SAN FRANCISCO ESTUARY INSTITUTE

REGIONAL MONITORING PROGRAM FOR TRACE SUBSTANCES

Sources, Pathways, and Loadings: Five-Year Work Plan (2005-2009)

A Technical Report of the Sources Pathways and Loading Workgroup (SPLWG) of the San Francisco Bay Regional Monitoring Program for Trace Substances (RMP)

Lester McKee
San Francisco Estuary Institute, Oakland, CA

CONTRIBUTION
NO. 406
NOV
2005

This report can be cited as:
McKee, L., 2005. Sources pathways and loadings: Five-year work plan (2005-2009). A Technical Report of the Sources Pathways and Loading Workgroup (SPLWG) of the San Francisco Bay Regional Monitoring Program for Trace Substances (RMP): SFEI Contribution #406. San Francisco Estuary Institute, Oakland, CA. 21pp.

ACKNOWLEDGEMENTS

I would like to thank the members of the Sources Pathways and Loadings Workgroup (SPLWG) of the Regional Monitoring Program for Traces Substances (RMP) for their attendance at meetings, development of ideas, critical review, and support for workgroup activities over the first 5 years. The work plan presented here has benefited from conceptual support at the inception of the idea at the March 2004 workgroup meeting, document scoping at the October 2004 workgroup meeting, and verbal review at the May 2005 workgroup meeting. Written review comments were received from Jon Konnan Fred Hetzel, Paul Salop, Richard Looker, Trish Mulvey, and Josh Collins. Sarah Pearce (SFEI) is acknowledged for the preparation of the map of South Bay watersheds and the GIS analysis of watershed areas.

Recent Workgroup Attendance

March, 2004	October, 2004	May, 2005
Workgroup Members		
Richard Looker, SFBRWQCB	Sarah Herbelin, Interested public	Jon Konnan, BASMAA
Andy Jahn, Port of Oakland	Andy Gunther, AMS	Terry Cooke, URS
Jeff Steuer, by phone, USGS	Jon Konnan, EOA Inc./ BASMAA	Carrie Austin, RWQCB
Neil Ganju, USGS	Tom Mumley, RWQCB	Rand Eads, RSL
Joe Domagalski, by phone, USGS	Carrie Austin, RWQCB	Neil Ganju, USGS
Fred Hetzel, R2 RWQCB	Andy Jahn, Port of Oakland	Richard Looker, RWQCB
Jan Null, Golden Gate Weather Services	Rand Eads, RSL	Fred Hetzel, RWQCB
Trish Mulvey, Clean South Bay	Karen Summers, Tetra tech	Trish Mulvey, Clean South Bay
Rand Eads, RSL	Jan Null, Golden Gate Weather Services	Jim Kuwabara, USGS
Larry Freeman, USGS	Kelly Moran, TDC Environmental	Jill Rooth, Interested public
Jon Konnan, EOA Inc. / BASMAA	Neil Ganju, USGS	Jim McGrath, Port of Oakland
Jim Kuwabara, USGS		Paul Salop, AMS/CEP
Carrie Austin, SFBRWQCB		David Drury, SCVWD
Jim McGrath, Port of Oakland		Andy Gunther, AMS
Paul Salop, AMS/CEP		Kit Conaway, UCSC
David Drury, SCVWD		James Erwin, CSJ
Roger, SCVWD		Lisa Windham, USGS
Sujoy Roy, Tetra Tech		Aaron Slowey, Stanford
Peter Kozelka, EPA		Luisa Valiela, USEPA
James Downing, CSJ		
Russ Flegal, UCSC		
Kelly Moran, TDC Environmental		
SFEI staff		
Lester McKee, Chair	Lester McKee, Chair	Lester McKee, Chair
Jon Leatherbarrow	Jon Leatherbarrow	Jon Leatherbarrow
Jay Davis, by phone	John Oram	John Oram
	Jay Davis	Jay Davis
		Meg Sedlak
		Nicole David
		Mike Connor
		Don Yee
		Letitia Grenier

SUMMARY

This work plan has been written to help direct the activities of the Sources Pathways and Loadings Work Group over the period 2005-09 (the second 5-year period of its existence). The work plan is not meant to be prescriptive or rigid but rather provide a living document that can be updated by annual revisions of the Gant Chart (Table 4). The work plan presented follows a typical format for such documents - summarizing previous activities and achievements, presenting objectives and management questions, discussing funding barriers, and providing some examples of external activities that will influence SPLWG work products over the next 5 years. This information is used as a basis for justification and prioritization of SPLWG activities in relation to SPLWG management questions. The Gant Chart at the end of document presents specific projects and funding allocations for projects that help to address the prioritized activities. This Chart will be updated periodically as new studies are proposed and developed through the Workgroup process and approved by the Technical Review Committee of the Regional Monitoring Program.

INTRODUCTION

The Regional Monitoring Program for Traces Substances (RMP) is an innovative collaborative effort created in 1993 between the San Francisco Estuary Institute (SFEI), the San Francisco Bay Regional Water Quality Control Board (RWQCB), and the regulated discharger community. The aim of the RMP is to develop and improve the understanding of contaminant impacts on the beneficial uses of San Francisco Bay through monitoring, research and communication. In 1997 the RMP underwent a five-year program review which helped to develop a revised set of RMP objectives including a new objective: “Describe general sources and loading of contamination to the Estuary” (Bernstein and O’Connor, 1997). The hope was to create a functional connection between the RMP and efforts to identify, eliminate, and prevent sources of pollution that influence the Bay. At the same time, SFEI was developing the Watershed Science Approach (WSA) in the context of its new Watershed Program (Collins et al. 1998). A main objective of the WSA was to help characterize local watersheds in terms of their sources and conveyance of sediment and water, based on the hypothesis that local watersheds significantly influence the quantity and quality of sediment along the margins of the Bay. The WSA also called for long-term monitoring of a regional network of local watersheds. In its review of the WSA, the Regional Board termed these “Observation Watersheds,” the establishment of which became a common objective of the RMP and the Watershed Program at SFEI. Together, SFEI and the Regional Board prioritized the creation of digital maps of local drainage systems including storm drains as a critical step in watershed characterization.

The Sources, Pathways, and Loading Workgroup (SPLWG) was formed in early 1999 to develop a vision for the collection, interpretation, and synthesis of data on general sources and loading of trace contaminants to the Estuary. The initial SPLWG recommendations were described in the first “Technical Report of the Sources Pathways and Loadings Workgroup” (Davis et al., 1999). Since that time the SPLWG has continued to provide management context and technical review on a series of desktop and field studies. The SPLWG ensures that the projects and products are relevant and help to answer ever developing management questions in the context of TMDLs and attainment of water quality standards.

SPLWG Activities and Achievements To-Date

A fundamental early product of the SPLWG was the development of a focus list of contaminants in the context of watershed sources. In 1999, the order of emphasis was highest for PCBs, PAHs, and organophosphate pesticides (OPs) (Table 1). By 2005 the emphasis had changed and polybrominated diphenyl ethers (PBDEs), endocrine disruptors, and pyethriods had been added. Scientific studies on sources, pathways, and loadings, the ongoing RMP monitoring of concentrations in the physical and biological components of the Bay, physical and food-web modeling, and an improved understanding of the relationship between contaminants and beneficial uses has helped to adjust the priority list.

Table 1. The evolution of priority contaminants in the San Francisco Bay Region in the context of the SPLWG.

