Simple Treatment-Related Model

FINAL REPORT

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Prepared for the
Nitrogen and Selenium Management Program (NSMP) Working Group

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This report fulfils the requirements under Task 2.3 of the NSMP Year 2 Work Plan, and fits within the overall NSMP framework as shown below:

NSMP Task - Document Key
Task 1 Complementary Monitoring
Task 2 Develop and Evaluate BMPs/Treatment Technologies
Task 2.1 Coordinate With Monitoring and Database Efforts
Task 2.2 Survey Current Selenium and Nitrogen Treatment Methods
➲ **Task 2.3 Simple Treatment-Related Model**
Task 2.4 Select and Pilot Test Candidate BMPs and Treatment
Task 2.5 Develop BMP and Treatment Technology Implementation Plan
Task 3 Develop Offset, Trading or Mitigation Program
Task 4 Evaluate Nutrient TMDL
Task 5 Develop Site-Specific Objective (SSO) for Selenium
Task 6 Management and Communication

Prior reports prepared by the NSMP Working Group are available for download from the "NSMP Library" section of the NSMP web at: www.ocnsmp.com.

Executive Summary

The purpose of this report is to describe the development of the draft version of an Excel spreadsheet model that predicts total selenium and nitrate-nitrogen concentrations in the Newport Bay watershed. The model will be used by the Working Group to estimate surface water total selenium and nitrate-nitrogen concentrations before and after the implementation of Best Management Practices (BMPs) for treatment of base flows (non-storm flows) in creeks. The primary objective of the model is its use as a tool for prioritizing locations and BMP funding such that the maximum water quality and ecological benefit can be gained from available resources.

The model is a pollutant mass balance calculator that divides the Newport Bay watershed into important concentration points and predicts seasonal pollutant concentrations as flow weighted averages of sources that contribute selenium and nitrate. Sources include surface water flows in creeks and storm drains, groundwater exfiltration, and point sources such as groundwater treatment and dewatering facilities.

The model contains a tool that allows the user to select any source and evaluate the cost and water quality improvements from implementing any one of three BMP treatment technologies at that source. In doing so, the user can determine the least expensive technology that will adequately treat varying sources of nitrate and selenium to Newport Bay.

The draft version of the model incorporates a wide array of input data obtained from a number of sources. Streamflow data, water quality sampling and analysis data, and BMP technology pilot testing performance and cost data have been collected and applied as appropriate to the development of the model. During the review period of the draft version of the model, additional water quality data has been obtained that was not available at the time of model development. Most significant is nitrogen data from several groundwater treatment facilities in the Newport Bay watershed. These data have not been incorporated into the model at this time. Future updates to the model will incorporate such data.

Model predictions of total selenium and nitrate-nitrogen concentrations at several locations throughout the watershed were within an acceptable level of accuracy for this type of simple model, and were typically within 5-15% of observed seasonal values. Groundwater exfiltration flow rates have not been quantified with the same level of accuracy as surface flows throughout the watershed and it is likely that this data gap contributes to the errors in water quality predictions, particularly in the Peter's Canyon Wash subwatershed.

Several potential future implementation scenarios have been simulated with the model to show watershed selenium and nitrate-nitrogen reductions possible and associated ranges of costs. The scenarios simulated include:

- implementation of the most cost effective BMP only at major watershed nodes,
- implementation of the most cost effective BMP at all channels,

- implementation of subsurface flow treatment wetlands at all channels with nearby open-space or vacant land, and
- implementation of the most cost effective BMP only at channels or sources with total selenium concentrations greater than 25 ppb.

The simulations presented in this report have been performed to illustrate the capabilities and potential uses of the model. It should be noted that some water quality data from groundwater treatment facilities in the watershed were not able to be obtained prior to model development, and the simulation results presented reflect this. However, future model updates will incorporate this data.

The model has been designed as a modular tool that can be revised and updated as water quality, hydrology, and surface water/groundwater interaction characterization of the Newport Bay watershed improves over time.

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Acronyms and Abbreviations

cfs: cubic feet per second

µg/g: microgram per gram

µg/L: microgram per liter (equivalent to parts per billion, or ppb)

BMP: best management practice

gpm: gallons per minute

gpd: gallons per day

GW: groundwater

GWTF: Groundwater Treatment Facility

IRWD: Irvine Ranch Water District

LA: load allocation

lbs/day: pounds per day

lbs/yr: pounds per year

mg/kg: milligram per kilogram

mg/L: milligram per liter (equivalent 2 parts per million, or ppm)

NO3: nitrate**NSMP :** Nitrogen-Selenium Management Program

NPDES: National Pollutant Discharge Elimination System

pH: potential of hydrogen (measurement of acidity of a water sample)

psi: pounds per square inch

Se: selenium

Se (IV): selenite

Se (VI): selenate

SSF: subsurface flow

TDS: total dissolved solids

TIN: total inorganic nitrogen (ammonia + nitrite + nitrate)

TMDL: total maximum daily load

TSS: total suspended solids

USEPA: United States Environmental Protection Agency

WLA: wasteload allocation

WWTP: Wastewater Treatment Plant

1.0 INTRODUCTION

Task 2 of the NSMP Work Plan involved developing and evaluating treatment technologies and approaches that might be applied in the Newport Bay watershed to reduce selenium and nitrogen levels to meet permit and California Toxics Rule criteria. Task 2.3 of the NSMP Work Plan requires the development of a "simple treatment-related model" to help assess and compare the effects of BMP implementation on concentrations of nitrate-nitrogen and selenium in the Newport Bay watershed. The model will be used in future tasks to aid in developing a system of BMP and treatment technology applications that meet the program's objectives.

Conceptual models and data sets developed in Task 1 were used to develop a simple spread-sheet based model to predict selenium and nitrate-nitrogen concentrations at selected locations. Excel was selected as the model platform because of its common application for performing calculations and compatibility across many types of computer systems. In conformance with the Year 2 scope of work, the model is not a mechanistic model that precisely simulates all ecosystem processes. The model is validated with observed data, and is structured as a mass balance (numerical accounting of quantities) for selenium and nitrate. The model has been calibrated to estimate the contributions of various watershed sources for different seasons. The model tracks and predicts concentrations of nitrate-nitrogen in lieu of total inorganic nitrogen (TIN) and concentrations of total selenium in lieu of different selenium species. This is based on conclusions from available water quality data and the findings of prior tasks which showed that nitrate-nitrogen makes up virtually all TIN and that selenate is the dominant form of selenium throughout the watershed. This is further discussed in Section 3.2 below.

