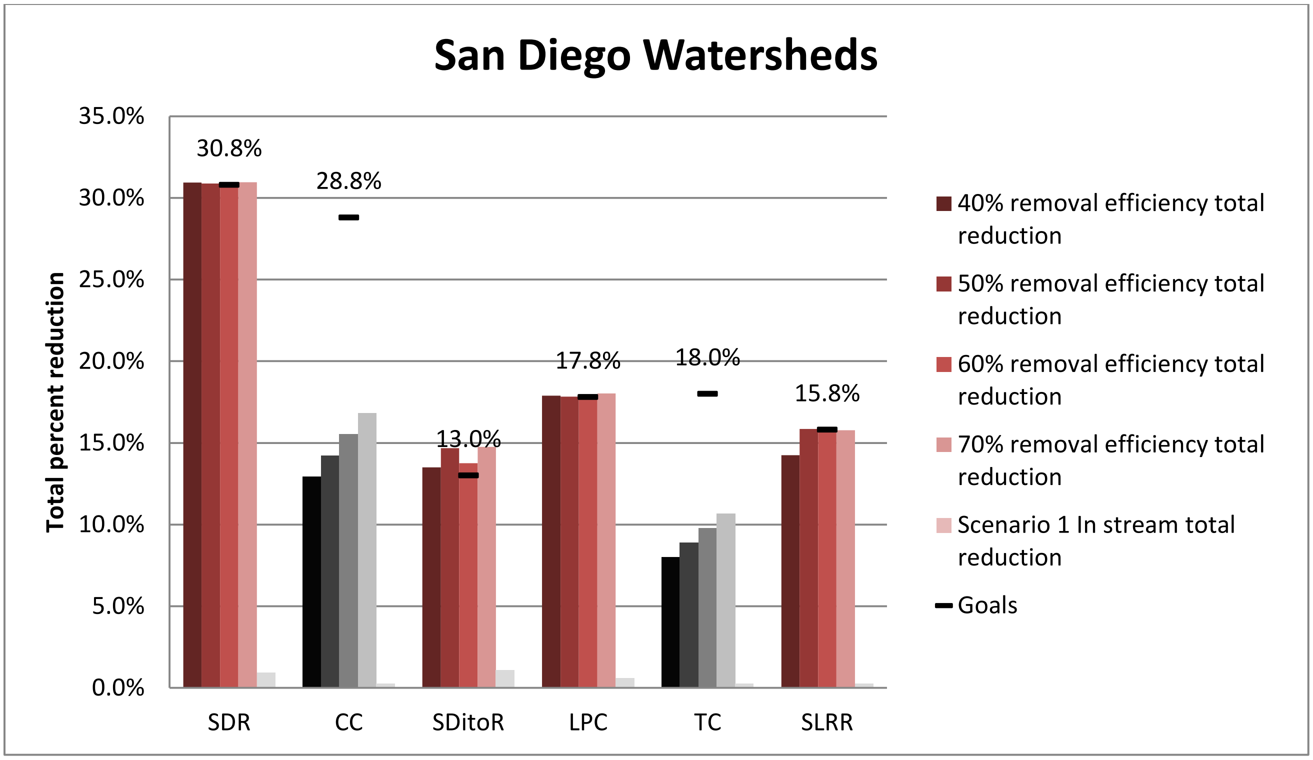

Figure 2. San Diego Watersheds Total Percent Reduction

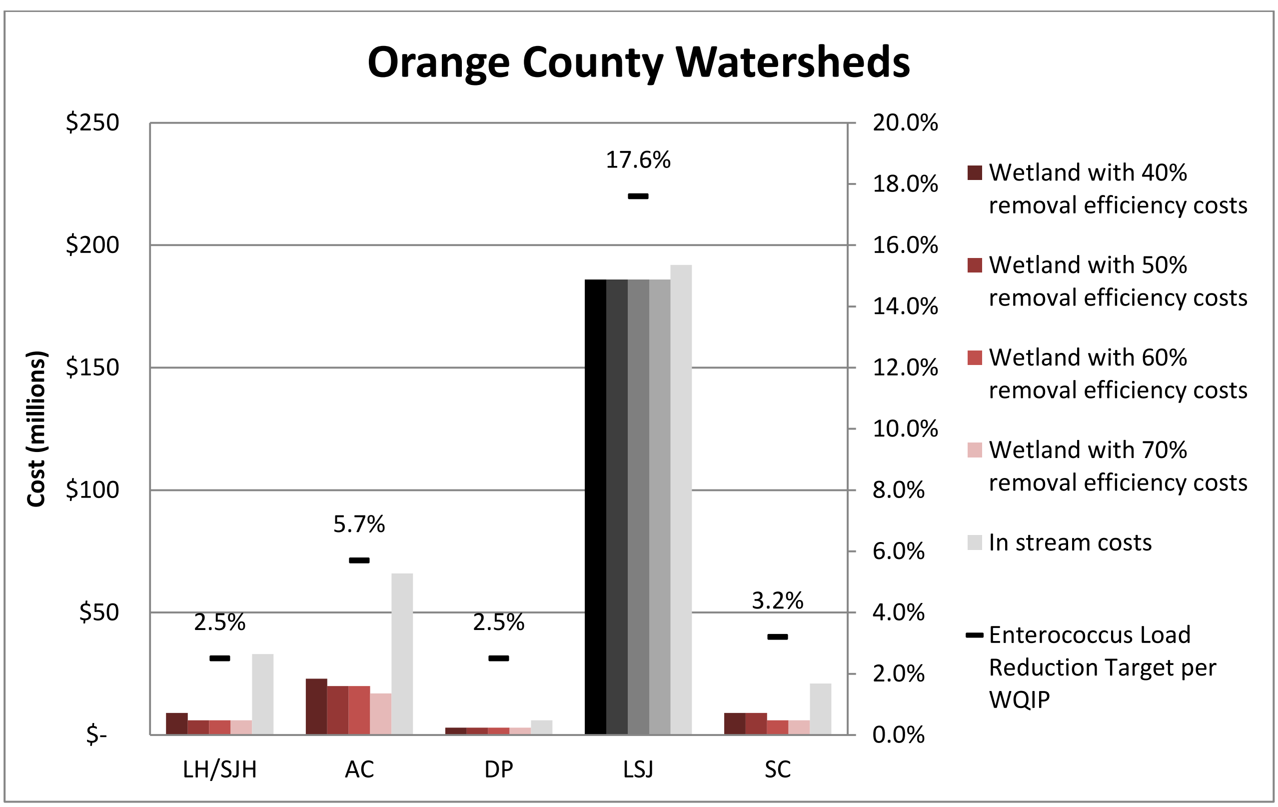

Figure 3. Orange County Wetlands Cost Comparison

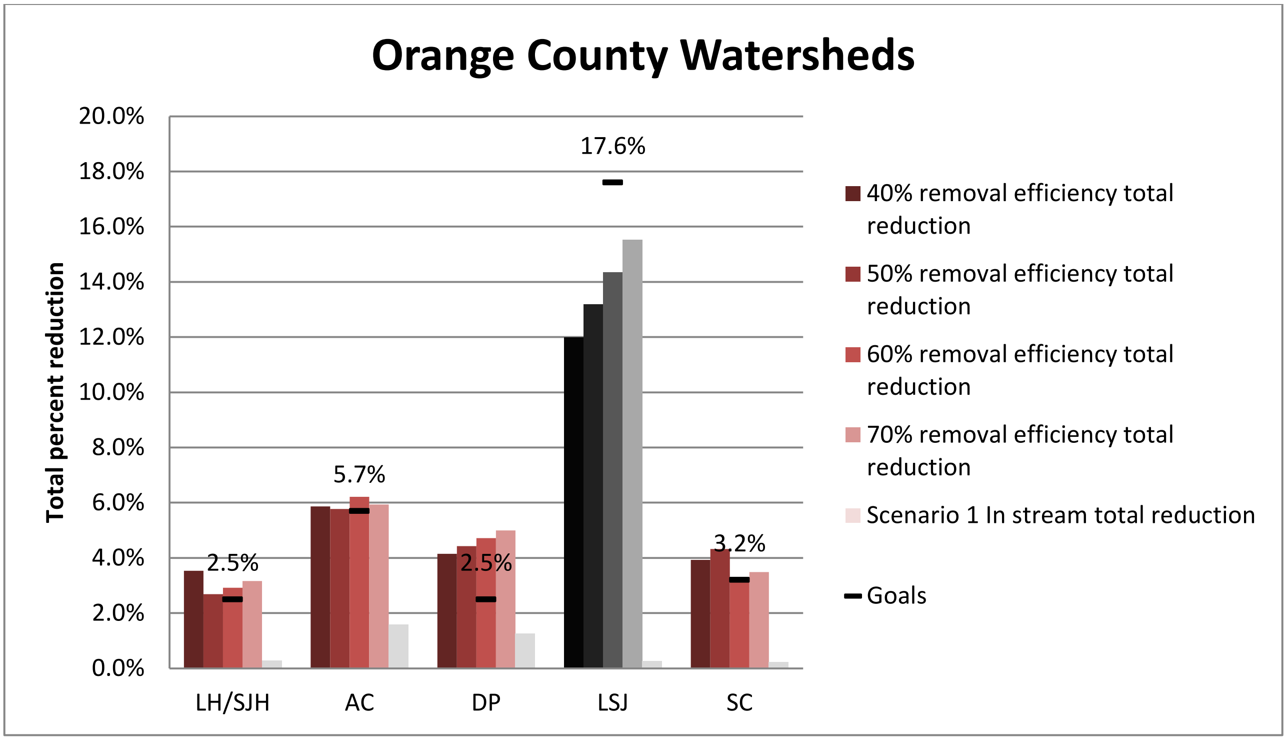

Figure 4. Orange County Watersheds Total Percent Reduction

As can be expected, increasing efficiency results in fewer projects needed and lower total costs per watershed. However, even with an increase in removal efficiency for the wetlands, some watersheds (**in greyscale coloring**) are not able to meet achieve the target load reductions consistent with the WQIPS due to the limitation of available feasible sites on public parcels and total drainage area. For the watersheds in San Diego County, Chollas Creek HSA and Tecolote Creek HSA are limited by available parcels and are not able to achieve the compliance loads reductions targets under all the removal efficiencies. San Luis Rey watershed achieves reduction goals for 50% and 60% wetland retention removal efficiency only. For the watershed in Orange County, Lower San Juan is the only watershed that doesn't achieve the compliance loads reduction targets with any of the removal efficiencies. The San Juan reduction goal is 17.6% which is higher than the range of 2-6% for the other watersheds in Orange County. Based on this analysis, the use of higher removal efficiencies does not significantly change the number of watersheds that achieve the enterococcus load reduction targets. Total costs are reduced with increased efficiencies, but not significantly for this level of analysis and cost estimating.

Wetland Case Study

A comment from the TAC included a request for additional presentation of the analysis performed with the recommendation to use an actual site to provide as an example of the methodology used. The following analysis presents an example case study of a wetland off-line project that represents the type of projects that were used to conduct the analysis for Scenario 2. Public parcels with determined generalized land use categories of open space, vacant, park, or right of ways designated as protected areas, <15% slope, and at least 1 acre in area were selected for consideration as a project site. This case study is located at the confluence of a San Diego River tributary and the San Diego River in the San Diego River Watershed Management Area. The project site is on a parcel owned by the County of San Diego and is currently a vacant grass field. There may be planned/projected use of this parcel that may not be consistent with this use, however, this analysis was based on the available information and the San Diego River in the San Diego River Watershed Management Area. The project site is on a parcel owned by the County of San Diego and is currently a vacant grass field. There may be planned/projected use of this parcel that may not be consistent with this use, however, this analysis was based on the available information and used to demonstrate a “representative” offline wetland project that was modeled for the Restoration Inputs Report. This site was analyzed and compared to the “model” used for this watershed to verify the representativeness of this example project and the model site.

Wetland Design for Case Study Off-line Wetland Project

The off-line restoration strategies mimic natural processes where water is diverted from a channel and retained off-line for longer periods. The tributary approach modeled in this study involves creating a distributary channel that draws low flows off the main channel and into bioinfiltration/filtration areas where percolation and evaporation can take place. In the case study presented in this analysis, a culvert diverts flows from a San Diego River tributary into the engineered wetland (Figure 5).

Figure 5. Wetland Case Study Aerial View

The wetland area becomes inundated with the inflow from the culvert, allowing stormwater to infiltrate, evaporate, or be retained before discharging through the controlled outlet structure. An adjustable flashboard weir allows controlled flow out of the wetland into a swale that leads back to the river. Figure 6 shows a profile view of the culvert, wetland and swale. Dimensions of the wetland design are in Table 3.

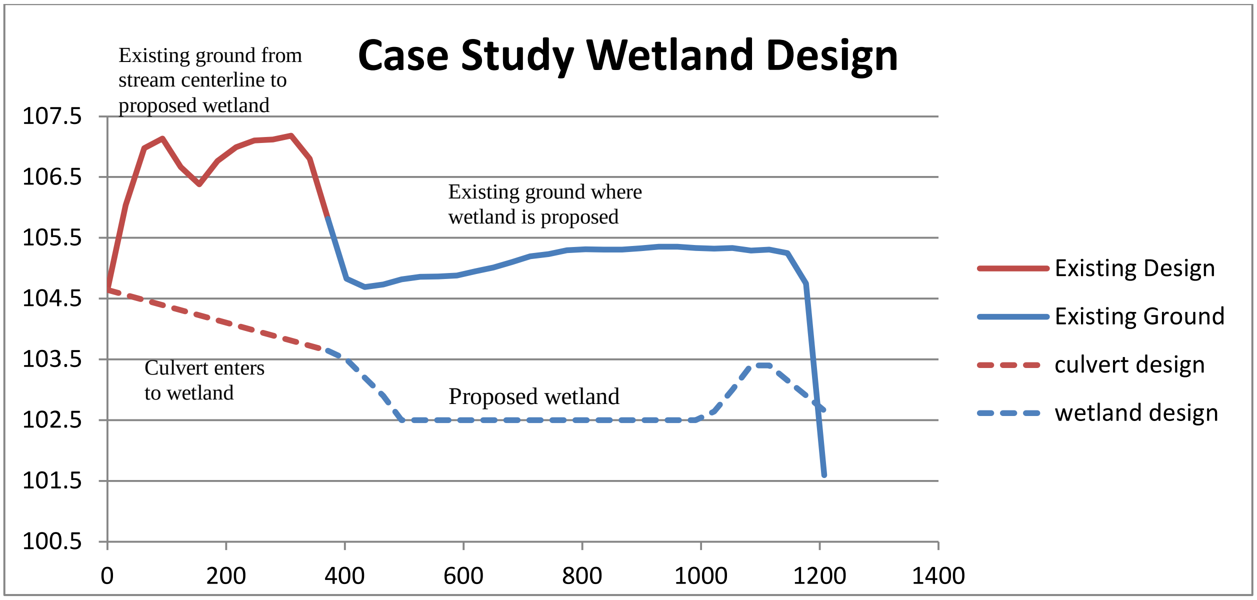

Figure 6. Case Study Wetland Design Profile

TABLE 3

WETLAND DESIGN SPECIFICATIONS

Culvert Length (ft)	372
Wetland Width (average) (ft)	352
Wetland Length (average) (ft)	495
Wetland area (acre,ft^2)	4, 174240
Wetland depth (max) (ft)	1
Wetland Volume (ft^3)	174240
Swale Length (ft)	92

Modeling Methods for Wetland Case Study

To simulate flow through the wetland, a simple “box model” was created in MATLAB to represent the wetland. The continuous model was run with an hourly timestep including inflow, percolation and evaporation processes. The water entering the wetland either evaporates, infiltrates, or is retained and slowly moves through the wetland towards the outlet structure. The water that slowly moves through the wetland is considered to be treated through increasing retention time and allowing constituents to settle out and also to be filtered through the vegetation. This retention mechanism is assumed to have an enterococcus removal efficiency between 40%-60%.The maximum amount of water that the wetland can treat is 1.5 cubic feet per hour per acre of wetland. Water that evaporates or percolates is considered to be treated with 100% efficiency.

The inflow data was developed from the San Diego Hydrology Model (SDHM). SDHM uses land coverage (aerial imagery), soil types (Web Soil Survey), drainage area (Streamstats and professional judgement) and local precipitation (Santee ALERT Station) to create a drainage area runoff timeseries. This timeseries was used for the wetland inflow data. The Santee ALERT Station precipitation and evaporation continuous timeseries were also used in the MATLAB wetland model.

The assumptions for this model include:

- 1 in/hr infiltration rate
- maximum amount wetland can retain is 1.5 cubic feet per hour per acre
- Storm drains in drainage area affect contributing watershed area
- 100% enterococcus reduction efficiency for wetland infiltration
- 40%-60% enterococcus reduction efficiency for wetland retention

Results of the Analysis for the Case Study Off-line Wetland

Table 4 presents the results of the wetland load reduction analysis including percent infiltrated, percent retained, and percent reduction from retention. The results of this analysis for the wetland case study are very similar to the results from the “model” site used in the Restoration Inputs Report to represent the San Diego River WMA wetland projects.

TABLE 4

WETLAND LOAD REDUCTION VALUE RESULTS

	This Case Study	Values used for Wetland “Model” in Report
Percent Infiltrated	13.05%	20.9%
Percent Retained	27.59%	29.2%
Percent reduced by retention (using 40%, 50%, 60%)	11.04%, 13.80%, 16.55%	11.7%, 14.6%, 17.5%
Total percent of enterococcus reduction (40%, 50%, and 60%)	24.09%, 26.05%, 29.60%	32.6% 35.5% 38.4%

Orange County Natural Treatment System Efficiency Data

A comment from the TAC included adding a discussion of local treatment wetland efficiency data form the NTS that have been installed and monitored in Orange County. The Irvine Ranch Water District recorded enterococcus concentrations and flow measurements at the inflow and outflow locations for twelve NTS within Orange County. ESA obtained these data and analyzed this data set to determine removal efficiencies of these NTS. Using the enterococcus and flow measurements from these sites, the average percent reduction was calculated at each site. Five of the twelve sites had monitoring events where increases in enterococcus concentration at the outlet were observed. In three of the twelve sites a negative average reduction rate was determined. The average reduction of the seven of twelve wetlands with a decrease in enterococcus concentrations for all measurements is 88%. Figure 7 presents a chart of average reduction rates for each of the twelve NTS sites. The sites with negative average reduction rate are evidence that in some cases the wetland can contribute bacteria to the storm flows resulting in a negative load reduction. The sources of these bacteria may be from wildlife attracted to the wetland habitat created by the NTS. This analysis of NTS data from Orange Counties will be added to the report. Although there are NTS with higher removal rates than the 50% used in the Restoration Inputs Report, there are also NTS site with negative reduction efficiencies. This variability in bacteria reductions rates for these NTS was considered in the analysis and the rate of 50% represents a reasonable average based on this local data set and the values obtained from the literature search summarized in the report.

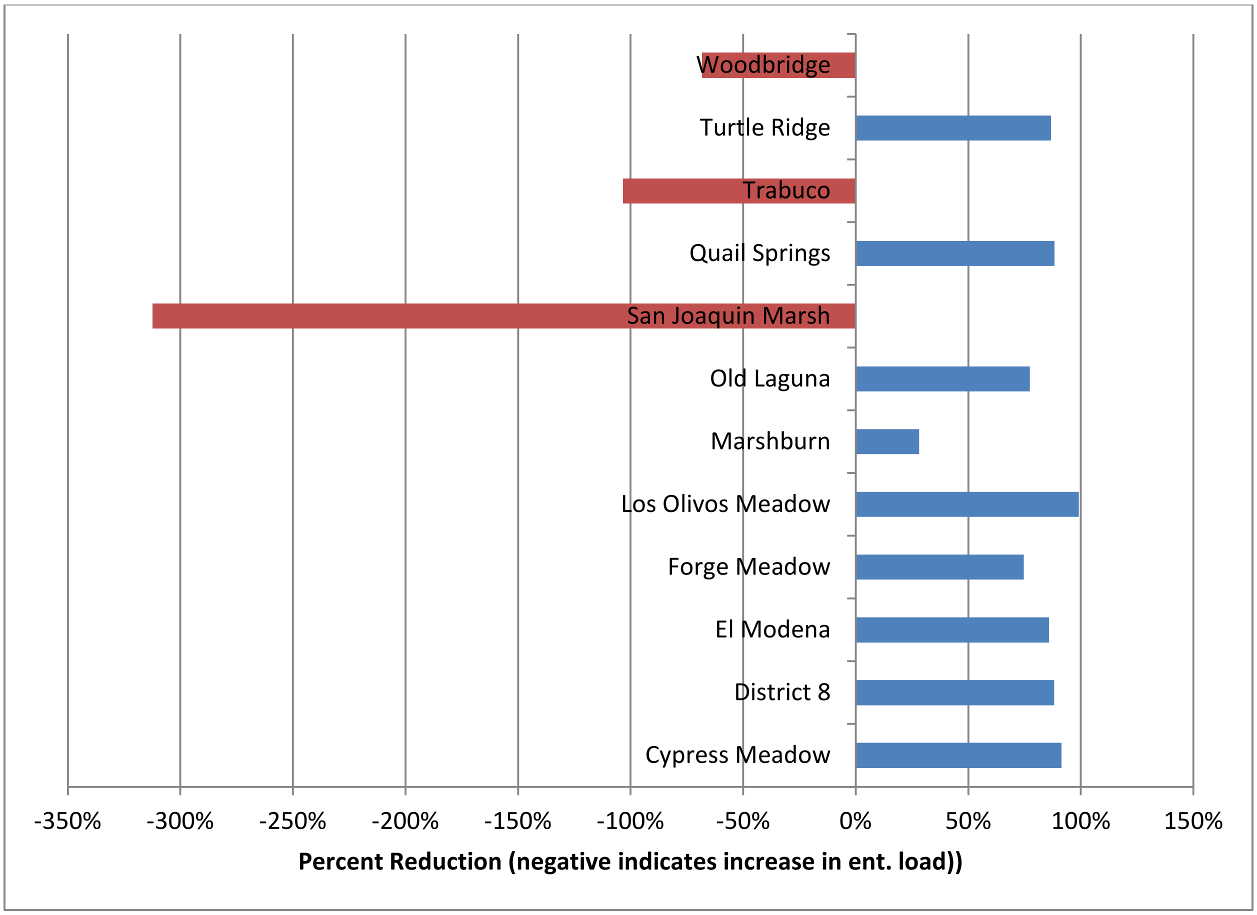

Figure 7. Average Percent Reduction from San Diego and Orange County NTS sites.

Co-benefits through Bacteria Reductions in Dry Weather Flows

In response to comments from the TAC regarding considering the co-benefits of reductions in bacteria loading in dry weather flows, additional text will be added to the report under the co-benefits discussion. Reductions of bacteria including enterococcus in dry weather flow can be expected from infiltration and retention mechanisms in both in-stream and off-line wetland restoration sites during these dry weather flows. The reduction of enterococcus and other FIB loading during dry weather flows from stream and wetland restoration projects therefore provides an additional co-benefit. During dry weather flows, flow rates are lower and rates of FIB removal from infiltration and retention mechanism will be higher for stream restoration projects. Data from Upper Sulfur Creek and Narco Channel Restoration projects located in Orange County indicate FIB reduction rates ranging from 40-80%. Wetland FIB reduction rates have a wide range and depend on the flow rates and FIB concentrations. The base flow FIB load varies depending on source, time of year and a number of other factors. The FIB load reduction for dry weather flows for in-stream and off-line systems occur through the same processes as in wet-weather flows: infiltration and retention. Dry weather flows are not analyzed in this analysis as the focus was on wet weather flows. Non storm water dry weather flows are prohibited in MS4 discharges under the current Permit. Non storm flow management measures are defined in the WQIPs in each of the watersheds.

Responses to SDRWQCB Comments

Responses to specific comments and questions from the SDRWQCB on the Restoration Inputs Report are provided in Attachment 2.

