SAN FRANCISCO BAY MODELING FOR THE ENVIRONMENTAL FATE AND TRANSPORT OF COPPER FROM VEHICLE BRAKE PAD WEAR DEBRIS

DRAFT WORK PLAN

Submitted to

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SECTION 1.0: INTRODUCTION AND OBJECTIVES

The Brake Pad Partnership (BPP) has embarked on a study to better understand the fate and transport of copper from brake pad wear debris (BPWD) in the environment. Studies include characterization and analysis of the physical and chemical properties of BPWD, air and stormwater monitoring, and environmental modeling. Three environmental modeling studies are being performed including air deposition modeling, watershed modeling, and modeling of the San Francisco Bay (Bay). The air deposition and watershed modeling provide results that will be used as inputs to the model of the San Francisco Bay so that the effect of copper loading on the Bay can be determined.

Even though recent studies have shown that current levels of copper in the Bay do not appear to be impairing its beneficial uses, there is still a need to ensure that water quality will not deteriorate in the future. Determining how current levels of copper loadings affect the concentrations of copper in the Bay sediments and water column provides a baseline for comparing against any increases or decreases in copper loadings that could occur in the future. The air deposition and watershed modeling will provide estimates of the quantity of copper entering the bay that originates from BPWD. By running model scenarios with and without the contributions of copper from the BPWD, the effects of BPWD on the dissolved and benthic copper concentrations in the Bay can be determined.

SECTION 2.0: MODELING APPROACH

A conceptual biogeochemical model of the processes affecting the fate and transport of copper in the Bay is shown in Figure 2-1. In addition to copper loads from air deposition and watershed runoff, loads from wastewater discharges and marinas where copper anti-fouling paints are used will be included.