Several terms, and their definitions, used in this report specific to the model are:

- **Reach:** A stream, storm channel, or other "pipe" that delivers a flow of water containing NO_3/Se.
- **Node:** Collection of two or more connecting streams, storm channels, or other NO_3/Se sources.
- **Concentration:** Mass of NO_3 or Se per volume of water.
- **Flow Rate:** Volume of water flowing past a specific point on a channel in a given length of time.
- **Load:** A quantity (mass) flow of NO_3 or Se, equal to concentration times flow rate, generally expressed in pounds per year.
- **Mass Balance:** An accounting of material entering and leaving a system, such as a watershed. The technique is used in this model to account for sources and loads of selenium and nitrate-nitrogen throughout the Newport Bay watershed.

This report describes the purpose, input data, model components, and model validation and testing of the treatment model.

2.0 PURPOSE

The treatment-related model has been developed from compiled water quality and flow data, as well as the results of the Task 2.4 BMP evaluation, as a tool for the evaluation of treatment performance and prioritization of implementation for water quality treatment Best Management Practices (BMPs) within the Newport Bay watershed. The model 1) estimates the concentration of total selenium and nitrate-nitrogen at regulated locations as a function of known sources; 2) can be used to determine the relative contribution of each source of selenium and nitrate, as well as changes due to seasonality; and 3) evaluates the change in selenium and nitrate concentrations as a function of changes in any source, taken individually or as a group of changes.

3.0 MODEL INPUT DATA

The Model calculates a mass balance for nitrate and selenium within the Newport Bay watershed. The watershed is described abstractly in the model as key hydraulic connection points or "nodes" and stream sections or “reaches”. Node locations chosen have been selected to facilitate modelling from existing data measurement points. Pollutant concentrations are calculated at those nodes as a flow-weighted average of contributing flow reaches. If the user specifies that a particular BMP should be implemented at a given reach, the model allows the user to compare the cost of treatment by each technology for the particular combination of flow and pollutant concentrations. The model assumes that BMPs treat each reach’s contaminant loads immediately upstream of their connection to the next reach or node downstream. The model also provides an estimate of implementation cost and calculates a new set of pollutant concentrations for that reach and all reaches downstream based upon anticipated treatment effectiveness. The sections below provide summaries of input data sets and sources.

3.1 Hydrology

Because the NSMP will propose BMPs for treatment of non-storm flows, the model has been based around wet and dry season base-flow hydrology in the Newport Bay watershed. Base-flow hydrology refers to average daily flow patterns exclusive of short-term high flow storm events. Average wet (October 1 through March 31) and dry (April 1 through September 30) season base flow rates have been estimated for each reach or pollutant source used in the Model. These data were obtained from multiple sources identified below, including stream gages, direct observations of channel flow, and flow values reported from groundwater dewatering sites.

3.1.1 Stream Gage Data

Average seasonal base flows were obtained through analysis of daily average stream flows measured at a fixed stream gage over several years. Table 1 lists the stream gages used in compiling the hydrologic data set and the available period of record (County of Orange Watershed and Coastal Resources 2006). Seasonal base flow was estimated for these channels by first computing wet and dry season average flow rates, and then removing all daily flow observations greater than three times the average seasonal flow rate. As removal of these high flow observations subsequently affects the calculation of "average" seasonal flow, this process of removing flow observations greater than three times in the seasonal average was iterated until the process no longer affected the seasonal average. This typically required two to four iterations. This process provided base flow estimates that effectively exclude storm events.

Table 1: Stream Gages in Newport Bay Watershed

Stream Gage Location	Period of Record
Peter's Canyon Wash at Barranca Parkway	1991-2005
Bonita Creek at Irvine	2004-2005
San Diego Creek at Campus Drive	1992-2005
San Diego Creek at Culver Drive	1991-2005
Santa Ana-Delhi Channel at Irvine Ave	1991-2005
El Modena Channel at Michelle	1991-2005
Sand Canyon Wash at Irvine	2004-2005

3.1.2 Other Streamflow Observations

For channels without stream gages (all other channels not listed in Table 1, hereafter referred to as "ungaged channels") and groundwater exfiltration sources, average seasonal base flows were calculated by proportion from observations of flow estimates measured simultaneously at both gaged and ungaged channels. With this approach, seasonal flow rates used in the model for ungaged channels were derived from multiplying their observed watershed flow proportion by seasonal averages of flow in either Peters Canyon Wash or San Diego Creek. Channel flow observations used to estimate ungaged channel flows were obtained from reported stream flow measurements in sources listed below in Table 2.

Table 2: Sources of Flow Observations in Newport Bay Watershed

Source	Dates of Observation
2000-2001 Annual Status Report (County of Orange 2001)	May 19-22, 2001
Total Maximum Daily Loads For Toxic Pollutants San Diego Creek and Newport Bay, California (USEPA 2002)	Sept 12-20, 1999
Sources of Selenium, Arsenic and Nutrients in the Newport Bay Watershed (Meixner et al 2004)	Various Dates between 7/2002 and 6/2003

3.1.3 Groundwater Dewatering and Treatment Sites

The final source of hydrologic inputs to the model comes from groundwater dewatering facilities located throughout the watershed. These sources are of concern because their concentrations of selenium and or nitrate can be very high and therefore have been included in the model where both flow and concentration data available (Appendix A). At this time, all groundwater facilities with the exception of the Marine Corps Air Station sources (for which no flow data were able to be obtained by the consulting group) have been included in the model. Table 3 provides a summary of these sources. Using data from published reports and other data provided to the consulting group (see Table 4), flow values from groundwater discharge facilities (usually reported in gallons per day) have been used to calculate seasonal averages of flow. Currently, the California Department of Transportation (Caltrans) facility Walnut directly to the watershed, but it may in the future. Therefore, the model includes a switch to activate or deactivate this source during simulations.

Table 3: Groundwater Point Sources in Newport Bay Watershed

Facility	Notes	Permittee
Caltrans GWTF at Walnut	Discharges to WWTP	Caltrans
Marine Corps Air Station at Tustin (2 Facilities)	Discharges to PCW	US Marine Corps
Lane Channel Dewatering	Discharge to San Diego Creek	Nexus
Culver Grade Dewatering	Discharges to PCW	City of Irvine
Jamboree Dewatering	Discharges to PCW	City of Irvine
Santa Ana-Delhi Channel Dewatering	Discharges to SADC	Nexus

3.2 Water Quality

The two chemical constituents tracked by the model are nitrate-nitrogen and total selenium. Nitrate-nitrogen is used in the model as a surrogate for TIN. Traditionally, TIN is the sum of ammonia, nitrite and nitrate concentrations from a given body of water. The model represents TIN as nitrate-nitrogen because the other components of TIN (i.e., nitrite and ammonium) are near or below the limit of detection throughout the watershed. This determination is based on water quality data from the Task 2.4 Report (NSMP 2007) and from water quality data used to build this model.