Attachment 1

Results of 40%, 50%, 60% Wetland Reduction Efficiency Analyses

TABLE 1
OFF-LINE WETLAND RESTORATION LOAD REDUCTION BY WATERSHED

Watershed	40% removal efficiency for wetland retention				50% removal efficiency for wetland retention				60% removal efficiency for wetland retention			
	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of wetland projects to achieve WQIP reductions	Annual Enterococcal Reduction (colonies/yr.)	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of wetland projects to achieve WQIP reductions	Annual Enterococcal Reduction (colonies/yr.)	Rate of Infiltration for Off-Line Wetlands (%)	Rate of Retention for Off-Line Wetlands Multiplied by Removal Efficiency	Number of wetland projects to achieve WQIP reductions	Annual Enterococcal Reduction (colonies/yr.)
San Diego County Watersheds												
San Diego River (Lower San Diego HA)	19.2%	10.7%	71	1.33E+15	17.6%	13.6%	65	1.E+15	16.3%	13.6%	60	1.E+15
Chollas Creek HSA	7.5%	5.2%	17	2.17E+14	7.5%	6.5%	17	2.E+14	7.5%	7.8%	17	3.E+14
San Dieguito River (Solana Beach HA)	7.7%	4.7%	7	9.17E+13	7.7%	5.9%	7	1.E+14	6.6%	6.1%	6	9.E+13
Los Peñasquitos (Miramar HA)	10.3%	7.0%	53	5.19E+14	9.3%	7.9%	48	5.E+14	8.5%	8.7%	44	5.E+14
Tecolote Creek HA	4.2%	3.5%	4	6.69E+13	4.2%	4.4%	4	7.E+13	4.4%	5.3%	4	8.E+13
San Luis Rey River (Lower Sa Luis Rey HA)	7.6%	6.4%	109	5.14E+14	7.6%	8.0%	109	6.E+14	6.9%	8.7%	99	6.E+14
Orange County Watersheds												
Laguna Hills HSA/ San Joaquin Hills HSA	1.8%	1.4%	3	8.69E+12	1.2%	1.2%	2	6.6E+12	1.2%	1.4%	2	7.2E+12
Aliso Creek HSA	2.3%	2.0%	8	7.80E+13	2.0%	2.2%	7	7.7E+13	2.0%	2.7%	7	8.3E+13
Dana Point HSA	1.8%	1.1%	1	1.17E+13	1.8%	1.4%	1	1.3E+13	1.8%	1.7%	1	1.3E+13
Lower San Juan HSA	7.0%	4.7%	64	3.10E+13	7.0%	5.9%	64	3.4E+13	7.0%	7.1%	64	3.7E+13
San Clemente HA	2.1%	1.6%	3	1.88E+13	2.1%	2.0%	3	2.1E+13	1.4%	1.6%	2	1.5E+13

TABLE 2

SUMMARY OF FEASIBILITY LEVEL UNIT COSTS

Watershed	Area of off-line Tributary Wetlands (acres)	Area needed for off-line Tributary Wetlands (ac)[1]	Feasibility Level Unit Cost	Number of Feasible Sites with 40% reduction	Number of Feasible Sites w/ 50% reduction	Number of Feasible Sitesw/ 60% reduction	Feasibility Level Costs for FIB Reduction with 40% removal Efficiency (off-line only) (millions)	Feasibility Level Costs for FIB Reduction with 50% removal Efficiency (off-line only) (millions)	Feasibility Level Costs for FIB Reduction with 60% removal Efficiency (off-line only) (millions)	Additional Feasibility Level Costs for In-Stream Projects
San Diego County Watersheds										
San Diego River (Lower San Diego HA)	4	10	$5.0	71	65	60	$355	$325	$300	$231
Chollas Creek HSA	2	5	$2.9	17	17	17	$49	$49	$49	$60
San Dieguito River (Solana Beach HA)	4	10	$5.0	7	7	6	$35	$35	$30	$48
Los Peñasquitos (Miramar HA)	4	10	$5.0	53	48	44	$265	$240	$220	$198
Tecolote HA	2	5	$2.9	4	4	4	$12	$12	$12	$18
San Luis Rey River (Lower San Luis Rey HA)	4	10	$5.0	109	109	99	$545	$545	$495	$275
Orange County Watersheds										
Laguna Hills HSA/San Joaquin Hills HSA	2	5	$2.9	3	2	2	$9	$6	$6	$33
Aliso Creek HSA	2	5	$2.9	8	7	7	$23	$20	$20	$66
Dana Point HSA	2	5	$2.9	1	1	1	$4	$3	$3	$6
Lower San Juan HSA	2	5	$2.9	64	64	64	$186	$186	$186	$240
San Clemente HA	2	5	$2.9	3	3	2	$9	$9	$6	$11

Attachment 2

Response to Comments from the San Diego Regional Water Quality Control Board

The finding that small watersheds cannot benefit from stream restoration is misleading and should be clarified to the context of this analysis. The report suggests small low-order streams can be valuable sites for benefits, it just doesn't include them because of the limitations of the study design. Also, for example, stream restoration or preservation in newly developing areas puts less pressure on the downstream reaches, etc.	Appendix D: Section 1 (or Fig ES-1)		Clarify the finding to more accurately describe the assumption. E.g., revise the * sentence in Figure Es-1 Scenario 2 to remind the reader of the context.	This statement in Figure ES-1 will be clarified to replace smaller with "*some*".
Co-benefits should be extended to dry weather.	Appendix D: Section 8		Include dry-weather benefits in the evaluation and analysis.	A discussion on the co-benefits of the reduction of FIB in dry weather flows will also be added to Chapter 8. See additional detailed response below.
The literature review bullet should identify whether local studies were reviewed.	Appendix D: Section 1	7	Clarify that the San Diego Region municipalities and NGOs have extensive experience with stream restoration projects, and then explain why they weren't used in this study.	Data was used from stream restoration projects in Orange and San Diego Counties. These data are however limited to dry weather flows. The data from Forester Creek indicated no reduction in FIB. We used over 200 sources of published data for stream and wetland restoration and there is very limited data on stream restoration and FIB reductions. We used these published data to develop the removal efficiency for wetlands. We are supplementing these data with data provided by Irvine Ranch Water District who has operated and monitored a number of natural treatment systems in Orange County. We received the data on April 25, 2017 and analyzed the inflow and outflow data to determine removal efficiency. This will be reported in the updated Report and compared to the rates used in the analyses. Based on the analysis, these rates are within the range analyzed, which has been expanded to assess removal rates of 40%, 50% and 60%.
In the "Feasibility Review of Restoration Approaches" section, a phrase was cut from the draft and now the sentence is incomplete. The phrase ends with *"…and restoring native that can improve… "*	Appendix D: Section 1	7	Insert the missing phrase about native vegetation and natural processes	The sentence will be edited to read: *As restoration approaches, these techniques focus on restoring natural stream and riparian habitat function through reducing channelization, thereby increasing residence time and infiltration opportunities, restoring natural sediment transport processes, and restoring native vegetation and natural processes that can improve water quality including removal of bacteria.*
Bullet for Mechanism for Bacteria Reduction: The finding about *"… no measurable increase in retention time was achievable from the in-stream restoration under storm flows."* phrase should be rephrased to say "during storm flows." Otherwise it doesn't account for the tail end of the storms, the water left in pools, etc.	Appendix D: Section 1	7	Clarify the finding to more accurately describe the assumption	The sentence will be edited to read: *It was determined that a measurable increase in retention time was not achievable from the in-stream restoration during storm flows (retention times increased by less than 30 minutes compared to several days needed to attain measurable removal efficiency of FIB in natural treatment systems – see more detailed discussion in Section 4)* .
Co Benefits Bullet: This should include the note about dry-weather flow benefits touched on in the report.	Appendix D: Section 1	8	Include dry-weather benefits as a co-benefit in the analysis summary.	A sentence will added to this bullet that reads: Co-benefits may include reduction of FIB loading in dry weather flows from infiltration and retention mechanisms during these lower flows. A discussion will also be added to Chapter 8 on dry weather flows. This will state: *The reduction of enterococcus and other FIB loading during dry weather flows from stream and wetland restoration projects provides an additional co-benefit. During dry weather flows, flow rates are lower and rates of FIB removal from infiltration and retention mechanism will be higher for stream restoration projects. Data from Upper Sulfur Creek and Narco Channel Restoration projects located in Orange County indicate a FIB reduction rates ranging from 40-80%. Wetland FIB reduction rates can be expected to range from 40-70% depending on the flow rates and FIB concentrations. Dry weather flows were not analyzed in this analysis as the focus was on wet weather flows. Non storm water dry weather flows are prohibited in MS4 discharges under the current Permit. Non storm flow management measures are defined in the WQIPs in each of the watersheds.*

ATTACHMENT 2 - RESPONSE TO COMMENTS FROM THE SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD

Were any stream restoration projects reviewed as part of the literature review, or mostly constructed treatment wetlands?	Appendix D: Section 2	8	Please explain the categories of what are the considered "natural treatment systems."	Data was used from stream restoration projects in Orange and San Diego Counties. These data are however limited to dry weather flows. The data from Forester Creek indicated no reduction in FIB. We used over 200 sources of published data for stream and wetland restoration and there is very limited data on stream restoration and FIB reductions.
The in-line stream restoration project doesn't really show a floodplain because it appears all flows are designed to be contained within the trapezoid. Thus, the reader might be misled when the report is referring to benefits of a wider floodplain.	Appendix D: Section 3	11	Replace the use of "floodplain" in the scenario if the intent is to keep all flows, especially those under a 5-10 year event, within engineered channel banks.	The example project caption will be edited to read" *In-Line Stream Restoration Project – Increase Channel Capacity and Flatten and vegetate the Former Steep Concrete Side Slopes to Create More Stable System "* As shown on Figure 6, the restoration approach expands the cross section from the incised channel to create a wider channel and floodplain.
The last sentence of the paragraph beginning *"A key constraint…"* is contradictory to other statements in the report. Specifically, this paragraph implies that streams with low flows present threats to water quality, whereas in earlier statements, the report suggests that flows under 1 cfs are effectively treated with stream restoration.	Appendix D: Section 3	12	Delete the concern that natural streams are always bad for FIB. Or clarify that a good practice for protecting water quality would be to ensure intermittent streams do not become perennialized.	The sentence has been edited to read: *A consideration with either the in-stream or off-line restoration approaches is likely feasible sites will be within sensitive habitat requiring mitigation for temporary disturbance that would be define in the natural resource permits. In addition, maintenance of these sites will also require likely mitigation and restrictions on the type and timing of the maintenance.* The following sentence will be deleted: *Maintenance of these systems often require special permitting and possible mitigation for temporary impacts.*
The opening sentence says that the approach would deepen confined reaches of streams. That appears to be a typo. From earlier sections, the approach seems to simply widen a confined reach, not actually deepen it.	Appendix D: Section 6.1.1	17	Clarify the mistake because that line was used in the main CBA several times.	In some cases the channel is deepened to increase capacity for stable flows.
The modelling methods section is a little unclear about how bacteria levels would be projected. The draft report had this in Section 7.1 (p.20)	Appendix D: Section 6.2.1	19	Include a clear statement of how the bacteria counts were extrapolated from the modeled infiltration, the discuss the what affects your confidence in this approach. I think the extrapolation is explained at the bottom of page 22, but I'm not sure.	The bacteria level projections and development of baseline loads is discussed in section 7.1.
If loads from allowable exceedance days are included in the model, doesn't that underestimate the ability to achieve the TMDL targets? That was a new line not in the earlier draft.	Appendix D: Section 7.1	23	Please clarify how this affects the conclusions and relevance for TMDL compliance.	This approach was taken to assure the continuous simulation hydrologic model for the "model" sties was consistent with the set of data used for the bacteria loading model. The continuous simulation model does not differentiate allowable exceedance days. This approach is likely to be within the margin of error. The assumption that the creeks were losing streams for all the vents would have a greater sensitivity than the exceedance days, and would likely offset any under estimation of ability to achieve the target.
This section says the baseline loads are from the WQIP, is that the same basis for the In-Stream scenario? It reads as though two different baseline loads are being used for the different scenarios.	Appendix D: Section 7.2	25	Please clarify.	The baseline loads are the same for each scenario. Section 7.1 – the instream scenario also describes the baseline wet weather loads as developed for the WQIP
This section says that the Alternative 3 analysis was run based on final effluent limits. Is that different than the other alternatives?	Appendix D: Section 7.2	27	Please clarify.	This will be clarified in the updated report to clarify the scenarios and alternatives. Alternative 3 using the enterococcus load reduction goals developed for the WQIP as the target. Alternatives 1 and 2 used a target of 10% and 20% reductions to assess the sensitivity of the model.
Description of co-benefits should include dry-weather benefits.	Appendix D: Section 8	29	Add the potential dry weather benefits discussed earlier in the document.	Addressed in the comment above.
Unclear how analysis of co-benefits was conducted.	Appendix D: Section 8	29	Add a brief discussion of	Text has been added to section 8 and reduction efficiencies have been

			methodology used to estimate reductions in other pollutants.	added to appendix E
The 50% contingency cost factor doesn't show up in the CBA estimates for other projects. So, the reader might interpret that as a bias.	Appendix D: Section 9	32	Contingency cost factor should be similar for other projects in the CBA. Or, the main report should explain differences in assumptions being used to craft the various cost estimates.	The contingency cost factor of 50% is consistent with feasibility level estimates. The costs were rerun with a contingency of 25% and will be presented in the updated report.
Costs attributed to habitat mitigation for off-line tributary wetlands should be better justified. E.g., verification from the public entities controlling the parcels. And, a doubling of costs for that seems high.	Appendix D: Section 9	32	Verify the potential mitigation costs or better justify the assumptions	The GIS analysis of the public parcels included identifying areas that are classified as sensitive habitat. Most of the stream segments and areas selected for wetlands treatment are within designated sensitive habitats. Temporary disturbances of these areas will require mitigation. There will also be permanent impacts for inflow and outflow structures for the wetland projects that will require mitigation at a higher ratio. A one to one ration was selected for the costs estimate. This may be greater and therefore the cost estimates may be higher than estimated. Because these are restoration focused projects, the lower ration was assumed.

APPENDIX D: HEALTH RISK ANALYSIS REFERENCES

Human Health Risk Evaluation Methodology Summary for the San Diego Bacteria TMDL Cost Benefit Analysis

May 2017, Soller Environmental

This Appendix provides a high level summary of the technical methodology employed for the CBA to characterize the estimated relative illness level associated with recreational exposures in San Diego and southern Orange Counties during wet weather for a series of scenarios and illness endpoints.

The watersheds included in this analysis include:

- San Luis Rey
- San Marcos
- San Dieguito
- Los Penasquitos
- San Diego River
- Tecolote
- Chollas
- Scripps
- Laguna
- Aliso
- Dana
- San Juan
- San Clemente

The scenarios under study are described in the main CBA report. The scenarios evaluated in this analysis are categorized as follows:

- Stormwater scenarios;
- Stream Restoration scenarios; and
- Human Source scenarios.

The health endpoints are consistent with the previously conducted epidemiological and Quantitative Microbial Risk Assessment (QMRA) components of the Surfer Health Study (SHS). Both the epidemiological and QMRA components have been peer reviewed and are available in the scientific literature. Those citations are as follows:

Arnold, B.F., Schiff, K.C., Ercumen, A., Benjamin-Chung, J., Steele, J.A., Griffith, J.F., Steinberg, S.J., Smith, P., McGee, C.D., Wilson, R., Nelsen, C., Weisberg, S.B. and Colford, J.M., Jr. (2017) Acute Illness Among Surfers After Exposure to Seawater in Dry- and Wet-Weather Conditions. Am J Epidemiol, 1-10.

Soller, J.A., Schoen, M., Steele, J.A., Griffith, J.F. and Schiff, K.C. (2017) Incidence of gastrointestinal illness following wet weather recreational exposures: Harmonization of quantitative microbial risk assessment with an epidemiologic investigation of surfers. Water Research. In Press.

The endpoints evaluated here include:

- Gastrointestinal (GI) illness; and
- Any infectious symptoms (AIS).

Each scenario category (stormwater, stream restoration, and human source) is evaluated independently from the others. For these evaluations, the scenario under consideration is assumed to contribute all of the fecal contamination causing the observed level of illness during the SHS, and the SHS results are assumed to apply in each of the watersheds. For example, in considering the stormwater scenario, it is assumed that observed level of excess illnesses during the SHS (average ~12 illnesses per 1000) is completely attributable to stormwater flows, and that reduction in stormwater fecal contamination could yield reductions in illness levels. The analyses characterize those illness reductions. This general approach yields an upper bound estimate of health benefit for each scenario since all of the observed illnesses are effectively (numerically) available for reduction through the scenario implementation. In reality, it is likely that the fecal contamination causing illness comes from a combination of sources (such as stormwater or direct human sources). However, an integrated (stormwater/human source) contamination analysis was beyond the scope of this analysis primarily due to the myriad uncertainties associated with in-depth modeling of this sort.

The results of these analyses are can be interpreted to represent predicted average health benefits for implementation of the scenario regionally across all of the watersheds evaluated. Due to the relatively coarse-scale of the health data available for anchoring the analysis, caution is warranted in interpretation of the results – sub-regional scale implementation decisions are likely not supported by this analysis (i.e. choosing one level of BMP implementation in one watershed and a different level in another watershed). Thus, this analysis represents a streamlined, parsimonious approach to evaluate the potential benefits associated with a range of regional implementation options.

The methods used for each of the scenarios are described below.

Stormwater Scenario Evaluation

Each of the stormwater scenarios are described previously in this report. The following stormwater scenarios are included in this analysis:

- Baseline (represents current conditions);
- 2010 TMDL
- 2012 REC criteria
- Move compliance locations
- Flow-based suspensions
- Beach-specific WQO

- Adjust all beach WQO.

GI Illness Methodology

1. For Baseline conditions and each stormwater scenario (as itemized above) in each watershed, Tetra Tech provided (in an Excel spreadsheet) enterococcus (ENT) wet weather daily modeling results for the time period of 1/2/1990 through 12/31/2014. Wet weather days are defined as days of storms and within 72 hours (each day is defined as one of the following: storm, storm +1, storm +2, or storm +3).
2. These enterococci concentration values are estimated average daily concentrations at a point in the watershed that is not tidally influenced (*i.e.* above the tidal prism). Documentation of these enterococci concentrations and the corresponding locations are provided by Tetra Tech under separate cover.
3. An estimated dilution factor is derived for each watershed to estimate ENT concentrations at the recreation sites. This factor is needed since the SHS results correspond to ENT densities at the recreation sites, but the Tetra Tech modeling represents ENT densities upstream (above the tidal prism). Estimation of this watershed-specific factor is achieved by normalizing the estimated ENT values described above in (2) for the time period of January 2014 – December 2014 (the SHS time period for which the Tetra Tech water quality modeling is available), to the observed average illness level in the SHS. The SHS observed an excess (swimmer associated) illness level of 12/1000 over the duration of the study. This step involves finding a watershed specific dilution value that results in an average predicted illness level in the watershed equal to 12/1000 for the of January 2014 – December 2014 time period. The step results in a watershed-specific "dilution value" estimate during wet weather conditions that is used is all subsequent stormwater scenario illness calculations for the full water quality modeling period (1/2/1990 through 12/31/2014).
4. The dilution value from (3) is applied to each of the daily values described in (2).
5. Predicted illness levels are computed for each wet day based on the GI illness / ENT relationship from the SHS, for Baseline conditions and each of the Stormwater scenarios itemized above (See p.26 in SHS Final Report). The excel formula used to compute the GI illness level is as follows:
   - =1000*(1-EXP(-3*EXP(-6.0529+0.77249*CELL)))-7.028
   - Where "CELL" is the Excel cell that contains the log10 value of the modeled ENT divided by the "dilution value" described in (3).
6. Excel pivot tables are used to summarize geometric mean ENT concentrations and predicted additional (attributable) GI illness levels for storm days, storm days +1, storm days +2, and storm days +3.
7. Results are summarized in tabular format.

Any Infectious Symptom Methodology

The methodology for the AIS endpoint is the same as that for GI illness as described above with the following exception:

Step 5 in the GI illness analysis is replaced with: Predicted illness levels are computed for each day based on the "any infectious symptom" / ENT relationship from the SHS, for Baseline and each of the Stormwater scenarios (See p.26 in SHS Final Report). The excel formula used to compute the "any infectious symptom" illness level is as follows:

- =1000*(1-EXP(-3*EXP(-5.75707+0.9218*CELL)))-9.436
- Where "CELL" is the Excel cell that contains the log10 value of the modeled ENT divided by the "dilution value" described in (3).

Stream Restoration Scenario Evaluation

Stream restoration characterization and predicted effectiveness was conducted by ESA and transmitted to the rest of the CBA team for use in the health benefit analysis. Each of the stream restoration scenarios are described previously in this report. Scenario 2 for MS4 Permit Goals was the focus of this analysis. Based on the data and analysis provided by ESA, the watersheds included in the stream restoration analysis include[1]:

- San Luis Rey
- San Dieguito
- Los Penasquitos
- San Diego River
- Tecolote
- Chollas
- Laguna
- Aliso
- Dana
- San Juan
- San Clemente

<u>GI illness Methodology</u>

1. This analysis starts with the enterococcus wet weather daily modeling results from Tetra Tech for the time period of 1/2/1990 through 12/31/2014. These are the baseline data from the Stormwater scenario analyses above. As above for the stormwater BMP analyses, wet weather days are defined as days of storms and within 72 hours (each day is defined as one of: storm, storm +1, storm +2, or storm +3).
2. The baseline enterococci densities are reduced by the predicted average levels provided by ESA. A summary of these reductions is provided below. For these analyses, the "Medium" efficiency values were used.

[1] San Marcos and Scripps are not included here because they are small and have little potential for load reductions through restoration.

SUMMARY OF ENTEROCCOCUS LOAD REDUCTION AND COSTS UNCERTAINTY ANALYSIS
FOR THE RESTORATION APPROACH (Prepared by ESA)

Restoration Approach (Wetland Restoration – Scenario 2 for MS4 Permit Goals)
Enterococcus Load Reduction Uncertainty Analysis

Watershed	Number of Wetland Projects***	MS4 Target Reductions per WQIPs	Low*		Medium*		High*	
			% Reduction**	Total Annual Load Reduction (#colonies/yr.)	% Reduction**	Total Annual Load Reduction (#colonies/yr.)	% Reduction**	Total Annual Load Reduction (#colonies/yr.)
San Diego River (Lower San Diego HA)	65	30.8%	28.4%	1.22E+15	30.9%	1.33E+15	35.8%	1.54E+15
Chollas Creek HSA	17	28.8%	12.9%	2.17E+14	14.2%	2.39E+14	16.8%	2.83E+14
San Dieguito River (Solana Beach HA)	7	13.0%	13.5%	9.17E+13	14.7%	9.97E+13	17.0%	1.16E+14
Los Peñasquitos (Miramar HA)	48	17.8%	16.3%	4.71E+14	17.8%	5.17E+14	21.0%	6.09E+14
Tecolote Creek HA	4	18.0%	8.0%	6.69E+13	8.9%	7.43E+13	10.7%	8.92E+13
San Luis Rey River (Lower San Luis Rey HA)	109	15.8%	14.3%	5.14E+14	15.9%	5.72E+14	19.1%	6.88E+14
Laguna Hills HSA/ San Joaquin Hills HSA	2	2.50%	2.4%	6.03E+12	2.7%	6.61E+12	3.2%	7.77E+12
Aliso Creek HSA	7	5.70%	5.3%	7.09E+13	5.8%	7.67E+13	6.7%	8.85E+13
Dana Point HSA	1	2.50%	4.1%	1.17E+13	4.4%	1.25E+13	5.0%	1.41E+13
Lower San Juan HSA	64	17.60%	12.0%	3.10E+13	13.2%	3.41E+13	15.5%	4.02E+13
San Clemente HA	3	3.20%	3.9%	1.88E+13	4.3%	2.07E+13	5.1%	2.45E+13

*Uncertainty analysis based on potential range of reduction efficiency for retention mechanism of wetland systems from literature values and local data (40%-70%) – Low= 40%, Medium =50%, High = 70% removal efficiency

**Enterococcus rate of reduction that includes both infiltration and retention mechanism from wetland systems

*** Number of projects determined using 50% removal efficiency to achieve the MS4 requirements if possible. Shaded cells indicate the requirements cannot be achieved at 50% removal efficiency

3. The resultant estimated enterococci concentration values are estimated average daily concentrations at a point in the watershed that is not tidally influenced.
4. The same estimated dilution factor derived for each watershed for the Stormwater scenario calculations was also used in these calculations. This factor normalizes the estimated baseline values described above in (1) for the time period of January 2014 – December 2014, to the observed average illness level in the SHS. The SHS indicates an excess (swimmer associated) illness level of 12/1000 over the duration of the study.
5. The dilution value from (4) is applied to each of the daily values described in (3).
6. Predicted illness levels are computed for each day based on the GI illness / ENT relationship from the SHS and dilution value for each the stream restoration scenario under consideration. The same Excel formula described above for GI illness was used here.
7. Excel pivot tables are used to summarize geometric mean ENT concentrations and predicted additional GI illness levels for storm days, storm days +1, storm days +2, and storm days +3.
8. Results are summarized in tabular format.

<u>Any infectious symptom (AIS) Methodology</u>

The methodology for the stream restoration AIS endpoint is the same as that for the stream restoration GI illness analysis described above with the following exception:

Step 6 in the GI illness analysis is replaced with: Predicted illness levels are computed for each day based on the "any infectious symptom" / ENT relationship from the SHS, for Baseline and each of the stream restoration scenarios.

