

Appendix 3: Linkage Analysis and Calculation of Background Loading

The linkage analysis describes the relationship between the numeric target and the attainment of water quality standards by defining the waterbody’s total assimilative capacity, or loading capacity, for the pollutant. The loading capacity represents the maximum amount of pollutant loading the waterbody can support and still attain water quality standards. This number, when adjusted by a margin of safety, defines the TMDL for a particular waterbody and pollutant.

A “box model” based on mass-balance principles was used to calculate the loading capacity of SIYB. This theoretical model, which was tailored to SIYB, describes copper fate and transport in and out of the Basin. This model was developed by Space and Naval Warfare Systems Command (SPAWAR) for use by the Regional Board (Chadwick, 2000).

Copper mass balance in SIYB was derived using general mass balance principles. In order to do so, a control volume must be defined. In this case, the control volume was defined as the volume of water in the entire Basin, where the only open boundary for tidal flushing occurs at the interface between the Basin and the rest of San Diego Bay, herein referred to as the “Basin entrance.” This control volume was chosen for two reasons: (1) the entire Basin is listed as impaired on the State’s Section 303(d) List, and (2) the geometry of the Basin as a whole is known, which results in increased confidence in the analysis.

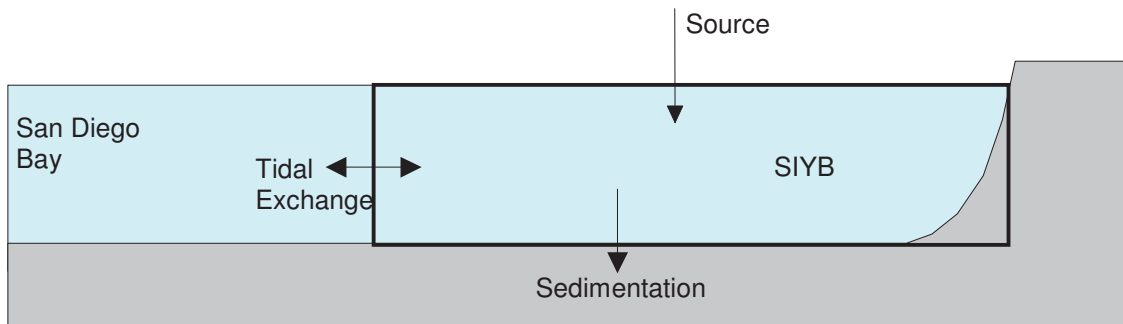


Figure A3.1. Schematic Profile of the Control Volume.

Movement of a constituent in and out of the defined control volume is described by conservation of mass. In conceptual form, this can be written as:

$$(a) \left[\begin{array}{l} \text{Rate of mass increase} \\ \text{in control volume} \end{array} \right] = \left[\begin{array}{l} \text{Rate of mass entering} \\ \text{control volume} \end{array} \right] - \left[\begin{array}{l} \text{Rate of mass leaving} \\ \text{control volume} \end{array} \right]$$

For this analysis, total copper (as opposed to dissolved copper) was analyzed as the constituent. By using total copper, this ensured that partitioning, or copper distribution among various chemical and biological forms, did not need to be accounted for in the analysis since total copper includes all forms. By not considering partitioning in the analysis, the mass generated and lost within the control volume is zero.

Although the analysis was performed for total copper, the loading capacity must be expressed in terms of dissolved copper, since the numeric target for this TMDL is expressed as dissolved copper. To account for this, the load reduction required to meet the numeric target was first calculated in terms of total copper, and then converted into a value for dissolved copper using a conversion factor.

General Equation for Conservation of Mass (Mass Balance)

There are two basic transport processes across the boundaries of the control volume: (1) advection, or transport of a constituent resulting from the flow of water in which the constituent is dissolved or suspended; and (2) dispersion, or transport due to turbulence, or mixing in the water. Dispersion is often driven by concentration gradients. For example, tidal flow reversals as well as secondary currents driven by salinity gradients tend to increase dispersion (Metcalf and Eddy, 1991).

Advection and dispersion take place in three dimensions; however, a one-dimensional simplification was used for this analysis because SIYB is much longer than it is wide or deep. This is a useful simplification that is often made in characterizing enclosed embayments (Metcalf and Eddy, 1991, Fischer *et al.*, 1979). Thus, constituent transport is governed by tidal flushing, or movement of water across the cross-sectional area of the Basin entrance.