2000			2005	
PCBs	Top		PCBs and Hg	Top
PAHs	High		PBDEs	High
OPs	High		Endocrine disruptors	High
Hg	Medium		Pyrethroids	High
Se	Medium		Se	Medium
Cu	Medium		Cu	Medium
Ni	Medium		DDT, chlordane, dieldrin	Low
TBT	Medium		Ag, As, Cd, Cr, Ni, Pb, Zn	Low
Ag	Medium		Dioxins/Furans	Low
Cd	Medium		PAH hotspots	Low
Chlordane	Low		OPs	Low
DDT	Low			

In 1999 and 2000, the SPLWG oversaw the completion of a project titled: "Contaminant Loads from Stormwater to Coastal Waters in the San Francisco Bay region: Comparison to other pathways and recommended approach for future evaluation" (Davis et al., 2000). Davis, McKee, Daum, and Leatherbarrow collated existing information on stormwater contaminant concentrations found in the urban storm drains and creeks tributary to San Francisco Bay. They used a simple model based on land use, rainfall, and estimated runoff generated using runoff coefficients, to estimate loadings based on land use specific concentration data where they existed. Loadings in stormwater runoff for suspended sediments, cadmium, chromium, copper, lead, nickel, and zinc were estimated. However, Davis et al. were not able to estimate loadings from the stormwater pathway of several contaminants of interest including PCBs, mercury, PAHs, pesticides, and selenium. They also presented loadings for suspended sediments, cadmium, chromium, copper, nickel, and zinc for the other pathways (wastewater, atmospheric deposition, and dredge material) and made comparisons between these and estimated loadings entering the Bay via the Delta from the Sacramento and San Joaquin Rivers. A refined and more detailed set of recommendations was perhaps the most important contribution made by Davis et al. (2000) (Figure 1). These recommendations, built on those of Davis et al. (1999), became the guiding philosophy of the SPLWG for the past 5 years and are the starting point for the development of the 5-year work plan presented here. Although these are great guiding principles, they lack specificity for each contaminant. For example, watershed characterization and classification for legacy contaminants would likely focus on historic land use and use distribution and might necessarily require a detailed understanding of hydrography in relation to heterogeneous sources. Contaminants with large atmospheric pathways and/or ubiquitous use might require little or no watershed characterization. In terms of conceptual models, these might be relatively simple or very complex depending on the contaminant and might be well founded in scientific literature or in the case of some of the emerging contaminants, undergoing basic scientific development in the areas of phase partitioning, breakdown derivatives, half lives, attenuation, or even source distribution. These things said, the recommendations in Figure 1 remain valid today and will help guide the SPLWG throughout the next 5 years.

Figure 1. Sources Pathways and Loadings Work Group (Davis et al., 2000).

A. **Watershed Characterization**: Characterize and classify the watersheds in the region with regard to factors that control stormwater transport of priority contaminants.
B. **Conceptual Model Development**: Develop conceptual models for the generation, distribution, transformation, transport, and effects of classes of priority contaminants.
C. **Develop Evaluation Strategies**: Design and implement appropriate evaluation strategies for classes of contaminants with similar properties.
D. **Establish Regional Network of "Observation Watersheds"**: Carefully select representative "Observation Watersheds" for detailed, long-term evaluation of stormwater loading and related functions.
E. **Extrapolate to Other Watersheds**: As appropriate, extrapolate results from the Observation Watersheds to other watersheds with similar characteristics.

Following early recommendations by the SPLWG (Davis et al., 1999), in 1999, 2000, and 2001, the SPLWG oversaw a study on atmospheric deposition of mercury (Tsai and Hoenicke, 2001), copper, nickel, cadmium, and chromium (Tsai et al., 2001), and PAHs and PCBs (Tsai et al., 2002). These studies confirmed that the mass loadings of these metals and chemicals to the watershed and to the Bay directly from the air pathway were small compared to other pathways such as the large rivers and stormwater except in the case of mercury where atmospheric deposition may account for about one third of the estimates of stormwater load. At the completion of these studies, the SPLWG recommended that periodic monitoring be continued at just one station to trace trends and measure atmospheric deposition of other contaminants as necessary. Given that several new pollutants (PBDEs, endocrine disruptors, and pyrethroids) have been added to the list of priority contaminants, atmospheric deposition studies may increase in importance again as conceptual models for these substances are developed.

Following recommendations in Davis et al. (1999, 2000), in 2001 and 2002, the SPLWG oversaw the development of two watershed characterization efforts (Figure 1: Recommendation A). The first was a map of PCB concentrations in sediment of the Bay and its watersheds http://www.ecoatlas.org/custom/pcbtool.html. This was used to further discussions and helped develop sampling strategies for contaminant concentrations in the bed sediment of urban drainages (Gunther et al., 2001; KLI, 2002). The second effort aimed to collate existing information on storm drain infrastructure in the Bay Area and make recommendations on how to compile a regional scale map of drainage lines and watershed boundaries (Wittner and McKee, 2002). This report concluded that digital storm drain data are not available in the Bay Area on a regional scale. Data in city and county jurisdictions are mostly stored on paper maps and in a variety of CAD packages and GIS data formats, are mostly not updated recently let alone systematically, and are commonly without data quality indicators or any other form of metadata often because of staff turnover and/or lack of resources. Wittner and McKee (2002) recommended that there be regional support and funding for the methodology being developed and implemented by the Oakland Museum of California and WLA that produces creek and watershed maps showing storm drains larger that 24 inches and watershed boundaries. To-date (November 2005) there have been eight maps completed in this series (for details speak to Janet Sowers, WLA or Christopher Richard, OMC) and there are four more in production. The only major gaps on the Bay margin are the cities of Marin, and the Vallejo, Benicia, and Fairfield/Suisun areas. These maps provide a valuable tool for understanding the relationship between sources of contaminants, transmission though drainage systems, and loading to the Bay. They will form an important input data set for proposed future watershed contaminant modeling. That said, we presently have no mechanism in place for regular updates, an issue that is important in industrial areas undergoing redevelopment and in urbanizing areas.

In 2000, 2001, and 2002, the SPLWG oversaw the interpretation of data collected in the "Estuary Interface Pilot Study" (Leatherbarrow et al., 2002). This report demonstrated that water and sediment concentrations were highest on the Bay margins relative to other parts of the Bay, strongly indicating a gradient of increasing concentrations of Hg, PCBs, and OC pesticides up the salt to freshwater gradient. This report also discussed artifacts caused by the normalization of bulk sediment contaminant concentrations to "%fines" (the fraction of sediment <0.0625 mm). However, the SPLWG never developed a consensus recommendation on how to proceed on this issue mainly because it was felt that the cost of making measurements on specific grain sizes was prohibitive. In addition, the method used to differentiate particle sizes in the lab may introduce handling artifacts if method physics and chemistry causes the breakdown of particle aggregates or causes adsorption or desorption. Literature review and perhaps even method development and validation are required to resolve these questions. In the case of organic trace contaminants and even some metals, it might be better to normalize to organic carbon. This issue will likely be revisited again when the BASMAA agencies storm drain sediment data (Salop et al., 2002; KLI, 2002) is reinterpreted during the SFEI Prop 13 project (See discussion below). Leatherbarrow et al. estimated loadings of Hg for the Guadalupe River based on data collected in Alviso Slough and strengthened recommendations that a small tributaries loading study should be started to estimate loadings more accurately; a small tributaries loading study was started on Guadalupe River later in 2002 (McKee et al., 2004; McKee et al., 2005). The finding from this report suggest that local watersheds are an important sources of water, sediment, and contaminants to the Bay margin and that the importance increases landward from the from the Baylands foreshore.