Selenium can occur in various forms depending on availability of oxygen and carbon in the environment. Water quality data from the Bioavailability Report (NSMP 2006b), the Task 2.4 Report (NSMP 2007), and recently collected but unpublished data (CH2MHill 2007) shows that selenium (VI) accounts for at least 95 percent of the total selenium in the Newport Bay watershed. Because the BMP treatment technologies have the potential to convert selenium between its different forms, analysis of all possible forms of selenium was essential to ensure that the BMPs were not generating bioavailable or harmful forms such as selenite (selenium IV) or organic selenium. As described further in the Task 2.4 Report (NSMP 2007), under normal operating conditions it is not expected that the selected BMP technologies will generate such forms of selenium.

Typical wet season (October 1 through March 31) and dry season (April 1 through September 30) concentrations of total selenium and nitrate-nitrogen are required for each pollutant source used in the model. Appendix A contains all data incorporated into the model with citations of data sources. A summary of these data are provided in Table 4. Median values of all available data points along each source or stream reach have been used as a proxy for "typical" concentrations. Median values provide a measure of central tendency that is less sensitive than averages to extreme high or low values. For reference, water quality at all sampling points that have been incorporated into this version of the model are attached as Appendix A. Additional data from groundwater treatment facilities were obtained during the review period of the draft version of this report, and will be incorporated into the model during future model revisions.

Table 4: Water Quality Data Sources

Author/Entity	Data Description	Reference
Meixner et al	Surface and groundwater nitrate and selenium throughout watershed	Meixner et al 2005
CH2MHILL	Surface water selenium throughout watershed	CH2MHILL 2007
Moore, County of Orange	Surface and groundwater nitrate and selenium throughout watershed	Moore 2005
Caltrans	Dewatering effluent selenium and nitrate	Obtained directly, listed in Appendix A
County of Orange	Nutrient studies performed throughout watershed	Obtained directly, listed in Appendix A
County of Orange	Warner Channel nutrient study; nitrate data	County of Orange 2005
Hibbs, State Water Resources Control Board (SWCRB)	Progress reports for SWRCB, include nitrate and selenium in surface and groundwater throughout watershed	Hibbs 2004a-b, Hibbs 2005a-d

Author/Entity	Data Description	Reference
Hibbs and Lee	Surface and groundwater nitrate and selenium throughout watershed	Hibbs and Lee 2000
City of Irvine	Dewatering facility effluent selenium and nitrate (nitrate data obtained after development of model, to be incorporated at future date)	Obtained directly, listed in Appendix A

3.3 San Joaquin Marsh Natural Treatment System

In the mid 1990's IRWD developed the San Joaquin Marsh, a free water surface (FWS) wetland designed for nitrogen removal. It was later adapted to treat the water in San Diego Creek which is the main source of fresh water going into Upper Newport Bay. While the San Joaquin Marsh was primarily intended to remove nitrogen, it has also been demonstrated to reduce concentrations of metals such as selenium. Therefore, it has been included in the treatment model given its long-standing record in removing selenium and nitrate from San Diego Creek. Effluent concentrations of nitrate-nitrogen and total selenium from the San Joaquin Marsh are estimated in the model by use of an accepted first order treatment wetland removal model presented in Kadlec and Knight (1996). Table 6 presents average inflow and outflow rates as well as average seasonal inflow/outflow selenium and nitrate concentrations based upon data provided by the IRWD (IRWD, 2007).

Table 6: IRWD San Joaquin Marsh Flows and Removal Efficiencies

	Season	
Parameter	**Wet**	**Dry**
Flow In (cfs)	4.7	4.7
Flow Out (cfs)	4.1	4.1
Average Total Se Inflow (ppb)	18.0	18.8
Average Total Se Outflow (ppb)	15.0	13.7
Average NO3-N Inflow (ppm)	9.0	6.5
Average NO3-N Outflow (ppm)	3.5	1.6

4.0 MODEL COMPONENTS

The treatment model has two major components: 1) pollutant mass balance calculations; and 2) BMP implementation cost and performance predictions. Based upon the input hydrologic and water quality data, the model performs a series of linked mass balance calculations that predict seasonal total selenium and nitrate concentrations at key nodes throughout the Newport Bay watershed. These predictions can be run under a number of potential BMP implementation scenarios - ranging from the base case of current watershed conditions to a full strategic implementation of BMP technology throughout the watershed designed to lower pollutant concentrations to the greatest extent practicable.

The treatment model also has a built in set of calculations that predict nitrate and selenium transformation and removal as water flows through the watershed. This topic is discussed in further detail in Sections 4.2 and 4.3.

In addition, IRWD is currently in the process of implementing its Natural Treatment Systems Master Plan which will result in the design and installation of a number of water quality treatment BMPs throughout the Newport Bay Watershed. The NSMP treatment-related model incorporates estimates of treatment performance of these proposed BMPs.

These features and the underlying mass balance and BMP implementation components of the model are described in this section. Figure 1 provides an example illustration of how individual sources are combined to make predictions at nodes and how hydrologic connections are used to track water quality downstream to Newport Bay.

4.1 Water Quality Mass Balance

Table 7 summarizes each of the key nodes at which water quality predictions are made, and for each node lists the contributing sources used in the model for prediction. Potential sources not included in the model are listed with reasons for their exclusion. Figure 2 displays these sources on a map of the watershed.

Table 7: Compilation of Sources and Nodes in Treatment Model

Nodes Included in Model	Sources Included in Model
Node: PCW at CIC	
	Peter's Canyon Wash u/s of Central Irvine Channel
	Hick's Canyon Wash
	Central Irvine Channel (CIC)
Node: PCW at Valencia Channel	

	Peter's Canyon Wash btw CIC and Santa Fe Channel
	Ground water exfiltration to Peter's Canyon Wash btw CIC and Santa Fe Channel
	Como Channel
	Edinger Circular Drain
	El Modena Irvine Channel
	Santa Fe Channel (SFC)
	Valencia Channel
	Culver Drive Dewatering
	Jamboree Drive Dewatering
Node: San Diego Creek at Jeffrey Rd	
	San Diego Creek u/s of Jeffrey
Node: San Diego Creek and PCW confluence (includes subnodes SDC upstream of PCW and PCW upstream of SDC)	
	Warner Channel
	Peter's Canyon Wash btw SFC and San Diego Creek
	Ground water exfiltration to Peter's Canyon Wash btw SFC and San Diego Creek
	San Diego Creek btw Jeffrey and PCW confluence
	Ground water exfiltration to San Diego Creek btw Jeffrey and PCW confluence
Node: San Diego Creek u/s of San Joaquin Marsh Intake	
	Barranca Channel