Combining the effects of advection and dispersion, and also accounting for sources and sinks of the constituent, results in the general conservation of mass equation. This serves as the basis for practically all water quality modeling (Metcalf and Eddy, 1991):

$$(b) \quad \frac{\partial C}{\partial t} = \underbrace{-U \frac{\partial C}{\partial x}}_{\text{Advection term}} + \underbrace{\frac{\partial}{\partial x} \left[K \frac{\partial C}{\partial x} \right]}_{\text{Dispersion term}} + \sum \text{sources} + \sum \text{sinks}$$

where C = the average concentration of the constituent within the control volume. The units are expressed as (mass/volume).

U = water velocity in the x- direction. (length/time).

K = dispersion coefficient. (length²/time).

For purposes of analyzing an enclosed embayment, the time derivative term describes the change per tidal cycle, and K expresses the result of all the mixing processes that occur within the tidal cycle. Source terms include external inputs into the control volume, including various non-point sources. The effects of these sources are additive, and the rates of input can simply be summed in the conservation of mass equation. A discussion of source terms specific to SIYB is contained in the text, Section 4, Summary of Loading Estimates. The sink terms can likewise be summed in the equation. The dominant sink is the loss of copper to sediment, as discussed further later.

Conservation of Mass to Describe “Salt Balance”

The unique dispersion coefficient K for the SIYB system can be calculated by analyzing the “salt balance” within the Basin. This is done by modifying the conservation of mass equation to describe the movement of salt across the boundary of the control volume, or the Basin entrance. Assuming tidally averaged conditions, the salt balance for an evaporative Basin with a single entrance can be described as Equation 3 (Chadwick, 2002).

$$(c) \quad u_e A_c = eA_s$$

where u_e = average advective velocity, (length/time)
 A_c = cross sectional area of Basin entrance, (length²)
 e = rate of evaporation within the Basin, (length/time)
 A_s = surface area of the Basin, (length²).

This equation states that loss of water due to evaporation within the Basin must be balanced by the average advective flow through the entrance of the Basin. This is depicted in Figure A3.2.

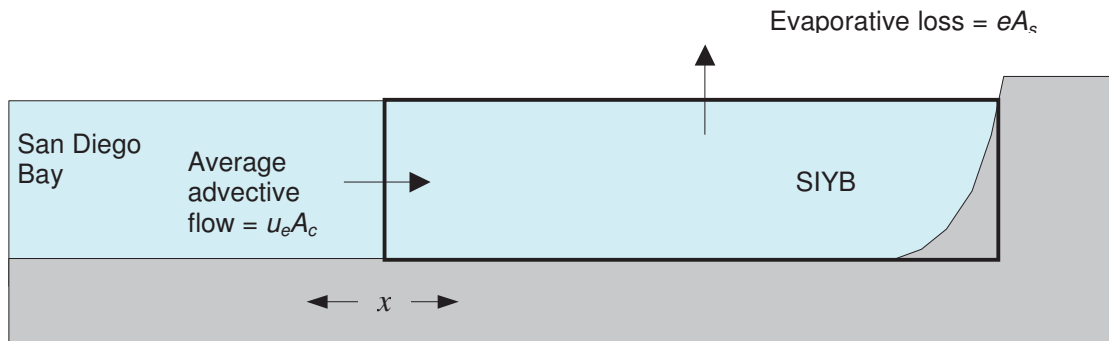


Figure A3.2. Salt Balance in SIYB.

Note that in this specific example, u_e replaces U in Equation (b) as the average cross-sectional velocity. Rearranging Equation (c) and solving for u_e ,

$$(d) \quad u_e = \frac{eA_s}{A_c}$$

Next, the conservation of mass equation is used to describe the salt balance. Since salt is the constituent under analysis, the variable C in Equation (b) now represents the concentration of salt within the Basin, denoted by the variable S . Assuming that the concentration of salt does not change over time, or steady state conditions:

$$(e) \quad \frac{\partial S}{\partial t} = 0$$

The assumption of steady state conditions is useful in describing changes over long-term time frames, as opposed to describing transient effects caused by storms. This assumption is appropriate in this analysis because of the relatively low level of rainfall occurring in the watershed (Largier *et al.*, 1997). After taking steady state conditions under consideration, Equation (b) becomes:

$$(f) \quad u_e \frac{dS}{dx} = \frac{d}{dx} \left[K \frac{dS}{dx} \right] + \sum sources + \sum sinks$$