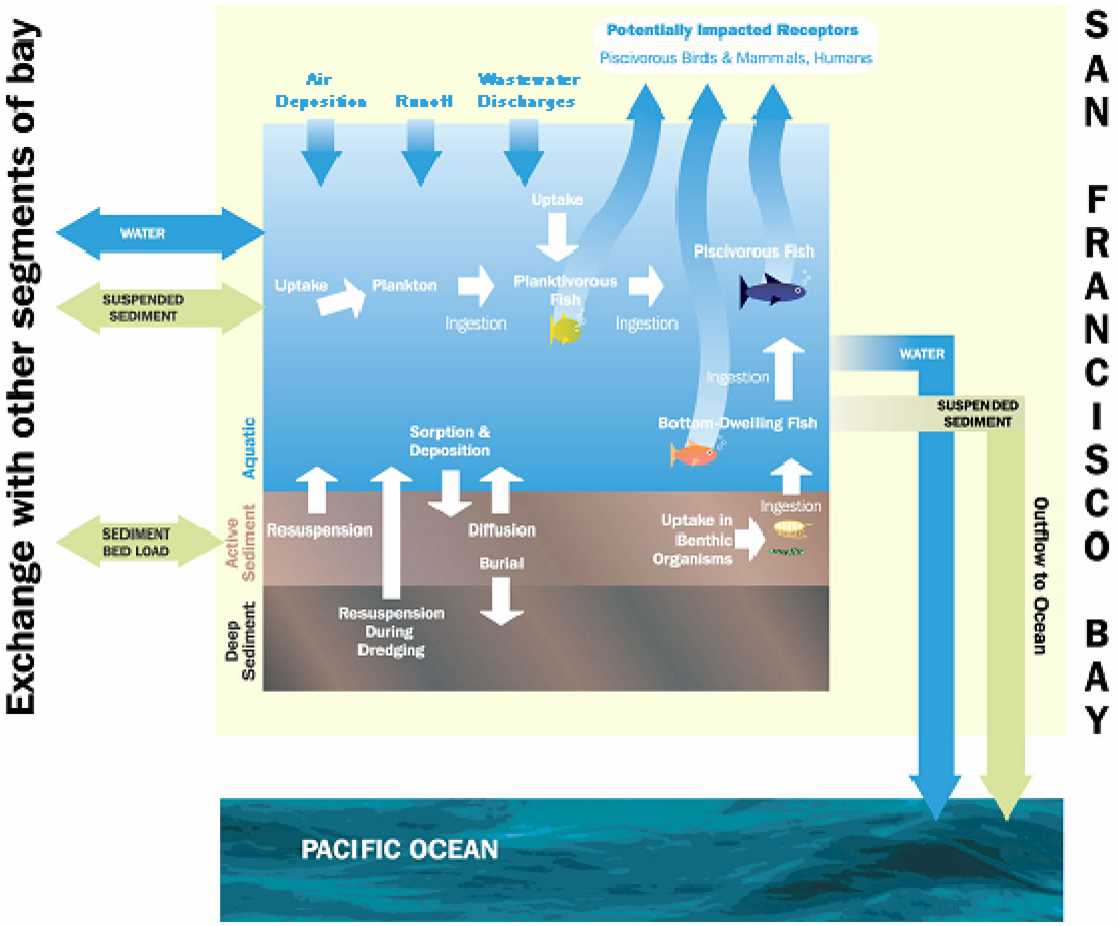

Figure 2-1. Conceptual model of biogeochemical processes affecting copper in the Bay

In order to model the long-term effects of changing the copper loadings to the Bay, two models will be developed. The short-term model will define the Bay using a finite element grid at a 200-meter resolution and will provide hourly, 4-day average, or monthly average copper concentrations. Results from the short-term model will be used as inputs to the long-term model, which will define the Bay using a series of boxes at a more regional scale and will show decadal trends in copper concentrations.

2.1 Short-Term Modeling

The MIKE 21 model developed by the Danish Hydraulic Institute (DHI) will be used to simulate the hydrodynamics, sediment transport, and water quality of the Bay. MIKE 21 is a two-dimensional, free-surface flow modeling system developed by DHI. It is used to simulate hydraulics and hydraulics-related phenomena in estuaries, coastal waters, and seas where stratification can be neglected. It consists of a hydrodynamic module to which other modules can be added to address different phenomena. For the proposed copper modeling, the heavy metals module (MIKE 21 ME) will be added to the hydrodynamics module (MIKE 21 HD). In MIKE 21 ME, four processes control dissolved metal concentrations: (1) adsorption/desorption, (2) sedimentation/resuspension, (3) porewater diffusion, and (4) advection/dispersion. The first three processes are shown in Figure 2-2.

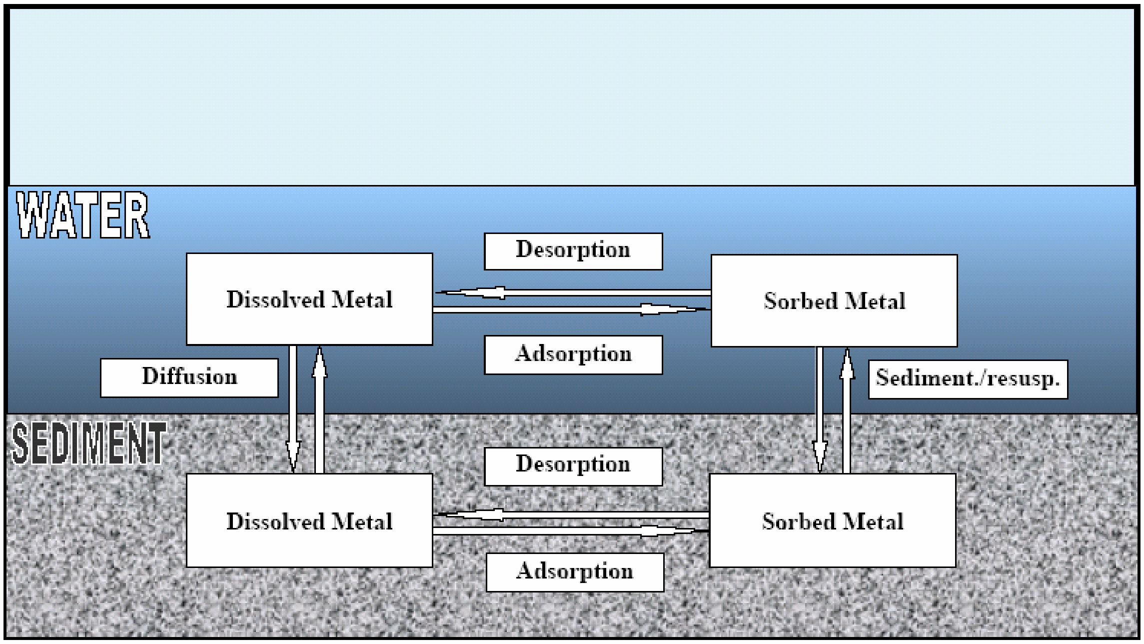

Figure 2-2. Summary of Processes Modeled by MIKE 21 ME

The first process, adsorption/desorption, is the essential link between metals in the aqueous and solid phases. Adsorption is the process by which dissolved metal ions or complexes attach themselves to the surface of particulate matter. Desorption is the detachment of the metal from the particulate surface and its return to the dissolved state. In MKE 21 ME, adsorption also includes the processes of absorption (incorporation of the metal into the solid phase) and surface precipitation.