Following a recommendation in Davis et al. (1999), in 2001, 2002, and 2003, the SPLWG oversaw the development of two literature review and data compilation efforts (Figure 1: Recommendation B & C). Data and literature were gathered to develop a methodology for estimating suspended sediment loadings entering the Bay via the Delta from Central Valley during "large resuspension events" (McKee et al., 2002). Available data at that time spanned the period from water year 1995-98 (4 years). The authors presented a hypothesis that the average load of suspended sediment was ~1 million metric tonnes annually or about 2.5x less than previous estimates. They suggested that the local urban watersheds were likely a larger contributor to the overall Bay sediment and contaminant budgets than had previously been thought. The report also linked the erosion in the Bay to a decrease in Delta sediment throughput and recognized a variety of implications of this load reduction, including less dredging, mobility of legacy contaminants due to Bay scour, and less suspended sediment for restoration projects. The report recommended that a study be conducted to collect trace contaminant concentration data during floods at Mallard Island on the Sacramento River (This study began in January 2002: Leatherbarrow et al., 2004). The second literature review and data compilation effort developed conceptual models of runoff processes in urban watersheds of the Bay Area (McKee et al., 2003). It included extensive review of rainfall and runoff data for the Bay Area. It also included a compilation of local suspended sediment data collected by the USGS over the past 40 years and used to this to make estimates of suspended sediment loadings from the local small urbanized tributaries. The report reviewed recent literature on PCBs, OC pesticides, and Hg in watershed environments and made recommendations on how to sample urban stormwater runoff in urban tributaries of the Bay Area.

In 2002, the first loadings field monitoring project overseen by the SPLWG was started at Mallard Island on the Sacramento River in collaboration with UCSC and USGS following the recommendations of McKee et al. (2002) (Figure 1: Recommendation D). The first report on this data was presented to the SPLWG in 2004 (Leatherbarrow et al., 2004). This report documented nine years of suspended sediment loadings and proved that the long-term average is ~1M metric tonnes annually. The report also presented mercury, PCB, OC pesticides and PAH loadings for WYs 2002 and 2003 and recommended that further evaluation be done to document loadings during "Yolo bypass events" at flows exceeding the magnitude already sampled (160,000 cfs). This is particularly important for the transport of mercury given the Yolo system in the receiving water body for the contaminated Cache Creek watershed. The sediment section has been accepted for publication in the Journal of Hydrology (McKee et al., in press). The SPLWG recommended that the study be continued using a combination "opportunistic" and "periodic" sampling strategy. The SPLWG also recommended that the variation in the cross-section be quantitatively determined during base and flood flow. To achieve this we have embarked on collaboration with the Region 5 RWQCB (C Foe) and the USGS in Sacramento (N Ganju and D Schoellhamer). To-date, we have completed the evaluation for flows <60,000 cfs.

Between 1999 and 2003, SPLWG recommended funding for two USGS efforts to better quantify the release of metals from bottom sediments in the Bay. The first of these studies reviewed knowledge about nickel sources to the Bay (comparing and contrasting nickel sources with copper sources) and addressed questions regarding nickel release from South Bay sediments (Topping and Kuwabara, 2003). The results indicted that benthic flux of nickel is significant relative to both wastewater and stormwater inputs and likely a primary process for controlling dissolved nickel concentrations in the water column during the majority of the annual cycle. The second study, also conducted in South San Francisco Bay, quantified dissolved mercury fluxes to the water column from bottom sediments (Topping et al., 2004). The study results from three locations, when extrapolated for the entire South Bay supported the conclusion that dissolved fluxes to the South Bay water column may be of the same magnitude as annual inputs from the Guadalupe River watershed.

In WY 2003, following recommendations by Davis et al. (2000), the first "small tributaries loading study" was begun with funding from the Clean Estuary Partnership (CEP) (Figure 1: Recommendation D). This study continued in WYs 2004, 2005, and 2006 with funding from the CEP, RMP, United State Army Corps of Engineers (USACE), the Santa Clara Valley Water District (SCVWD), and the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP). So far data from the first three years have been interpreted (McKee et al., 2004; McKee et al., 2005). In WY 2005, the data collection effort was expanded to include methyl-mercury, bedload sediment Hg, and PBDEs. There have been some major outcomes from this study so far. These include 1. Concentrations of PCBs up to 90,000 pg/L during storms (these are some of the highest concentrations ever measured in an urban watershed in the world although it should be kept in mind that methods used influence results comparability), 2. PCB loadings from this one watershed alone are in excess of 1 kg/year and may influence recovery times substantially (Davis, 2004; Leatherbarrow et al., 2005), 3. Total Hg concentrations up to 19 µg/L (concentrations this high far exceed those normally found in urban systems and are typical of mining impacted systems such as the Guadalupe River), and 4. Measured loadings of 116 kg (WY 2003) and 15 kg (WY 2004). In addition McKee et al. (2005) made a hypothesis of long-term average annual load (157 kg) with a range from 0.026 kg in very dry years to 1,070 kg in a water year like 1983. Further, they hypothesized that the average loadings over each 5-year period would be expected to vary from 6.2-443 kg or about 4%-282% of the estimated annual average load (157 kg).

The data and interpretations presented in a mounting list of reports recommended and overseen by the SPLWG have caused some major changes in our perception on the way San Francisco Bay functions. For example, in 2000 it was thought that 80% of the suspended sediments entering the Bay annually were derived from the Central Valley; our present hypothesis is now closer to 60:40 (Central Valley: Small Tributaries in the nine-county Bay Area). In 2000, it was thought that the majority of allochthonous Hg and PCB load was also derived from the Central Valley; we now (March 2005) estimate the ratio to be about 50:50 (Central Valley: Small Tributaries in the nine-county Bay Area) for both substances. These findings have wide reaching implications for management initiatives that aim for improvement of the water quality of the Bay; the collective SPL studies have played an important role in the development of TMDLs for Hg and PCB (Looker and Johnson, 2004; Hetzel, 2004). To complete the circle of adaptive management, implementation actions recommended by the TMDLs provide an emphasis for future SPLWG study efforts. For example, the Hg TMDL recommends:

1. *Evaluate and report on the spatial extent, magnitude, and cause of contamination for locations where elevated mercury concentrations exist.*
2. *Develop and implement a mercury source control program.*
3. *Develop and implement a monitoring system to quantify either mercury loads or the loads reduced through treatment, source control, and other management efforts.*

The Guadalupe Watershed received special attention in the Hg TMDL (Looker and Johnson, 2004) because of the history of Hg mining at New Almaden. The following implementation recommendations in the proposed revision of the Basin Plan also have implications for SPL activities:

1. *Quantify the annual average mercury load reduced by implementing:*
    - *i) Pollution prevention activities*
    - *ii) Source and treatment controls, and*
    - *iii) If applicable, other efforts to reduce methylation or mercury-related risks to humans and wildlife consistent with the watershed-based strategy. The Water Board will recognize loads reduced resulting from activities implemented after 1996 (or earlier if actions taken are not reflected in the 2001 load estimate) to estimate load reductions.*
2. *Quantify the mercury load as a 5-year annual average mercury load using data on flow and water column mercury concentrations.*
3. *Quantitatively demonstrate that the mercury concentration of suspended sediment that best represents sediment discharged from the watershed to San Francisco Bay is below the suspended sediment target.*

The PCB TMDL for San Francisco Bay is on a slower timeline relative to the Hg TMDL. The staff report (Hetzel, 2004) however, contains implementation recommendations similar in many ways to those of Hg and will similarly influence future SPLWG activities:

1. *Demonstrate attainment of the sediment target in discharges*
2. *Demonstrate load reductions in discharges*
3. *Demonstrate loads removed by actions taken that might include:*
    - *i) Cleanup of hotspots on land, in storm drains, and in the vicinity of storm drain outfalls*
    - *ii) Capture, detention, and treatment of highly contaminated runoff*
    - *iii) Implementation of urban runoff management practices and controls that have PCBs removal benefit.*

The recommendations written into the Hg and PCB TMDLs suggest that studies overseen by the SPLWG should focus on estimation of loadings over 5-10 years in strategic watersheds where there are known Hg and PCB sources and where management activities are being applied specifically to try to reduce loadings. The starting date for such studies is funding dependant. It is well known that tributary loading studies need a long time series of data in order to determine the inter-annual variability, be it only from climactic variability. Since there are initial data for both Mallard island and the Guadalupe river and annual sediment loads for a number of other small tributaries in the Bay Area, it may be worth the effort to determine statistically the number of annual samples and the number of sampling years needed to obtain various confidence levels for average annual loads and to be able to measure a decrease in loads.