Human Source Scenario Evaluation

The human source BMP evaluation was conducted in a manner that was as parallel as possible to the other BMP evaluations. However, the human source scenario evaluation is different than the stormwater and stream analysis in that it relies on the SHS QMRA rather than the SHS epidemiological relationships. The QMRA is used for these analyses because fecal contamination from human sources has a more direct linkage to adverse health effects (exposure to and illness from human viruses) as compared more diffuse sources in the stormwater and stream restoration scenarios. The QMRA yields estimated average illness values associated with the human source scenarios evaluated – the Baseline conditions (current conditions) were evaluated as part of the SHS. Following is a very brief synopsis of the SHS QMRA methods. Readers interested in more detail are referred to the Water Research publication (Soller et al., 2017).

<u>SHS QMRA Methodology Overview</u>

The SHS QMRA modeled an exposure scenario that is conceptually as similar as possible to the concurrently conducted SHS epidemiological investigation that reported the associations between ocean exposure in dry versus wet weather and acute illness (Arnold et al. 2017). The SHS epidemiological component evaluated gastrointestinal illness (GI) symptoms, as defined previously, from multiple exposure sites in southern California (Colford et al. 2007, 2012, Dwight et al. 2004, U.S. EPA 2012). Exposure was limited to surfing (largely head underwater exposure which typically involves head submersion - Surfers reported immersing their head in 96% and swallowing water in 38% of the 10,081 exposure days) and the wet weather definition mimicked the County Public Health Department definitions - within 3 days of 0.1 inch (2.5 mm) or more of rain in 24 hours.

Specifically, the ingestion of water was modeled through ocean recreation during a wet weather period at a hypothetical recreational site that was constructed to be broadly representative of the SHS area in terms of ocean water quality. Pathogen data were collected from two areas influenced by wet-weather associated flows - the San Diego River Watershed discharge and the Tourmaline Watershed discharge during storm events. Fecal indicator data collected during storm events over two winters (January-March 2014 and December 2014- March 2015) were included as well so that dilution from the discharge to exposure could be modeled. All these data construct a hypothetical ocean exposure scenario that is representative of pathogen and FIB stormwater discharges in the SHS area.

Conceptually the QMRA analyses require the density of pathogens at the point of exposure, the volume of water ingested during recreation, pathogen dose -response relationships, and the fraction of infections that result in illness. The SHS collected pathogen concentration data in the stormwater discharges to provide a better chance of finding pathogen levels above detectable limits, rather than offshore (where surfing, and thus, exposure actually occurs). To characterize the estimated concentration of pathogens at the points of exposure, paired fecal indicator measurements collected at differing distances from various surfing locations and at the point of discharge were used to estimate the extent of dilution and transport effects between the stormwater discharge points and the exposure points, to characterize the estimated concentration of pathogens at the points of exposure. The volume of water ingested during recreation, pathogen dose -response relationships for a series of reference pathogens, and the fraction of infections that result in illness were derived from peer-reviewed scientific literature.

The SHS QMRA model relies on a stochastic, static QMRA methodology that estimates the daily probability of illness from pathogenic microorganisms through ingestion of water from ocean recreation (Soller and Eisenberg 2008, U.S. EPA 2014). Computations were performed in R. For each Monte Carlo iteration (N=10,000), the probability of illness associated with each pathogen for a surfing event at a given exposure point was calculated. Using this approach, the Monte Carlo approach accounted for variation in all of the input parameters. The total probability of illness (accounting for all pathogens) for a surfing event was then calculated.

<u>CBA QMRA</u>

As part of the SHS QMRA study, it was shown that human enteric viruses, in general, and norovirus, in particular, could have been a major contributor to recreational water illness during the study. This finding is consistent with analyses on US EPA's NEEAR epidemiological studies conducted in both fresh and marine waters. In this evaluation, norovirus is used as the etiologic contaminant of concern and the SHS QMRA model is used to characterize risk and risk reduction from the various human source scenarios. The following graphic from the SHS QMRA study illustrates (1) NoV risk can account for a vast majority of the predicted illness from the SHS and (2) the results of the QMRA match those from the epidemiological study quite well.

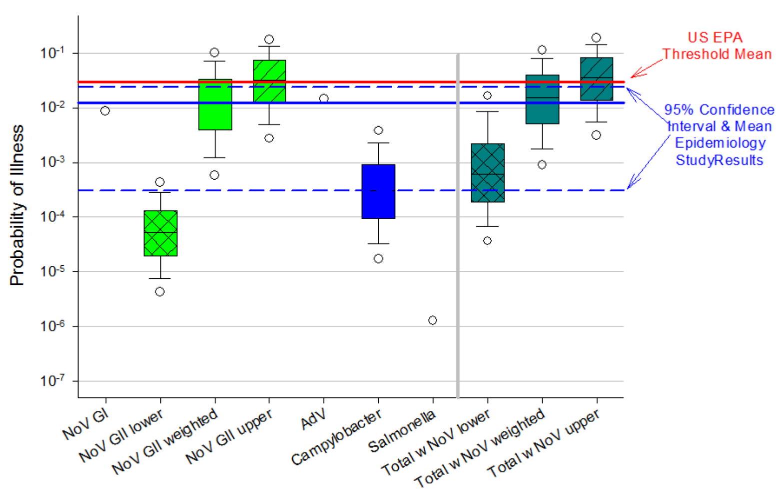

Figure 3 from Soller et al. (2017).

NoV – Norovirus; AdV – Adenovirus; lower, weighted, and upper define the approach used for NoV dose response; Total – cumulative risk from all pathogens evaluated; US EPA Threshold corresponds to 32 illnesses per 1000 recreation events

Given the findings from the SHS, the analyses for human source scenario are focused on GI illness. A scientifically defensible methodology to estimate via QMRA the level of illness for the any infectious symptom endpoint is not currently available.

The human source scenario calculations start with the engineering results provided by Brown and Caldwell which are provided under separate cover. For each watershed, human contamination is assumed to derive from a combination of the following sources (following the engineering calculations from Brown and Caldwell):

- Sewer mains;
- Sewer laterals;
- Septic systems; and
- Transient encampments.

<u>San Diego County GI illness Methodology</u>

Watersheds for which data were available to estimate the relative contribution from each of the above sources included the following watersheds in San Diego County:

- San Luis Rey
- San Marcos
- San Dieguito
- Los Penasquitos
- San Diego River
- Tecolote
- Chollas
- Scripps

1. This analysis starts with an estimate of the relative contribution from each of the above human contamination sources for each watershed. This proportion was supplied by Brown and Caldwell. An example for the San Dieguito watershed follows - the total contribution is shown under the H+M+L column (equals 100%). As indicated in the Brown and Caldwell report, these data are used to derive the human source scenario efficacy, but the individual components are highly uncertain and should not be used for implementation decisions.

	Percent Load Contribution /Reduction		
SAN DIEGUITO	H	H+M	H+M+L
Septic Systems	0%	0%	3%
SSOs	0%	0%	14%
PLSDs	0%	0%	0%
Sewer Mains	2%	4%	6%
Sewer Laterals	0%	1%	1%
Transient Population	76%	76%	76%
TOTAL	78%	81%	100%

Low confidence on individual source allocation. Not recommended for implementation actions

2. For each watershed, the SHS QMRA model is parsed into four components using the relative contributions described in (1). For each watershed, the sum of illnesses from the four components under baseline conditions is assumed to be equal to the reported SHS QMRA results.
3. In each watershed, the BMP effectiveness predicted by Brown and Caldwell is characterized, as the predicted HF183 percent reduction for the scenarios as follows (Refer to Tables above for examples)
    a. Human waste: high
    b. Human waste: high+med
    c. Human waste: high+med+low
4. In each watershed, the norovirus (NoV) density used in the SHS QMRA model was reduced in each of the four components by the same proportion of HF183 reduction reported by Brown and Caldwell in their documentation of HF183 effectiveness. Using the example provided above, in the San Dieguito watershed, the estimated HF183 reduction associated with CIPP rehabilitation of high priority site sewer mains is 2% of the total (refer to Table above). For this component of the analysis, the NoV loading to the San Dieguito watershed is also assumed to be reduced by 2% of the total watershed contribution. This methodology is based on the assumption that reduction of HF183 occurs through elimination of a specified proportion of raw sewage to the watershed under consideration. Thus, the same proportion of NoV can be assumed to be eliminated as HF183, given the assumed relatively short time and close linkage that is expected between contamination and exposure.
5. For each watershed, the QMRA model is run for the four components under the three scenarios specified in (3). The results from the four components are combined to yield the final result for the scenario.
6. The results are documented in summary tables.

<u>Orange County GI Illness Methodology</u>

Watersheds for which data were available to estimate the relative contribution from each of the above sources included the following watersheds in Orange County:

- Laguna
- Aliso

- Dana
- San Juan
- San Clemente

The Orange County GI illness methodology follows that conducted for San Diego watersheds, as described above.

Sensitivity Analyses

Sensitivity analyses were conducted for each of the three scenarios – stormwater, stream restoration, human sources. For each of these, a representative scenario was selected to determine how strongly the simulation output was impacted by changes to input parameters. In each scenario, the sensitivity analyses were conducted on three representative watersheds for one alternative scenarios considered above.

The sensitivity analyses for each of the scenarios are described below:

<u>Stormwater scenarios</u>

For the Stormwater scenarios Tetra Tech supplied the methodology and data to conduct the sensitivity analysis. The analyses are conducted for the 2010 TMDL scenario on the following three watersheds selected by Tetra Tech – San Diego River, Scripps, and San Juan.

Following is a description of the method provided by Tetra Tech:

1. Start with the raw data where risk per day is calculated
2. Sort the computed daily risks by storm day type (Storm, Storm +1, etc.)
3. Calculate the following statistics of the risks per storm day type:
    a. 5th and 95th percentiles,
    b. mean,
    c. upper/lower 95% confidence limits

The output yields risk values (illness /1000) that correspond to the mean (as presented in the base analysis described previously), upper and lower 95% confidence intervals of the mean, and 5th and 95th percentile values. Note that the 5th and 95th percentile values correspond to the whole distribution of predicted risk, whereas the confidence interval of the mean, is variance about the mean estimate.

Following is a summary of the results of these analyses:

Watershed	Scenario	Storm day	Predicted illness per 1000 Mean	Predicted illness per 1000 Mean Lower 95CL	Predicted illness per 1000 Mean Upper 95CL	Predicted illness per 1000 5th %ile	Predicted illness per 1000 95th %ile
SDR	Baseline	Storm-0	13.9	13.4	14.4	5.5	21.5
		Storm-1	11.2	10.6	11.8	2.6	19.6
		Storm-2	8.1	7.4	8.7	-0.9	17.0
		Storm-3	5.4	4.7	6.0	-2.5	15.0
	2010 TMDL	Storm-0	11.5	11.1	12.0	4.0	18.2
		Storm-1	9.1	8.6	9.6	1.5	16.5
		Storm-2	6.3	5.8	6.9	-1.6	14.3
		Storm-3	3.9	3.3	4.5	-3.1	12.4
	Scenario	Storm day	Predicted illness per 1000 Mean	Predicted illness per 1000 Mean Lower 95CL	Predicted illness per 1000 Mean Upper 95CL	Predicted illness per 1000 5th %ile	Predicted illness per 1000 95th %ile
Scripps	Baseline	Storm-0	16.7	16.0	17.3	5.7	27.4
		Storm-1	8.3	7.1	9.5	-4.4	25.0
		Storm-2	-0.6	-1.5	0.3	-4.4	18.9
		Storm-3	-3.1	-3.8	-2.4	-4.4	0.8
	2010 TMDL	Storm-0	15.8	15.2	16.5	5.2	26.2
		Storm-1	7.7	6.6	8.9	-4.5	23.9
		Storm-2	-0.8	-1.7	0.1	-4.5	18.0
		Storm-3	-3.3	-3.9	-2.6	-4.5	0.6
	Scenario	Storm day	Predicted illness per 1000 Mean	Predicted illness per 1000 Mean Lower 95CL	Predicted illness per 1000 Mean Upper 95CL	Predicted illness per 1000 5th %ile	Predicted illness per 1000 95th %ile
San Juan	Baseline	Storm-0	12.4	11.8	13.0	0.7	22.4
		Storm-1	13.1	12.4	13.8	3.0	22.1
		Storm-2	7.5	7.0	8.1	-0.2	15.3
		Storm-3	3.4	2.9	3.8	-2.0	8.1
	2010 TMDL	Storm-0	12.3	11.8	12.9	0.7	22.3
		Storm-1	13.0	12.4	13.7	2.9	22.0
		Storm-2	7.5	6.9	8.1	-0.2	15.2
		Storm-3	3.4	2.9	3.8	-2.1	8.0

Stream Restoration scenarios

ESA conducted an uncertainty analysis for the Stream Restoration scenario. That analysis is provided under separate cover. Essentially, the uncertainty analysis was based on potential ranges of reduction efficiency for the retention mechanism of wetland systems from literature values and local data (40%-70%) – Low= 40%, Medium =50%, High = 70% removal efficiency. The base analysis described above, is based on the Medium values reported. This sensitivity analysis evaluated the Low and High reduction efficiency values for the San Diego River, Los Penasquitos, and San Juan watersheds. Recall that the Scripps watershed is not included here because there is little potential for load reductions through restoration. Thus, Environmental Incentives selected the Los Penasquitos watershed to replace the Scripps watershed for these sensitivity analyses.

The analyses were conducted exactly as the base analyses were conducted except the reported Low and High removal efficiencies were used in place of the Medium removals, as were used in the base analyses. Representative results for the San Diego River Watershed are provided below:

Current Conditions Scenario		
Day	Geometric Mean Entero Concentration in Discharge (#/100ml)	Additional Illness/1000 exposure (from SHS model)
Storm	26701	13.9
Storm +1	16884	11.2
Storm +2	8858	8.1
Storm +3	4515	5.4

MS4 - LOW	
Geometric Mean Entero Concentration in Discharge (#/100ml)	Additional Illness/1000 exposure (from SHS model)
19118	11.7
12089	9.3
6342	6.5
3233	4.1

MS4 - Medium	
Geometric Mean Entero Concentration in Discharge (#/100ml)	Additional Illness/1000 exposure (from SHS model)
18450	11.5
11667	9.1
6121	6.3
3120	3.9

MS4 - High	
Geometric Mean Entero Concentration in Discharge (#/100ml)	Additional Illness/1000 exposure (from SHS model)
17142	11.1
10840	8.7
5687	6.0
2899	3.7

<u>Human Source scenarios</u>

The human source sensitivity analyses were conducted for the High Priority scenario on the following three watersheds– San Diego River, Scripps, and San Juan. These watersheds were used to provide as much consistency as possible with the stormwater and stream restoration scenarios. For these analyses, Brown and Caldwell provided percent load reduction tables for the three selected watersheds for the sensitivity analysis. For each watershed there are three tables – base, 5th percentile and 95th percentile. For example, the load reduction tables for the Scripps watershed follow (Note - Only the “H” category data are used for the sensitivity analyses)

Base	**Percent Load Reduction**		
SCRIPPS	H	H+M	H+M+L
Septic Systems	0%	0%	0%
SSOs	0%	0%	0%
PLSDs	0%	0%	0%
Sewer Mains	7%	14%	17%
Sewer Laterals	0%	[illegible]	9%
Transient Population	74%	74%	74%
TOTAL	81%	96%	100%
5th Percentile	**Percent Load Reduction**		
SCRIPPS	H	H+M	H+M+L
Septic Systems	0%	0%	0%
SSOs	0%	0%	1%
PLSDs	0%	0%	0%
Sewer Mains	9%	20%	24%
Sewer Laterals	1%	11%	13%
Transient Population	63%	63%	63%
TOTAL	73%	94%	100%
95th Percentile	**Percent Load Reduction**		
SCRIPPS	H	H+M	H+M+L
Septic Systems	0%	0%	0%
SSOs	0%	0%	0%
PLSDs	0%	0%	0%
Sewer Mains	5%	11%	15%
Sewer Laterals	0%	7%	8%
Transient Population	77%	77%	77%
TOTAL	82%	95%	100%

Low confidence on individual source allocation. Not recommended for implementation actions

Low confidence on individual source allocation. Not recommended for implementation actions

Low confidence on individual source allocation. Not recommended for implementation actions

For each of the three watersheds, Brown & Caldwell calibrated the 5th and 95th percentiles from the watershed calibration calculations and provided the tables above. They also provided the total estimated watershed HF183 loading values for these calibrations (See Table below). Details are provided in separate documentation provided by Brown and Caldwell.

Watershed	Total Average Wet Weather Day Load Contribution (copies of HF183)		
	At Reported Value	95% poisson confidence interval	5% poisson confidence interval
San Diego River	2.97E+12	4.08E+12	1.97E+12
Scripps	4.07E+11	5.43E+11	2.86E+11
San Juan Creek	5.09E+11	6.66E+11	3.72E+11

Since those total loading values varied for the sensitivity analyses from the base conditions, it was necessary to scale the provided percent reductions to the base case scenario. The numerical method was to compute the HF183 reduction associated with each "H" scenario (5th and 95th percentile scenario), and then compute the normalized percent relative to the base scenario. Those normalized percentages were the values used in the QMRA for percent reductions associated with each of the human components for the sensitivity analysis. A summary of the QMRA sensitivity analysis results follow:

WATERSHED		Normalized % Reduction - High Priority			Baseline		Base High Scenario		Lower CI High Scenario		Upper CI High Scenario	
SDR	Overall % Human Contamination Contribution	Base	Lower - 5th Percentile	Upper - 95th Percentile	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)
Septic Systems	1%	0%	0%	0%	10th %ile	0.7	10th %ile	0.1	10th %ile	0.3	10th %ile	0.0
SSOs	1%	0%	0%	0%	25th %ile	3.2	25th %ile	0.4	25th %ile	1.4	25th %ile	0.0
PLSDs	0%	0%	0%	0%	Median	15.2	Median	2.1	Median	7.1	Median	0.0
Sewer Mains	11%	4%	4%	4%	75th %ile	58.0	75th %ile	9.7	75th %ile	30.3	75th %ile	0.0
Sewer Laterals	3%	0%	0%	0%	90th %ile	136.1	90th %ile	38.0	90th %ile	91.8	90th %ile	0.0
Transient Population	84%	84%	53%	96%								
					Baseline		Base High Scenario		Lower CI High Scenario		Upper CI High Scenario	
Scripps	Overall % Human Contamination Contribution	Base	Lower - 5th Percentile	Upper - 95th Percentile	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)
Septic Systems	0%	0%	0%	0%	10th %ile	0.7	10th %ile	0.13	10th %ile	0.34	10th %ile	0.0
SSOs	0%	0%	0%	0%	25th %ile	3.2	25th %ile	0.6	25th %ile	1.6	25th %ile	0.0
PLSDs	0%	0%	0%	0%	Median	15.2	Median	3.2	Median	8.0	Median	0.0
Sewer Mains	17%	7%	6%	7%	75th %ile	58.0	75th %ile	14.9	75th %ile	33.6	75th %ile	0.0
Sewer Laterals	9%	0%	1%	0%	90th %ile	136.1	90th %ile	54.5	90th %ile	98.6	90th %ile	0.0
Transient Population	74%	74%	44%	93%								
					Baseline		Base High Scenario		Lower CI High Scenario		Upper CI High Scenario	
San Juan	Overall % Human Contamination Contribution	Base	Lower - 5th Percentile	Upper - 95th Percentile	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)	Result	Additional Illness/1000 exposure (from QMRA model)
Septic Systems	0%	0%	0%	0%	10th %ile	0.7	10th %ile	0.21	10th %ile	0.41	10th %ile	0.0
SSOs	19%	0%	0%	0%	25th %ile	3.2	25th %ile	1.01	25th %ile	1.96	25th %ile	0.0
PLSDs	0%	0%	0%	0%	Median	15.2	Median	5.0	Median	9.5	Median	0.0
Sewer Mains	19%	8%	8%	8%	75th %ile	58.0	75th %ile	22.3	75th %ile	39.0	75th %ile	0.0
Sewer Laterals	1%	1%	1%	0%	90th %ile	136.1	90th %ile	74.2	90th %ile	108.8	90th %ile	0.0
Transient Population	61%	61%	32%	92%								

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Incidence of gastrointestinal illness following wet weather recreational exposures: Harmonization of quantitative microbial risk assessment with an epidemiologic investigation of surfers

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ABSTRACT

We modeled the risk of gastrointestinal (GI) illness associated with recreational exposures to marine water following storm events in San Diego County, California. We estimated GI illness risks via quantitative microbial risk assessment (QMRA) techniques by consolidating site specific pathogen monitoring data of stormwater, site specific dilution estimates, literature-based water ingestion data, and literature based pathogen dose-response and morbidity information. Our water quality results indicated that human sources of contamination contribute viral and bacterial pathogens to streams draining an urban watershed during wet weather that then enter the ocean and affect nearshore water quality. We evaluated a series of approaches to account for uncertainty in the norovirus dose-response model selection and compared our model results to those from a concurrently conducted epidemiological study that provided empirical estimates for illness risk following ocean exposure. The preferred norovirus dose-response approach yielded median risk estimates for water recreation-associated illness (15 GI illnesses per 1000 recreation events) that closely matched the reported epidemiological results (12 excess GI illnesses per 1000 wet weather recreation events). The results are consistent with norovirus, or other pathogens associated with norovirus, as an important cause of gastrointestinal illness among surfers in this setting. This study demonstrates the applicability of QMRA for recreational water risk estimation, even under wet weather conditions and describes a process that might be useful in developing site-specific water quality criteria in this and other locations.

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1. Introduction

Epidemiology studies have historically been the standard basis for setting marine recreational water quality criteria in the United States (U.S. EPA, 1986, 2012). These studies have typically focused on beaches known to be impacted by human sources of fecal contamination from Publicly Owned Treatment Works (POTWs). The result has been water quality standards based on relationships between gastrointestinal illness and fecal indicator bacteria such as enterococci (Prüss, 1998; Wade et al., 2003).

In their most recent water quality criteria, the US Environmental Protection Agency (US EPA) recognized that not all recreational waters may be impacted predominantly by POTWs, or even exclusively by human sources of fecal contamination (U.S. EPA, 2012). This recognition acknowledges that non-human sources may have different illness risk– enterococci relationships than human sources of fecal contamination (Soller et al., 2010b). To address the difference in health risk relationships among fecal sources, the US now allows for the development of site-specific objectives using health risk (QMRA) models (U.S. EPA, 2012).

Marine beaches in southern California represent an ideal opportunity to test the new US approach of using QMRA. During the summer, ~98% of southern California shorelines meet State water quality criteria (Noble et al., 2000). During the long, dry summers, more than 175 million beachgoers each year (Schiff et al., 2003) drive an economic engine estimated at roughly $40B annually (Schiff et al., 2015). When it rains, however, the story is quite different. On average, 10-12 storms occur annually in southern California from October to April (Ackerman et al., 2005). These few, but frequently intense storms result in large volumes of surface

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runoff and substantially increased levels of enterococci at marine beaches. In fact, nearly two-thirds of beaches exceed the State water quality standards for maximum daily levels during periods of wet weather (Noble et al., 2003).

By default, most County Health Agencies routinely warn the public to stay out of the ocean for at least three days following rainstorms ≥0.1 inch (Thoe et al., 2014). Since sanitary sewer and storm sewer systems are separate in southern California, there is no treatment of stormwater prior to discharge and there are no combined sewer overflows that often plague other parts of the US. Recreational water illness estimation in southern California beaches has been carried out and reported in several previous studies (Arnold et al., 2013; Colford et al., 2005, 2007, 2012; Haile et al., 1999; Turbow et al., 2008). For example, Colford et al. (2012) found that enterococci were associated with health risks of swimming from stormwater discharges in an urban catchment area, and Turbow et al. (2008) reported results of a web-based survey that found a correlation between water quality impairment and the number of illness complaints in coastal counties. However, at this point, it is not clear the extent to which the enterococci associated with wet weather stormwater discharges are of human origin, and there are limited data available to characterize wet weather health risks.

Although most Southern California beachgoers tend to stay out of the water during the cold, rainy season, surfers are a notable exception. Thousands of surfers frequent beaches year round, attracted to the especially sought-after conditions that follow storms. In fact, a coalition of Southern California beach managers recently funded a first-of-its-kind epidemiological and QMRA study to quantify the adverse health risks associated with entering coastal waters following storm events (Surfer Health Study - SHS) (Arnold et al., 2017). The epidemiological portion of the SHS surveyed 654 surfers (of ages 18 and over due to ethics considerations as explained in Arnold et al., 2017) about their ocean exposure and illness symptoms through internet and smartphone apps, logging 10,081 surfing sessions and making it one of the largest beach epidemiology studies in the last 30 years.

The goal of the QMRA portion of the SHS, presented here, was to model the risk of gastrointestinal (GI) illness associated with wet weather marine water recreational exposures in San Diego County, CA. There are several factors that make this study unique: 1) this is the first QMRA conducted in conjunction with an epidemiologic study at a marine beach on the west coast of the US; 2) the study focuses on wet weather associated stream flows affecting coastal nearshore waters; and; 3) we are able to compare our model results with the concurrently conducted recreational water epidemiological study (Arnold et al., 2017).