The second important process is resuspension and sedimentation of particulate matter within the Bay. Resuspension and sedimentation are influenced by the wind and currents.

The third process illustrated in Figure 2-2 is diffusion of metal-enriched water between the ambient Bay and porewater, depending on the concentration gradient. Diffusion rates are dependent on the chemical environment in the pore spaces of the sediment, which may be significantly different than the overlying water. Adsorption and desorption rate constants are used to represent chemical transformation in the porewater.

The final process incorporated into the ME module is advection and dispersion of dissolved and adsorbed metals. Both dissolved and adsorbed metals are treated identically in the ME module, and parameters calculated in the simultaneous run of MIKE 21 HD govern the advection and dispersion.

2.1.1 Inputs to Hydrodynamic Module

The inputs to the hydrodynamics module include the bathymetric grid, wind, freshwater sources, and boundary conditions (tides in the Pacific Ocean and Delta inflow). Descriptions of these inputs and the source of the data are included in Table 2-1. Calibration parameters include the bottom roughness coefficients and the eddy viscosity. The Manning's n values range from 0.01 to 0.035. The eddy viscosity is determined using the Smagorinsky formula based on velocity, with the Smagorinsky coefficient ranging from 0.05 to 0.5.

Table 2-1
Input Data for the MIKE 21 Hydrodynamics Module

Input Data	Description	Data Source
Bathymetric Grid	Made up of a combination of grids:	
	30-m resolution NOAA Digital Elevation Model (DEM) for San Francisco Bay (most recent survey was from 1993)	NOAA/NOS 1999
	25-m resolution grid for South San Francisco Bay below Dumbarton Bridge	Smith and Cheng 1994
	100-m resolution San Francisco Bay grid	Cheng and Smith 1998
	grid created by URS from NOAA soundings in the Pacific Ocean	
	Resulting grid used the UTM Zone 10 NAD 1927 projection, rotated 35.40 degrees counterclockwise from North to align flow direction with the model coordinate system in the South Bay and in San Pablo Bay.	
	The Delta was modeled as a "box" with surface area equal to 61,000 acres, an average depth of 5.1 m (16.7 ft), and volume of 1,145,000 acre-feet.	DWR 1995
Wind	Wind time series collected by the National Climatic Data Center (NCDC) at SFO at hourly intervals was applied to the entire Bay.	NCDC wind data recorded at SFO
Freshwater Sources	Daily averaged flows for Alameda Creek, Coyote Creek, Guadalupe River, Napa River, and Petaluma River were obtained from USGS gaging stations. For streams with no measured flows available, results of correlation analysis to available data were used to estimate runoff based on rainfall and watershed characteristics. Smaller tributaries and streamflow downstream of gaging stations were omitted.	USGS gage data and watershed area/ runoff correlation
Flow Boundary Conditions	Delta outflow (provides 90% of freshwater to Bay) specified as the average daily flow from DWR's DAYFLOW program.	DWR's DAYFLOW

Input Data	Description	Data Source
Tidal Boundary Conditions	Applied recorded time series of water surface elevations from the NOAA tide station at Point Reyes to ocean boundary located approx. 15 km outside of the Golden Gate Bridge. For periods without data at Point Reyes, water levels from the NOAA tide station at Monterey were substituted (without correction, even though Pt. Reyes lags Monterey by about 20 min, and the high water elevations were about 0.12 m lower).	NOAA (Primarily Pt. Reyes tide station with Monterey as a backup)

2.1.2 Inputs to Heavy Metals Module

The inputs to the heavy metals module include the initial benthic sediment concentrations, point source (POTW and Industrial Wastewater) inputs, tributary loads, loads from marinas, wet and dry air deposition, and boundary conditions at the Pacific Ocean and Delta. Descriptions of these inputs and the previously used (URS 2003) and proposed source of the data for the BPP modeling are included in Table 2-2. The initial water column adsorbed copper concentrations were calculated by multiplying the initial suspended sediment concentration (SSC) field by the initial benthic sediment field determined from the San Francisco Estuary Regional Monitoring Program (RMP) annual reports (SFEI 1994-1999). Initial dissolved concentrations were then calculated by assuming that the dissolved phase is in equilibrium with the adsorbed phase. Calibration parameters include: the settling velocity, critical velocity, and resuspension rate of the sediment; copper adsorption and desorption rate constants in the water column and porewater; and the initial active sediment layer thickness. The wet and dry season ranges of settling velocities, critical velocities, and resuspension rates are given in Table 2-3. The adsorption and desorption rate constants previously used are given in Table 2-4. The initial approximations of the adsorption and desorption rates were based on site-specific data and laboratory studies conducted on samples collected in the Bay. The initial active sediment layer previously used was 0.1 meters thick.