Recently, the PCB workgroup of the CEP oversaw the development of a multi-box PCB model (Leatherbarrow et al., 2005) that built upon the single-box model work of Davis (2004). Improvements included a more spatially explicit set of loading functions from a variety of pathways, better modeling of remobilization from bed sediments, modeling of sediment mixing and tidal flushing, and spatially explicit modeling of Bay segments. There are plans to complete version 2 of that modeling effort in late 2005. Improvements in version 2 will include a better (separate) treatment of erosion and deposition, dynamic box volumes, dynamic changes to velocity and bed shear stress, improved spatial resolution of tributaries loadings with the exclusion of bed load, a dynamic Delta boundary that allows for sediment loss to the Delta, and improved treatment of erosion and deposition in the Lower Far South Bay box. Outcomes so far suggest that the Bay is sensitive to watershed loadings and that the southern parts of the Bay are most sensitive. This might suggest a prioritization of loadings studies in the South Bay, however this is inconsistent with the "Observation Watershed Approach" proposed by Davis et al. (2000) and still presently supported by SPLWG members. It is anticipated that the improvements in the model will provide further insight into the influence of small tributaries on recovery time for each of the segments; information that will provide context for SPLWG debate on activities and priorities.

The main tributaries of the South Bay include Alameda Creek, Coyote Creek, Guadalupe River, Stevens Creek, Permanente Creek, Adobe Creek, Baron Creek, Matadero Creek, San Thomas Aquino Creek, Calabazas Creek, and San Francisquito Creek (Figure 2). In addition there are numerous "storm drain tributaries" that enter the Bay directly (Sowers, 1999; Sowers, 2004; Sowers and Thompson, 2005). If we assume that during most years, no sediment and attached pollutants passes through reservoirs in the tributaries, the area associated with "storm drain tributaries" in the South Bay and Lower South Bay is ~6% of the total runoff producing area below reservoirs (Figure 2; Table 2). Further, if we assume a runoff coefficient of 60-80%, an average annual rainfall of 254-381 mm (10-15 inches) and a flow-weighted mean PCB concentration of 26-55 ng/L (observed on Guadalupe (McKee et al., 2004; McKee et al., 2005), these minor "storm drain tributaries" alone might account for ~1.2 kg of PCBs annually (Table 3). It seems likely that concentrations in stormwater associated with "storm drain tributaries" on the Bay margin might be greater than we have observed in Guadalupe River because these tributaries drain areas that were formally or presently industrialized and in many cases, being urbanized through redevelopment. A better understanding of PCB concentrations and loadings in some of the minor "storm drain tributaries" would help us to understand how to extrapolate limited data across the Bay Area watersheds (Figure 1: Recommendation E) and provide data to measure success of management aimed at reducing loadings. In addition, future versions of the PCB multi-box model could incorporate more spatially explicit loading functions, or better still, develop an integrated watershed-Bay model. Such a model would allow the direct evaluation of the influence of management actions on both watershed concentrations and loadings, and the response of the Bay in terms of spatial water quality and change through time.

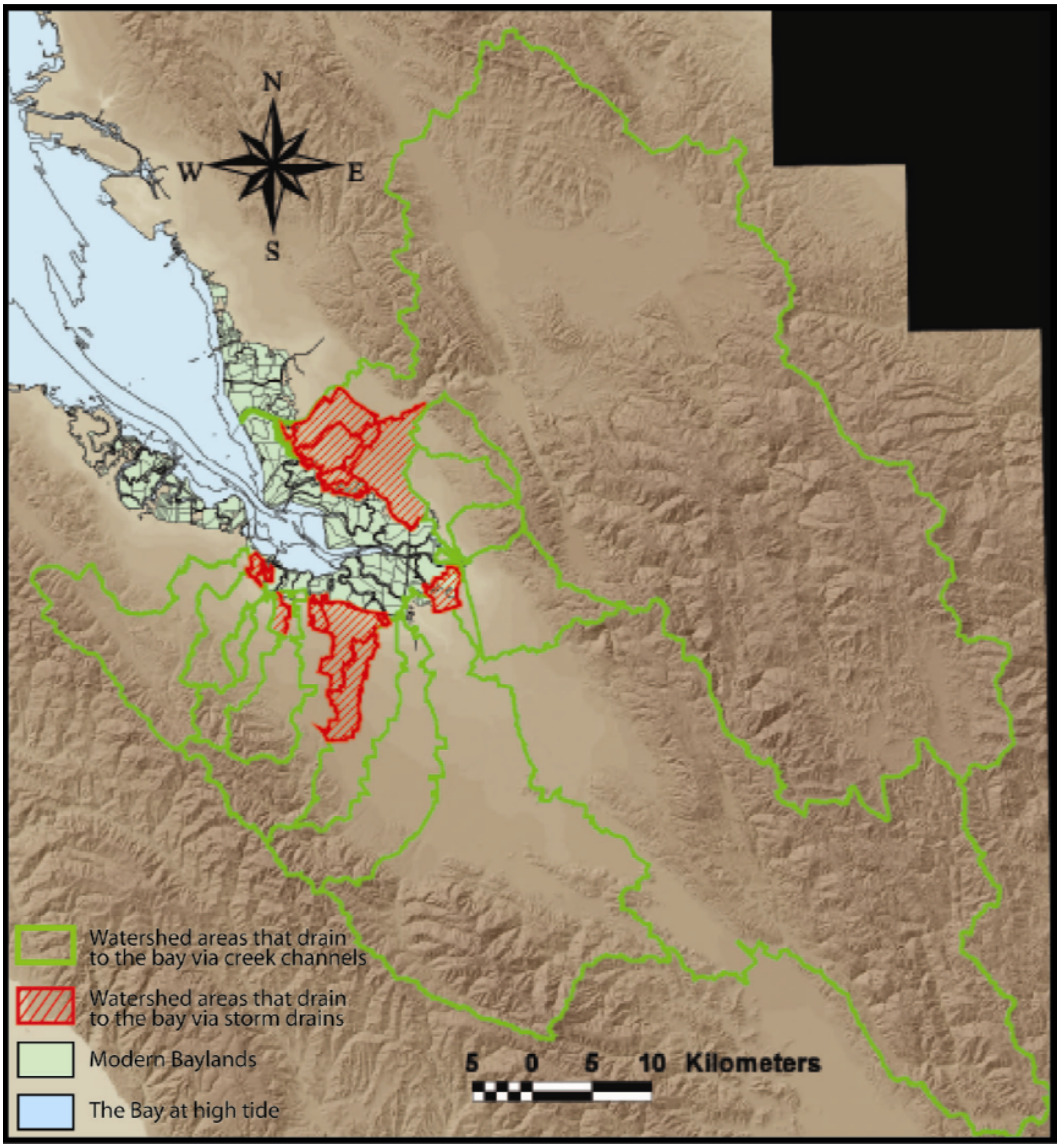

Figure 2. Small tributaries and "storm drain tributaries" entering the South Bay and Lower South Bay segments.