	San Joaquin Channel
	Lane Channel
	Sand Canyon Wash
	Lane Channel Area Dewatering site
Node: San Diego Creek at Campus	
	San Diego Creek u/s of San Joaquin Marsh Intake
	San Joaquin Marsh Effluent
Node: Santa Ana Delhi Channel at Irvine Ave	
	Santa Ana Delhi Channel u/s of 405
	Santa Ana Delhi Channel btwn 405 and Irvine Ave
	Santa Ana Delhi Channel Dewatering Site in Costa Mesa
Node: Newport Bay input	
	Bonita Creek
	San Diego Creek at Campus
	Santa Ana-Delhi Channel at Irvine Ave
Sources Not Included	
Marshburn Creek	No water quality data available, no evidence for elevated pollutants
Agua Chinon Wash	No water quality data available, no evidence for elevated pollutants
MCAS Tustin GW Treatment	No flow data able to be obtained
Caltrans GWTF (included in	No discharge to creeks, discharges to OC WWTP

treatment model as optional source)	

Each source listed in Table 7 has a corresponding input data set of average seasonal flow rates and median seasonal total selenium and nitrate-nitrogen concentrations.

4.2 In-Channel Nitrate-Nitrogen Model

Meixner et al (2004) found that not all of the nitrate that originates from within the Newport Bay watershed ultimately flows into the bay. To date, no study has quantified the exact amount of nitrate loss within each region of the watershed or characterized every removal mechanism responsible. However, natural processes such as algal uptake, bacterial denitrification, and many others remove or transform nitrate within the surface channels. To factor in these nitrate losses in the treatment-related model, a simple first-order empirical removal function was used (Kadlec and Knight 1996) to estimate removal in stream channels as if they were very long and narrow wetland reactors. The channels modeled are typically open, vegetated systems that include sections that function similarly to wetland treatment systems, but are anticipated to be less efficient because of their highly channelized structure.

This in-channel nitrate loss model was calibrated using known nitrate concentrations, flows, and channel width and flow path lengths along both Peter's Canyon Wash and San Diego Creek. By selecting a reference reach where there are no tributary inputs of nitrate and data is available for both upstream and downstream concentrations, the Kadlec and Knight model can be calibrated based upon the approximate area of the reach and its upstream (inflow) and downstream (outflow) concentrations. This calibrated model is then extrapolated to estimate in-channel nitrate loss in other portions of the Creek in which it was calibrated.The calibrated rate constant was used to predict nitrate loss along other reaches of Peter's Canyon wash and San Diego Creek based on average width, flow path length, and upstream nitrate concentration. Appendix B provides more information on calibration and implementation of this nitrate loss model.

4.3 In-Channel Selenium Model

The same model described above for in-channel nitrate loss was also implemented to estimate selenium transformations. It is known that numerous processes exist by which selenium can be lost from the water column to sediments and biota. It should be noted that these processes do not remove selenium from the environment, but do result in decreased water column concentrations. The selenium in-channel loss model was calibrated using known total selenium concentrations, flows, and channel width and flow path lengths along San Diego Creek between Michelson Drive and the San Joaquin Marsh inlet. It has only been implemented in the treatment model for San Diego Creek, as water quality data from Peter's Canyon Wash does not exhibit the same in-channel losses of selenium. While such selenium loss processes are likely still occurring, they are not generally observed as downstream reductions in selenium concentration. The likely explanation for this is the significant and widespread groundwater seepage of selenium known to exist along many tributaries in the Peter's Canyon Wash subwatershed, especially as PCW and its tributary channels course through the area of the historic Swamp of the Frogs. Appendix B provides more information on calibration and implementation of this selenium loss model.

4.4 BMP Implementation Modeling

Given the anticipated use of the model to estimate BMP implementation costs and resulting water quality changes in the Newport Bay watershed, the model was configured to allow multiple BMP implementation scenarios while predicting associated treatment results and estimated capital and operations and maintenance costs.

4.4.1 Water Quality Treatment

During Task 2.4, BMP treatment technologies were evaluated based on criteria described further in the Task 2.4 Report (NSMP 2007). Testing of the BMPs (Task 2.4) indicated that three of the BMPs had potential to achieve effluent concentrations at or near the target values of 5 ppb selenium/5 ppm nitrate-nitrogen in their effluent. Both the RO and ABMET/GE systems could meet the target values. The SSF wetland may require a 20 to 40 percent increase in residence time to remove nitrate-nitrogen and selenium at the upper range influent concentrations. This information was provided by the vendors as treatment abilities for full-scale systems. While the pilot testing did not conclusively show that the selected technologies could meet target affluent concentrations under all conditions, results were considered promising enough that modifications to BMP operation and optimization of the processes could result in desired treatment effectiveness. Therefore, this treatment model has been developed with the assumption that implementation of these BMPs will meet target affluent criteria. For additional discussion of the results and implications of the pilot testing, please refer to the Task 2.4 Report (NSMP 2007).

In the treatment model, when a particular BMP is selected for application along a reach or other source, a target effluent concentration (5ppm nitrate / 5ppb selenium) is assigned to treated BMP flows and a new flow-weighted set of nitrogen and selenium concentrations are calculated for that reach or source. In addition, an approximate area for the treatment system is calculated based upon assumptions provided by vendors or through the Kadlec and Knight wetland treatment model (for wetland BMPs) referenced above.

4.4.2 BMP Technology Cost Functions

To predict water quality effects and cost of implementation of BMP technologies, simple models relating the inflow rate and concentration to unit cost of treatment were developed from cost quotes provided by selected vendors and prior analyses performed in Task 2.4. These data consist of construction and operations costs for each technology to treat any combination of "high" (i.e., $\geq$5.0 cfs) or "low" (i.e., $\leq$0.5 cfs) flow and "high" (i.e., 30 ppm nitrate or 100 ppb selenium) or "low" (i.e., 10 ppm nitrate or 10 ppb selenium) concentration. Present worth values have been tabulated for construction and 10 years of operation.