Table 2-2
Input Data for the MIKE 21 Heavy Metals Module

Input Data	Description	Current Data Source	Revised Data Source for BPP
Initial Benthic Sediment Concentrations	Average benthic sediment concentrations from the RMP Annual Reports (SFEI 1994-1997, 1998, 1999) were assigned to the Delta, Suisun Bay, San Pablo Bay, Central Bay, South Bay, and Lower South Bay. The North and Central Bays were also subdivided into shoals and channels.	SFEI 1994-1997, 1998, 1999	More recent data will be included, if available.
	Toxic hotspots identified by BPTCP (SFBRWBCB 1999) were overlain on existing sediment fields. Hotspot was assigned to single 200 m x 200 m grid cell of sample.	SFBRWQCB 1999	
Point Source Input	37 industrial and wastewater treatment plants (POTW sources) were included. Daily average flows and concentrations were input when electronic data were available, otherwise monthly averages were used (from 1996 and 1997 NPDES self-monitoring reports). Metals were assumed to be in the dissolved state since SSCs were generally low.	NPDES self-monitoring reports	Will incorporate more recent NPDES self-monitoring reports for larger dischargers.
Atmospheric Deposition	Wet and dry deposition rate for copper (ug/m^2-day)	Not used	Air Basin Modeling
Tributary Loads	69 watersheds were delineated. Flows were based on USGS gage data, either measured or normalized by watershed area. Different SSC and metal concentrations were used for low and high flows. High flows were classified as greater than twice the July and August base flow for a given year. SSC and metal concentrations for base flows were obtained from BASMAA (1996) data. Storm event concentrations were obtained from a land-use summary of this data (Daum and Davis 2000).	USGS gage data and watershed area/ runoff correlation, BASMAA 1996, Daum and Davis 2000	BASINS Model will provide daily flow, SSC, and total copper concentrations for each tributary source. Optional: use leaching data to develop fraction of total copper discharged that may be solubilized

Input Data	Description	Current Data Source	Revised Data Source for BPP
Ocean and Delta Boundaries	Dissolved and adsorbed metal concentrations specified at each boundary.	Calculated from equilibrium distribution coefficients, either adsorbed metal concentrations on the suspended sediment or total water column concentrations, and total SSCs (set at 20 mg/L at the Pacific Ocean and as a time series at the Delta).	
	Distribution coefficients and metal concentrations on suspended sediment for the Delta boundary were derived from the average of all measurements from the San Joaquin and Sacramento RMP monitoring stations. Distribution coefficients for the Pacific Ocean boundary were derived from the average of all measurements from the Golden Gate station.	SFEI 1994-1997, 1998, 1999	
	Adsorbed and dissolved concentrations for the Pacific Ocean were calculated from the relationship between the distribution coefficient and the adsorbed, dissolved, and total water-column metal concentrations measured in the northern Pacific Ocean.	Burton and Statham 1990	

Table 2-3
Sediment Calibration Parameters for the MIKE 21 ME Module

Sediment Parameter	Notes	Min Value	Max Value	Units
Settling Velocity	Spatially varying w/ lowest values in the mudflats near Dumbarton Bridge and highest values in the deepest water of the Golden Gate. Wet season values are the same as dry.	0.04	6	m/d
Critical Velocity	Spatially varying w/ lowest values in the mudflats south of the Dumbarton Bridge and highest values near the Golden Gate. Wet season values are the same as dry except near the Golden Gate. Wet season values near the Golden Gate are approx. 10 to 15% less than dry season.	0.02	1.6	m/s
Resuspension Rate	Spatially varying w/ lowest values near the Golden Gate and highest values in the San Pablo, Suisun, and Honker Bay mudflats. Dry season values are generally larger than wet season values.	0.5	500	g/m2/d