2. Methods

2.1. QMRA exposure scenario

We modeled an exposure scenario that is conceptually as similar as possible to the concurrently conducted epidemiologic study that reported the associations between ocean exposure in dry versus wet weather and acute illness (Arnold et al., 2017). The SHS evaluated gastrointestinal illness (GI) symptoms, as defined previously, from multiple exposure sites in southern California (Colford et al., 2007, 2012; Dwight et al., 2004; U.S. EPA, 2012). Exposure was limited to surfing (which typically involves head submersion - Surfers reported immersing their head in 96% and swallowing water in 38% of the 10,081 exposure days) and the wet weather definition mimicked the County Public Health Department definitions - within 3 days of 0.1 inch (2.5 mm) or more of rain in 24 h.

Specifically, we modeled the ingestion of water through ocean recreation during a wet weather period at a hypothetical recreational site that was constructed to be broadly representative of the SHS area in terms of ocean water quality. Pathogen data were collected from two areas influenced by wet-weather associated flows, the San Diego River Watershed discharge and the Tourmaline Watershed discharge during storm events between December 2014 and March 2015 (Fig. 1). Fecal indicator data collected during storm events over two winters (January–March 2014 and December 2014–March 2015) were included as well so that dilution from the discharge to exposure could be modeled. All these data construct a hypothetical ocean exposure scenario that is representative of pathogen and FIB stormwater discharges in the SHS area.

Conceptually the QMRA analyses require the density of pathogens at the point of exposure, the volume of water ingested during recreation, pathogen dose-response relationships, and the fraction of infections that result in illness. As described by Steele et al. (2016), pathogen concentration data were collected in the stormwater discharges to provide a better chance of finding pathogen levels above detectable limits, rather than offshore (where surfing, and thus, exposure actually occurs). To characterize the estimated concentration of pathogens at the points of exposure, we used paired fecal indicator measurements collected at various surfing locations and at the point of discharge so we could estimate dilution and transport effects between the stormwater discharge points and the exposure points.

2.2. QMRA model parameters

2.2.1. Reference pathogens

The reference pathogens in this study include norovirus (NoV), adenovirus (AdV), enterovirus, *Campylobacter jejuni*, and *Salmonella enterica*. Together these pathogens make up a large portion of potentially waterborne gastrointestinal illnesses from known pathogens in the US (calculated based on data from Mead et al. (1999) and Scallan et al. (2011) and consistent with findings from Hlavsa et al. (2014, 2015)), are representative of other pathogens potentially of concern from this waterborne exposure route (Soller et al., 2010a, 2010b; U.S. EPA, 2010), and have corresponding dose-response relationships in the peer-reviewed literature (Crabtree et al., 1997; Haas et al., 1999; Medema et al., 1996; Messner et al., 2014; Teunis et al., 2008). The use of reference pathogens is an accepted practice in the field of QMRA (Regli et al., 1991; Roser and Ashbolt, 2007; Schoen et al., 2011; Soller et al., 2003; Soller and Eisenberg, 2008; U.S. EPA, 2012) to represent the potential adverse health effects of members of each microbial group as well as the infectivity of known and unknown members of each microbial group (WHO, 2004).

2.2.2. Pathogen and fecal indicator density

Sample collection and processing is described in Steele et al. (2016). Briefly, time-weighted composite Tourmaline Watershed discharge and San Diego River Watershed discharge stormwater samples were collected during the first 6–12 h of rainfall, and then daily grab samples were collected for tailing flows in the following 72 h following the initial rainfall (Fig. 1). In total, 6 storm events ranging in size from <0.25 cm to >25 cm were sampled over the 2013–14 and 2014–15 wet seasons. Stormwater samples were processed for fecal indicator bacteria using standard methods. Viral RNA and DNA, and bacterial DNA were extracted using commercial kits (Steele et al., 2016). *Enterococcus* and human marker (HF183) were quantified using a previously described digital PCR assay (Cao et al., 2015). AdV, enterovirus, human NoV genotypes I and II were quantified using digital PCR and digital RT-PCR assays (da Silva et al., 2007; Gregory et al., 2006; Jothikumar et al., 2005). *Salmonella* spp. were quantified using digital PCR assays adapted from

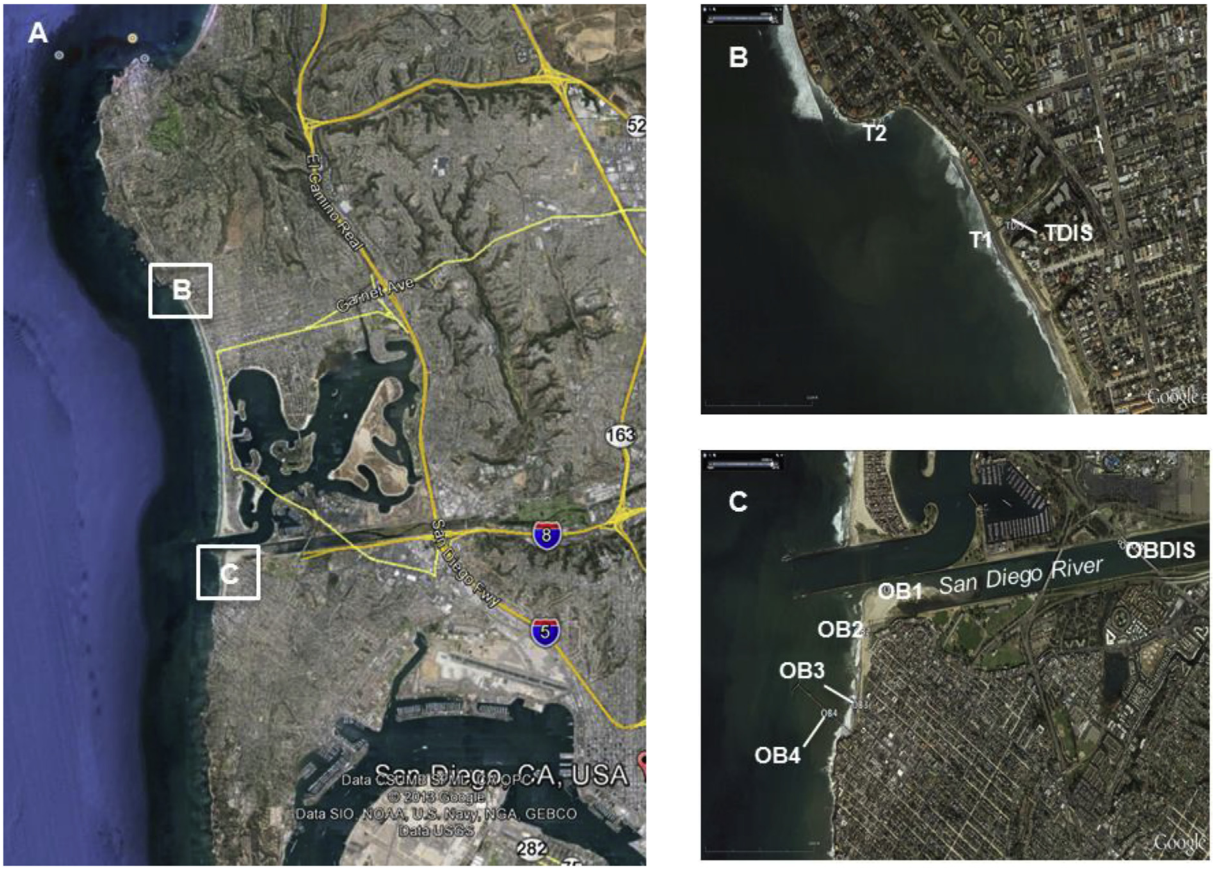

Fig. 1. (A) Map of study area showing Tournaline (Box B) and Ocean Beach (Box C) sampling locations (B) Inset of Tourmaline Watershed discharge and (C) Inset of San Diego River Watershed discharge.

QPCR assays that targeted pathogenic and non-pathogenic *Salmonella* spp. (Cao et al., 2016; Gonzalez-Escalona et al., 2009; Malorny et al., 2004, 2008). These genus-level assays targeted genes coding for proteins involved in invasion of intestinal epithelial cells by pathogenic Salmonella (*inv*A) and involved in anaerobic respiration (ttr). *Campylobacter* spp. were quantified using a genus-wide digital PCR assay (Cao et al., 2016; Lund et al., 2004; Steele et al., 2016). Samples which were identified as containing *Campylobacter* using the genus-wide assay were investigated using single-copy gene digital PCR assays specific to *C. coli* and *C. jejuni* that were adapted from QPCR assays (He et al., 2010; LaGier et al., 2004; Vondrakova et al., 2014). All quantifications had to meet minimum quality standards (Cao et al., 2015).

2.2.3. Volume ingested

A statistical distribution for the volume of water ingested was derived based on a pilot study of recreational swimmers in an outdoor community swimming pool (Dufour et al., 2006). For this analysis, we assume that surfers ingest similar amounts of water that occurred during swimming in swimming pools (Stone et al., 2008). The best-fit volume distribution (in mL) is log-normal with natural log (ln) mean (2.92) and ln standard deviation (1.43) (Dufour et al., 2006; Soller et al., 2007; U.S. EPA, 2010). The median value of this distribution is 0.0186 L. The ingestion volume distribution is based on data from adults and children ($\leq$18 years of age) combined (Dufour et al., 2006). Since the SHS focused on adults >18 yrs of age, we based our ingestion distribution on data from adults in Dufour et al. (2006) and truncated the volume ingested distribution at 0.06 L. The upper end of this distribution is greater than any value observed for adults (>18 yrs of age) in the Dufour et al. study.

2.2.4. Dose-response relationships and probability of illness given infection

The dose-response relationships and conditional probabilities of illness given infection are presented in Table 1 (Atmar et al., 2008, 2014; Crabtree et al., 1997; Haas et al., 1999; Medema et al., 1996; Messner et al., 2014; Teunis et al., 2008). We chose the dose-response *Campylobacter* relationship that was derived from adults (Medema et al., 1996) rather than the more recent relationship that includes children (Teunis et al., 2005), since children were excluded from the current study (Arnold et al., 2017). The use of these relationships and the conditional morbidity probabilities is consistent with prior work (Schoen et al., 2011; Soller et al., 2010a, 2010b, 2015a; Viau et al., 2011).

Currently, there is not universal agreement in the risk assessment field regarding the optimal dose-response relationship for NoV (Schmidt, 2015; Van Abel et al., 2017). Following the best practices recommended by Van Abel et al. (2017), we characterized risk using multiple dose-response models that represent an upper and lower bound of predicted risk over the range of predicted doses. The upper bound of the predicted risk is based on the hypergeometric dose-response relationship along with an assumption of disaggregation of the norovirus in the environment (Teunis et al., 2008). This is the most commonly used model in the literature (Van Abel et al., 2017), but has been questioned since the mechanistic dose-response relationship relies on assumptions that may or may not be valid (Schmidt, 2015). Moreover, the extent to

Table 1
Dose-response models and parameter values.

Reference Pathogen	Distributional Form	Parameter of Distribution	Parameter Values	Units	Reference	Morbidity
Norovirus (G1 & G2) (upper bound)	Hypergeometric	alpha beta	0.04 0.055	Genome copies	Teunis et al., 2008	0.6
Norovirus (G1 & G2) (lower bound)	Fractional Poisson	P u	0.72 1106	Genome copies	Messner et al., 2014; Atmar et al., 2008, 2014	0.6
Adenovirus	Exponential	r	0.4172	PFU	Crabtree et al., 1997	0.5
Campylobacter jejuni	Beta-Poisson	alpha beta	0.145 7.59	CFU	Medema et al., 1996	0.28
Salmonella enterica	Beta-Poisson	alpha beta	0.3126 2884	CFU	Haas et al., 1999;	0.2

which NoV are aggregated or disaggregated in environmental waters is unknown. The lower bound is generated using a fractional Poisson model (Messner et al., 2014) along with an assumption of aggregation of NoV in environmental waters. This model along with the aggregation assumption roughly aligns with the majority of the available dose-response models in the predicted dose range and can be viewed as an empirical fit to much of the available dose-response data (Van Abel et al., 2017).

To evaluate the model results to the sensitivity of the NoV dose-response relationship selection, we developed and evaluated a set of plausible approaches for modeling of the NoV dose-response relationship. That set included the use of: a) the lower bound NoV infectivity model; b) randomly weighting the lower and upper bound models using uniformly distributed weights (weighted model); c) randomly sampling from a log-uniform distribution where the lower and upper limits of the distribution are set to the logarithm of the lower and upper bound risks (loguniform risk model); d) randomly sampling either the weighted or loguniform risk model; e) randomly sampling either the lower or upper bound model; f) randomly sampling either the lower, upper, weighted, or log uniform risk model (Sample 4); and g) the upper bound NoV infectivity model. The weighted and the loguniform model take on the full uncertainty of the available dose-response data in linear and log space, respectively. Model (e) randomly selects the lower or upper feasible bounds of the dose-response data, and Models (d) and (f) are composite models that essentially result in average values from simpler models. We used this set of models to evaluate a feasible spectrum of NoV dose-response relationships, with the understanding that the epidemiological portion of the investigation provided a unique opportunity to conduct this evaluation.

2.2.5. Pathogen fate and transport — estimates of dilution between discharge and exposure

We evaluated dilution of discharge waters through the use of paired enterococci data for the historical beach monitoring sites, and the San Diego River and Tourmaline Watershed discharges collected at approximately the same time on the same day. We assumed that dilution alone accounted for differences in concentrations of enterococci at varying distances from the point of discharge. Using paired data from the discharge points and monitoring stations, we fit statistical distributions to the estimated dilution values at each site for each of the 44 wet weather days during which pathogen data were collected. Since enterococci can be found in sediment and sand, it is possible that this method under-estimates dilution of human pathogens in storm water, since they do not have a sand/sediment source as enterococci does.

2.2.6. Assumptions used to develop the exposure scenario

Consistent with prior work, we employed a series of assumptions to conduct the modeling (Schoen and Ashbolt, 2010; Soller et al., 2010a, 2010b, 2015b). We assumed that exposure occurs in the ocean rather than in the discharges. We assumed that pathogen loading to the ocean derives from the discharges and that paired culturable enterococci data (discharge and standard monitoring sites) can be used to estimate pathogen dilution between the discharge and the exposure sites. Because the time between discharges and exposures are assumed to be relatively short (minutes to hours), we assumed that the contamination is fresh and thus, we assumed no die-off of pathogens between discharge and exposure. No adjustment for the recovery of pathogens in the analytical methods was employed. We assumed that pathogen densities in units of genome copies/100 mL represent viable and infectious pathogens, and that the monitored strains/genogroups are consistent with dose-response relationships (Steele et al., 2016). For NoV, we assumed that G1 and G2 strains exhibit similar infectivity. For *Campylobacter spp*., we assumed that only *C. jejuni* and *C. coli* are infectious to humans, and that other strains are not. We also assumed that each *Campylobacter* copy approximates one colony forming unit (CFU) consistent with the dose-response relationship because *Campylobacter* spp. are presumed to be fragile in the environment and decay quickly with exposure to UV (Sinton et al., 2007) at similar rates to *Bacteroidales* in freshwater (Bae and Wuertz, 2012); in addition, we used single copy gene assays which correlated to CFUs from cultures (He et al., 2010; LaGier et al., 2004; Vondrakova et al., 2014). Finally, we assumed that surfing and recreation (i.e. swimming) result in similar levels of water ingestion because little data are available to quantitatively characterize the volume of water ingested during surfing (Dorevitch et al., 2011; Dufour et al., 2006; Schijven and de Roda Husman, 2006; Stone et al., 2008).

2.3. Numerical simulations

We used a stochastic, static QMRA methodology to estimate the daily probability of illness from pathogenic microorganisms through ingestion of water from ocean recreation (Soller and Eisenberg, 2008; U.S. EPA, 2014). Computations were performed in R. For each Monte Carlo iteration (N = 10,000), the probability of illness ($Pill_{p,b}$) associated with pathogen (p) for a surfing event at a given exposure point was calculated as:

$$Pill_{p,b} = DR_p\left(V^*C_{p,b}{}^*Dil_b\right)^*M_p \tag{1}$$

where

DR_p is the dose-response function for pathogen p
V is the volume of water ingested
$C_{p,b}$ is the pathogen concentration (i.e. density) at discharge point b
Dil_b is the estimated dilution from the discharge point b to the exposure point

M_p is probability of illness given infection for pathogen p

Using Eq. (1), the Monte Carlo approach accounted for variation in V, $C_{p,b}$, and Dil_b. The total probability of illness ($TPill_b$) (accounting for all pathogens) for a surfing event was calculated as:

$$TPill_b = 1 - \prod_p \left(1 - Pill_{p,b}\right) \quad (2)$$

2.4. Data analysis

Pathogen and fecal indicator data were tabulated and fit to statistical distributions. We developed statistical distributions to characterize the concentration of each of the pathogens in the discharges and in the hypothetical combined discharge. The combined discharge represents overall stormwater discharge water quality in the SHS area. Briefly, two types of distributions were used — bimodal and lognormal. For pathogens in which greater than 50% of the observations were reported below detectable limits, we used a bimodal distribution. For the bimodal distribution, the probability of a zero pathogen density was set equal to the proportion of observations reported below detectable limits. Other choices could have been made for observations below detectable limits, however, for the sake of parsimony, in this case we chose to set those values at zero. This choice is justified because once dilution is accounted for (see above), there is little practical difference, in this case, between the various detection limits and an assumption of a zero density. For the second mode, the complement was set to a loguniform distribution with bounds equal to the minimum and maximum of the observed detectable densities (Eisenberg et al., 2005; Soller et al., 2006; Soller and Eisenberg, 2008). For pathogens in which a smaller proportion of observations were reported below detectable limits, a lognormal distribution was used using the best fit parameter values derived as maximum likelihood estimates (U.S. EPA, 1991).

The epidemiological portion of the SHS used water quality data from daily monitoring of culturable enterococci taken at representative monitoring sites at the sentinel beaches (Fig. 1) (Arnold et al., 2017). In cases where a single exposure occurred within the 3-day wet weather timeframe, the geometric mean enterococci level for that day was used to represent the water quality for that exposure. In cases where multiple exposures occurred within a 3-day time frame, the daily geometric mean enterococci levels were weighted by time spent in the ocean each day to generate a single average estimate of water quality for that exposure period. Use of monitoring data in this way indicates that the water quality characterization is intended to be reasonably representative of the water quality at each of the sites for the entire day (or days) in which those exposures occurred. Data from this component of the study are consolidated and used in the QMRA model in a manner to be consistent with that interpretation.

We used a Classification and Regression Tree (CART) algorithm to determine which parameters or combinations of parameters in the model impacted the model output most strongly (Steinberg and Colla, 1997). In general terms, the CART algorithm categorizes the 10,000 simulation iterations into distinct bins, in this case with respect to $TPill_b$. These bins are based on specific model parameter combinations which define a tree structure that highlights combinations of model parameters with the strongest influence on the model output (Eisenberg and McKone, 1998; Soller and Eisenberg, 2008).

3. Results

3.1. QMRA model parameter results

3.1.1. Pathogen and indicator density

The FIB data and the HF183 data collected during storm events in the San Diego River and Tourmaline watershed discharges are described in detail by Steele et al. (2016). High levels of total coliform, *E. coli* and enterococci were observed in both sites. Observed median levels of enterococci exceeded 10^3 MPN/100 mL in both stormwater discharges. The observed stormwater pathogen data from the discharges are summarized in Table 2. Nov G1 was below detectable limits in 93% (41/44) of the samples. NoV G2 was present much more commonly (<MDL in ~15% of samples) and found at median levels of ~100 copies/100 mL. Enterovirus, AdV, and *salmonellae* were reported < MDL in the vast majority of samples. *Campylobacter spp.* were always observed above the MDL in the San Diego River discharge and observed above the MDL in the Tourmaline discharge in about half of the samples (10/21).

The statistical distributions used to characterize the concentration of each of the pathogens in each of the discharges and the constructed combined discharge are presented in Table 3. The best fit lognormal model for human infectious *campylobacters* (*C. jejuni* and *C. coli*) has GM = 40 copies/100 mL with 98th percentile = 450 copies/100 mL. This distribution was used for the QMRA modeling.

3.1.2. Dilution estimate results

Our modeling of the paired enterococci data indicated that lognormal distributions fit the observed dilution data reasonably well and that dilution varied substantially within and between

Table 2
Summary results of human pathogens in stormwater discharges (gene copies/100 mL).

Pathogen	Site	N	# < MDL	Median	Mean	Max
Norovirus G1	San Diego River Discharge	23	21	1	3	32
	Tourmaline Watershed Discharge	21	20	1	23	465
Norovirus G2	San Diego River Discharge	23	1	135	158	495
	Tourmaline Watershed Discharge	21	6	70	77	231
Enterovirus	San Diego River Discharge	23	23	1	1	1
	Tourmaline Watershed Discharge	21	21	1	1	1
Adenovirus	San Diego River Discharge	23	18	1	6	42
	Tourmaline Watershed Discharge	21	18	1	3	16
Campylobacter	San Diego River Discharge	23	0	320	457	1136
	Tourmaline Watershed Discharge	21	11	1	283	3072
Salmonella invA	San Diego River Discharge	23	17	1	3	14
	Tourmaline Watershed Discharge	21	19	1	6	90
Salmonella ttr	San Diego River Discharge	23	23	1	1	1
	Tourmaline Watershed Discharge	21	19	1	6	83

Note: For summary purposes, values < MDL computed at 1 copy/100 mL.

Table 3
Summary of pathogen density distributions in San Diego river and Tourmaline watershed discharges.

Pathogen	Site	N	# <MDL	Distribution	Parameter 1	Parameter 2
Norovirus G1	San Diego River Discharge	23	21	Bimodal P(0) = 0.913 P(loguniform) = 0.087	Lower = 11	Upper = 32
	Tourmaline Watershed Discharge	21	20	Bimodal P(0) = 0.952 P(loguniform) = 0.048	Lower = 465	Upper = 465
	Constructed Combined Discharge	44	41	Bimodal P(0) = 0.932 P(loguniform) = 0.068	Lower = 11	Upper = 465
Norovirus G2	San Diego River Discharge	23	1	Lognormal (GM, 97.5th %ile)	135	600
	Tourmaline Watershed Discharge	21	6		70	350
	Constructed Combined Discharge	44	7		92.5	500
Enterovirus	San Diego River Discharge	23	23	Not modeled - all values reported < MDL	NA	NA
	Tourmaline Watershed Discharge	21	21			
Adenovirus	San Diego River Discharge	23	18	Bimodal P(0) = 0.783 P(loguniform) = 0.217	Lower = 16	Upper = 42
	Tourmaline Watershed Discharge	21	18	Bimodal P(0) = 0.857 P(loguniform) = 0.143	Lower = 12	Upper = 16
	Constructed Combined Discharge	44	36	Bimodal P(0) = 0.818 P(loguniform) = 0.182	Lower = 12	Upper = 42
Campylobacter	San Diego River Discharge	23	0	Lognormal (GM, 97.5th %ile)	320	2000
	Tourmaline Watershed Discharge	21	11	Bimodal P(0) = 0.524 P(loguniform) = 0.476	Lower = 14	Upper = 3072
	Constructed Combined Discharge	44	11	Lognormal (GM, 97.5th %ile)	100	5000
Salmonella invA	San Diego River Discharge	23	17	Bimodal P(0) = 0.793 P(loguniform) = 0.261	Lower = 6	Upper = 14
	Tourmaline Watershed Discharge	21	19	Bimodal P(0) = 0.905 P(loguniform) = 0.095	Lower = 8	Upper = 90
	Constructed Combined Discharge	44	36	Bimodal P(0) = 0.818 P(loguniform) = 0.182	Lower = 6	Upper = 90
Salmonella ttr	San Diego River Discharge	23	23	Not modeled - almost all values reported < MDL	NA	NA
	Tourmaline Watershed Discharge	21	19			

Note: For summary purposes, values < MDL computed at 1 copies/100 mL.
Campylobacter results refer to total *Campylobacter* observed.

monitoring sites (Fig. 2). The median dilution factors (value of 50 percent in Fig. 2) among ocean monitoring sites ranged from 25 to 150 relative to the discharges. We used these median values in the QMRA for the lower and upper bounds of a triangular distribution, with a most likely value of 85, which was the median among all sites.

3.2. QMRA simulation results

The QMRA analyses estimate wet weather risks from recreational exposure in the ocean impacted by stormwater. The QMRA analyses used the fitted pathogen distributions for the "combined discharge" including the infectious Campylobacter distribution, a lognormal ingestion distribution truncated at 60 mL, a triangular distribution of dilution, and reported morbidity and dose-response relationships including a range of possible interpretation of the NoV dose-response relationship. A summary of the QMRA simulation results is presented in Table 4 along with the estimated excess risk of GI illness from wet weather ocean exposure (excess cases per 1000 people compared to unexposed periods) yielded by the epidemiological study for comparison (Arnold et al., 2017). The lower and upper bound NoV dose-response models are presented in Table 4, along with the series of approaches to account for the full spectrum of uncertainty associated with the NoV dose-response relationship (Atmar et al., 2014; Teunis et al., 2008; Van Abel et al., 2017).