Assuming that there are no sources of salt except for the seawater entering the Basin entrance causes the source term to become zero. Also, at equilibrium, there is no sink and the Basin becomes hypersaline (Largier *et al.*, 1997):

$$(g) \quad u_e \frac{dS}{dx} = \frac{d}{dx} \left[K \frac{dS}{dx} \right]$$

Multiplying both sides of the equation by the cross-sectional area A_c ,

$$(h) \quad u_e A_c \frac{dS}{dx} = \frac{d}{dx} \left[K A_c \frac{dS}{dx} \right]$$

Integrating both sides of the equation with respect to dx , the equation describing the long-term salt balance between evaporative advection (u_e), and tidal dispersion (K) is

$$(i) \quad u_e A_c S_1 = K A_c \frac{dS}{dx} \cong K A_c \frac{(S_2 - S_1)}{\Delta x}$$

where S_1 and S_2 = data describing the salinity gradient in SIYB. Salinity is measured in practical salinity units (psu).

Δx = a “typical” mixing length corresponding to the salinity gradient in SIYB.

S_1 and S_2 were obtained from salinity data in San Diego Bay in late summer when evaporation is dominant and the bay is near steady state. Figure A3.3 depicts the salt balance in SIYB.

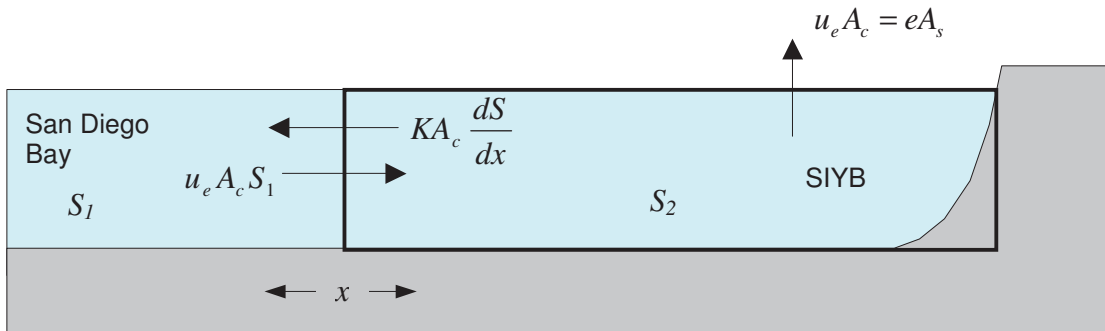
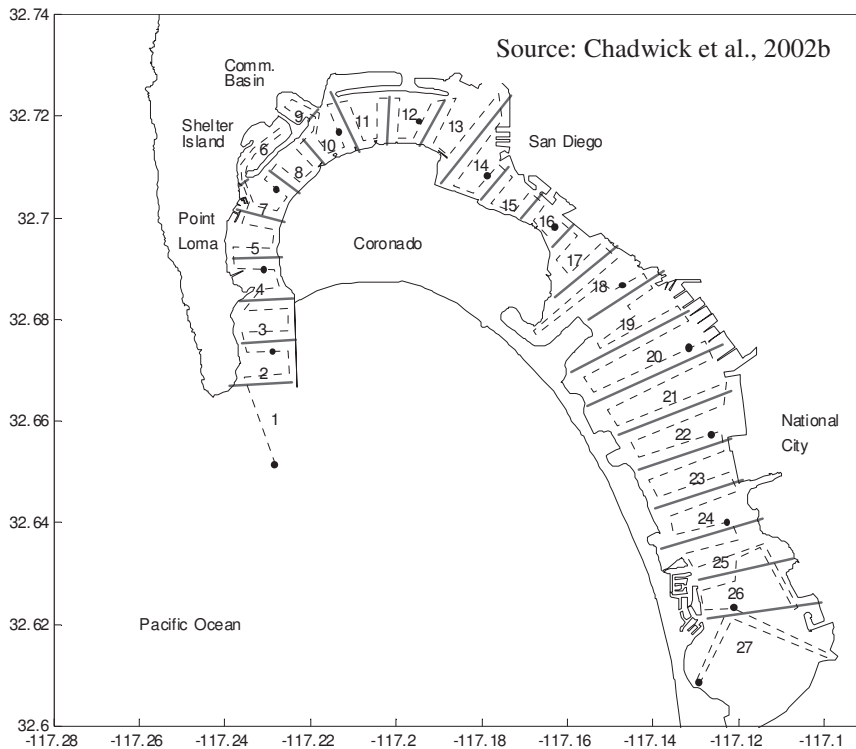


Figure A3.3. Salt Balance for K Determination.