Another recent study of interest to the SPLWG was titled "Analysis of pollutants in sediment cores near storm water inputs – final report" (AMS, 2004). This study concept was originally discussed by the SPLWG in 2001 and 2002 and then developed and implemented in the context of PCB removal with funding from the CEP. Sites on the Bay margin were selected based on the likelihood of near-field deposition of sediment with high PCB concentrations. Twenty six cores were analyzed in six locations. Two cores (one in San Leandro Bay and the other in Moffett Channel) showed concentrations higher than the rest and provide context for watershed loadings studies.

Table 2. Watershed and “storm drain tributary” areas of watersheds of the greater South Bay.

Drainage name	**Area (km^2)**	**Area (mi^2)**	**Drains via**
Adobe Creek	29	11	Creek
Agua Fria Creek	20.4	7.9	Creek
Alameda Creek	1,663	642	Creek
Arroyo de la Laguna	37	14	Creek
Barron Creek	8.0	3.1	Creek
Calabazas Creek	53	21	Creek
Coyote Creek	831	321	Creek
Coyote Hills West	1.0	0.4	Creek
Coyote Laguna	0.1	0.1	Creek
Guadalupe River	445	172	Creek
Lake Elizabeth Creeks	28	11	Creek
Lower Penitencia Creek	74	28	Creek
Matadero Creek	12.5	4.8	Creek
Permanente Creek	47	18	Creek
San Francisquito Creek	117	45	Creek
San Tomas Aquino Creek	115	44	Creek
Stevens Creek	78	30	Creek
Ardenwood Crandall Creeks	16.9	6.5	Storm drain
Coast Casey Forebay	3.6	1.4	Storm drain
Golf Course	1.8	0.7	Storm drain
Mallard Slough	6.7	2.6	Storm drain
Moffat West	2.8	1.1	Storm drain
Mowry Slough	32	12	Storm drain
Newark Slough	12.4	4.8	Storm drain
Plummer Creek	6.5	2.5	Storm drain
Salt Evaporators	3.1	1.2	Storm drain
Sunnyvale East	17.2	6.6	Storm drain
Sunnyvale West	18.6	7.2	Storm drain
Treatment Plant	0.6	0.2	Storm drain
Summed Creek area	3,578	1,381	
Summed Storm drain area	122	47	
Total area	**3,700**	**1,428**	
Del Valle Reservoir	373	147	
San Antonio Reservoir	102	40	
Calaveras Reservoir	354	139	
Anderson Reservoir	491	193	
Calero Reservoir	17.5	6.9	
Almaden Reservoir	30	12	
Guadalupe Reservoir	15.0	5.9	
Vasona Reservoir	112	44	
Stevens Creek Reservoir	44	18	
Total reservoir area	1,539	606	
Total area minus reservoir area	2,161	822	
% draining via creeks	**94.3**		
% draining via storm drains	**5.7**		

Table 3. Thought experiment on the PCB loading potential for minor "storm drain tributaries" that drain formally industrialized or presently industrialized areas.

	Area (km2)	Rainfall (mm)	Runoff Coefficient (%)	Runoff (Mm^3)	PCB (ng/L)	Annual PCB load (kg)
Min	122.37	254	60	18.6	26	0.48
Max	122.37	381	90	42.0	55	2.31
Mean	122.37	318	75	29.1	41	1.18

SFEI recently performed a small reconnaissance survey of the Sausal Creek outfall delta (Figure 3). At this location, we measured a minimum volume of sediment in the delta of 5,900 m^3. It is not known over what time period this delta has built up but our casual observations suggest it has been getting larger over the past 3 years. It is likely that significant tidal reworking occurs each year dispersing even the larger size fractions away from the outfall point. It is likely that many of these deltas occur on the Bay margin adjacent to storm drain outfalls. A screening level survey of a number of these deltas including the measurement of volume, TOC, and grainsize could be used to develop a list of priority sites. A detailed field study of 3-5 priority outfall locations over a wet season would determine if removal is a viable option for improving water quality in the Bay. This type of study could be completed along side a new small tributaries loading study to gain an understanding of the portion of load that is stored in the delta.

There are a number of ongoing studies that will continue to provide information that is relevant to the activities of the SPLWG. For example, SFEI received a Proposition 13 grant entitled "Regional Stormwater Monitoring and Urban BMP Evaluation: A Stakeholder-Driven Partnership to Reduce Contaminant Loadings". Although this project as a whole has its own oversight structure, several tasks within the project were recommended and developed by the SPLWG. Task 3.2: "Map of Natural and Urban Drainage" will further our efforts to characterize the watersheds on the Bay Area (Figure 1: Recommendation A). The outcome of this task will be a completed contiguous map of USGS natural rivers and creeks ("blue lines") for the Bay Area, a compiled map of storm drains and engineered channels (larger than 24 inches in diameter) and watershed boundaries. The National Wetlands Inventory (NWI) of the USFWS is being updated for the Bay Area through the Wetlands Program at SFEI to classify and map all wetlands, lakes, and riverine systems in terms of their ecological form and water sources (Cowardin et al. 1979, NWI 2002, Collins 2004). At the same time, the Wetlands Program is testing new tools to assess wetland condition relative to natural variability and stressors at the watershed scale (Brown 2005). The new NWI and the related tools to assessing wetland condition will be helpful in monitoring the effects of watershed management actions.

Task 3.3 in our Prop 13 grant is to "Develop Methods for Extrapolation of Spatially and Temporally Limited Datasets" was also developed and recommended by the SPLWG. This task will analyze 40 years of USGS suspended sediment data to determine trends and the causes of trends and determine if it is possible to extrapolate data to non-gauged watersheds. Both of these tasks will provide important input data for future modeling efforts that aim to improve regional scale loading estimates. Task 3.3