The weighted NoV dose-response model most closely described the potential health risks reported in the SHS (Table 4) (Arnold et al., 2017). The weighted NoV dose-response model is a parsimonious approach that effectively models a dose-response "cloud" rather than a simple line by acknowledging and taking on all of the known uncertainty in the various previously published dose-response relationships.

The QMRA results also strongly suggest that NoV could be an important cause of gastrointestinal illness among surfers in this setting (Fig. 3) with other pathogens predicted to contribute a small fraction of the total predicted risk. The SHS observed illness levels and the QMRA predicted risk levels during wet weather are below the US EPA threshold mean of 32 (excess) illnesses/1000 (U.S. EPA, 2012).

The confidence interval of the QRMA results is wider than that reported by the epidemiological study. Approximately 75% of the QMRA simulations produced risk estimates that were below the upper 95% CI of the SHS. The CART analysis indicated that the simulation risks above the upper 95% CI of the SHS results occur when one or more of three model parameters (volume of water ingested, NoV density, and NoV dose-response) are in the upper percentiles of their respective distributions. The highest predicted illness levels occurred when all three of these model parameters occurred in the upper percentiles of their respective distributions

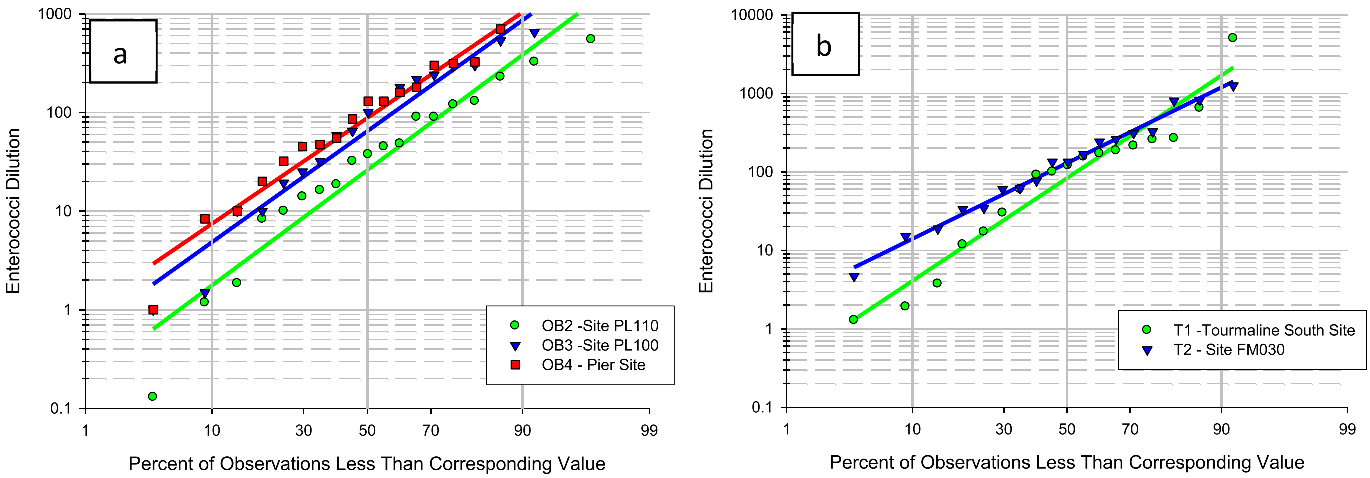

Fig. 2. Enterococci dilution estimates for a) San Diego River Watershed - Ocean Beach and b) Tourmaline Monitoring Sites. Site locations defined in Fig. 1.

Table 4
QMRA results from all monitored pathogens—stormwater-impacted ocean exposure.

Approach	Predicted or Observed Illnesses/1000		
	5th %ile	Median	95th %ile
Epidemiology results	0.3	12.2	24.0
Lower bound NoV	0.0	0.6	25.2
Randomly weighted NoV	0.5	15.5	146.2
Loguniform risk NoV	0.0	2.3	77.3
Sample weighted/loguniform	0.0	7.0	121.2
Sample lower/upper	0.0	7.1	120.6
Sample 4	0.0	6.8	157.7
Upper bound NoV	1.9	36.0	226.2

simultaneously.

4. Discussion

To our knowledge this is the first study in which an epidemiological investigation and QMRA were conducted concurrently in temperate marine water not impacted by POTW effluent. A QMRA was conducted concurrently with an epidemiological study at a tropical marine location and helped to interpret the empirical results (Soller et al., 2015b). Colford et al. (2012) found an increased risk of swimming-associated gastrointestinal illness at an urban-runoff affected beach in Southern California and found that when the source of FIB flowed freely (berm open), several traditional and rapid methods for Enterococcus spp. measurement were strongly related to illness. When the source of FIB was weak or diffuse (berm status not taken into account) fewer significant associations with illness were seen. These observations by Colford et al. can be considered to be generally consistent with the results reported by Arnold et al. (2017) and this current QMRA study – pathogenic microorganisms can be present in urban-runoff and have the potential to cause human illness through recreation. Dorevitch et al. (2015) evaluated indicator microbes, protozoan pathogens, and turbidity as predictors of gastrointestinal illness following a cohort study of incidental contact water recreation at wastewater impacted freshwater sites in the Chicago, USA area. Although a QMRA was previously conducted on the Chicago area waterway

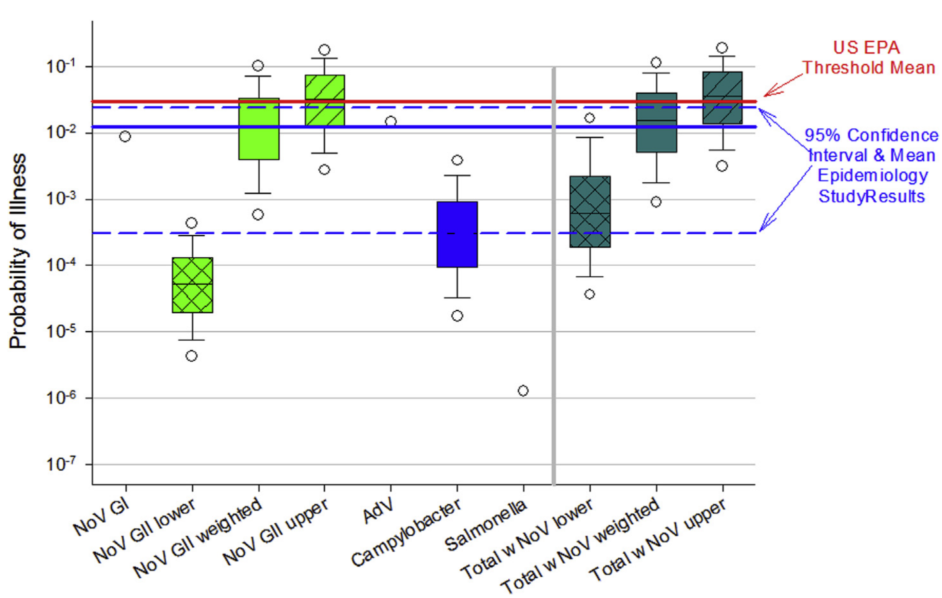

Fig. 3. Risk of illness from wet weather ocean exposure NoV – Norovirus; AdV – Adenovirus; lower, weighted, and upper define the approach used for NoV dose response; Total – cumulative risk from all pathogens evaluated; US EPA Threshold corresponds to 32 illnesses per 1000 recreation events.

system (Rijal et al., 2011), the epidemiological and QMRA risk estimates were substantially different. Tseng and Jiang (2012) used QMRA based on enterococcus and fecal coliform data without an epidemiological study to compare health risks associated with surfing during dry weather and storm conditions at several popular Southern California beaches. Their results also showed elevated levels of gastrointestinal illness risks from surfing post-storm events, but predicted higher risks than are documented here. The differences in predicted risks may be attributable to the difference in methods employed – whereas Tseng and Jiang (2012) used fecal indicator/health relationships to estimate health risks, our results are based on empirical pathogen data collected specifically for this study.

The average illness rates predicted by the QMRA for the present study were in broad agreement with the SHS epidemiological results from the same location (Arnold et al., 2017). Average illness rates were nearly identical, but the study results differed in two aspects. The QMRA provided wider confidence estimates, an artifact of taking on the full range of uncertainty in the model and not just measured uncertainty about the mean. In contrast, the epidemiology study lacked the ability to confirm the etiologic agent(s); doing so was not part of the study design as laboratory analyses are resource intensive. Epidemiological studies do not typically include specific pathogen monitoring (Fleisher et al., 2010; Griffith et al., 2016; Wade et al., 2010). The QMRA was able to predict that norovirus, or other pathogens associated with norovirus, is an important cause of gastrointestinal illness among surfers in this setting. Human enteric viruses are also suspected to be of concern in marine and freshwaters impacted by wastewater effluent sources (Cabelli et al., 1982; Soller et al., 2010a) and tropical waters impacted by dry weather run-off (Viau et al., 2011).

This study had several important limitations. First, the population evaluated was a relatively narrow component of the general population (Arnold et al., 2017). Second, the geographic extent of the study was limited to San Diego County. Third, the time period evaluated included only wet periods during the winters of 2014 and 2015, and the subsequent 72-hr. time periods that are typically of concern locally. And finally, infectious disease dynamics including person-to-person transmission of infection and immunity were not included (Hethcote, 1976; Soller and Eisenberg, 2008). Although each of these factors is reasonable and justifiable, their implications will need to be carefully evaluated as potential management decisions and remedial actions within the watershed are considered.

There are several important lessons we learned during the conduct of this evaluation. First, we wanted to evaluate the importance of uncertainty from NoV dose-response model selection. Several researchers have published dose-response relationships, infectivity data, and perspectives on issues with prior work (Atmar et al., 2014; Messner et al., 2014; Schmidt, 2015; Teunis et al., 2008; Van Abel et al., 2017). Rather than selecting one dataset or dose-response relationship over another from those reported in the literature, we chose to model the dose-response relationship in a number of ways to take on the existing uncertainty in the dose-response model selection. The approach that performed the best relative to the SHS observed results, essentially modeled the dose-response as a cloud, rather than as a line. The downside to this approach was that it yielded a large uncertainty range in our results, particularly in iterations where high infectivity was matched with large ingestion volumes and/or high NoV densities. This was most apparent in the CART analysis. We also realized the interdependence of our assumptions on our results. For example, if the fecal contamination was not fresh, as we assumed, our predicted results would have been different, and may have influenced our interpretation about the most appropriate dose-response model. Nevertheless, in the absence of new information, our recommendation would be that future QMRAs addressing recreational risks from exposures that include NoV, consider the same approach as we used in this study.

Second, *a priori*, we believed that dilution from the discharges to the points of exposure would be a critically important factor in our evaluation. Given the spectrum of choices to conduct fate and transport modeling, and the potential associated costs and levels of effort, we chose a simple approach over more complex and costly alternatives. There are limitations to our choice. Notably, our small sample size of water quality data limits our ability to critically evaluate conditions which require parsing our data or results into smaller components. For example, we attempted to model risks from various storm sizes to determine if a differential risk exists between small, medium, or large storms. We found our small sample size and lack of dilution fidelity limited our ability to match or refine the estimates from the epidemiological study with respect to storm size (Arnold et al., 2017). Furthermore, given that our dilution estimates are site-specific, this component of our work should not be applied to other locations or settings. Our efforts, do, however, highlight the need to critically evaluate the necessary complexity of fate and transport modeling for other locations with similar contamination dynamics and where QMRA is used to estimate potential human health risks from recreational exposures to the contaminated waters.

Third, we found that the combined use of sanitary survey data, fecal indicator monitoring, human marker monitoring, and pathogen monitoring was a reasonable and prudent undertaking. The resources required for this total effort were a small fraction of the potential costs associated with remediation and/or water quality criteria refinement. This general approach which was employed, tested, and vetted here can serve as a template for future work in other locations, both in conjunction with or in the absence of a simultaneously conducted epidemiological study.

Finally, we found that transparent discussion of the results from this study is yielding a healthy and fruitful conversation about potential management decisions and remedial actions within the watershed. Our findings highlight an interesting and challenging management situation. On one hand, human enteric viruses were found in the discharges and are predicted to be important etiologic agents. The use of HF183 as a human marker confirmed the presence of human contamination. On the other hand, the predicted average illness levels were substantially lower at substantially higher levels of culturable enterococci (and other FIB) when compared to the sites characterized by EPA during the NEEAR study (U.S. EPA, 2012; Wade et al., 2006, 2008, 2010). In fact, because the predicted and observed illness levels in this study are shorter term predictions than specified by the federal water quality criteria, they likely represent a higher than average illness scenario for a 30-day period since they are only based on wet weather exposures (and wet weather is unlikely to persist for any continuous 30-day period in southern California). Taken together this interesting set of circumstances highlights the potential utility of the QMRA to inform future regional decision-making as managers consider how to move forward in a manner that ensures public health protection through the efficient allocation of limited public resources.

5. Conclusions

This study provided QMRA estimates of GI illness from recreational exposure to stormwater impacted marine beaches due to municipal separate storm sewer system discharges not known to be impacted by POTW effluents. The QMRA estimates matched empirical measurements from the concurrent epidemiology study well. Sensitivity analysis indicated several factors that QMRA practitioners at marine beaches can use for future applications, including utilizing the full range of Norovirus dose-response uncertainty.

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Wade, T.J., Calderon, R.L., Brenner, K.P., Sams, E., Beach, M., Haugland, R., Wymer, L., Dufour, A.P., 2008. High sensitivity of children to swimming-associated gastrointestinal illness: results using a rapid assay of recreational water quality. Epidemiology 19 (3), 375–383.
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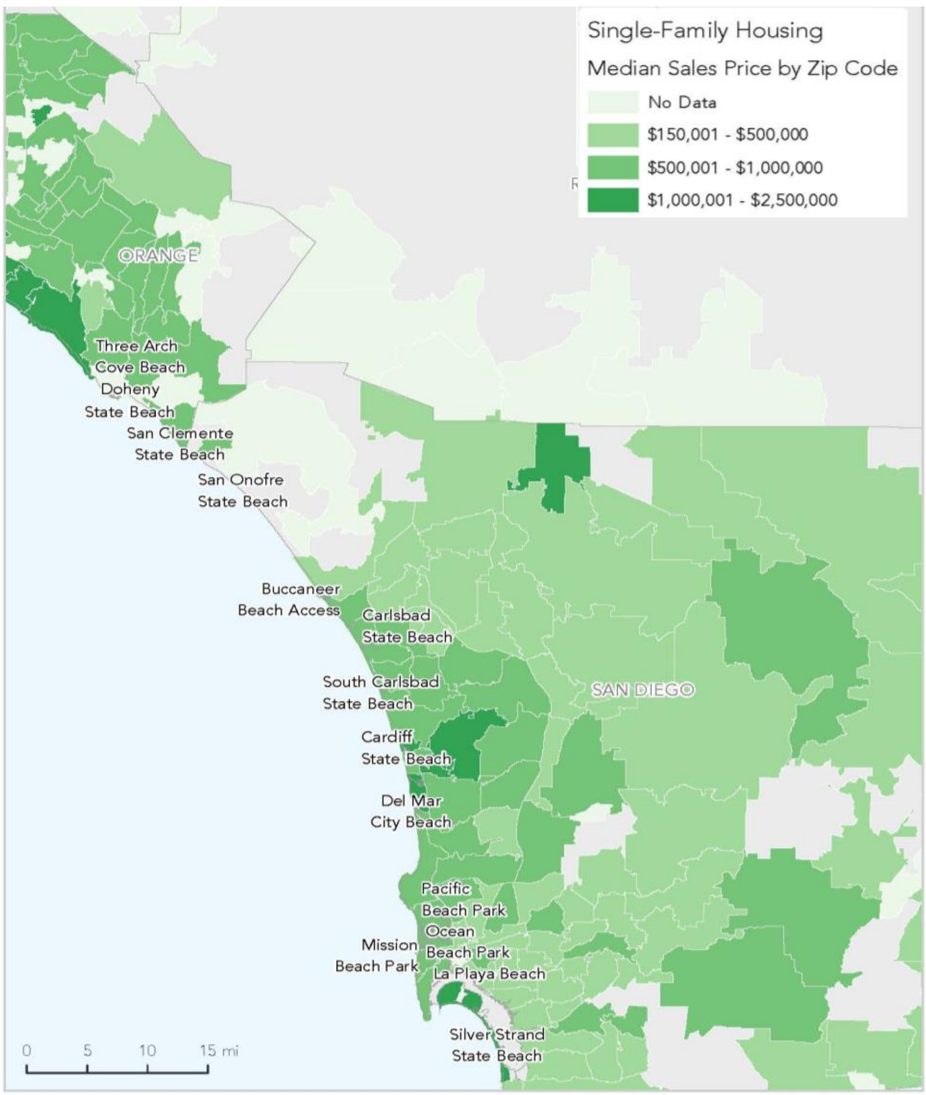
APPENDIX E: HEDONIC ANALYSIS

PROPERTY VALUE (RESIDENTIAL WATER QUALITY AMENITY)

People pay more for homes that have desirable amenities. Analyses of variation in property values, when controlling for other factors that drive variation in home prices, can allow quantification of the premium paid in home purchases for specific amenities, including water quality. Beaches and waterbodies are particularly attractive amenities that elicit higher prices than otherwise. Generally homes in the project area have higher prices near beaches, although substantial variation does exist in prices along the coast (Map F-1). Changes in water quality have discernable effects on public health and the ability to recreate in an area. Empirical research has shown that both coastal proximity and water quality improvement positively affects the implicit price of home values. [87]



Map F-1 - Map of Median Residential Property Values, Study Area

[87] Artell, J. 2014. "Lots of value? A spatial hedonic approach to water quality valuation." *Journal of Environmental Planning and Management*. 57: 862-882.

APPROACH

Hedonic methods are the specific empirical tools for this type of analysis. They are useful for isolating the implicit value of small changes in nonmarket goods, such as environmental amenities using home prices as a proxy for value. Hedonic methods are needed because homes are not a single-characteristic good, but represent a bundle of different attributes valued by the homeowner. These attributes can include square footage, number of bedrooms, and age of the home. It is important to identify and measure all important drivers of home value, both in terms of characteristics of the homes themselves such as numbers of bedrooms and lot size as well as neighborhood effects and proximity to other desirable amenities such as golf courses, parks, and transportation. It is also important to review the literature to support specification of the most appropriate functional form of the hedonic model that best characterizes the specific types of water quality benefits associated with the scenarios.[88]

Accounting for all of these similarities across characteristics and space allows the researcher to isolate the differences in home values, which are attributable to the underlying characteristics of the property. By selecting a large enough sample size of homes to obtain sufficient variation in the model to construct a statistical model of the determinants of home sales price, represented generally as:

$$Price = f(Physical\ Attributes, Neighborhood, Environmental\ Amenities, etc)$$

In this representation, the variables identified in the parentheses represent characteristics that can have a marginal effect on the sales price of a home. For example, a small change in environmental amenities (e.g. water clarity) may result in a change in a home's sale price. The magnitude and significance of that change will need to be determined by identifying the appropriate model to accurately capture these relationships.

This analysis will entail a preliminary screening analysis of property value effects associated with changes in water quality conditions at nearby beaches. If data and model results allow and suggest, secondary analyses would entail greater investigation into specific effects of wet weather water quality events.

Property Value Methods

People pay more for homes that have desirable amenities. Changes in water quality have discernable effects on public health and the ability to recreate in an area. Empirical research has shown that both coastal proximity and water quality improvement positively affects the implicit price of home values [89]. Analyses of variation in property values, when controlling for other factors that drive variation in home prices, can allow quantification of the premium paid in home purchases for specific amenities, including water quality.

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[88] E.g. Walsh, Patrick. 2009. "Hedonic property value modeling of water quality lake proximity, and spatial dependence in central Florida.: University of Central Florida.

[89] Artell, J. 2014. "Lots of value? A spatial hedonic approach to water quality valuation." *Journal of Environmental Planning and Management*. 57: 862-882.

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Modeling the impact of water quality on home prices

In order to perform this analysis, the project team gathered data on housing transactions in County of San Diego between 2013 and 2015 using information from Property Radar. The transaction data we obtained included information on sales prices and individual characteristics to account for variation across properties. We then narrowed the sample to include only homes that occurred within two miles of a beach with an associated water quality score. Finally, we dropped homes that in the dataset that did not have information on year built, lot size, or structure size, which are important attributes of transactions. This resulted in a sample size of 3,028 homes.

Previous research has identified that the aesthetic value of water, such as clarity, can have a statistically significant effect on implicit home values by reducing pollution .[91] Heal the Bay, a nonprofit organization provided beach report cards, which provided annual information on water quality. Using this data, we were able to identify how water quality varied both across beaches, and between wet and dry weather events. Figure F-1 below, illustrates the combined transaction and water quality data used for the analysis.

[90] E.g. Walsh, Patrick. 2009. "Hedonic property value modeling of water quality lake proximity, and spatial dependence in central Florida.: University of Central Florida.

[91] Leggett, C. and N. Bocks. "Evidence on the Effects of Water Quality on Residential Land Prices." 2000. *Journal of Environmental Economics and Management*. 39: 121-144.

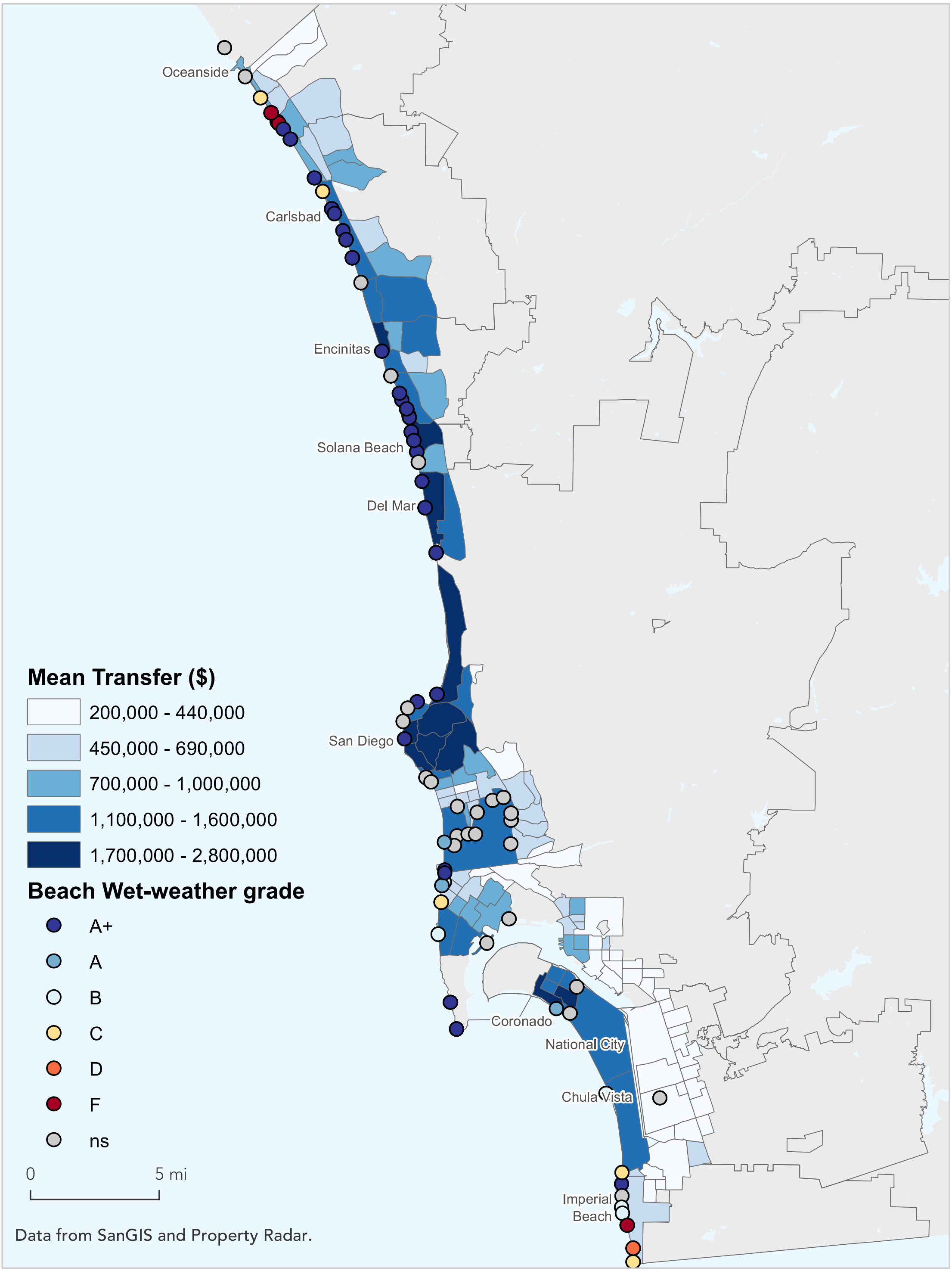

Figure F-1: Mapping transactions within 2 miles of San Diego beaches (2013-2015)

The study team concentrated on this subset of homes because we believed that prices are more likely to be sensitive to changes in water quality if they are geographically close to beachfront areas. The hedonic price equation used to predict transaction prices for home i in year t is specified in the following equation:

$$lnP_{it} = \alpha_i + f(D_{it}) + \sum_{i=1}^{I} \beta_i X_{ik} + \sum_{k=1}^{K} \beta_i T_{it} + \sum_{i=1}^{I} \beta_i S_{it} + \sum_{m=1}^{M} \beta_m F_{im} + \varepsilon_{it}$$

There is not a "standard" functional form for structure for hedonic regression. However, it is common for the dependent variable of home sales to be transformed as a natural logarithm to account for nonlinearity in the demand for housing. The dependent variable lnP_{it} represents the transformed sales price of a home for the observed transaction i in year t. The variable X_{it} represents the water quality score for beach k. The variables D_{it}, T_{it}, and S_{it}, represent spatial, structural, and neighborhood characteristics of the homes. The variable F_{im} represents the fixed effect variable for census tract m. The parameter ε_{it} is the error term, and α_i represents the intercept for a given observation.