Salinity Measurements and K Determination

Salinity measurements for S_1 and S_2 were made by SPAWAR in a series of surveys from August 2000 through September 2001 to provide distribution data for salinity and copper in San Diego Bay (Chadwick *et al.*, 2002b). Sampling occurred across several portions of San Diego Bay in the form of “boat transects.” For this study, San Diego Bay was split into 27 distinct regions, or boxes shown in Figure A3.4. SIYB was included in this survey, and is identified as Box 6.



Sampling boxes = solid lines with numbers,
Survey transect = dashed line,
Vertical profile locations = solid circles.

Figure A3.4. Map of San Diego Bay Showing Sampling Boxes.

For each survey, each transect layout was developed to include two transverse legs within each of the 27 regions. During the transect, continuous measurements and composite samples were collected for salinity and copper, as well as several other parameters including temperature, depth, pH, and dissolved oxygen. The details of these surveys and a discussion of the findings will be available in the near future (Chadwick *et al.*, 2002b).

Data from the boat survey in September 2001 was used as input parameters for the box model. Specifically, salinity data from Box 7 was used to describe S_1 , and salinity data from Box 6 was used to describe S_2 . In addition, a “typical” mixing length (Δx) was estimated to represent the length of the salinity gradient. This value corresponds to an estimated distance between the endpoints for S_1 and S_2 . This mixing length (Δx) corresponds to an average mixing length, which follows the natural contours of the shape of the Basin and surrounding area. In other words, this is not a straight-line distance. A rough schematic of the length of the salinity gradient (Δx) is provided in Figure A3.5.

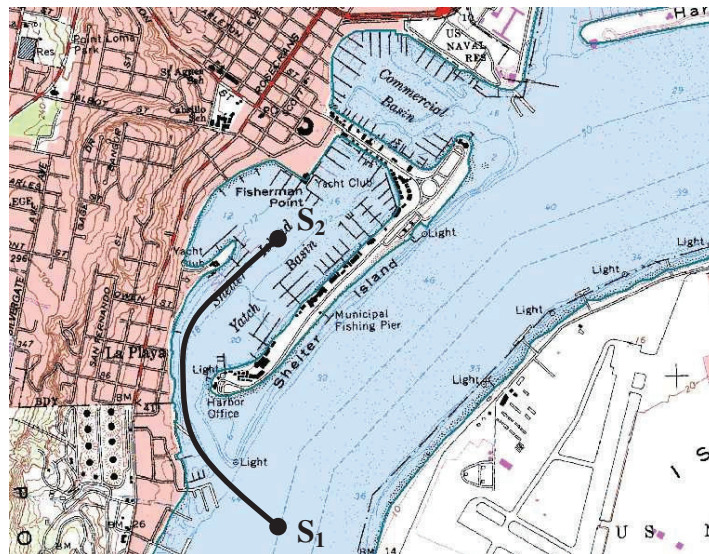


Figure A3.5. Salinity Gradient for SIYB.

Once (Δx) is estimated, the dispersion coefficient for this system can be approximated. Solving Equation (i) for K ,

$$(j) \quad K \cong \frac{u_e S_1 \Delta x}{S_2 - S_1}$$

Combining Equations (d) and (j),

$$(k) \quad K \cong \frac{e A_s S_1 \Delta x}{A_c (S_2 - S_1)}$$

Conservation of Mass to Describe Copper Fate and Transport

Now that the dispersion term K has been calculated for this particular system, the conservation of mass equation can be solved for total copper. Equation (i) is re-written to reflect the analysis of copper, denoted by the variable C . The source and sink terms are once again present since the analysis is for copper and not salt.

$$(l) \quad u_e A_c C_1 = K A_c \frac{dC}{dx} + \sum \text{sources} + \sum \text{sinks}$$

The additive effects of both sources and sinks can be incorporated into the equation by assigning one variable for each parameter. Copper loading to the Basin is represented by R_s . This describes the additive rates from all point and nonpoint sources discussed in the text, Section 4.7. Sources include contributions from boat hull cleaning, passive leaching, urban runoff, and others. The sink term is represented by R_L , or loss rate of copper from the Basin. Equation (l) now becomes:

$$(m) \quad u_e A_c C_1 = K A_c \frac{dC}{dx} + R_L - R_s$$

In addition to tidal flushing, movement of copper out of the Basin is dominated by loss to sediment (Chadwick, 2002). The loss to sediment is a first-order reaction with respect to the concentration of copper in the water column was assumed. This means that the loss rate of copper is directly proportional to the concentration of copper in the water column. This loss rate of copper is represented by:

$$(n) \quad R_L = k_L V_2 C_2$$

where k_L = rate constant describing total copper loss to sediment in SIYB. This is expressed as (percent/time).