Table 2-4
Copper Calibration Parameters for the MIKE 21 ME Module

Ads./Des. Rate Constant	Material	Dry Season Value	Wet Season (if different from Dry)	Units
Adsorption	Copper in North Bay Water	0.012		1/d/(mg/L)
Adsorption	Copper in Central Bay Water	0.015		1/d/(mg/L)
Adsorption	Copper in South Bay Water	0.011		1/d/(mg/L)
Adsorption	Copper in Lower South Bay Water	0.005	0.008	1/d/(mg/L)
Adsorption	Copper in Porewater	10		1/d/(mg/L)
Desorption	Copper in Bay Water	0.47	0.23	1/d
Desorption	Copper in Porewater	0.01		1/d

2.1.3 Model Calibration and Verification

The MIKE 21 hydrodynamic model was previously calibrated by URS (URS 2003) and will not be recalibrated as part of this study. In the previous hydrodynamic model calibration, model parameters were adjusted until the model reproduced observed current velocities and water levels. Two parameters were adjusted during calibration:

- Roughness coefficient – used in the bottom friction formulation;
- Eddy viscosity – parameterizes horizontal mixing of momentum.

The MIKE 21 heavy metals model was also calibrated previously (URS 2003), however there has been more data collected by the San Francisco Estuary Institute (SFEI) as part of their Regional Monitoring Program (RMP). Also, air deposition had not been included in the previous modeling, and the watershed inputs will also be changing slightly. The previous MIKE 21 ME calibration will be verified against the additional measured data, and will be recalibrated if necessary. If possible, calibration parameters (settling velocity, critical velocity for erosion, and resuspension rate of sediment, as well as adsorption and desorption rate constants for copper) will be chosen such that they remain constant year-round, rather than changing seasonally. However, this will depend on how well modeled concentrations match the measured data.

Separate years of observed data will be used for calibration and subsequent verification.

2.1.4 Sensitivity Analysis

The sensitivity analyses conducted previously (URS 2003) will be summarized. An analysis of model sensitivity to major parameters not addressed previously will be conducted, which will include the sensitivity to the initial concentration of benthic sediments.

2.2 Long-Term Modeling

A compartmental water quality model will be selected for use in modeling the long-term impacts of copper from BPWD. Possible models include WASP, developed by EPA; ECOLab, developed by DHI; or the multi-box model developed by SFEI. SFEI is in the process of incorporating a sediment model developed by USGS into their multi-box model, however this updated version may not be ready in time to be used by URS for this study. URS will make a choice on the model to be used in February 2006.

Regardless of the choice of model, the compartmental model will operate on the principle of conservation of mass. The water volume and total mass of copper would be accounted for over the duration of the simulation. The initial conditions and flows at the boundaries of each compartment would be based on output from the MIKE 21 model. The MIKE 21 model would give the flux of water, suspended sediment, and the mass of copper across each of the boundaries used for each compartment. The initial concentrations within each compartment would be based on the average concentration within that region of the MIKE 21 model.

2.2.1 Inputs to Box Model

Inputs to the box model will include geometry, initial conditions, boundary conditions, time-series of external loads, physical properties of sediment, the transport scheme and kinetic parameters.

The geometry will be described using a number of segments and defining the volume and type of each segment. Typical types of segments that could be included would be:

- Surface water segment – has an interface with the atmosphere;
- Sub-surface water segment – water segment without atmospheric or benthic interface;
- Surface benthic segment – benthic segment with a water interface
- Sub-surface benthic segment – defines all benthic segments below the surface benthic segment

The initial conditions within each segment will include the average initial benthic copper concentrations, initial suspended sediment concentrations, and initial total copper concentrations and the fraction dissolved. These initial concentrations will be based on the average concentrations in the MIKE 21 model within regions corresponding to each segment.

The boundary conditions will be the same as the MIKE 21 model, except that they will be averaged over a longer time step, and will depend on the computational time step used in the model.

The external tributary and atmospheric loads defined by the air deposition and watershed models will be applied to the corresponding segment in the compartmental model.

The sediment parameters such as settling velocity, critical velocity for erosion, and resuspension rate will be based on the average values determined in the recalibration of the MIKE 21 model. The methods and parameters needed to calculate erosion and deposition may vary depending on the choice of model.

The parameters describing the transport scheme may also vary depending on the choice of model. Parameters will need to define advection and dispersion, as well as diffusion in the pore water.

2.2.2 Verification

The box model will be verified by comparing the results from the same period modeled with MIKE 21. Parameters used in the box model will be adjusted until results show agreement with the calibrated MIKE 21 model.