In our model, we use census tracts as fixed effects to account for variations in neighborhood characteristics across County of San Diego. We then clustered our errors around beach polygons to account and correct for spatial correlations associated with beach quality. For instance, there may be characteristics about a particular beach where a home is co-located, which effects the price of the home. Any of these characteristics, which aren't captured in the model, then fall into the error term. Accounting for this endogeneity in the error terms adjusts the standard errors to help ensure the estimated coefficients are unbiased.

Table F-1: Variables used for San Diego sales within 2 Miles of beaches with a water quality score (2014-2016)

VARIABLE	DESCRIPTION	MEAN	STD. DEV.	MIN	MAX
Dependent variable					
Price	Sales price of house	1,105,106.0	624,254.3	125,000.0	3,000,000.0
Sqft_price	Price of house in square feet	637.1	304.7	95.6	3,557.0
Ln_price	Natural logarithm of sales price	13.8	0.6	11.7	14.9
Structural characteristics					
Sqft	Square footage of house	1,807.8	862.2	336.0	6,748.0
Lotsize	Square footage of lot on which house is built	40,633.7	85,489.9	1,001.0	561,053.0
Ln_lotsize	Natural logarithm of lot size	9.5	1.3	6.9	13.2
Year_built	Year house was built	1962	16	1905	2004
Bedrooms	Number of bedrooms	2.9	1.0	0.0	7.0
Bathrooms	Number of bathrooms	2.3	0.9	1.0	6.5
Year	Year that sale occurred	2015	1	2014	2016
Distance variables					
Coast_mi	Distance to non-beach coast	0.7	0.4	0.1	1.0
Beach_mi	Distance to beach	0.7	0.3	0.0	1.7
Stream_mi	Distance to nearest stream	2.7	1.5	0.1	6.1
Water quality variable					
Wet_Score	Beach grade during wet weather events	5.1	1.4	1.0	6.0

RESULTS

An initial exploration of the data appeared to show a spatial relationship between increased housing transactions and distance to beaches. This relationship has been confirmed for San Diego in earlier research[92]. The study team also looked at how transactions varied across beaches with associated water quality scores. Early analysis of the data did appear to confirm a positive relationship between high water quality scores, and increased sales prices. A more robust analysis of the relationship of transactions and water quality scores, however, yielded more inconsistencies across beach scores, distance to the beach, and water quality.

Figure F-2 displays these relationships across the three primary variables of interest: sales price (per square foot), distance to beach (in feet), and water quality score (1 = low grade, 6 = high grade). While the price premium across distance to the beach appears consistent, the relationship between beach grade and housing prices appears to break down. We would expect that for homes closest to beaches with a water quality score the price premium would be consistently higher than a similar home located next to a beach with a lower water quality score. What Figure F-2 shows though, are nonlinear and inconsistent relationships across water quality scores and sales prices.

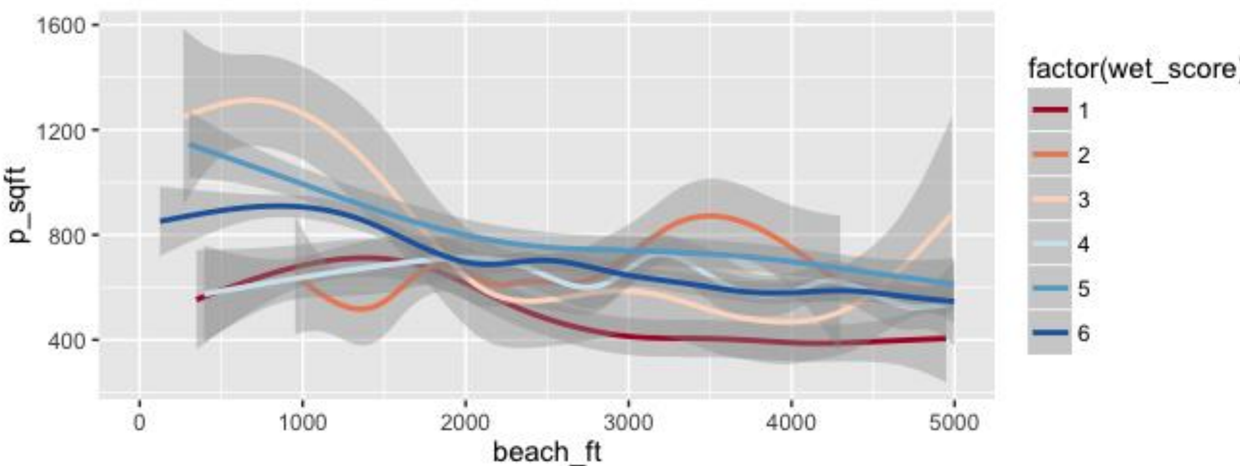

Figure F-2: Sales price per square foot by distance to beach, by beach grade during wet weather events

To account for the attributes of individual homes and other neighborhood characteristics, the study team developed models to measure the impact of proximity to beaches with high water quality scores on sales prices between 2013 and 2015. The model below includes the explanatory variables listed in Table F-1 for the year of transaction, along with the spatial fixed effects for the census tract where the transaction occurred.

[92] Conroy, Stephen J. and Jennifer L. Milosch. "An Estimation of the Coastal Premium for Residential Housing Prices in County of San Diego." *Journal of Real Estate Finance and Economics* (2011) 42:211–228.

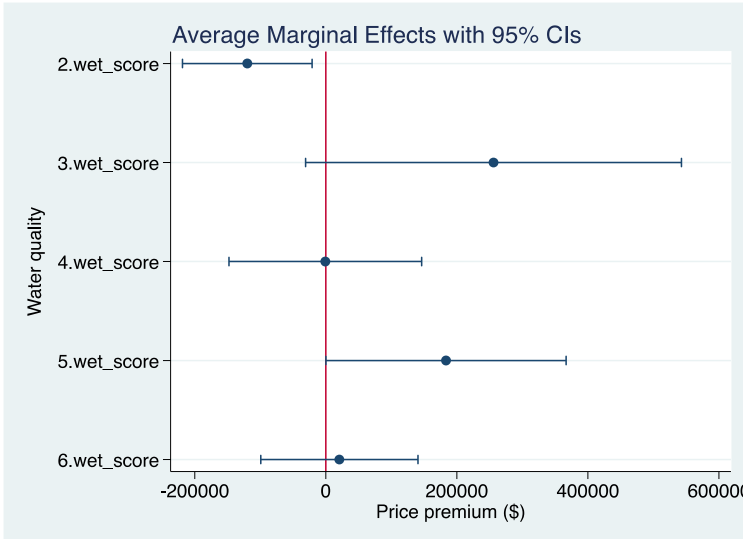

Figure F-3: Model results for the impact of water quality scores on sales price in San Diego (2013-2015)

Based on these results, we do not find a relationship between water quality and sales prices that are statistically significant and consistent. While the coastal premium remains intact, variations in water quality across those beaches generally do not appear to strongly influence the sales premium obtained from being collocated near those beaches. The exception appears to be for homes with low water quality. These initial results suggest that for homes located within two miles of a beach with a low water quality grade, the price penalty could be up to $119,715.

Conversations with the steering committee, however, indicate that this effect may be driven by Imperial Beach, which deals with noxious sewage runoff during wet weather events. When we run the model with Imperial Beach excluded, we do find that the effect for low grade beaches does not remain significant at 95 percent confidence.

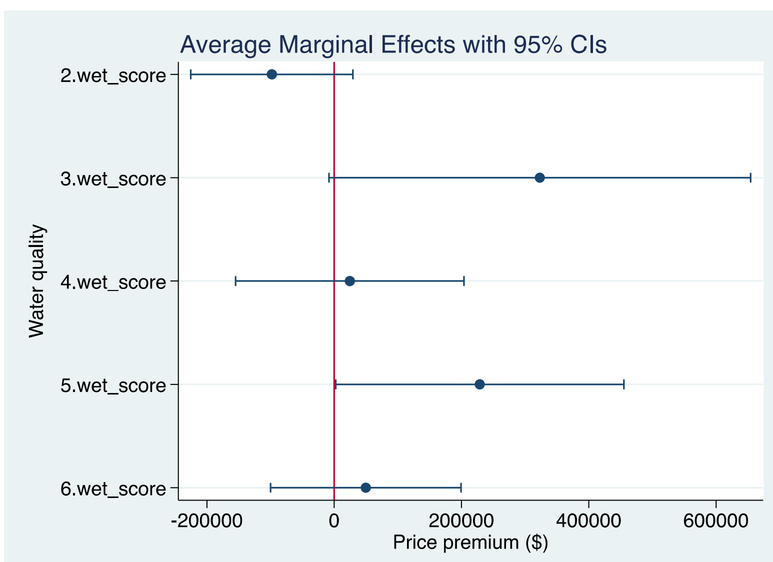

Figure F-4: Model results for the impact of water quality scores on sales price in San Diego, excluding Imperial Beach (2013-2015)

Overall, this analysis could not confirm that water quality affected the transaction prices of homes along the San Diego beachline. This is not to say that is does not occur, or has not occurred in the past. As discussed earlier in this analysis, previous research has confirmed that various attributes of beaches can affect the transaction price of homes close to San Diego beaches. A broader set of research has found evidence that improving water quality or water clarity can improve the value of homes.

LIMITATIONS

Many previous water quality/clarity studies have designed their studies around lakefront properties, where small environmental changes affect a concentrated water supply and therefore, may have a discernable effect on WTP for water quality improvements. Applying a similar analysis to San Diego beaches may be ineffective if the benefits of the water quality improvements are to diffuse to have a noticeable impact when consumers are calculating their WTP for homes within the study corridor.

An alternative scenario may also be that much of the improvements in San Diego's coastal waters have already occurred, and the effects may be localized to the Tijuana River near Imperial beach. The broader coastal improvements may already be accounted for in local transaction prices. Since our analysis only explores transactions going back through 2013, the time series on our dataset may not be long enough to capture the treatment effect of previous improvements. This can be confirmed by extending the data back to capture the effects of previous initiatives.

Finally, our results may also be driven by lack of variation in our explanatory variables. A key link in this analysis was obtaining a robust set of water quality indicators, which could be tied directly to transaction prices in the area. The data we were able to obtain for this analysis, however, was limited to annual beach scores (A+ through F) for wet and dry weather events. These broad scores are likely not nuanced enough to small variations both across and within beaches. Additionally, several beaches did not have current water samples with an assigned beach score. This further limited the sample of homes, which could be used for this analysis.

APPENDIX F: BMP EFFECTS ANALYSIS

The effects of BMPs employed within stormwater, human sources and stream scenarios typically involve infiltration, pollutant source reduction and hydrologic retention. The positive and negative results of these generalized effects are described for each type of scenario.

FOCUS ON STORMWATER IMPLEMENTATION SCENARIO BMPS

The stormwater scenarios focus on prevention and treatment of stormwater runoff through a set of broad categories of BMPs that are defined in the Water Quality Improvement Plans developed by permittees. These broad BMP strategies include (1) non-modeled, non-structural BMPs, (2) modeled, non-structural BMPs, (3) multi-use treatment areas, (4) green infrastructure and (5) green streets.

- **Non-modeled non-structural BMPs** include institutional, programmatic actions such as inspection, enforcement, education and outreach activities.
  - Effects
    - (+) Greater public awareness of stormwater effects can reduce pollutant sources carried in stormwater (e.g. cleanup of pet waste by the public)
    - (+) Certainty of inspection will improve the behavior of polluters that may otherwise make illicit discharges or connections to storm sewers
    - (+) Public awareness of the benefits of stormwater treatment will build public support for funding stormwater programs.
    - (-)
- **Modeled non-structural BMPs** include street sweeping, catch basin cleaning, irrigation runoff reduction, downspout disconnection, and rain barrel installation.
  - Effects
    - (+) Controls sources of bacteria such as pet waste on streets/sidewalks
    - (+) Controls hydrologic sources that increase the volume of runoff and carry bacteria to surface waters
    - (+) Rain barrels and downspouts can provide free, local water sources for landscape irrigation
    - (-)
- **Multi-use treatment areas** include region-wide treatment basins that infiltrate stormwater or detain it to reduce peak flows.
  - Effects
    - (+) Reduced runoff, reduced bacteria from surface runoff
    - (+) Increased infiltration increases water supply in certain groundwater basins
    - (-) Base flow could discharge indicator bacteria from groundwater
    - (-) Increased contact with gravel jackets on pipelines can deliver existing bacteria and pathogens to surface waters
    - (-) **Infiltration concerns**: additional groundwater movement can cause problems with infrastructure (e.g. buildings, highways), bring heavy metals to the surface (e.g. selenium), move contamination plumes in groundwater and enhance infiltration and inflow issues with other pipes.
    - (+) Neighborhood improvement from landscaped amenities, traffic calming.
    - (+-) Increased base flows in streams from interflow could have good or bad effects depending on stream habitat type. One example of a negative effect would be conversion of a historically dry wash to vegetated channel.

- **Green infrastructure** includes pollutant control measures that function at the parcel scale- for example bioretention and permeable pavement.
  - Effects
    - (+) Reduced runoff, reduced bacteria from surface runoff.
    - (+) Neighborhood improvement from landscaped amenities and traffic calming.
    - (-) **Infiltration concerns**: additional groundwater movement can cause problems with infrastructure (e.g. buildings, highways), bring heavy metals to the surface (e.g. selenium), move contamination plumes in groundwater and enhance infiltration and inflow issues with other pipes.
    - (-) Increased contact with gravel jackets on pipelines can deliver existing bacteria and pathogens to surface waters.
- **Green streets** include bioretention/biofiltration and permeable pavement within the road right of way.
  - Effects of green streets are very similar to those of green infrastructure (listed above).

WASTEWATER SCENARIO BMPS

The wastewater scenario focuses direct reduction of human pathogen and bacteria sources through retrofit of existing treatment infrastructure. These treatment practices include (1) sewer line retrofit, (2) septic system replacement and (3) transient encampment cleanup efforts.

- **Sewer line retrofit** includes cast in place pipe retrofit in which uses a thermoset resin to create a new pipe within the old sewer pipe.
  - Effects
    - (+) Substantial decrease in infiltration of groundwater and stormwater
    - (+) Substantial decrease in exfiltration of sewage that could contaminate groundwater and surface waters with human pathogens and harmful bacteria
    - (-) previously leaked sewage could be released to surface waters when replacement earth movement is undertaken, particularly if best practices for controlling bacteria and sediment are not followed. This seems unlikely since professional excavation services are likely to be used and extensive trenching is not necessary.
- **Septic system replacement** includes replacement of pvc piping from home, replacement of 1000-1500 gallon septic tank and replacement of drainfield components
  - Effects
    - (+) reduced leakage of human pathogens and bacteria from septic tank and pipe joints
    - (+) fewer pathogens and bacteria released with water running out of subsurface drainfield due to proper design, capacity and integrity of tank and distribution piping
    - (-) previously leaked sewage could be released to surface waters when replacement earth movement is undertaken, particularly if best practices for controlling bacteria and sediment are not followed. This seems possible based on the broad distribution of septic systems throughout the watershed.
- **Transient encampment clean-up** includes collection of feces from ad-hoc latrines and removal of trash from encampment areas.
  - Effects
    - (+) reduced introduction of human waste into surface waters during wet weather wash off or improper disposal such as dumping latrines into creeks

        - (+) reduced trash washed into creeks, thus some reduced introductions of bacteria associated with trash
        - (-) Disturbance of camps could result in transient community backlash, creating some additional direct pollutant loading to creeks.

REDUCE BACTERIA THORUGH STREAM RESTORATION SCENARIO BMPS

The stream scenario involves treatment of bacterial pollutant loads within the stream channel and surrounding riparian area. There are two types of restoration practices considered, including (1) in-stream, channel enhancement and (2) off-line, wetland restoration.

- **In-stream, channel enhancement** includes widening and increasing the wetted parameter of stream channels
    - Effects:
        - (+) Increased infiltration through bottom and sides of the channel which will reduce bacteria loads carried down the river
        - (+) Increased residence time of water in the channel allowing time for ultra-violet and biological processes to treat or render harmless bacteria and other pathogens
        - (+) Additional treatment of metals and sediment pollutants.
        - (+) Habitat enhancement for animals and plants including listed, special status species.
        - (-) Construction of restoration features is likely to disturb sensitive wildlife and requires mitigation in protected areas.
        - (-) **Infiltration concerns**: additional groundwater movement can cause problems with infrastructure (e.g. buildings, highways), bring heavy metals to the surface (e.g. selenium) and enhance infiltration and inflow issues with other pipes.
        - (-) Extremely long residence times for pools of water may allow for additional bacteria growth due to attraction of wildlife, warming of water leading to more rapid bacteria growth and senescence of plant matter.
- **Off-line, wetland restoration** includes restoration of wetlands with hydrologic control structures at the outlet and inlet of the wetlands such that residence time can be controlled
    - Effects:

The effects of the off-line, wetland restoration is qualitatively similar to the in-stream, channel enhancement effects listed above because similar types of processes are at work. However, the much longer residence time of the water creates substantially greater bacteria reduction. Thus, the effects may be of greater (or lesser) magnitude.

APPENDIX G: SCREENING FINANCIAL CAPABILITY ASSESSMENT

Screening Financial Capability Assessment (FCA) results indicate the burden on residents of paying for water services (stormwater and wastewater). The RIS is calculated to indicate a permittee's average cost per household (CPH) for water treatment as a percentage of the local median household income (MHI). RIS results are reported as a "low," "mid-range" or "high" financial burden on residential users. The RIS is calculated according to USEPA guidance documents by dividing the cost-per household by the median household income (Figure H-1).[93]

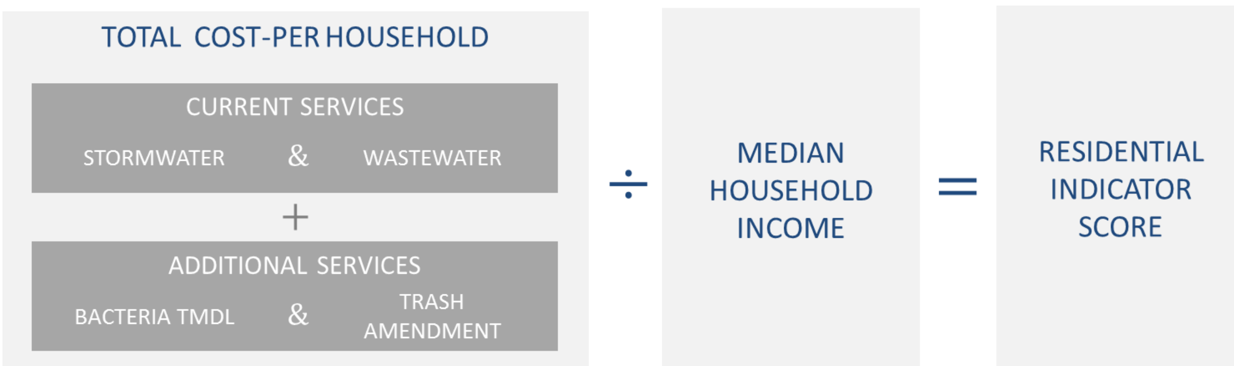

Figure H-1. Overview of residential indicator score calculation methodology. Current costs and future costs are summed and then divided by the median household income to determine the residential indicator score.

A full FCA would also include the financial capability score (FCS) which examines additional indicators such as the permittee's debt burden, socioeconomic conditions, and financial. Water supply service costs are also included in the FCS calculation. FCA and RIS scores are combined to determine the final burden. Because this is only a screening FCA the FCS analysis is not performed.

DATA SOURCES

According to federal USEPA guidance, several categories of data are necessary to complete the FCA. The following sources were used for each category of data to complete the FCA.

WASTEWATER

The wastewater analysis is based on data provided by the City of San Diego's Public Utilities Department Deputy Director in charge of developing the City's wastewater costs. The data provided represents costs for the entire wastewater system. The wastewater system consists of two sub-systems, the municipal sub-system and the metropolitan sub-system. The metropolitan sub-system treats and disposes of the wastewater generated by the City of San Diego and 12 other nearby districts.

Data was collected for the years 2015 to 2026. O&M data was only available for the years 2016-2020 while debt service data was available for the entire period. Specific data sources include

- O&M costs incurred through City of San Diego wastewater service
  - Report (pg.64) Table 16 Public Facilities Financing Authority of the City of San Diego Senior Sewer Revenue Refunding Bonds
- Debt service incurred through City of San Diego wastewater service

[93] USEPA, Office of Water, Office of Wastewater Management. Combined Sewer Overflows - Guidance for Financial Capability Assessment and Schedule Development. N.p.: n.p., 1997. Print.

    - Report (pg.18) Table 2 Public Facilities Financing Authority of the City of San Diego Senior Sewer Revenue Refunding Bonds
- Proportion of wastewater system costs attributed to the City of San Diego
    - Report (pg. 26) Table 3 Public Facilities Financing Authority of the City of San Diego Senior Sewer Revenue Refunding Bonds
- The residential fraction of total City of San Diego wastewater service
    - (pg.53) Public Facilities Financing Authority of the City of San Diego Senior Sewer Revenue Refunding Bonds
- The number of households in County of San Diego
    - 2014 U.S. Census data[94]
- The number of new households in County of San Diego since the census was performed
    - SANDAG demographic & socioeconomic estimates 2015[95]
- The median household income of County of San Diego
    - 2014 U.S. Census data

STORMWATER ANALYSIS

The following data sources identify current costs related to stormwater services for the City of San Diego.

Data was collected for the years 2013 to 2026.

- O&M Costs incurred through City of San Diego wastewater service
    - City of San Diego Stormwater Fee Study 2016[96]
- Debt service incurred through City of San Diego wastewater service
    - City of San Diego Stormwater Fee Study 2016[97]
- The residential fraction of total City of San Diego wastewater service
    - Fiscal Impact of New Stormwater Regulations 2013[98]
- The number of households in County of San Diego
    - 2014 U.S. Census data[99]
- The number of new households in County of San Diego since the census was performed
    - SANDAG demographic & socioeconomic estimates 2015[100]
- The median household income of County of San Diego
    - 2014 U.S. Census data
- Costs associated with Bacteria TMDL compliance
    - City of San Diego WQIP cost database

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[94] "Households, 2010-2014." *San Diego County California QuickFacts from the US Census Bureau*. US Census, n.d. Web. https://www.census.gov/quickfacts/table/PST045216/00

[95] SANDAG. "Data Surfer." *SANDAG Data Surfer | Your Go-to Data Warehouse for the San Diego Region*. N.p., n.d. Web. https://www.sandiego.gov/sites/default/files/csd_stormwaterfeestudy_submission.pdf

[96] Geosyntec.*Https://www.sandiego.gov/sites/default/files/csd_stormwaterfeestudy_submission.pdf*. Rep. San Diego: n.p., 2016. Print. https://www.sandiego.gov/sites/default/files/csd_stormwaterfeestudy_submission.pdf

[97] Geosyntec.*Https://www.sandiego.gov/sites/default/files/csd_stormwaterfeestudy_submission.pdf*. Rep. San Diego: n.p., 2016. Print. https://www.sandiego.gov/sites/default/files/csd_stormwaterfeestudy_submission.pdf

[98] City of San Diego Office of the Independent Budget Analyst. Rep. no. IBA 13-44. N.p., n.d. Web.https://www.sandiego.gov/sites/default/files/13_44_131011.pdf

[99] "Households, 2010-2014." *San Diego County California QuickFacts from the US Census Bureau*. US Census, n.d. Web. http://www.census.gov/quickfacts/table/HSD410214/06073,00

[100] SANDAG. "Data Surfer." *SANDAG Data Surfer | Your Go-to Data Warehouse for the San Diego Region*. N.p., n.d. Web. http://datasurfer.sandag.org/download/sandag_estimate_2015_region_san-diego.pdf

BACTERIA TMDL COSTS

The following data sources identify projected Bacteria TMDL compliance costs for the City of San Diego.