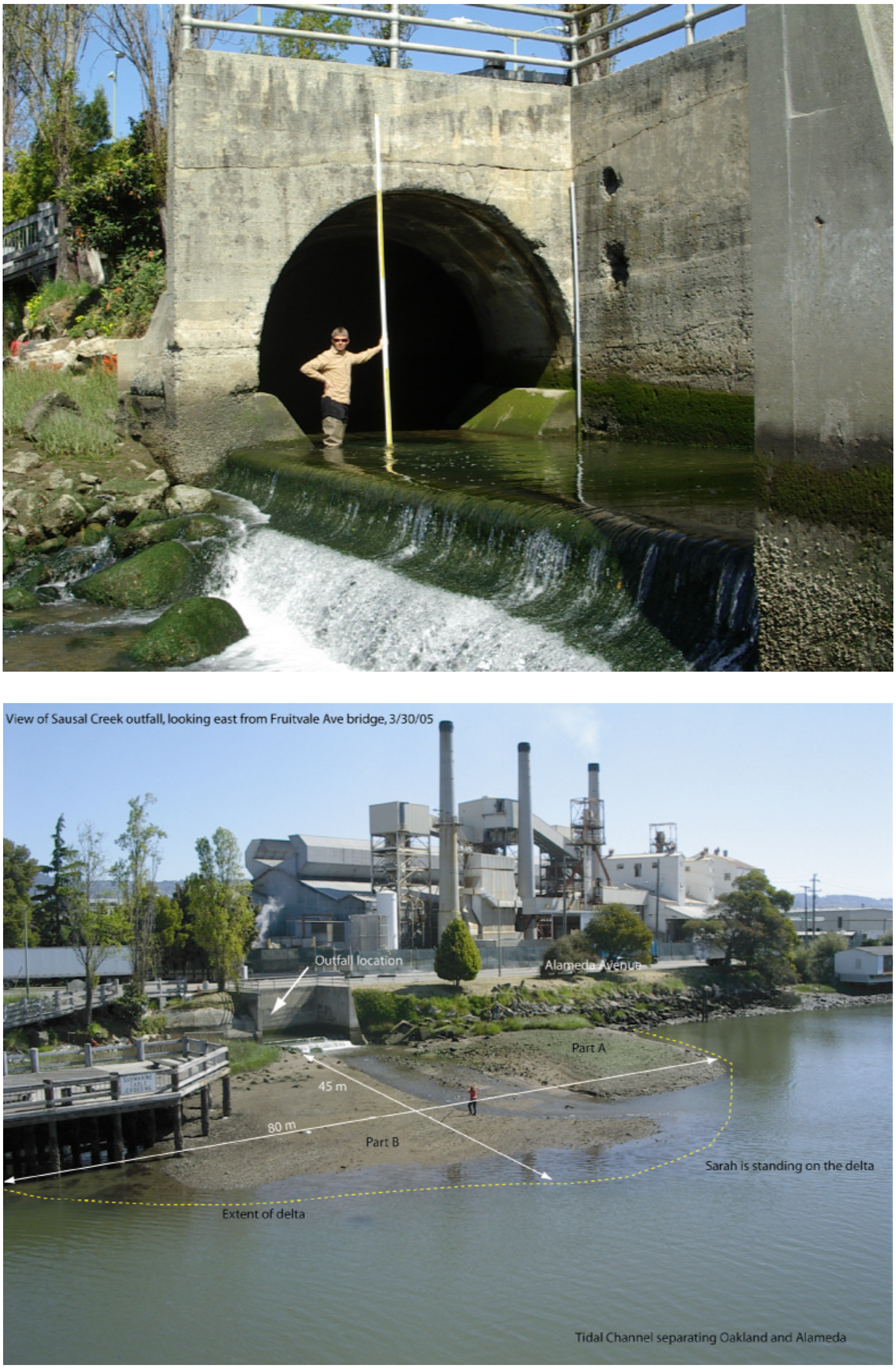

Figure 3. Sausal Creek outfall Delta located near the Fruitvale Avenue Bridge to Alameda. Note the prominent delta impinging on the shipping channel at this location.

will be completed in September 2005 and Task 3.2 will be completed in December 2006. These dates then represent milestones that might influence the direction of the SPLWG. For example, collation and modeling of sediment data along with other modeling efforts through the Guadalupe small tributaries loading study, the break-pad partnership (Sierra Club, friction material manufacturers, BASMAA, and the EPA), and the CEP plus geomorphic studies on sediment processes in flood control channels might radically change our understanding of the distribution and loadings of sediment to the Bay. Interim products from the mapping task (Task 3.2) will also allow discussion and perhaps decisions during 2006 on how best of extrapolate data from one watershed to another using modeling techniques.

A study is presently under way (March 2005) to develop a conceptual model and impairment assessment for PBDEs (Oros and Werme, 2005). Funding for this study was provided by the CEP (Task#4.45). One of the aims of this study is to determine the important sources and loadings of PBDEs to the Bay. In particular, the project will provide comparisons of PBDE loadings from a variety of pathways including small tributaries, wastewater, and atmospheric deposition. This will provide important context for SPLWG activities and prioritization of future studies. The draft report is due in March 2006 and the final report will be presented in September 2006.

ACCWP is funding a current investigation that will generate better pollutant concentration data from sediments collected from different parts of the stormwater system (street sweeping, inlets, depositional facilities, and de-silting projects). The last sampling is scheduled for October 2005 and an interpretive report will be produced in 2006. In addition, there is a Proposition 13 study presently ongoing that is investigating PCB concentrations in many locations within the Ettie Street Pump-station watershed. These two studies have the potential to greatly enhance our present understanding and conceptual models of source-release-transport processes in urban and industrial areas and will likely influence SPL activities.

This section has exemplified how projects funded outside the RMP and SPLWG budgets help to influence the direction of activities and priorities. Continued or even enhanced coordination with other studies (discussed below in more detail) is an essential part of workgroup activities.

REVISED SPL MANAGEMENT QUESTIONS

In 2003, the RMP underwent a 10-year program review (Schubel et al., 2004). In response to that review, the general management questions that guide the RMP were revised to reflect achievements to-date and the current state of our knowledge about priority and emerging contaminants that threaten beneficial uses of San Francisco Bay. The following management questions are pertinent to the SPLWG:

RMP Objective 3. Describe sources, pathways, and loadings of pollutants entering the Estuary

3.1 Where are/were the largest pollutant sources, in what context are/were these pollutants applied or used, and what are/were their ultimate points of release into the aquatic environment?

3.2 What are the circumstances and processes that cause the release of pollutants from both internal (Bay) and external (watershed, wetland) source areas?

3.3 Once released, how do pollutants travel from source areas to the Bay, what are the temporal and spatial patterns of storage, and are they transformed along the way or after deposition?

3.4 What is the annual mass of each pollutant of concern entering the Bay from each pathway?

3.5 Can data with high temporal resolution from a few watersheds be projected to other watersheds and the Basin as a whole?

3.6 For each pollutant of concern, what forms are released from each pathway and what are the magnitude and temporal variation of concentrations and loadings?

3.7 How do loads change over time in relation to management activities?

3.8 What is the relative importance of pollutant loadings from different sources and pathways, including internal inputs, in terms of beneficial use impairment?

SPLWG 5-YEAR WORK PLAN (2005-2009)

In October 2004, the SPLWG met to discuss the pertinent RMP SPL management questions and prioritize SPLWG activities for the next 5 years. The work group members generally agreed that unless large amounts of funding from outside the current RMP structure is successfully procured it will be impossible to address all of these management questions over a 5-year time frame. It was recognized that the SPLWG and other organizations have already generated adequate information for PCBs, Hg and other trace metal in wastewater loadings and dredge material. Atmospheric deposition is quantified for PCBs, other trace metals and Hg, but in the case of Hg, atmospheric loading makes up about one third of the estimated stormwater loading. The issue of sediment resuspension and atmospheric deposition of Hg, PBDEs, and other emerging contaminants (endocrine disruptors and pyrethroids) needs further debate by the workgroup. There remains little spatially explicit information on concentrations and loadings of priority contaminants entering the Bay from urbanized small tributaries and sediment resuspension remains a difficult input to quantify. Given that the Hg and PCB TMDL implementation recommendations ask for the measurement of loadings and trends over time-scales of 5 years and more, the measurement of tributary loadings is an agreed priority for the member agencies of the SPLWG. The SPLWG will focus on:

- Improving estimates of stormwater loadings from urban areas

This should be achieved through the implementation of additional small tributaries loadings studies (Figure 1: Recommendation D). There is a small amount of funding allocated in 2005 to explore potential sampling locations. Davis et al. (2000) recommended that six observation watersheds be picked on the basis of land use and climate. This recommendation remains valid however it should be recognized that stratification based on rainfall and land use is not mutually exclusive. Historic and current industrialized areas are found mainly on the lower-rainfall Bay margin. Data evaluated to help pick future observation watersheds will likely include the GISs of source areas and known use areas, existing stormwater monitoring data, storm drain sediment data, watershed size, land use, population density, the contribution of water and sediment from upper watershed areas, and existing USGS discharge and sediment data. However, the criterion for making the decision will need to be further discussed by the workgroup.