This data set was obtained for each of the three BMP technologies evaluated in Task 2.4 of the NSMP Work Plan and selected for inclusion in the model. These three technologies include:

- ◆ **Biological Treatment (ABMET/GE)**
- ◆ **Reverse Osmosis**
- ◆ **Subsurface Flow Wetland System**

Therefore, for each of these three technologies, an implementation cost has been calculated for each of four conditions:

- High flow rate and high concentration (5.0 cfs and 30 ppm nitrate or 100 ppb selenium)
- Low flow rate and high concentration (0.5 cfs and 30 ppm nitrate or 100 ppb selenium)
- High flow rate and low concentration (5.0 cfs and 10 ppm nitrate or 10 ppb selenium)
- Low flow rate and low concentration (0.5 cfs and 10 ppm nitrate or 10 ppb selenium)

Regression analysis on these four points provided an equation for each technology to calculate cost to treat any stream, channel, or source down to threshold concentrations of 5 ppb selenium/5 ppm nitrate given its flow and nitrate and selenium concentration. A regression analysis is a statistical technique used to find relationships between variables (in this case the variables are pollutant concentration to be treated, flow rate to be treated, and BMP cost). Table 5 summarizes the regression coefficients for the selected treatment technologies. To estimate construction and operations costs for any technology, the following equation is used in conjunction with the coefficients listed in Table 5:

$Cost = Y + \beta_1 * C_i + \beta_2 * Q_i$, where

Cost = Total 10 year Net Present Value ($)
Y = Intercept ($)
β_1 = Concentration regression coefficient
C_i = Inflow concentration (ppb for Se, ppm for nitrate)
β_2 = Flow regression coefficient
Q_i = Inflow rate (cfs).

Table 5: BMP Cost Regression Coefficients

Equation Parameter	Reverse Osmosis	Anaerobic Bacteria (ABMet)	Subsurface Flow Wetlands
Intercept (Y)	1817923	1994240	207448
Concentration Coefficient (β_1)	7366	5167	13072
Flow Coefficient (β_2)	2042966	857887	507380

For example, to estimate a cost to treat 10 ppb selenium at 1 cfs with a reverse osmosis treatment train:

$Y = 1817923$
$\beta_1 = 7366$
$\beta_2 = 2042966$

And therefore,

Cost = 1,817,923 + 10 * 7,366 + 1 * 2,042,966 = $3,934,549 or approximately $3.9 million. This cost includes design, permitting, construction, and operations and maintenance for 10 years.

Any costs developed and provided in this analysis are order-of-magnitude budgetary-level costs. The Association for the Advancement of Cost Engineering International defines order-of-magnitude costs as Class 5 cost estimates that are approximate without detailed engineering data. Examples of such would include: (1) an estimate from cost-capacity curves, (2) an estimate using scale-up or scale-down factors, and (3) an approximate ratio estimate. The cost estimate regressions and any resulting conclusions on financial or economic feasibility have been prepared for guidance in evaluation of the BMP technologies from information available at the time of the analysis.

When a particular BMP technology is selected to be implemented at any particular model reach, its highest seasonal base flow rate (wet or dry) and corresponding nitrate and selenium concentrations are input into the regression formula and a cost to implement that technology is calculated. This process provides a conservative cost estimate based upon the "worst-case" flow to be treated on each reach.

In addition, the model incorporates cost for land purchase to site BMPs. BMPs such as treatment wetlands are especially land intensive and may require a significant area for implementation. For each stream or storm drain channel in the model, a GIS land-use data set has been used to estimate availability of vacant or open-space land near channels or streams. This allows the user to determine the maximum footprint possible for such treatment technologies. In addition, based upon vendor data in the case of reverse osmosis and ABMet, and the Kadlec and Knight wetland treatment model described above in the case of wetlands, the model estimates the area required to implement a treatment system to treat each source. The user may input an assumed land cost per acre (default value is $1 million per acre), and the land purchase costs are then added to the total cost of implementation for each technology.

4.5 Irvine Ranch Water District Natural Treatment System Master Plan

Irvine Ranch Water District is currently involved in development and implementation of a series of natural treatment systems for pollutant removal throughout the Newport Bay watershed. To facilitate partnership of watershed management efforts and coordinate strategies, proposed IRWD natural treatment sites can be "activated" within the model so that predictions of selenium and nitrate concentrations can be made at any stage of implementation. For the draft version of the model, IRWD "regional/retrofit" natural treatment systems have been incorporated.

The treatment model uses the Kadlec and Knight (1996) wetland performance model to calculate each IRWD natural treatment system nitrate removal performance under any desired scenario using total nitrogen model parameters reported in Appendix D of the IRWD NTS Master Plan document (IRWD 2005). The IRWD natural treatment system's removal rates for total nitrogen are assumed to be comparable to removal rates for nitrate, given the proposed surface flow wetland configuration and loading rates.

The IRWD Natural Treatment System Master Plan does not provide modeling results for removal of selenium. Therefore, when estimating selenium treatment by IRWD natural treatment systems, the same treatment wetland model has been used with a removal rate constant for selenium used in the in-channel selenium loss model for San Diego Creek described above in Section 4.3. This provides a locally calibrated value specific to the watershed.

5.0 MODEL VALIDATION AND TESTING

Model predictions were compared to observed values at selected nodes to characterize model error. Because the model predicts average seasonal flow and water quality patterns, predictions were compared with average seasonal observations of flow and median seasonal observations of water quality.

5.1 Calibration

Preliminary predictions by the model were generally found to be consistent with expectations given the scope, intended use, and wide array of input data sources of the model. However, selenium concentrations predicted by the model in lower Peter's Canyon Wash were underpredicted by approximately 40%. Given that it has been well documented that the primary source of selenium in the Newport Bay watershed is leaching from groundwater (Meixner 2004, Hibbs and Lee 2000), it was hypothesized that selenium underpredictions in Peter's Canyon Wash were due to underestimation of contributions of groundwater in gaining reaches of lower Peter's Canyon Wash. In addition, the model underpredicted flow rates at the downstream end of Peter's Canyon Wash. Therefore, groundwater exfiltration (seepage from generally high-selenium groundwater into surface water channels) rates in lower Peter's Canyon Wash were modified to calibrate the model. This was accomplished by manually increasing the groundwater exfiltration flow rate in the "groundwater exfiltration to Peter's Canyon Wash between Santa Fe Channel and San Diego Creek," which effectively increases selenium inputs to the watershed through the addition of greater groundwater flows. This affected model predictions in two ways -- by increasing flow rates of groundwater exfiltration, flow rate predictions at the confluence of Peter's Canyon Wash and San Diego Creek were improved, and selenium predictions in lower Peter's Canyon Wash increased, strengthening the model's accuracy.

5.2 Hydrology Validation

Two stream gages in the Newport Bay watershed were used to validate model hydrologic predictions. Because the stream gage on Peter's Canyon Wash at Barranca Parkway is located just upstream of the confluence with San Diego Creek, the stream gage location is appropriate to validate the model's predictions for all of Peter's Canyon Wash. Based upon the comparison shown in Table 8, the model is accurate to within 2% of the observed values.

The stream gage on San Diego Creek at Campus Drive provides an additional validation location. Because the stream gage is located near the termination of San Diego Creek at Newport Bay and includes all tributaries with the one exception of Bonita Creek, this location is appropriate to compare predictions for virtually all of the Newport Bay Watershed, which is the major source of water for Newport Bay. Similarly, the model is accurate to within 14% of observed flows, with a slight tendency to overpredict flow in San Diego Creek.