V_2 = volume of the Basin (control volume)

C_2 = the average concentration of copper within the Basin, (mass/volume).

The mass balance for total copper is depicted in Figure A3.6. Note that the sign convention for the source and sink terms corresponds with the direction of copper movement specified by the arrows.

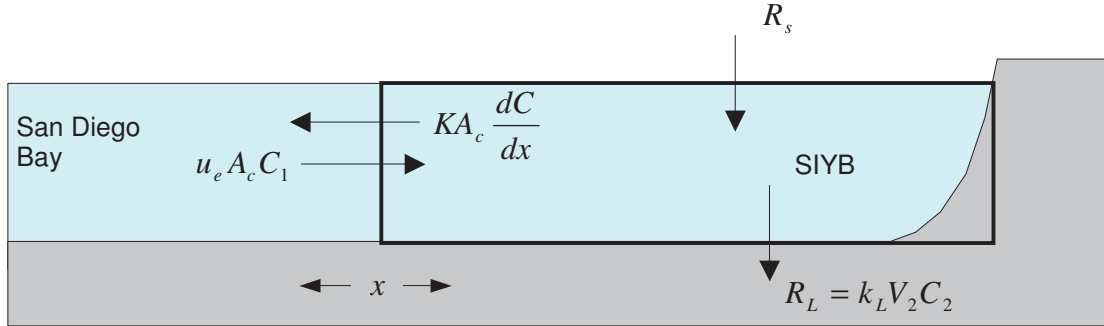


Figure A3.6. Mass Balance for Total Copper in SIYB.

Results for calculating dissolved copper concentrations using the approximation described by Equation (n) have been in close agreement with copper concentrations measured throughout San Diego Bay in a study conducted by SPAWAR. The range of values that were calculated for the rate constant k_L was four to seven percent/day for San Diego Bay (Chadwick *et al.*, 2002b). However, a rate constant k_L was not calculated specifically for SIYB in the study.

Combining Equations (m) and (n), the modified conservation of mass equation describes SIYB specifically. The final version becomes:

$$(o) \quad u_e A_c C_1 = K A_c \frac{(C_2 - C_1)}{\Delta x} + k_L V_2 C_2 - R_s$$

The maximum rate of copper loading into the Basin can now be determined by solving Equation (o) for R_s . Thus the maximum rate of copper loading, or loading capacity, is:

$$(p) \quad R_s = C_2 \left(\frac{K A_c}{\Delta x} + k_L V_2 \right) - A_c C_1 \left(u_e + \frac{K}{\Delta x} \right)$$

Finally, Equation (p) is combined with Equation (d) to yield an expression for R_s where all the input variables can be supplied. Each variable, and the corresponding unit expressions, is described below.

$$(q) \quad R_s = C_2 \left(\frac{K A_c}{\Delta x} + k_L V_2 \right) - A_c C_1 \left(\frac{e A_s}{A_c} + \frac{K}{\Delta x} \right)$$

where C_1 = average background concentration of copper (measured in the area of San Diego Bay adjacent to SIYB, expressed as total copper), (mass/volume).

- C_2 = average target concentration for copper in the Basin (expressed as total copper), (mass/volume)
- K = dispersion coefficient calculated from salinity measurements and mixing length approximation (length²/time)
- A_c = cross-sectional area of entrance to Basin (length²)
- A_s = surface area of Basin (length²)
- Δx = average mixing length between SIYB and adjacent area (length)
- V_2 = volume of Basin (volume)
- e = evaporation rate (length/time)
- R_S = rate of all point and nonpoint sources of copper to Basin, expressed as total copper (mass/time).

Measured values and other calculated parameters can be substituted into Equation (q). The model solves this mass balance equation for R_S , or the value describing the loading rate that results in a target value of C_2 . In other words, when C_2 is set equal to the numeric target for copper, the model calculates the maximum loading rate R_S that the Basin can receive and still achieve the numeric target. R_S is calculated by way of an iterative process, as described below. The numeric target was set at a level to ensure attainment of water quality standards. Determination of C_2 is further discussed under the description of output variables below.