2.2.3 Uncertainty Analysis

The uncertainty in the model output will be estimated by performing additional model runs using a range of values that bound the likely sediment transport and water quality parameters.

2.3 Model Output

Output from the model verification runs will be provided to show how well modeled dissolved copper concentrations correspond to measured concentrations throughout the Bay. Results from the modeled scenarios will be focused on the South San Francisco Bay.

Output will include plots showing the baseline benthic and dissolved copper concentrations as well as the differences between the modeled scenarios (either increasing or decreasing copper input loads) and the baseline concentrations. Changes between the modeled scenarios and the baseline dissolved copper concentrations will be shown as differences between the mean and maximum 4-day average concentrations over different water years. Changes between the modeled scenarios and the baseline benthic copper concentrations will be shown as differences between the mean and maximum 30-day average concentrations. Output from the long-term modeling will be used to show decadal trends comparing the seasonal average concentrations of the modeled scenarios to the baseline. The long-term model will be used to estimate the rate at which the Bay reaches equilibrium with different levels of copper in the input loads.

SECTION 3.0: REPORT, COORDINATION, AND MEETINGS

Coordination with the air and watershed modeling teams will be required prior to receiving the final results. This will ensure that the output from those models will provide the necessary input to the Bay model. URS will work with the project team to help develop appropriate input information for the Bay models, such as a method to extrapolate copper loads from the Castro Valley study watershed to estimate copper loads in storm water runoff from other watersheds surrounding the Bay.

URS will meet with the BPP Steering Committee and Scientific Advisory Team members as needed to review progress, interpret results, and address any issues that arise. Meetings may be by teleconference or in person. Meetings will be at least quarterly but may be more frequent.

URS will also give presentations on the project at BPP stakeholder meetings and provide information to support implementation of the BPP's Stakeholder Communication Plan.

URS will provide brief written monthly progress reports to the BPP and stakeholders via e-mail and brief quarterly verbal updates to the BPP Steering Committee.

Both draft and final reports summarizing the Bay modeling results and including all input data will be prepared. The draft report will be completed by August 15, 2006, provided that final report for the watershed modeling is completed on schedule (by April 14, 2006). The final report will be submitted four weeks after receiving all comments from the BPP. Deliverables shall be provided in hard copy and Adobe Acrobat and Microsoft Word electronic formats. As appropriate, numerical results and data shall be provided in Microsoft Excel.

SECTION 4.0: SCHEDULE

Table 4-1 provides a schedule of tasks to complete this project and the estimated completion dates.

Table 4-1
Project Schedule

Task	Date
Start date	Dec 15, 2005
Task 1 – Re-calibrate MIKE 21 copper model and perform verification runs using results from final report for air deposition modeling (due Oct 14, 2005) and results from draft report for watershed modeling (due Dec 20, 2005)	Jan 30, 2006
Task 2 – Run scenarios for preliminary short-term modeling	Feb 28, 2006
Task 3 – Develop box model	Feb 28, 2006
Task 4 – Run scenarios for preliminary long-term modeling	Mar 31, 2006
Task 5 – Perform final calibration and verification runs after receiving final report for watershed modeling (due Apr 14, 2006)	May 31, 2006
Task 6 – Sensitivity study and analysis of uncertainty	June 20, 2006
Task 7 – Complete final scenario runs.	July 15, 2006
Task 8a – First draft of report	Aug 15, 2006
Task 8b – Final report	Nov 17, 2006
Task 9 – Coordination, meetings (including what has already occurred)	As needed

SECTION 5.0: BUDGET

Table 5-1 provides an estimate of the budgeted costs of performing the tasks listed in Section 4.0.

Table 5-1
Project Budget

Task	Budget
Task 1 – Re-calibrate MIKE 21 copper model and perform verification runs using results from final report for air deposition modeling (due Oct 14, 2005) and results from draft report for watershed modeling (due Dec 20, 2005)	$10,200
Task 2 – Run scenarios for preliminary short-term modeling	$5,500
Task 3 – Develop box model	$10,000
Task 4 – Run scenarios for preliminary long-term modeling	$8,000
Task 5 – Perform final calibration and verification runs after receiving final report for watershed modeling (due Apr 14, 2006)	$14,955
Task 6 – Sensitivity study and analysis of uncertainty	$8,500
Task 7 – Complete final scenario runs.	$10,000
Task 8a – First draft of report	$17,772
Task 8b – Final report	$11,850
Task 9 – Coordination, meetings (including what has already occurred)	$22,839

SECTION 6.0: REFERENCES

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