Table 8: Model Hydrologic Validation

	Observed Flows (cfs)		Predicted Flows (cfs)		Percent Error in Prediction	
Node	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
PCW u/s of SDC (PCW at Barranca Pkwy stream gage)	7.1	7.0	7.0	6.9	0%	-2%
SDC at Campus stream gage	12.1	12.2	12.9	13.8	6%	14%

Sources of error include the lack of long-term stream gaging data on many of the creeks and storm drains within the watershed, and the sparse data on groundwater contributions to the stream channels. However, the estimates of error returned by the model are within the range of error typically encountered in preparing water balance models, particularly given the predominantly urban land use, and are acceptable for the purposes of this simple, treatment-related model.

5.3 Water Quality Validation

Three locations were selected for comparing observed and predicted concentrations of nitrate and selenium: the downstream end of Peter's Canyon Wash at Barranca Parkway, San Diego Creek at the inlet to the San Joaquin Marsh treatment wetlands, and San Diego Creek at Campus Drive. These sites integrate numerous watershed sources and have long-term and an appropriate sample size of water quality data.

5.3.1 Total Selenium

Table 9 presents comparisons of observed and predicted total selenium values. All predicted values are within 10% of observed values. In all cases, seasonal selenium concentrations have been well predicted by the model. For example, observed selenium concentrations are higher in Peter's Canyon Wash during the dry season than in the wet season, and this is reflected in the model predictions. Conversely, observed wet season total selenium concentrations are higher in San Diego Creek than dry season concentrations, and the model captures this as well.

Table 9: Comparison of Model Selenium Performance

	Observed Total Se (ppb)		Predicted Total Se (ppb)		Percent Error in Prediction	
Node	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
PCW u/s of SDC (PCW at Barranca Pkwy stream gage)	27.4	31.0	30.0	30.7	10%	-1%
SDC u/s of San Joaquin Marsh Inlet	19.2	18.6	18.3	17.5	-5%	-6%
SDC at Campus stream gage	19.4	15.0	17.4	16.2	-10%	8%

5.3.2 Nitrate-Nitrogen

Table 10 presents comparisons of observed and predicted nitrate values. Both wet and dry season concentrations were predicted within -6 to 13% of the observed values.

Table 10: Comparison of Model Nitrate Performance

	Observed NO3-N (ppm)		Predicted NO3-N (ppm)		Percent Error in Prediction	
Node	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
PCW u/s of SDC (PCW at Barranca Pkwy stream gage)	7.9	6.5	8.9	6.1	13%	-6%
SDC u/s of San Joaquin Marsh Inlet	9.0	5.8	9.0	5.1	0%	-12%
SDC at Campus stream gage	8.2	4.3	7.3	3.9	-11%	-9%

5.3.3 Sources of Error

Sources of error for the selenium and nitrate models include variable input data with different sampling frequencies and different sampling agencies over a long time, and the uncertainty over the volume and concentration of groundwater contributions to surface water channels. The model incorporates best available estimates of groundwater inflows, along with estimates of groundwater selenium and nitrate concentrations, but by definition, the full complexity of the groundwater/surface water interactions in the watershed is not explicitly described in this simple, treatment-related model. However, the estimates of error returned by the model are within the range of error typically encountered in preparing water balance models, and all are acceptable for the purposes of this model.

5.4 BMP Implementation Scenario Simulations

The following section presents the results of simulating several different potential future BMP implementation scenarios. The scenarios simulated include the following:

- "Base case" or current conditions

- Scenario 1: implementation of the least expensive technology at major watershed nodes under four different potential watershed conditions:
  - 1A: IRWD NTS Master Plan Regional/Retrofit sites ***NOT IMPLEMENTED*** and CalTrans GWTF ***NOT DISCHARGING*** to the watershed,
  - 1B: IRWD NTS Master Plan Regional/Retrofit sites ***NOT IMPLEMENTED*** and CalTrans GWTF ***DISCHARGING*** to the watershed,
  - 1C: IRWD NTS Master Plan Regional/Retrofit sites ***IMPLEMENTED*** and CalTrans GWTF ***NOT DISCHARGING*** to the watershed,
  - 1D: IRWD NTS Master Plan Regional/Retrofit sites ***IMPLEMENTED*** and CalTrans GWTF ***DISCHARGING*** to the watershed,

- Scenario 2: implementation of the least expensive technology at each model reach (otherwise assuming current watershed conditions),

- Scenario 3: implementation of subsurface flow treatment wetlands on each model reach where open space or vacant land was available (otherwise assuming current watershed conditions). In addition, in reaches where in open space or vacant land was not available in a sufficient acreage to treat the reach's full flow to model discharge criteria (5 ppm nitrate-nitrogen/5 ppb total selenium), only a portion of the reach's flow was treated by the subsurface flow wetland, and

- Scenario 4: implementation of the least expensive technology only at reaches with total selenium concentration of 25 ppb or greater (otherwise assuming current watershed conditions).

Appendix C provides detailed model simulation output tables for all model reaches under all the above scenarios. Table 11 provides a summary of simulation results at key watershed locations under all seven scenarios described above.

Table 11: Summary of Simulation Output.

Scenario	Base Case	1A	1B	1C	1D	2	3	4
Model Prediction Quantity								
Nitrate-Nitrogen in ppm:								
Downstream end of PCW, Wet Season	8.7	5.9	5.9	4.7	4.7	3.8	6.1	5.4
Downstream end of PCW, Dry Season	6.0	5.5	5.4	3.7	3.8	2.9	4.6	3.6
SDC at confluence with PCW, Wet Season	10.1	5.0	5.0	5.0	5.0	4.0	7.9	7.3
SDC at confluence with PCW, Dry Season	6.0	5.0	5.0	4.0	4.1	3.2	4.8	4.0
SDC at Campus, Wet Season	7.3	4.8	4.8	4.5	4.5	4.3	6.1	5.9
SDC at Campus, Dry Season	3.9	3.5	3.6	2.8	2.9	2.9	3.5	3.2
Combine flow to Newport Bay, Wet Season	6.2	4.2	4.2	3.9	4.0	3.8	5.3	5.1
Combine flow to Newport Bay, Dry Season	3.5	3.2	3.3	2.6	2.7	2.7	3.2	2.9
Total Selenium in ppb:								
Downstream end of PCW, Wet Season	29.3	17.9	16.8	17.4	16.4	5.0	23.6	19.5
Downstream end of PCW, Dry Season	30.0	20.0	18.4	19.5	18.0	5.0	25.5	21.9
SDC at confluence with PCW, Wet Season	26.1	5.0	5.0	5.0	5.0	5.0	21.3	17.9
SDC at confluence with PCW, Dry Season	26.5	5.0	5.0	5.0	5.0	5.0	22.7	19.6
SDC at Campus, Wet Season	17.2	6.0	5.9	5.9	5.9	5.7	14.7	12.8
SDC at Campus, Dry Season	16.0	6.0	5.9	5.9	5.9	5.4	14.2	12.8
Combine flow to Newport Bay, Wet Season	15.5	5.6	5.6	5.6	5.6	5.4	12.8	11.9
Combine flow to Newport Bay, Dry Season	14.4	5.7	5.7	5.7	5.7	5.3	12.7	11.7
Total Cost of Implementation ($ millions)	0	20.7	22.0	20.7	22.0	45.6	23.6	12.4