- Bacteria TMDL compliance costs for the City of San Diego
  - Compliance Period Total Costs (FY16-31)

STORMWATER TRASH AMENDMENT COSTS

The following data sources identify costs associated with the SWRCB amendment requiring Statewide Water Quality Control Plans to control trash.

The following data source was used to determine whether City of San Diego-specific costs could be included in the analysis

- Phone and email correspondence with the Senior Planner in charge of developing trash costs at the City of San Diego's Transportation & Stormwater Department

The following data source was used to include stormwater-specific trash costs in the FCA

- Draft Amendments to Statewide Water Quality Control Plans to Control Trash

ANALYSIS OF FUTURE HOUSEHOLD INCOME

The following data source identifies annual per capital income for San Diego County from 2006-2040. Data from 2006-2013 is historical and data from 2014-2040 is forecasted. Data from the Department of Transportation was used because SANDAG's household income data is under review and therefore temporally unavailable.

- Department of Transportation San Diego County Economic Forecast[101]

METHODS

Development of the RIS starts with calculation of the current and proposed wastewater service costs per household (CPH). Next, the service area's CPH estimate and the median household income (MHI) are used to calculate the Residential Indicator. Finally, the Residential Indicators are compared to national averages to establish financial impact ranges to determine whether CWA compliance will produce a possible high, mid-range or low financial impact on the permittee's residential users.

INDIVIDUAL WATER SERVICES

The first step in calculating the RIS is to collect data for all relevant data categories for all relevant years, or as data is available (See *FCA DATA* section).

a. Collect data on annual O&M and debt service for the City.
   i. Collect wastewater costs for the first five years (2016-2020) and then project costs for the remaining 5 years (2021-2026) because data is unavailable for the entire analysis period.
   ii. Collect stormwater costs for all relevant years (2016-2031).
   iii. Collect available annual Bacteria TMDL compliance costs (2016-2026).
b. Identify the percent of total water use that is residential in the City for the current year.
c. Identify the number of households in the City of San Diego is for the current year.

[101] California Department of Transportation. Rep. N.p., n.d. Web. http://www.dot.ca.gov/hq/tpp/offices/eab/socio_economic_files/2014/SanDiego.pdf .

d. Collect CPI for the previous 5 years (2010-2015).
e. Identify median household income in County of San Diego for the current year.

After collecting the necessary data sources calculate the cost per household for each water service following USEPA guidance methodology (Figure H-2).

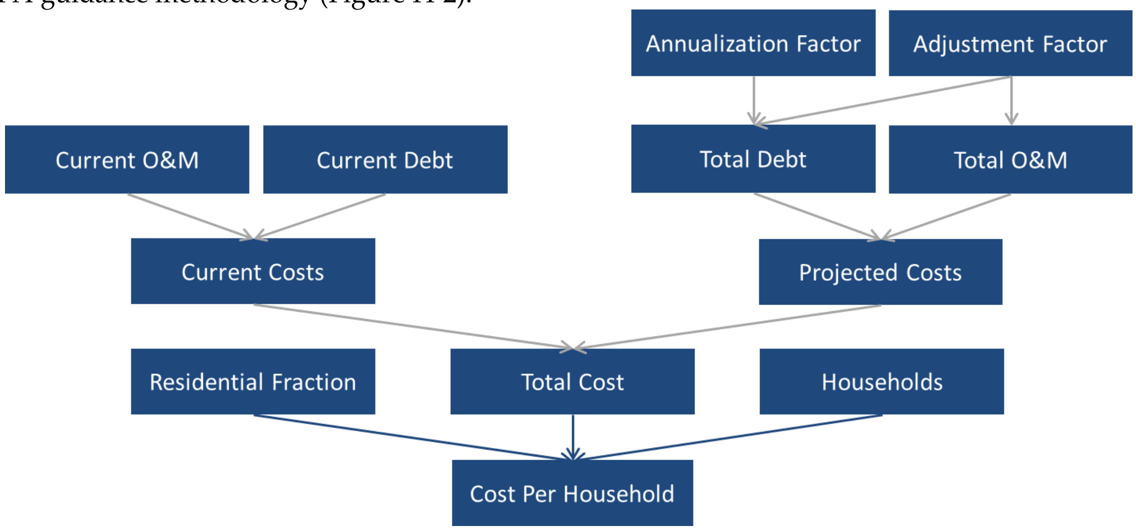

Figure H-2. Steps for calculating the cost per household for each water service. O&M and debts costs are adjusted using USEPA factors and summed. The portion of total cost attributable to residential customers and the number of households in the study are determined. The result is the cost per household.

1. Calculate current costs.
   a. For wastewater services, stormwater services, and the Bacteria TMDL the current O&M cost is the O&M value for the current year (2016). (see Table H-1).

Table H-1. 2016 O&M cost by water service

	CURRENT SERVICES		ADDITIONAL SERVICES
	Wastewater	Stormwater	Bacteria TMDL
O&M (2016 dollars)	$144,000,000	$58,400,000	$1,730,000

   b. For wastewater services, the current debt value is the debt value for the current year (2016). For stormwater services there is no debt value for the current year so it is necessary to deflate the O&M value to current costs (see Table H-2). For the Bacteria TMDL the debt value is combined with O&M costs and therefore not calculated separately.

Table H-2. Current costs deflated to 2016 dollars

Deflate "current" costs in future years to 2016

	WASTEWATER	STORMWATER
Year (debt value)	2016	2017
Current Year	2016	2016
Difference in Years	0	1
Annual Debt Service	$56,400,000	$10,315,102
Average CPI	0.0165	0.0165
Adjustment Factor	1.0000	0.9838
Adjusted debt (to 2016 dollars)	$56,400,000	$10,100,000

   c. The current (2016) O&M and debt values are summed and the result is the current cost (see Table 80).

Table H-3. Subtotal of current costs by water service

	CURRENT SERVICES		ADDITIONAL SERVICES
	Wastewater	Stormwater	Bacteria TMDL
Subtotal	$200,700,000	$68,600,000	$1,730,000

2. Calculate projected costs.
   a. Sum O&M costs for all relevant years (2016-2026).
   b. Implement the adjustment factor formula to deflate the sum of projected O&M costs to current dollars (see Table H-4).

$$\frac{1}{(1 + Average\ CPI^{(Debt\ Value\ Year - Current\ Year)})}$$

$$\frac{1}{(1 + 0.0165^{(2026-2016)})}$$

Table H-4. Future O&M costs deflated to 2016 dollars

Deflate projected costs in future years to 2016

	CURRENT SERVICES		ADDITIONAL SERVICES
	Wastewater	Stormwater	Bacteria TMDL
Total O&M	$1,780,000,000	$769,000,000	$513,000,000
Year (end O&M payment)	2026	2026	2026
Year (current)	2016	2016	2016
Difference in years	10	10	10
Average CPI	0.0165	0.0165	0.0165
Adjustment Factor	0.8491	0.8491	0.8491
Adjusted projected O&M (to 2016 dollars)	$1,510,000,000	$653,000,000	$435,000,000

   c. Sum debt service costs for all relevant years (2016-2026).
   d. Implement the adjustment factor formula to deflate the sum of projected debt service costs to current dollars (see Table H-5).

Table H-5. Future debt service costs deflated to 2016 dollars

Deflate projected costs in future years to 2016

	WASTEWATER	STORMWATER
Total Debt Service	$644,000,000	$400,000,000
Year (end debt payment)	2026	2026
Year (current)	2016	2016
Difference in years	10	10
Average CPI	0.0165	0.0165
Adjustment Factor	0.8491	0.8491
Adjusted projected debt (to 2016 dollars)	$547,000,000	340,000,00

   e. Annualize the deflated sum of debt service costs using the USEPA's annualization factor table. Identify the interest rate associated with the debt service schedule. Look up the annualization factor based on the interest rate and the length of the barrowing term (see Table H-6).

Table H-6. Annualization factor calculation

Interest rate	5.00%
Length of barrowing term (years)	10
Annualization Factor	0.1295

f. Calculate debt service costs by multiplying the annualization factor by the adjusted projected debt cost (see Table H-7).

Table H-7. Annual debt service costs

	WASTEWATER	STORMWATER
Annual Debt Service Costs	$70,900,000	$44,000,000

g. The total projected cost is the sum of the annual debt service cost and the adjusted projected O&M cost. Bacteria TMDL costs include both O&M and debt service costs. Therefore, the total projected cost is equal to the adjusted projected cost (see Table H-8).

Table H-8. Subtotal of projected costs by water service

	CURRENT SERVICES		ADDITIONAL SERVICES
	Wastewater	Stormwater	Bacteria TMDL
Subtotal	$1,582,000,000	$697,000,000	$435,000,000

3. Calculate the total cost.
   a. Sum the subtotal current cost and subtotal projected cost to determine the total cost (see Table H-9).

Table H-9. Sum of total current and projected costs

		CURRENT SERVICES		ADDITIONAL SERVICES
		Wastewater	Stormwater	Bacteria TMDL
Current				
100	O&M	$144,000,000	$58,400,000	
101	Debt Service	$56,400,000.	$10,100,000	
102	Subtotal	$201,000,000	$68,600,000	$1,730,000
Projected				
103	O&M	$1,510,000,000	$653,000,000	
104	Debt Service	$70,900,000	$44,000,000	
105	Subtotal	$1,580,000,000	$697,000,000	$435,000,000
106	**Total Cost (current and projected)**	**$1,780,000,000**	**$766,000,000**	**$437,000,000**

b. Multiply the residential fraction of the accounts served by the total cost to determine the residential share of costs (see Table H-10).

Table H-10. Residential share of total costs

		CURRENT SERVICES		ADDITIONAL SERVICES
		Wastewater	Stormwater	Bacteria TMDL
	Residential fraction	56%	45%	45%
107	Residential share of total costs	$ 995,000,000	$346,000,000	$198,000,000

c. Divide the residential share of costs by the number of households served to determine the cost per household for wastewater and stormwater (see Table H-11).

Table H-11. Cost per household by water service

		CURRENT SERVICES		ADDITIONAL SERVICES
		Wastewater	Stormwater	Bacteria TMDL
107	Residential share of total costs	$995,000,000	$346,000,000	$198,000,000
108	Households (2014)	479,000	479,000	479,000
	New households (2015)	26,200	26,200	26,200
	Total (households)	505,000	505,000	505,000
109	Cost per household	$1,970	$ 685	$391

4. Add the cost per household for trash costs to the cost per household for stormwater costs. The result is the cost per household of stormwater costs including compliance with the new trash requirement of the stormwater permit (see Table H-12).

Table H-13. Cost per household of current Stormwater service and Tash Amendment

Stormwater	Original Stormwater permit	
	Cost per household	$685
Trash	SD River Trash TMDL	
	Cost per household	$18.5
109	Total Cost per household	$ 704

After calculating the cost per household, calculate the median household income (Figure H-3).

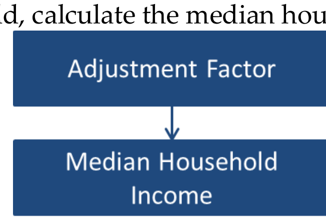

Figure H-3. Calculate the median household income using an adjustment factor.

5. Determine the median household income and adjust it to current (2016) dollars.
   a. Adjust the MHI to the current year using the adjustment factor (see Table H-14).

$$(1 + Averate\ CPI)^{(Current\ Year - Data\ Year)}$$

$$(1 + 0.0165)^{(2016-2014)}$$

Table H-14. Adjusted median household income

Line	202	
	Adjust MHI to current year	
		All Water Services
	MHI (2014)	$64,000
	Year (current)	2016
	Year (census)	2014
	Difference in years	2
	Average CPI	0.0165
	Adjustment Factor	1.03
202	**Adjusted MHI (to 2016 dollars)**	**$66,100**

To calculate the RIS the CPH is divided by the MHI (Figure 60).

Figure H-4. Dive the CPH by the MHI to determine the RIS.

6. Determine RIS and corresponding level of burden.
   a. The RIS indicates a permittee's average cost per household (CPH) for water services as a percentage of the local median household income (MHI). RSI is the residential portion of current and planned water service operations to meet CWA and other regulatory requirements. The RIS is determined by dividing the cost per household by the adjusted MHI (see Table H-15).

Table H-15. Cost per household as a percent of median household income

		CURRENT SERVICES		ADDITIONAL SERVICES	
		Wastewater	Stormwater	Bacteria TMDL	Trash
203	Adjusted MHI	$66,100	$66,100	$66,100	$66,100
204	CPH	$1,970	$658	$391	$18.5
205	Residential Indicator				
	CPH as a % of adjusted MHI	2.98%	1.04%	0.59%	0.03%

COMBINED ANALYSIS

FCA results indicate the burden on residents in San Diego County of paying for water services. Because results are determined at the County scale the categories of water service costs (wastewater, and stormwater) and the additional future costs (Bacteria TMDL, Trash amendment) must be combined and normalized from other jurisdictional-scales to the County-scale. Water service costs are normalized using the number of household and median household income for San Diego County. Water service costs are combined by summing the cost-per household numbers for each category.

1. Sum CPH values to determine the combined FCA CPH (Table H-16).

Table H-16. Cost per household by water service

	CURRENT SERVICES	CURRENT SERVICES + BACTERIA TMDL	CURRENT SERVICES + BACTERIA TMDL + TRASH
CPH	$2,660	$3,050	$3,070

2. Use the median household income for County of San Diego for the combined FCA (see Table H-17).

Table H-17. County of San Diego median household income

	COUNTY SD MHI
202	$66,100

3. Determine RIS and corresponding level of burden for each combination of costs.
   a. The RIS indicates a permittee's average cost per household (CPH) for water services as a percentage of the local median household income (MHI). RSI is the residential portion of current and planned water service operations to meet CWA requirements. The RIS is determined by dividing the cost per household by the adjusted MHI (Table H-18).

Table H-18. Residential indicator score by water services

	CURRENT SERVICES	CURRENT SERVICES + BACTERIA TMDL	CURRENT SERVICES + BACTERIA TMDL + TRASH
Average Adjusted MHI	$66,100	$66,100	$66,100
Total CPH	$2,660	$3,050	$3,070
RIS	4.02%	4.61%	4.63%

   a. The level of burden is determined by the RIS. RIS results are reported as a "low," "mid-range" or "high" financial impact on residential users (see Table H-19). To assess the financial impact CWA compliance may have on the permittee's residential users, Residential Indicator is compared to the financial impact ranges as follows:

Table H-19. Level of burden and residential indicator according to USEPA guidance

LEVEL OF BURDEN	RESIDENTIAL INDICATOR
Low	<1%
Mid-range	1-2%
High	>2%

ANALYSIS OF FUTURE HOUSEHOLD INCOME

This additional analysis is not part of USEPA guidance on FCAs, but was performed to better understand how resident's ability to pay for the Bacteria TMDL will change as incomes rise in the future. Bacteria TMDL compliance is expected by 2031 according to the regulation. Over the period of compliance median household income is expected to rise. To understand whether this increase income substantially changes the burden of Bacteria TMDL compliance on residents the RIS is recalculated with the forecasted income.

4. Use the median household income for the County of San Diego in 2031 according to Department of Transportation forecasts (see Table H-20).

Table H-20. County of San Diego median household income

COUNTY SD MHI FORECASTED FOR 2031	
202	$84,500

5. Determine RIS and corresponding level of burden for the Bacteria TMDL using the increased MHI.
   a. The RIS indicates a permittee's average cost per household (CPH) for water services as a percentage of the local median household income (MHI). RSI is the residential portion of current and planned water service operations to meet CWA and other regulatory requirements. The RIS is determined by dividing the cost per household by the adjusted MHI (see Table H-21).

Table H-21. RIS results based on the projected household income

	BACTERIA TMDL
Forecasted MHI (2031)	$84,500
Total CPH	$391
RIS	0.46%

1. Determine RIS and corresponding level of burden for the Bacteria TMDL and current services (Table H-22). The RIS for the Bacteria TMDL is based on the forecasted MHI of $84,500 in 2031 and the RIS for current services is based on the average adjusted MHI for 2016 of $66,100.

Table H-22. RIS results based on the current water service and Bacteria TMDL costs with projected household income

	CURRENT SERVICES	BACTERIA TMDL	CURRENT SERVICES + BACTERIA TMDL
RIS	4.02%	0.46%	4.48%

ASSUMPTIONS

FCAs are traditionally performed at the utility scale for the wastewater sector. This FCA is performed at the county scale and not for an individual utility. It is not within the scope of this analysis, or practical, to include data for every jurisdiction within County of San Diego. Representative jurisdictions are used and results are extrapolated the County. To capture the full burden of water service costs on residents, several water-related service fees paid by county residents including wastewater, and stormwater are included in the FCA. Water supply costs are part of the second phase of the FCA, the financial capability score calculation, which is not included in this screening analysis

WASTEWATER

The population of the City of San Diego is an appropriate representative jurisdiction for the wastewater analysis because its population (1.3 million) is significantly larger than the next most populous city (Chula Vista 240,000) in the County of San Diego (see Figure H-5. The population of the City of San Diego is substantially higher than other cities in County of San Diego.) Therefore, it is assumed the City covers a large enough portion of the population of the county to be representative of costs related to wastewater throughout the County of San Diego.

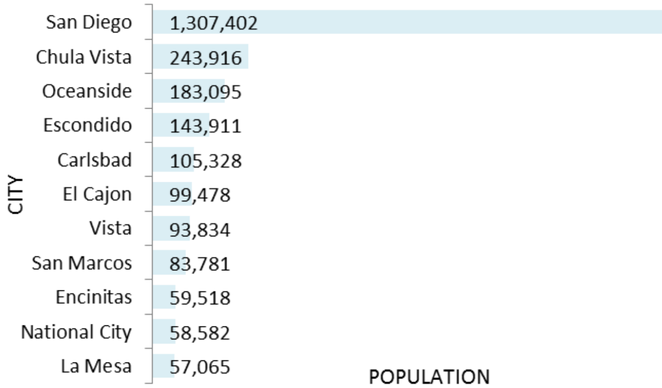

Figure H-5. The population of the City of San Diego is substantially higher than other cities in County of San Diego.

One limitation of using City of San Diego data for the wastewater portion of the FCA is that cost data is only available for the years 2016-2020. As a result, this data must be extrapolated to the remaining years in the analysis period 2021-2026. This analysis assumes the extrapolation of this data is an accurate representation of costs in this period.

A second limitation of data provided by the City it that the data represents the cost of service for the entire wastewater system, including 12 other cities in addition to the City of San Diego. Through conversations with the City's Deputy Director the conclusion was reached that San Diego-specific costs could not be extracted from the total system cost. Therefore, an alternative method for determining San Diego-specific costs was developed. The 13 districts served each have a right to a portion of the wastewater system's capacity (see Table 100). It is assumed the City's costs are proportional to their capacity right. This is assumed to be the best available method to determine the City's wastewater costs since data is not available.

Table H-23. Cities and participating agencies flow and capacity rights in the metropolitan sub-system.

PARTICIPATING AGENCIES	ESTIMATED POPULATION	CAPACITY RIGHTS (IN MGD)	% OF TOTAL CAPACITY
City of Chula Vista	257,000	20.9	8.2%
City of Coronado	25,500	3.25	1.3%
City of Del Mar	4,400	0.88	0.3%
City of El Cajon	102,000	10.9	4.3%
City of Imperial Beach	29,500	3.76	1.5%
City of La Mesa	59,000	7	2.7%
City of National City	59,800	7.5	2.9%
City of Poway	44,000	5.9	2.3%
San Diego County - Spring Valley Sanitation Districts	157,000	17.5	6.9%
Lemon Grove Sanitation District	25,600	3.03	1.2%
Otay Water District	5,300	1.29	0.5%
Padre Dam Municipal Water District	53,400	6.23	2.4%
Subtotal	**823,000**	**88.1**	**34.5%**
City of San Diego	1,370,000	166.9	65.5%
Total	**2,190,000**	**255**	**100.0%**

TRASH COSTS

The SWRCB recently amended Statewide Water Quality Control Plans to require trash control. As a result, the City of San Diego's stormwater permit was revised to include the trash requirement. Because trash control is a recent addition to the City's stormwater permit, these costs aren't included in the City's current cost of service estimates for stormwater. Through multiple communications with the City the conclusion was reached that updated costs would not be developed in time for inclusion in this FCA. Cost-per household estimates for the additional trash requirement are provided in the Draft Amendments to Statewide Water Quality Control Plans to Control Trash document from the SWRCB. These estimates are used for the FCA as a proxy for City-specific cost estimates assuming that City costs will be similar.

RESULTS AND DISCUSSION

The level of burden is determined by the RIS. RIS results are reported as a "low," "mid-range" or "high" financial impact on residential users (see Table H-24). To assess the financial impact CWA compliance may have on the permittee's residential users, Residential Indicator is compared to the financial impact ranges as follows:

Table H-24. Level of burden and residential indicator according to USEPA guidance

LEVEL OF BURDEN	RESIDENTIAL INDICATOR
Low	<1%
Mid-range	1-2%
High	>2%

Wastewater and stormwater service costs are combined to determine the current service cost (see Table 102). Adding Bacteria TMDL-related costs to current service costs results in a 0.59% increase in the RIS, and therefore the financial burden on residents. Although the Bacteria TMDL does increase the financial burden by more than half a percent, the burden was already high. Adding stormwater trash costs borne by residents as a result of new stormwater permit requirement increases the RIS by 0.03%. Comparing the burden of current services (wastewater and stormwater) with the inclusion of Bacteria TMDL and trash costs the RIS varies from 4.02-4.63%.

Final screening FCA results (current + additional services) indicate the financial burden on County of San Diego residents of paying for water services is high. For the result to qualify as a high financial burden the RIS must be above 2%. Screening analysis results are over 4% and therefore more than double the high burden requirement.

Table H-25. Screening FCA results indicating the level of burden for current service and the level of burden including TMDL costs

	ADJUSTED MHI	CPH	RIS	LEVEL OF BURDEN
CURRENT SERVICES				
Wastewater	$66,100	$1,970	2.98%	
Stormwater	$66,100	$658	1.04%	
Combined	$66,100	$2,660	4.02%	High
ADDITIONAL SERVICES				
Bacteria TMDL	$66,100	$391	0.59%	
Trash	$66,100	$18.5	0.03%	
Combined	$66,100	$410	4.63%	High
CURRENT + ADDITIONAL SERVICES	$66,100	$3,070	4.63%	

This result indicates the results of a full FCA may also indicate the financial burden on residents is high. The USEPA requires a full FCA to be completed as evidence for justifying a schedule extension for Bacteria TMDL compliance.

ANALYSIS OF FUTURE HOUSEHOLD INCOME

Because the median household income will increase overtime as residents pay for Bacteria TMDL implementation, the level of burden on residents of paying for the Bacteria TMDL with increased MHI is also analyzed. The burden on residents of paying for Bacteria TMDL costs using the 2016 MHI ($66,100) is compared to the burden on residents of paying for Bacteria TMDL costs using the 2031 MHI ($84,500). Results indicate that using the increased MHI only decreased the burden by 0.13% (Table H-26).