- Evaluating trends in individual watersheds

This should be achieved by implementing loadings studies over 5-10 years (consistent with Hg TMDL recommendations (Looker and Johnson, 2004) and Figure 1: Recommendation D). Given Guadalupe is likely the largest small tributary loading of Hg to the Bay Area and the fact that there is three years of existing data, monitoring on Guadalupe river should be continued to develop the first long-term dataset in the Bay Area. The Guadalupe River watershed is an ideal testing ground for determining trends associated with TMDL implementation because very large load reductions are required by the Hg TMDL. Change detection will likely require long-term datasets because inter-annual variability of loadings is large, however, this might be better achieved through the evaluation of change in particle concentrations that likely have a closer relationship to source characteristics than does the magnitude of annual loads which is strongly influenced by climate. In addition, evaluation of management actions that lead to loads avoided and the effectiveness of such actions should also be determined. Special studies are needed to test the amount of data required to observe the sediment concentration changes required by the TMDLs and the assist managers to decides on the best management methods to meet the TMDL goals.

- Estimating loadings entering the Bay from local small tributaries in the region as a whole

In the past this has been achieved by a simple area extrapolation without regard to land use, rainfall/runoff, or historic and current sources of pollution. Resources should be allocated to explore the use of more sophisticated models with calibrated and verified rainfall / runoff processes as the foundation. Such modeling will require continued improvement of watershed characterization (hydrography, rainfall distribution, imperviousness, vegetation, and land use characteristics) (Figure 1: Recommendation A). Improvements in our regional understanding of hydrography (flow pathways and watershed boundaries) are being developed through SFEI's Proposition 13 grant. The improvement of our understanding of the influence of aspect, topography, and storm track direction on rainfall distribution is an area that might need further work.

In addition, given that both the Hg and PCB TMDLs call for reductions of loadings from the Central Valley entering the Bay via the Delta, the SPLWG should continue to improve knowledge on the magnitude and annual variation of loadings from that pathway.

- Measure loadings entering the Bay from the Central Valley via the Delta

  This will be achieved by the continuation of the Mallard Island study on the Sacramento River near the Region 2 / Region 5 RWQCB boundary.

Given the regional needs and priorities and the limited funding available, the following Gant Chart summarizes the presently recommended activities of the SPLWG over the next 5 years (Table 4). However, as noted above, some members support a better balance between "sources", "pathways", and "loadings" and continued work on quantification of sediment resuspension in the Bay and atmospheric deposition as a source to urban watersheds rather than a more limited focus on loadings alone. These issues require further discussion and might add to or change work plan priorities that could be reflected in subsequent annual revisions of the Gant Chart.

SPLWG COORDINATION WITH OTHER STUDIES (2005-2009)

There are many important studies and programs in the Bay Area (and similar efforts in greater California and other states) that provide data, ideas, and analogies that can enhance the efforts of the SPLWG. Examples at the local level include studies by other staff at SFEI (e.g., method to monitor methylmercury in wetlands, Proposition 13 BMP assessment, NWI updates, wetland and riparian habitat rapid assessment methods (CRAM), and landscape-level wetland and stream stressor assessment methods), BASMAA, BACWA, USGS, universities, special districts, ABAG, Sustainable Conservation, SFEP, TBI, and the CEP. At the state level there are relevant projects and programs being conducted by the State Water Resources Control Board (SWRCB), other Regional Water Quality Control Boards (e.g. RB5), and CALTRANS. Notable programs in other parts of the Country include the Willamette Hg TMDL, Chesapeake Bay Programs, the Great Lakes studies, and research on environmental Hg and PCBs in the Everglades. The Sources Pathways and Loading component of the RMP can be made more successful through a plan for coordination and financial support for SPL staff to implement the plan.

Given that the SPLWG focus at present is on loadings to the Bay, a particularly pertinent issue is the enhancement of coordination between studies on loadings and interdependent processes affecting biological targets such as bottom sediment fluxes, mercury methylation, and other food web linkages. The TMDL reports describe linkages between mass loadings and biological effects. Ongoing effort is needed to quantitatively

Table 4. 5-year work plan for the Sources Pathways and Loadings Workgroup.

Activity	Funding Sources	Tools / Products	2005	2006	2007	2008	2009
*Workgroup meetings	RMP	Power Point presentations / verbal communications	$22k	$22k	$22k	$22k	$22k
*External Coordination	RMP	Attend key meetings hosted externally, review external reports	$0	$7k	$7k	$7k	$7k
*SPLWG expert review and meeting attendance	RMP	3 experts attend 2 meetings a year to provide independent comment	$4k	$4k	$4k	$4k	$4k
**Development of the next 5-year plan	RMP	SPLWG meeting preparation, Written reporting					[4]$15k
		Subtotal	$28k	$35k	$35k	$35k	$50k
Mallard Island Large River Loadings Study	RMP	Empirical field data collection, Written reporting	$51k	$60k	[1]Contingency		$120k
Guadalupe Small Tributaries Loadings Study	CEP, RMP, USACE, SCVURPPP	Empirical field data collection, Written reporting	$50k +$123k[2]	$50k +$77k[2]	?	?	?
Reconnaissance Survey of Loading Study Sites	RMP	Field observations, desktop review, Technical Memo	$7.5k				
Additional small tributaries loadings studies	RMP 1st year (with cost match during subsequent years?)	Empirical field data collection, Written reporting	[3]In-kind	[4]In-kind	[5]150k	[5]125k	[5]125k
		Subtotal	$109k	$110k	$150k	$125k	$245k
		Total	**$137k**	**$145k**	**$185k**	**$160k**	**$295k**

*Funded though normal SPLWG RMP budget (i.e. not the special and pilot studies budget)
**Funded though normal SPLWG RMP budget (i.e. not the special and pilot studies budget)
[1]TRC provides RMP contingency funds to sample large floods as necessary - large is defined as a flood that is predicted to be larger than already observed during the period of study so far.
[2]Note that the total cost for WY 2005 was $173k ($123k match funds provided by USACE/SCVWD, SCVURPPP).The cost for WY 2006 is $127k ($77k match funds provided by USACE/SCVWD).
[3]Laboratory budget only was provided by the RWQCB for a reconnaissance study on Coyote Creek. A total of seven samples were collected during wading stage as opportunity allowed (when sampling team was able to get away from Guadalupe River study) and analyzed for Hg, PCBs, and PBDEs at the USGS gauge at HWY 237. The results will be presented to SPLWG via PowerPoint presentations.
[4]Laboratory budget only provided by RWQCB for a reconnaissance study on two stormwater outfalls in San Jose, sampling when opportunity allows during the Guadalupe study, analysis for Hg only.
[5]Not approved yet by the TRC.

relate changes in mercury loadings to methyl mercury in target species (an attempt to integrate physical with biogeochemical processes). For example, one hypothesis might be that concentration and loading trends evaluated for watersheds correspond empirically to certain trophic transfer parameters? One might therefore examine how the proposed loading studies might spatially link to any RMP-supported or externally-supported monitoring of methyl mercury in water, phytoplankton, zooplankton, fish, and birds. Studies of methymercury problems in tidal wetlands are developing sentinel species indicators that can also be used in local riverine and riparian systems. These kinds of linkages might require special funding consideration.