Table 12: Summary of Selected BMPs for Implementation Scenarios

Scenario	BMP Location(s)	BMP Implmented
1A	PCW@Valencia, SDC@PCW	ABMet
	SADC@Irvine Ave	SSF Wetland
1B	PCW@Valencia, SDC@PCW	ABMet
	SADC@Irvine Ave	SSF Wetland
1C	PCW@Valencia, SDC@PCW	ABMet
	SADC@Irvine Ave	SSF Wetland
1D	PCW@Valencia, SDC@PCW	ABMet
	SADC@Irvine Ave	SSF Wetland
2	CIC, SDC Jeffrey to PCW, Lane Dewater, SADC Dewater, SADC between I-405 and Irvine	SSF Wetland
	Como, Valencia, Edinger Circular Drain, Santa Fe, Culver Dewater, Jamboree Dewater, Warner, SDC u/s of PCW, PCW@SDC, Lane,	ABMet
3	CIC, Santa Fe, Warner, SDC upstream of Jeffrey Rd, SDC Jeffrey Rd to PCW, SADC between I-405 and Irvine	SSF Wetland, 100% of flow
	Como	SSF Wetland, 26% of flow
	Valencia	SSF Wetland, 54% of flow
	PCW between Valencia to SDC	SSF Wetland, 12% of flow
4	Lane Dewater	SSF Wetland
	Como, Valencia, Edinger Circular Drain, Culver Dewater	ABMet

The four major implementation scenarios presented above were chosen to evaluate a wide range of potential implementation schemes. For example, Scenario 1 only implements BMPs at major watershed nodes. This provides a regional, "end-of-pipe" level of treatment for a relatively modest cost, but because treatment BMPs are not applied along individual tributaries upstream of the major nodes, there is potential for ecological impacts associated with elevated pollutant concentrations along individual tributaries. This scenario has been simulated with and without the effect of IRWD NTS Master Plan regional/retrofit sites and with and without contribution from the Caltrans GWTF. Note that the two scenarios that include the Caltrans GWTF (1B and 1D) result in a higher total cost of implementation due to increased selenium contributions. The two scenarios that include IRWD NTS sites (1C and 1D) result in lower nitrate-nitrogen concentrations throughout the watershed for a comparable cost to the scenarios that do not include them.

Scenario 2 implements BMPs on every model reach. Therefore, this scenario results in the highest cost of implementation. However, because all flows are treated, this scenario results in the least potential for ecological impacts due to reduction in pollutant concentrations watershed-wide. Scenario 3 implements subsurface flow wetlands along reaches where the GIS-based land availability analysis (described above in Section 4.4.2) located open space or vacant land. This scenario does not reduce pollutant concentrations to the same degree as

Scenario 2 due to the fact that land availability in the Peter's Canyon Wash subwatershed is not high. However, its total cost of implementation is significantly lower than that of Scenario 2. Finally, Scenario 4 targets only "hot spot" reaches, and therefore has the lowest cost of implementation. Because it only treats a limited number of reaches, it does not achieve the same pollutant reductions as Scenarios 1 and 2. For calculation of implementation costs, a land value of $1 million per acre was assumed.

6.0 CONCLUSIONS

This report describes the data and structure of a simple, treatment-related model to be used for prioritizing locations and BMP technologies for implementation to reduce selenium and nitrate concentrations in the Newport Bay watershed. The model has been developed in Excel format and results for several model scenarios have been presented as examples of evaluating the relative effectiveness of alternative approaches to watershed-wide BMP implementation. While preliminary, these results corroborate the general conclusion of Task 1.5 "Multiple Lines of Evidence" that effective locations for the implementation of BMPs include the upstream drainage channels in the Swamp of the Frogs area (reaches such as "Como," "Valencia," "Santa Fe," "Edinger Circular Drain," "Warner," and "Lane Channel") and the SADC ("SADC between I-405 and Irvine Ave" reach and "SADC at Irvine" node). Future BMP implementation plan development will focus on determining an optimal solution based upon the results of this preliminary modeling and the results of Tasks 1.5 and 2.4. Future application of the model can further determine which reaches of the watershed should be prioritized for the implementation of BMPs as funding is available.

The model has been designed in a modular fashion so that sources such as streams, storm drain channels, etc. can be rapidly and easily added to the model as new data or watershed characterization is produced. Also, as more water quality data is collected over time, input data can be modified to reflect these new sources of information.