Input Variables for Box Model

Input variables are entered into the model by the user and affect the determination of each output variable, which are discussed in the next section. As discussed above, the loading capacity, R_S , was determined from Equation (q) using the model. Since the target copper concentration within the Basin, C_2 , is an output variable that depends on the loading capacity, R_S , the value for R_S can be determined by iteration. Various values for R_S were input into the model until the maximum allowable loading rate was found that did not exceed the numeric target for copper in the Basin. The means of determining the value of each input variable necessary for the analysis is discussed below.

- S_1, S_2 -- Salinity data was obtained from a SPAWAR sampling survey in September 2001. Data from the composite sampling of sampling Box 6 (SIYB) and sampling Box 7 (Bay adjoining SIYB) was used in the box model analysis (Figure A3.4). These values were 33.62 practical salinity units (psu) and 33.46 psu, respectively.
- C_1 -- This represents the concentration of total copper in ambient seawater, or background concentration levels outside the control volume. Background copper concentrations in San Diego Bay were also measured by composite sampling by SPAWAR on two occasions, August 2000 and September 2001. Composite measurements for total copper were 0.69 $\mu\text{g/L}$ and 0.39 $\mu\text{g/L}$, respectively, for sampling Box 7 (Bay adjoining SIYB). For the input variable C_1 , the average of the two values, 0.5 $\mu\text{g/L}$, was used.

- A_c -- This represents the cross-sectional area of the control volume at the boundary (Basin entrance), which is tidally dependent. This area was determined by using nautical charts to estimate cross-sectional width and average depth at mean lower low water. Multiplying the two results in a cross-sectional area of roughly 1,000 square meters (m^2).
- A_s -- This represents the surface area of the control volume, which is tidally dependent. Using bathymetry, a value measured at mean lower low water provided by the Port District was used (Moore, 2000). This area was determined to be roughly 740,000 m^2 .
- e -- This represents the evaporation rate within the control volume, which was stated to be about 0.43 centimeter/day (cm/day) for San Diego Bay (Chadwick *et al.*, 2002b).
- Δx -- This represents a “typical” mixing length, or approximate length of the salinity gradient. This value corresponds to an estimated distance between the endpoints for S_1 and S_2 , which was 2,000 meters (s). A rough schematic of the length of the salinity gradient (Δx) is provided in Figure A3.5.
- V_2 -- This represents the control volume, which is tidally-dependent. This volume was provided by the Port, and was measured using bathymetry at mean lower low water to be approximately 31,000,000 cube meters (m^3) (Moore, 2000).
- k_L -- This represents the rate constant describing the total copper loss to sediment, which is the dominating sink mechanism. A Bay-wide study found this rate to be about four to seven percent/day, depending on the area measured. A value of seven percent/day was chosen for the input parameter, since loading of copper into SIYB is probably high compared to most areas in the Bay due to elevated concentrations in the water column. That the drive towards equilibrium would cause this rate to likewise be high was assumed.
- R_S -- This represents the maximum allowable copper input rate, or loading capacity, into SIYB. This input rate was determined by iteration to yield the maximum possible value without exceeding the numeric target, expressed as C_2 under “output variables” (see below). This value is expressed in kilograms/day (kg/day).

Output Variables from Box Model

The box model generates output variables based in part on input variables entered into the model by the user.

K -- This represents the dispersion coefficient, specifically describing mixing characteristics of SIYB, described by Equation (k). For SIYB, this was found to be 15.3 square meters/second (m^2/sec).

u_e -- This represents the average evaporative advective velocity, given in Equation (d). This was found to be 3.68×10^{-5} meters/second (m/s).

dS/dx -- This represents the salinity gradient, or difference in salinity measurements over an approximate measured distance. This is expressed as:

(r)
$$\frac{S_2 - S_1}{\Delta x}$$
 This was found to be 8.04×10^{-5} psu/m.

C_2 -- This represents the “target” concentration of total copper within SIYB. “Target” concentration means the concentration equal to the numeric target established in this TMDL. By definition, the attainment of the numeric target will result in the attainment of water quality standards in the Basin. The value for C_2 was determined by expressing the numeric target for dissolved copper as total copper for use in the box model. The chronic water quality objective for dissolved copper is 3.1 $\mu g/L$. Since this concentration is a maximum level that cannot be exceeded, it must be adjusted to represent an average concentration. This is because the model relies on average values for most measured parameters. The average concentration was calculated using the ratio of average to maximum dissolved copper concentrations measured during a sampling survey by the Regional Board (Appendix 6). As shown below, the average concentration of dissolved copper measured by the Regional Board in SIYB was 5.45 $\mu g/L$, and the maximum concentration measured was 8 $\mu g/L$. Therefore the target average concentration for dissolved copper inside the Basin was determined by this ratio:

(s)
$$\left[\frac{5.45 \mu g/L}{8 \mu g/L} \right]_{measured} = \left[\frac{average\ concentration,\ dissolved\ copper}{3.1 \mu g/L} \right]_{target}$$

Solving for Equation (s), the average target concentration of dissolved copper in the Basin was found to be 2.11 $\mu g/L$. Finally, this number was adjusted to represent a value for total copper to be used in the box model. This was done by assuming that the ratio of dissolved copper to total copper in seawater is 0.83 (USEPA 2000). Therefore the target concentration of total copper, C_2 , was determined to be 2.54 $\mu g/L$. This value was used to determine the Basin’s maximum loading capacity, R_s , through the process of iteration. Various values for R_s were input into the model, until the maximum value was found that did not cause C_2 to exceed 2.54 $\mu g/L$. The value for R_s represents the maximum loading

rate of copper that the Basin can receive and still attain the numeric target.

R_L -- This represents the rate of copper loading to sediment, given in Equation (n). This is the same as the rate of copper loss from the water column in SIYB to the sediment. This was found to be 0.55 kg/day.

Assumptions and Limitations of Box Model

1. The model provides only an estimate of average concentration for the entire Basin. Some areas of the Basin, particularly the back portions where copper loading is high and flushing rates are low, are more impacted with copper than areas close to the entrance to San Diego Bay. This was verified by sampling by the Regional Board in 2000 and 2001 (Appendix 6). This shortcoming of the box model could be improved by dissecting the Basin into components and analyzing them individually. However, this would require knowledge of the geometry of the individual segments, as opposed to the geometry of the Basin as a whole. This is not readily available information at this time.
2. The model assumes tidally averaged conditions. The model does not resolve fluctuations that occur over tides, but rather averages them out.
3. The model assumes steady state conditions. The model does not resolve changes associated with transient sources, loss and mixing fluctuations on time scales shorter than the time to establish steady state.
4. The model does not represent the actual individual processes that lead to loss of copper from the water column such as complexation, sorption, and settling. Rather, settling, or loss to sediment, is treated as the dominant mechanism and assumed to behave as a first-order reaction. This means that loss to sediment is directly proportional to the concentration of copper in the surrounding water column.
5. The calibration of the dispersion coefficient depends on an adequate salinity gradient, (i.e. measurable difference), assumption of a steady-state salt balance, and knowledge of the evaporation rate.
6. A Bay-wide study found the rate constant k_L rate to be about four to seven percent/day, depending on the area measured. A value for the rate constant k_L is not specifically known for SIYB. The value for k_L was assumed to be seven percent/day for reasons discussed earlier.
7. The model assumes a constant background concentration, C_I . In reality, the background concentration may fluctuate because of general variations in San Diego Bay. Also, San Diego Bay is treated as “background” when in reality, levels of copper in the Bay are probably elevated over true ambient seawater conditions due to numerous point and nonpoint source discharges.

8. The values for A_c and Δx were roughly estimated from nautical charts.
9. The values of salinity and copper concentrations used in the analysis were based on limited sampling.

Results from Analysis Using Box Model

Using the input parameters described above, the model results are as follows:

$$\begin{aligned} R_S = \text{loading capacity} &= 1.87 \text{ kg/day total copper} \\ &= 683 \text{ kg/year total copper} \\ &= 567 \text{ kg/year dissolved copper (using a ratio of dissolved copper/total} \\ &\quad \text{copper of 0.83 in seawater)} \end{aligned}$$

The loading capacity defines the TMDL for SIYB. The margin of safety (MOS) calculation is provided in Appendix 4.

Calculation of Background Loading Using Box Model

In addition to using the box model to calculate the loading capacity for SIYB, the model was also used to calculate a loading rate of copper into the Basin from ambient seawater. This information is included in Tables 4.2 and 7.1 of the text. Copper loading from ambient seawater is expressed as “background” loading.

Because the box model is specific to SIYB (i.e., uses information such as geometry and unique dispersion coefficient), various parameters can be calculated if all others are known. For purposes of calculating background loading, the input value for R_S was set at zero. In other words, analysis of copper movement was performed as if all input sources such as hull cleaning, passive leaching, urban runoff and atmospheric deposition were nonexistent.

At steady state, net copper loading into SIYB from ambient seawater is assumed to be deposited in the sediment at the rate described by R_L . This is because at steady state, the net background copper loading is equal to the loss of copper to the sediment. Therefore all excess copper loading from ambient seawater (which has not been flushed back to San Diego Bay) must be deposited into a sink.