Table H-26. Change in residential indicator score as a result of using projected MHI

	BACTERIA TMDL (2016 MHI)	BACTERIA TMDL (2031 MHI)	DIFFERENCE
MHI	$66,100	$84,500	
CPH	$391	$391	
RIS	0.59%	0.46%	0.13%

FCA DATA

WASTEWATER DATA
GEOGRAPHIC EXTENT: CITY OF SAN DIEGO
AGENCIES: City of San Diego

Year	O&M[1]	Annual Debt Service[2]	% residential[3]	Households[4]	Annual Avg CPI[5]	CPI % Change	MHI6
2010					218.056		
2011					224.939	3.06%	
2012					229.594	2.03%	
2013					232.957	1.44%	
2014					236.736	1.60%	$ 66,124
2015			56%	505,255	237.017	0.12%	
2016	$220,498,000	$86,176,594					
2017	$226,703,000	$108,227,538					
2018	$231,557,000	$108,784,815					
2019	$236,567,000	$109,923,700					
2020	$241,737,000	$106,897,712					
2021	*$247,115,000*	$105,997,321					
2022	*$252,349,200*	$106,149,136					
2023	*$257,583,400*	$105,348,582					
2024	*$262,817,600*	$85,600,276					
2025	*$268,051,800*	$84,705,426					
2026	*$273,286,000*	$63,361,676					
Total	**$2,718,265,000**	**$1,071,172,776**	**56%**	**505,255**		**1.65%**	**$ 66,124**

DATA SOURCES

1 (pg.64) Public Facilities Financing Authority of the City of San Diego Senior Sewer Revenue Refunding Bonds
2 (pg.18) Public Facilities Financing Authority of the City of San Diego Senior Sewer Revenue Refunding Bonds
3 (pg.53) Public Facilities Financing Authority of the City of San Diego Senior Sewer Revenue Refunding Bonds
4 2014 U.S. Census data; SANDAG ESTIMATE 2015 http://datasurfer.sandag.org/download/sandag_estimate_2015_region_san-diego.pdf
5 US Bureau of Labor Statistics Consumer Price Index http://www.bls.gov/cpi/
6 2014 U.S. Census data http://www.census.gov/quickfacts/table/INC110214/06073,00

STORMWATER DATA

GEOGRAPHIC EXTENT: CITY OF SAN DIEGO

Year	O&M[1]	Annual Debt Service[2]	Total Cost	% residential[3]	Households[4]	Annual Avg CPI[5]	CPI % Change	MHI[6]
2010						218.056		
2011						224.939	3.06%	
2012						229.594	2.03%	
2013						232.957	1.44%	
2014						236.736	1.60%	$65,753
2015				45%	505,255	237.017	0.12%	
2016	$58,436,304	$0	$58,436,304					
2017	$63,870,389	$10,315,102	$74,185,491					
2018	$54,413,832	$10,315,102	$64,728,934					
2019	$76,597,776	$10,315,102	$86,912,878					
2020	$71,173,467	$29,733,354	$100,906,821					
2021	$61,156,057	$29,733,354	$90,889,411					
2022	$66,454,801	$29,733,354	$96,188,155					
2023	$71,090,814	$57,903,662	$128,994,476					
2024	$92,147,847	$57,903,662	$150,051,509					
2025	$77,875,315	$57,903,662	$135,778,977					
2026	$76,180,733	$106,537,102	$182,717,835					
Total	**$769,397,335**	**$400,393,456**	**$1,169,790,791**	**45%**	**505,255**		**1.65%**	**$65,753**

DATA SOURCES

1	City of San Diego Stormwater Fee Study 2016	https://www.sandiego.gov/sites/default/files/csd_stormwaterfeestudy_submission.pdf
2	City of San Diego Stormwater Fee Study 2016	https://www.sandiego.gov/sites/default/files/csd_stormwaterfeestudy_submission.pdf
4	Fiscal Impact of New Stormwater Regulations 2013	https://www.sandiego.gov/sites/default/files/13_44_131011.pdf
5	2014 U.S. Census data; SANDAG ESTIMATE 2015	http://datasurfer.sandag.org/download/sandag_estimate_2015_region_san-diego.pdf
6	US Bureau of Labor Statistics Consumer Price Index	http://www.bls.gov/cpi/
7	2014 U.S. Census data	http://www.census.gov/quickfacts/table/INC110214/06073,00

STORMWATER DATA

GEOGRAPHIC EXTENT: CITY OF SAN DIEGO

Year	TMDL Costs[1]	% Residential[2]	Households[3]	Annual Avg CPI[4]	CPI % Change	MHI[5]
2010				218.056		
2011				224.939	3.06%	
2012				229.594	2.03%	
2013				232.957	1.44%	
2014				236.736	1.60%	$65,753
2015		45%	505,255	237.017	0.12%	
2016	$1,730,854					
2017	$3,294,076					
2018	$3,903,968					
2019	$16,727,304					
2020	$18,972,726					
2021	$30,615,463					
2022	$38,219,606					
2023	$44,868,104					
2024	$83,012,919					
2025	$109,930,350					
2026	$161,378,762					
Total	**$512,654,131**	**45%**	**505,255**		**1.65%**	**$65,753**

DATA SOURCES

1	City Cost database	
2	Fiscal Impact of New Stormwater Regulations 2013	https://www.sandiego.gov/sites/default/files/13_44_131011.pdf
3	2014 U.S. Census data; SANDAG ESTIMATE 2015	http://datasurfer.sandag.org/download/sandag_estimate_2015_region_san-diego.pdf
4	US Bureau of Labor Statistics Consumer Price Index	http://www.bls.gov/cpi/
5	2014 U.S. Census data	http://www.census.gov/quickfacts/table/INC110214/06073,00

Annualization Factors

Year \ Interest Rate	0.005	0.01	0.015	0.02	0.025	0.03	0.035	0.04	0.045	0.05	0.055	0.06
1	1.0050	1.0100	1.0150	1.0200	1.0250	1.0300	1.0350	1.0400	1.0450	1.0500	1.0550	1.0600
2	0.5038	0.5075	0.5113	0.5150	0.5188	0.5226	0.5264	0.5302	0.5340	0.5378	0.5416	0.5454
3	0.3367	0.3400	0.3434	0.3468	0.3501	0.3535	0.3569	0.3603	0.3638	0.3672	0.3707	0.3741
4	0.2531	0.2563	0.2594	0.2626	0.2658	0.2690	0.2723	0.2755	0.2787	0.2820	0.2853	0.2886
5	0.2030	0.2060	0.2091	0.2122	0.2152	0.2184	0.2215	0.2246	0.2278	0.2310	0.2342	0.2374
6	0.1696	0.1725	0.1755	0.1785	0.1815	0.1846	0.1877	0.1908	0.1939	0.1970	0.2002	0.2034
7	0.1457	0.1486	0.1516	0.1545	0.1575	0.1605	0.1635	0.1666	0.1697	0.1728	0.1760	0.1791
8	0.1278	0.1307	0.1336	0.1365	0.1395	0.1425	0.1455	0.1485	0.1516	0.1547	0.1579	0.1610
9	0.1139	0.1167	0.1196	0.1225	0.1255	0.1284	0.1314	0.1345	0.1376	0.1407	0.1438	0.1470
10	0.1028	0.1056	0.1084	0.1113	0.1143	0.1172	0.1202	0.1233	0.1264	0.1295	0.1327	0.1359
11	0.0937	0.0965	0.0993	0.1022	0.1051	0.1081	0.1111	0.1141	0.1172	0.1204	0.1236	0.1268
12	0.0861	0.0888	0.0917	0.0946	0.0975	0.1005	0.1035	0.1066	0.1097	0.1128	0.1160	0.1193
13	0.0796	0.0824	0.0852	0.0881	0.0910	0.0940	0.0971	0.1001	0.1033	0.1065	0.1097	0.1130
14	0.0741	0.0769	0.0797	0.0826	0.0855	0.0885	0.0916	0.0947	0.0978	0.1010	0.1043	0.1076
15	0.0694	0.0721	0.0749	0.0778	0.0808	0.0838	0.0868	0.0899	0.0931	0.0963	0.0996	0.1030
16	0.0652	0.0679	0.0708	0.0737	0.0766	0.0796	0.0827	0.0858	0.0890	0.0923	0.0956	0.0990
17	0.0615	0.0643	0.0671	0.0700	0.0729	0.0760	0.0790	0.0822	0.0854	0.0887	0.0920	0.0954
18	0.0582	0.0610	0.0638	0.0667	0.0697	0.0727	0.0758	0.0790	0.0822	0.0855	0.0889	0.0924
19	0.0553	0.0581	0.0609	0.0638	0.0668	0.0698	0.0729	0.0761	0.0794	0.0827	0.0862	0.0896
20	0.0527	0.0554	0.0582	0.0612	0.0641	0.0672	0.0704	0.0736	0.0769	0.0802	0.0837	0.0872

Annualization Factors

Year \ Interest Rate	0.065	0.07	0.075	0.08	0.085	0.09	0.095	0.1	0.105	0.11	0.115	0.12
1	1.0650	1.0700	1.0750	1.0800	1.0850	1.0900	1.0950	1.1000	1.1050	1.1100	1.1150	1.1200
2	0.5493	0.5531	0.5569	0.5608	0.5646	0.5685	0.5723	0.5762	0.5801	0.5839	0.5878	0.5917
3	0.3776	0.3811	0.3845	0.3880	0.3915	0.3951	0.3986	0.4021	0.4057	0.4092	0.4128	0.4163
4	0.2919	0.2952	0.2986	0.3019	0.3053	0.3087	0.3121	0.3155	0.3189	0.3223	0.3258	0.3292
5	0.2406	0.2439	0.2472	0.2505	0.2538	0.2571	0.2604	0.2638	0.2672	0.2706	0.2740	0.2774
6	0.2066	0.2098	0.2130	0.2163	0.2196	0.2229	0.2263	0.2296	0.2330	0.2364	0.2398	0.2432
7	0.1823	0.1856	0.1888	0.1921	0.1954	0.1987	0.2020	0.2054	0.2088	0.2122	0.2157	0.2191
8	0.1642	0.1675	0.1707	0.1740	0.1773	0.1807	0.1840	0.1874	0.1909	0.1943	0.1978	0.2013
9	0.1502	0.1535	0.1568	0.1601	0.1634	0.1668	0.1702	0.1736	0.1771	0.1806	0.1841	0.1877
10	0.1391	0.1424	0.1457	0.1490	0.1524	0.1558	0.1593	0.1627	0.1663	0.1698	0.1734	0.1770
11	0.1301	0.1334	0.1367	0.1401	0.1435	0.1469	0.1504	0.1540	0.1575	0.1611	0.1648	0.1684
12	0.1226	0.1259	0.1293	0.1327	0.1362	0.1397	0.1432	0.1468	0.1504	0.1540	0.1577	0.1614
13	0.1163	0.1197	0.1231	0.1265	0.1300	0.1336	0.1372	0.1408	0.1444	0.1482	0.1519	0.1557
14	0.1109	0.1143	0.1178	0.1213	0.1248	0.1284	0.1321	0.1357	0.1395	0.1432	0.1470	0.1509
15	0.1064	0.1098	0.1133	0.1168	0.1204	0.1241	0.1277	0.1315	0.1352	0.1391	0.1429	0.1468
16	0.1024	0.1059	0.1094	0.1130	0.1166	0.1203	0.1240	0.1278	0.1316	0.1355	0.1394	0.1434
17	0.0989	0.1024	0.1060	0.1096	0.1133	0.1170	0.1208	0.1247	0.1285	0.1325	0.1364	0.1405
18	0.0959	0.0994	0.1030	0.1067	0.1104	0.1142	0.1180	0.1219	0.1259	0.1298	0.1339	0.1379
19	0.0932	0.0968	0.1004	0.1041	0.1079	0.1117	0.1156	0.1195	0.1235	0.1276	0.1316	0.1358
20	0.0908	0.0944	0.0981	0.1019	0.1057	0.1095	0.1135	0.1175	0.1215	0.1256	0.1297	0.1339

APPENDIX H: PEER REVIEW: WQIP COST ESTIMATES

This peer review compares BMP unit costs between the City of San Diego, San Diego County, the Los Angeles EWMPs and the Bacteria TMDL. **This analysis is independent of the cost estimates used for the CBA** in that this analysis uses the cost estimates from the WQIP documents, EWMPs and Bacteria TMDL rather than costs that were extrapolated to all watersheds for implementing each CBA scenario.

REVIEW OF DATA PROVIDED

The accounting analysis examines the cost estimates provided by each jurisdiction to understand how cost estimates were developed, identify limitations, and determine whether any inconsistencies in calculation methodologies exist.

COST ESTIMATING METHODS

City of San Diego

City of San Diego costs provided include capital (CIP) costs, not O&M costs, developed from the City's cost database.[102] Although the cost database itself is not included in the cost peer review, understanding the level of detail in the database provides insight into the cost estimates provided for the peer review: WQIP cost estimate.

The City's database of costs uses a granular, bottom-up approach to account for each line item involved in long-term implementation of each strategy. The cost assumptions were generated through workshops, interviews, literature review, local vendor quotes, and historical bid documents to collect this line-item-scale information from those who are actually performing the activities on a daily basis. For example, the number of personnel hours for each activity were used to forecast how many full-time employees (considering specific salaries and fringe benefits for each job type) would be needed during each year of WQIP implementation. The personnel estimates were used to compute annual overhead costs associated with the new staff, including information technology fees, supplies, services, and additional supervisory staff. Non-structural strategy costs were determined using data from San Diego field crews, including line items for equipment rental and materials disposal (when appropriate for activities like street sweeping and catch basin cleaning), in addition to the personnel costs. For structural strategies, the design, construction, and maintenance costs were also developed with this level of detail. Structural strategy cost estimates included full-time maintenance staff and supervisor costs, specific equipment rental fees, materials replacement costs, disposal fees, construction contracts, and design support costs. The unit construction costs of each structural strategy were verified using WERF's BMP and LID Whole Life Cycle Cost Model. Multi-use Treatment Area (MUTA) construction costs were developed using conceptual designs to develop site-by-site engineering cost estimates.

County of San Diego

County of San Diego costs provided through two spreadsheets and memos are extracted from analyses conducted as part of the San Diego River WQIP. Although these spreadsheets and memos are not included in the cost peer review, understanding them provides insight into the cost estimates provided for the peer review: WQIP cost estimate.

Cost estimates provided are based on the estimated capital cost to construct or implement each strategy and associated annual O&M costs. A range of costs (low to high) were developed to account for various BMP design alternatives, configurations, site-specific constraints and uncertainties in BMP unit costs derived from literature or estimated. Costs were discounted to 2015 dollars by performing present value analysis using an assumed discount rate of 5%. The discount rate was assumed to account for both a return

[102] *Cost_Database_102615_v1_SeptWQIPSubmittal*. N.p.: TetraTech, n.d. Excel

on investment and inflation. A range of costs (low to high) was developed to account for various BMP design alternatives, BMP configurations, site-specific constraints and the uncertainty inherent in the BMP unit costs available from literature or estimated BMP unit costs. For planning and budgeting purposes the capital costs for structural BMPs are discounted to year 6 (2020) and O&M costs for structural BMPs are included for 2029-2031.

Cost estimates provided the formulas for converting unit capital costs to total costs for each BMP category. These formulas reference both capital and operation and maintenance costs, unit costs, BMP size, units, O&M %, and discount rate. Calculation steps vary slightly by BMP category. For every BMP category except Programmatic BMPs, there conversion of unit cost to total present value cost can be traced through the formulas in the worksheet.

CONSISTENCY AMONG PERMITTEES

A comparison of cost estimates for structural Best Management Practice (BMP) types indicated in Water Quality Improvement Plans (WQIP) developed by the County of San Diego (County) and the City of San Diego (City) is provided through a technical memo prepared by the County of San Diego's consultant.[103]

BMPs included in cost estimates

The technical memo provided presents standardized cost estimate reporting (i.e., total BMP implementation cost and unit costs) and BMP types between the plans to allow for direct comparison. Furthermore, the San Diego region WQIP compliance cost estimates are compared to those presented in other related or similar plans including: the San Diego Region Twenty Beaches and Creeks Bacteria TMDL (Bacteria TMDL) and Los Angeles-area Enhanced Watershed Management Plans (EWMPs).

BMP costs reported in the technical memo are presented as average capital cost per square foot of implemented BMP. Capital costs are defined to include design, permitting and construction activities, and do not include consideration of funding for personnel costs, operations and maintenance activities (O&M) and non-structural controls. BMP types have been grouped into the three major categories developed for the City WQIPs for consistency: Multi-Use Treatment Areas (MUTA), Green Streets and Green Infrastructure. These categories are defined as follows:

- MUTA: provide community co-benefits and efficiently collect and treat large drainage areas (usually 10 acres or more)
- Green Infrastructure: small-scale infiltration on publicly owned parcels such as rain gardens and permeable parking lots
- Green Streets: infiltration and filtration BMPs located within in the public right-of-way along transportation corridors

[103] Alsop, Gummadi, Hanley, Questad, and Streets. *Water Quality Improvement Plan – Structural Best Management Practice Cost Estimate Comparison*. Tech. N.p.: Geosyntec, 2017. Print.

The relationship between County BMP types to the three major City BMP categories is shown in Table I-1 which is extracted from the technical memo provided.

Table I-1: Relationship of BMP Categories for City and County WQIPs.

BMP TYPE	COUNTY OF SAN DIEGO WQIPS	CITY OF SAN DIEGO WQIPS
Multiuse Treatment Areas		
MUTA		X
Wetpond	X	
Infiltration Basin	X	
Gross Solids and Trash Removal	X	
Subsurface Flow Wetland	X	
Green Infrastructure		
Green Infrastructure		X
Green Streets		
Green Streets	X	X

Comparison of BMP costs between jurisdictions

The implementation plans used as sources for BMP cost estimates are presented in Table I-2 which is extracted from the technical memo provided.

Table I-2. List of implementation plans that are source of BMP cost estimate data.

CITY OF SAN DIEGO WQIPS1	COUNTY OF SAN DIEGO WQIPS	LOS ANGELES
▪ Mission Bay ▪ Los Peñasquitos ▪ San Dieguito River ▪ San Diego River ▪ San Diego Bay ▪ Tijuana River	▪ San Luis Rey River ▪ San Diego River	▪ Upper Santa Clara River ▪ Rio Hondo/San Gabriel River ▪ East San Gabriel Valley ▪ Malibu Creek ▪ North Santa Monica Bay Coastal (NSMB) ▪ Santa Monica Bay Jurisdictions 2 & 3 (J23) ▪ Beach Cities (Santa Monica Bay & Dominguez Channel) ▪ Palos Verdes Peninsula

1 – The City WQIPs serve as the source of BMP cost estimates; however, cost estimates for City BMPs reported in this memo were taken from the City of San Diego WQIP Strategies Costing Tool Fact Sheet.

Aggregated, standardized BMP unit cost and total BMP implementation cost estimates for San Diego area plans and unit costs for Los Angeles area plans and the Bacteria TMDL are presented in Table 106 which is extracted from the technical memo provided.

Table I-3. Cost estimates for three BMP types across three jurisdictions and the Bacteria TMDL.

	GREEN STREETS	GREEN INFRASTRUCTURE	MULTI-USE TREATMENT AREAS (MUTA)
City of San Diego			
Acreage of Structural Strategies in WQIP (acres)	309.6	56	84.5
Average CIP Cost per Square Foot Implemented	$66.14	$66.53	$56.78
Total Cost	$892M	$162M	$209M
County of San Diego[1]			
Acreage of Structural Strategies in WQIP (acres)	10.1	Not Proposed3	141.1
Average CIP Cost per Square Foot Implemented ($/SF)	$62.75		$17.70 4
Total Cost	$28M		$109M
Los Angeles EWMPs[1]			
Average CIP Cost per Square Foot Implemented ($/SF)	$52.35	_5	$31.83
Bacteria TMDL[1,2]			
Average CIP Cost per Square Foot Implemented ($/SF)	_6	$32.16	_6

[1] Costs are reported as or have been adjusted to 2015 dollars using the US Department of Labor Bureau of Labor Statistics Inflation Calculator.

[2] CASQA, 2003.

[3] Not applicable as the required targets are met using non-structural BMPs, MUTAs and Green Streets.

[4] Approximately 85% of the County MUTA area is from two BMP locations (out of 12 total regional BMPS in the County WQIPs): 1) The Guajome Project in San Luis Rey watershed and 2) The Lakeside Conservancy in San Diego River watershed. Both projects are in open space land uses adjacent to the main waterbody.

[5] Some LA EWMPs provided green infrastructure costs; however, the footprints of these projects were not available and therefore a unit cost could not be calculated.

[6] Not considered.

The average CIP cost per square foot implemented is compared across jurisdictions for three different BMP types based on data in Table 106 (Figure I-1). Results indicate none of the BMPs considered have cost data available for all four sources of information considered. Unit cost is highest for Green Street in the City of San Diego and lowest in the Los Angeles EWMPs. There is a 21% range in Green Street unit costs. MUTA unit costs are highest for the City of San Diego and Lowest for the County of San Diego. There is a 69% range in costs. Limitations to this cost comparison are presented in the footnotes of Table 115 and the *Limitations of this comparison* section.

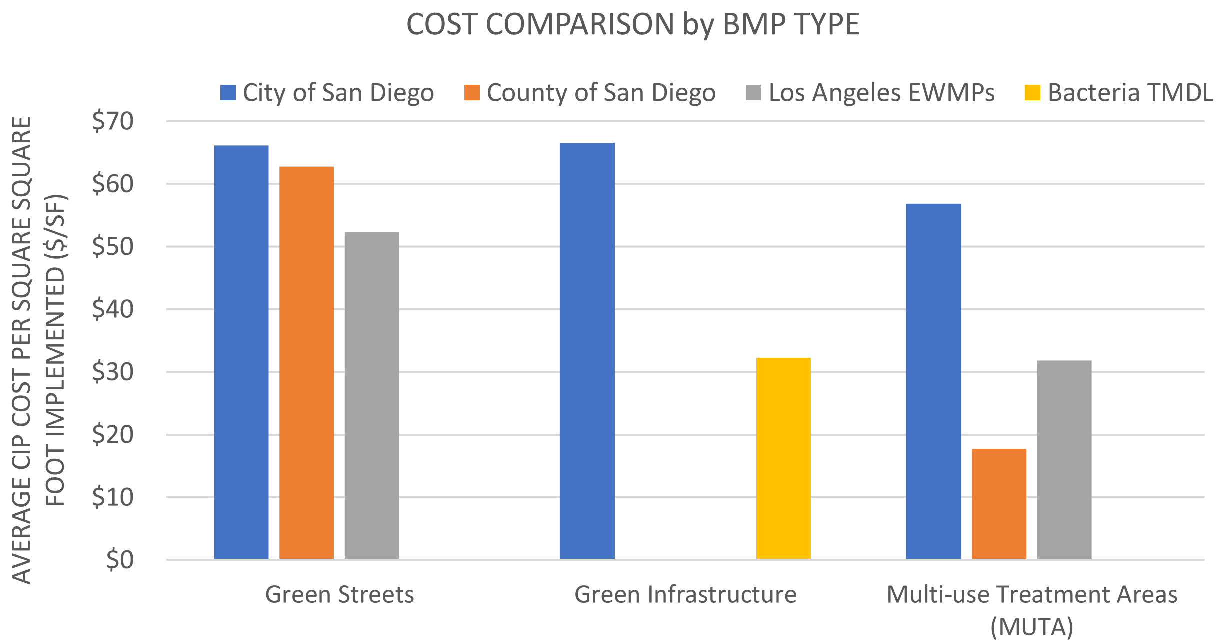

Figure I-1: Cost per square foot comparison for three BMP categories across three jurisdictions and the Bacteria TMDL. Unit costs for all BMP categories are highest for the City of San Diego, but data is not provided for all BMPs for all sources.

Cost comparison considerations

San Diego County WQIPs

BMP cost estimates for the specific regional structural BMP projects identified in the County WQIPs were aggregated into a single cost for the MUTA category (see Table 115), and reflect the total BMP cost for multi-jurisdictional BMPs. Wherever a range of costs was reported, the average of the high and low ends of the range was calculated. The costs for the County WQIP regional BMPs are area-weighted and are therefore influenced most by the cost of the largest BMPs (see footnote #4 in Table 115).

Los Angeles EWMPs

The EWMPs evaluated regional multi-use projects including infiltration basins/trenches, subsurface infiltration basins, subsurface flow wetlands, bioretention basins, lake improvements (e.g., dredging or greening features), and harvest/reuse cisterns. However, in order to accurately compare EWMP unit costs to City and County unit costs, only infiltration basins/trenches and subsurface flow wetlands were included in the calculated MUTA costs. A low and high range was calculated for each EWMP and the average of these two values was determined to be the comparative unit cost. It should be noted that the quantity of Green Street implementation in the East San Gabriel Valley EWMP was reported as length of Green Street and therefore a 5-foot width was assumed to determine an approximate footprint.Where unavailable, costs reported in the LA EWMPs were assumed to have been reported in dollars of the year the EWMP was submitted (2015 or 2016).

San Diego Region Bacteria TMDL

Capital unit costs for structural BMPs that may be implemented to comply with the requirements of the San Diego Region Bacteria TMDL were obtained from Appendix R (Environmental Analysis and Checklist) of the Final Technical Report for the Bacteria TMDL (SWRCB, 2010). Unit cost information was only available for Green Infrastructure BMPs, which include commercial and industrial bioretention projects. These costs are cited from the Stormwater Best Management Practice Handbook – New Development and Redevelopment (CASQA, 2003) and are for new construction costs only (i.e., estimates generally do not take into account retrofit of BMPs into existing development).

Limitations of this comparison

It is important to note that evaluating unit costs on a per square foot basis can be misleading due to the varying design parameters associated with each project. A more meaningful comparison, although difficult to execute due to lack of data available, would be comparing dollar per pollutant load reduced of each BMP type. Due to economies of scale, comparing these BMP types based on dollar per pollutant load reduced would likely result in a much larger difference between MUTA and Green Streets/Infrastructure. In other words, Green Streets/Infrastructure projects and MUTA projects will share similar line item costs (e.g., mobilization, excavation, etc.); however, larger regional projects are expected to be constructed more efficiently and provide a substantially larger amount of pollutant load reduction compared to Green Streets/Infrastructure projects which may be constructed with less efficiency due to their smaller size and consequently provide a lower pollutant load reduction.