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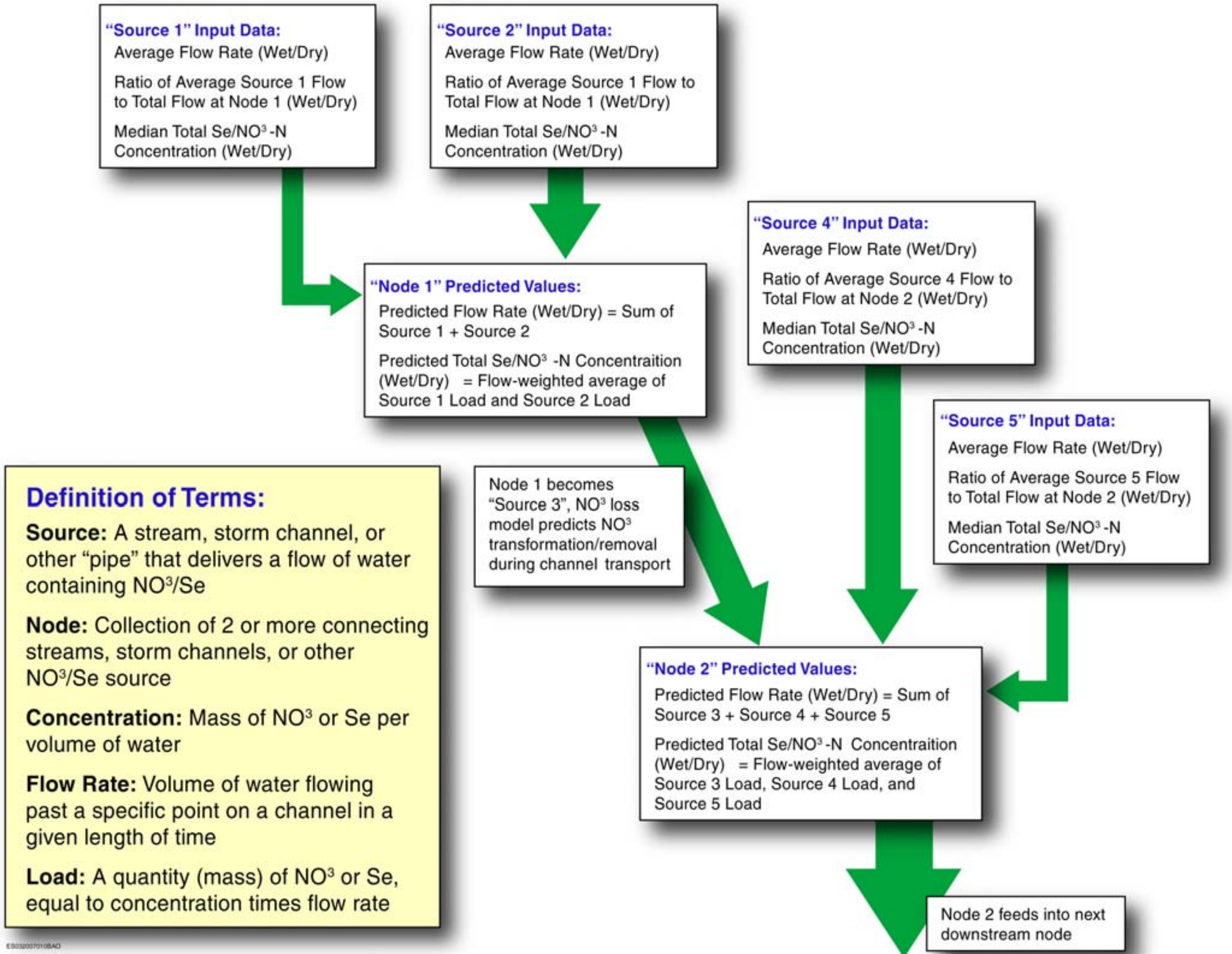
8.0 FIGURES

Figure 1: Treatment Model Water Quality Mass Balance



INSERT FIGURE 2

APPENDIX A

Tabulation of water quality data

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APPENDIX B

In-Channel Nitrate and Selenium Loss Model Development and Calibration

A first-order, area-based, plug flow model was used to predict nitrate and selenium loss as water flows down channels in the Newport Bay watershed (Kadlec and Knight, 1996):

$$C_O = C^* + \left(C_I - C^*\right) e^{\left(\frac{-k_T * L * W}{0.0365 * Q}\right)}$$

where

$$k_T = k_{20}\left(\Theta\right)^{(T-20)}$$

and C_O = concentration in effluent, mg/L NO3 or Se
C_I = concentration in influent, mg/L NO3 or Se
C^* = irreducible background concentration, mg/L NO3 = 0 mg/L, 0 ug/L Se
k_T = first-order areal reaction rate constant at T°C, m/yr
k_{20} = first-order areal reaction rate constant at 20°C, m/yr
Θ = temperature correction factor for nitrate = 1.09
Q = influent water flow rate, cubic meters per day
L = stream channel flow path length in meters
W = average channel width in meters
T = temperature, °C.

Application of this model to nitrate and selenium losses in the Newport Bay watershed requires initial calibration by calculating a local, watershed specific value for $k_{20}$for each pollutant. This was accomplished for nitrate by taking two reference reaches with in the watershed, one on Peter's Canyon Wash, and the other on San Diego Creek and rearranging the above equation to solve for k_{20} from observed values for all other parameters. For selenium, the same was done for one reference reach on San Diego Creek. Reference reaches were chosen where upstream and downstream water quality data were available and as few external gains or losses of selenium or nitrate were present. For example, reference reaches were chosen upstream of the San Joaquin Marsh, as it is known to significantly reduce both pollutant's concentrations. Reference reaches also were chosen where possible to avoid significant known sources of selenium or nitrate external to the reaches, such as tributaries or high concentration groundwater. Median observed nitrate concentrations, average wet and dry season air temperatures, and channel dimensions measured by aerial photography were used to accumulate necessary values. Then, a single watershed wide k_{20} was calculated by solving for such a value that resulted in the smallest sum of the square of errors between model predicted and observed effluent nitrate concentrations in each of the two reference reaches. A watershed-wide rate constant is less subject to local variations and is based upon more data points than the individual calibrations. Summaries of calculations are provided below for reference.

Nitrate Loss Model

Co = C* + (Ci - C*) exp (-kA/0.0365Q)

PCW Reference Reach: between Central Irvine Channel and Valencia Channel				SDC Reference Reach: between PCW Confluence and Michelson			
Parameter	Wet Season	Dry Season	unit	Parameter	Wet Season	Dry Season	unit
C_I (Cin)	18	10.4	ppm	C_ICin	11.84	7.98	ppm
C_O (Cout)	12.2	5.5	ppm	C_OCout	11.3	7.4	ppm
Qin	2324.27	2348.736	m^3/dcmd	Qin	20708.6	20376.62	m^3/dcmd
Length	2515	2515	m	Length	1933	1933	m
Width	10	10	m	Width	13	13	m
area	25151	25151	m2	area	25129	25129	m2
area	2.5	2.5	ha	area	2.5	2.5	ha
C*	0	0	ppm	C*	0	0	ppm
k_T	13.2	21.6	m/yr	k_T	13.2	21.6	m/yr

	Wet Season	Dry Season	
theta	1.09	1.09	
Average Air Temp '(C)	14.3	20	Centigrade

k20	21.61462

	Square of Residual (Predicted-Observed)
PCW	
Wet	3.2
Dry	7.2
SDC	
Wet	0.0
Dry	2.184473891
Sum of Squares	12.6

Selenium Loss Model

Co = C* + (Ci - C*) exp (-kA/0.0365Q)

SDC from Michelson to Alton Reference Reach					
	wet	dry			

Cin	22.65	15.39	ppm		
Cout	21.8	14.8	ppm		
Qin	14484	14680	cmd		
length	1250	1250	m		
width	13	13	m		
area	16250	16250	m2		
area	1.625	1.625	ha		
C*	1	1	ppm		
k	13.1	13.1	m/yr		

	wet	dry
theta	1	1
temp '(C)	14.3	20

k20	13.10828

	Square of Residual (Predicted-Observed)
SDC	
Wet	6.5
Dry	14.5
Sum of Squares	
	21.0

APPENDIX C

Simulation Output

[ATTACHED]