Using the same input parameters described previously, the model results are as follows:

$$\begin{aligned} R_L = \text{loading from ambient seawater (background)} &= 0.09 \text{ kg/day total copper} \\ &= 33 \text{ kg/year total copper} \\ &= 27 \text{ kg/year dissolved copper (using a ratio} \\ &\quad \text{of dissolved copper/total copper of 0.83)} \end{aligned}$$

Copper loading from ambient seawater (background) \approx 30 kg/year.

Additional Capabilities of Box Model

In addition to the output variables previously described, the box model supplied by SPAWAR also has the capability to calculate two additional parameters, the flushing rate of copper to San Diego Bay, and the average residence time of water within SIYB. These two parameters were not used by the Regional Board for analysis of the loading capacity.

F -- This represents the flushing rate of total copper to San Diego Bay, i.e. the rate of copper loss from SIYB to San Diego Bay. Since tidal flushing and loading to sediment are almost entirely responsible for movement of copper out of the control volume, the rate of copper loss from SIYB to San Diego Bay is described by Equation (t). This was found to be 1.32 kg/day.

(t) $F = R_S - R_L$

T_{res} -- This represents the average residence time of water in SIYB. This was found to be 4.7 days.

Determination of SIYB Loading Capacity Using Copper Box Model

Model based on advection dispersion equation

$$U_e A_e C_1 = K A_c (dC/dx) + k_L V_2 C_2 - R_S$$

Assumes:	tidally averaged steady state first order loss to sediment
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Inputs:	S ₁ : background salinity S ₂ : box salinity C ₁ : background concentration A _c : cross sectional area at boundary A _s : surface area of box e: evaporation rate dx: gradient length scale V ₂ : box volume k _L : loss rate coefficient R_S: loading capacity (target loading)
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Outputs:	K: dispersion coefficient dS/dx: salinity gradient U _e : evaporative advective velocity T _{res} : residence time C ₂ : box concentration F: flushing rate to bay R _L : sediment loading
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Various values for R_S were input into the model. From iteration, a value was reached describing the maximum loading (loading capacity) that SIYB can receive and still attain the numeric target (C₂).

S ₁ =	33.46	psu
S ₂ =	33.62	psu
C ₁ =	0.5	µg/L
A _c =	1,000	m ²
A _s =	740,000	m ²
e=	0.43	cm/d
dx=	2000	m
V ₂ =	3,100,000	m ³
k _L =	7	%/d
R_S=	1.87	kg/d

K=	15.3	m ² /s
dS/dx=	8.04E-05	psu/m
U _e =	3.68E-05	m/s
T _{res} =	4.7	d
C ₂ =	2.54	µg/L
F=	1.32	kg/d
R _L =	0.55	kg/d

Numeric target C₂ =
2.54 µg/L (expressed as
average total copper)

Determination of Background Copper Loading for SIYB Using Copper

Model based on advection dispersion equation

$$U_e A_c C_1 = K A_c (dC/dx) + k_L V_2 C_2 - R_S$$

Assumes:	tidally averaged steady state first order loss to sediment
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Inputs:	S ₁ : background salinity S ₂ : box salinity C ₁ : background concentration A _c : cross sectional area at boundary A _s : surface area of box e: evaporation rate dx: gradient length scale V ₂ : box volume k _L : loss rate coefficient R _S : external loading
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Outputs:	K: dispersion coefficient dS/dx: salinity gradient U _e : evaporative advective velocity T _{res} : residence time C ₂ : box concentration F: flushing rate to bay R_L: sediment loading
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To determine loading from ambient seawater, i.e., “background,” the value for R_S was set to zero (this assumes there are no external sources of copper). Then, at steady state, the net background copper loading is equal to the loss of copper to the sediment, R_L. The resulting R_L value was used as “background” in the TMDL analysis and resulting load allocations.

S ₁ =	33.46	psu
S ₂ =	33.62	psu
C ₁ =	0.5	µg/L
A _c =	1,000	m ²
A _s =	740,000	m ²
e=	0.43	cm/d
dx=	2,000	m
V ₂ =	3,100,000	m ³
k _L =	7	%/d
R _S =	0	kg/d

K=	15.3	m ² /s
dS/dx=	8.04E-05	psu/m
U _e =	3.68E-05	m/s
T _{res} =	4.7	d
C ₂ =	0.41	µg/L
F=	-0.09	kg/d
R_L =	0.09	kg/d