Funding for general coordination is handled through the "external coordination" component of the RMP. In 2004, SFEI SPL staff was provided with $7,000 to complete this task. This was dropped in 2005 due to funding pressures. A funding level of $7,000 or more should be reinstated in future years (Table 4) to carry out the following activities:

- Attend meetings and read other relevant reports and products from other parts of the RMP, USGS, universities, CEP, BASMAA, ABAG, other RBs (RB5), and other States
- Review and incorporate others work into SPL reports and work products

In addition a further $3,000 and travel costs (~$1000) has been made available for paying for invited "experts" to attend SPLWG meetings and review SPLWG work products. This level of funding should be continued for the next 5 years (Table 4):

- Invite speakers to SPL to discuss new methods or pertinent recent studies
- Invite national experts to be part of the work group

CONCLUSIONS

This plan has summarized the work products completed by the SPLWG over the past 5 years based in recommendations recorded in the "First Technical Report of the Sources Pathways and Loadings Work Group" (Davis et al., 1999) and refined in "Contaminant Loads from Stormwater to Coastal Waters in the San Francisco Bay region: Comparison to other pathways and recommended approach for future evaluation" (Davis et al., 2000). In addition, a number of other pertinent efforts (in particular the TMDL reports (Looker and Johnson, 2004; Hetzel, 2004) as well as ongoing studies have been summarized to provide a literature resource and overview of our current understanding of Sources, Pathways and Loadings of suspended sediments and contaminants of concern that enter the Bay annually. Taking this amassed information into account along with verbal feedback gained from the October 2004 and May 2005 SPLWG meetings, in the context of budgetary constraints, a Gant chart was developed to provide guidance for SPLWG activities from 2005-2009. We anticipate the next planning phase will occur in 2009 but recognize that the results from SPLWG studies and studies by other groups in the Bay Area and nationally may cause modification of this work plan during this 5-year period.

REFERENCES

AMS, 2004. Analysis of pollutants in sediment cores near storm water inputs – final report. Report prepared for the Clean Estuary Partnership (CEP) by Applied Marine Sciences Inc. (AMS), Livermore, CA. July 2004. 26pp.

Bernstein, B., and O'Connor, J., 1997. Five-Year Program Review Regional Monitoring Program for Trace Substances in the San Francisco Estuary. Report to the Technical Review Committee of the Regional Monitoring Program for Trace Substances, San Francisco Estuary Institute, Richmond, CA.

Brown, M.T. and M.B. Vivas. 2004 A Landscape Development Intensity Index. E*nvironmental Monitoring and Assessment.* 101: 289–309

Collins, J.N., L.M. Collins, and R.Hoenicke. 1998. Bay Area Watershed Science Approach version 3.0. San Francisco Estuary Institute, Richmond CA.

Cowardin, L. M. V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Dep. Interior, Fish and Wildl. Serv. FWS/OBS - 79/31.

Davis, J.A., Abu Saba, K., and Gunther, A.J. 1999. Technical report of the Sources Pathways and Loadings Workgroup. San Francisco Estuary Institute, September 1999. 55pp.

Davis, J.A., McKee, L.J., Leatherbarrow, J.E., and Daum, T.H., 2000. Contaminant loads from stormwater to coastal waters in the San Francisco Bay region: Comparison to other pathways and recommended approach for future evaluation. San Francisco Estuary Institute, September 2000. 77pp.

Davis, J.A., 2004. Long-term fate of polychlorinated biphenyls in San Francisco Bay (USA). Environmental Toxicology and Chemistry 23, 2396-2409.

Gunther, A.J., Salop, P., Bell, D., Feng, A., Wiegel, J., and Wood, R., 2001. Initial characterization of PCB, mercury, and PAH contamination in drainages of western Alameda County. Report prepared by Applied Marine Sciences for the Alameda Countywide Clean Water Program. 43pp.

Hetzel, F. 2004. PCBs in San Francisco Bay: Total Maximum Daily Loads Report. San Francisco Bay Regional Water Quality Control Board. Oakland, CA. January 2004. 69pp. http://www.waterboards.ca.gov/sanfranciscobay/TMDL/SFBayPCBs/pcbs_tmdl_project_report010804.pdf

KLI, 2002. Joint stormwater agency project to study urban sources of mercury, PCBs, and organochlorine pesticides. Report prepared by Kinnetic Laboratories, Inc. for Santa Clara Valley Urban Runoff Pollution Prevention Program, Contra Costa Clean Water Program, San Mateo Countywide Stormwater Pollution Prevention Program, Marin County Stormwater Pollution Prevention Program, Vallejo Flood Control and Sanitation District, Fairfield-Suisun Sewer District. 71pp.

Leatherbarrow, J.E. Hoenicke, R. and McKee, L.J., 2002. Results of the Estuary Interface Pilot Study, 1996-1999, Final Report. A Technical Report of the Sources Pathways and Loading Work Group (SPLWG) of the San Francisco Estuary Regional

Monitoring Program for Trace Substances (RMP). San Francisco Estuary Institute, Oakland, CA. March 2002. 90pp.

Leatherbarrow, J.E., McKee, L.J., Schoellhamer, D.H., Ganju, N.K., and A.R. Flegal, 2004. Concentrations and loads of organic contaminants and mercury associated with suspended sediment discharged to San Francisco Bay from the Sacramento-San Joaquin River Delta, California RMP Technical Report. SFEI Contribution #X. San Francisco Estuary Institute. Oakland, CA.

Leatherbarrow, J.E., Oram, J.J., and Davis, J.A., 2005. A model of long-term PCB fate and transport in San Francisco Bay, CA. Draft report submitted for review. SFEI contribution 388, San Francisco Estuary Institute, Oakland, CA. 74pp.

Looker, R., and Johnson, W., 2004. Mercury in San Francisco Bay Total Maximum Daily Load (TMDL): Proposed Basin Plan Amendment and Staff Report. California Regional Water Quality Control Board San Francisco Bay Region, September 2, 2004. 118pp + appendix (A, B). http://www.waterboards.ca.gov/sanfranciscobay/Agenda/09-15-04/September%2015,%202004%20Board%20Meeting_files/09-15-04-10_appendix_c.pdf

McKee, L., Ganju, N., Schoellhamer, D., Davis, J., Yee, D., Leatherbarrow, J., and Hoenicke, R., 2002. Estimates of suspended sediment flux entering San Francisco Bay from the Sacramento and San Joaquin Delta. Report prepared for the Sources Pathways and Loading Workgroup (SPLWG) of the San Francisco Bay Regional Monitoring Program for Trace Substances (RMP). SFEI contribution 65. San Francisco Estuary Institute, December 2002. 28pp.

McKee, L., Leatherbarrow, J., Pearce, S., and Davis, J., 2003. A review of urban runoff processes in the Bay Area: Existing knowledge, conceptual models, and monitoring recommendations. A report prepared for the Sources, Pathways and Loading Workgroup of the Regional Monitoring Program for Trace Substances. SFEI Contribution 66. San Francisco Estuary Institute, Oakland, Ca.

McKee, L., Leatherbarrow, J., Eads, R., and Freeman, L., 2004. Concentrations and loads of PCBs, OC pesticides, and mercury associated with suspended sediments in the lower Guadalupe River, San Jose, California. A Technical Report of the Regional Watershed Program: SFEI Contribution #86. San Francisco Estuary Institute, Oakland, CA. 79pp.

McKee, L., Leatherbarrow, J., and Oram, J., 2005. Concentrations and loads of mercury, PCBs, and OC pesticides in the lower Guadalupe River, San Jose, California: Water Years 2003 and 2004. A Technical Report of the Regional Watershed Program: SFEI Contribution 409. San Francisco Estuary Institute, Oakland, CA. 72pp.

McKee, L., Ganju, N., Schoellhamer, D., (in press). Estimates of suspended sediment entering San Francisco Bay from the Sacramento and San Joaquin Delta, San Francisco Bay, California. Journal of Hydrology.

NWI. 2002. HGM Mapping Codes for Additional Attributes of Wetlands Depicted on NWI Maps. National Wetlands Inventory, USFWS.

Oros, D., and Werme, C., 2005. PBDE conceptual model and impairment assessment report: Detailed Scope of Work. Clean Estuary Partnership (CEP) Task#4.45 February 15th 2005. 9pp.

Salop, P., Abu-Saba, K., Gunther, A., and Feng, A., 2002. 2000-01 Alameda County watershed sediment sampling program: Two-year summary and analysis. Alameda Countywide Clean Water Program, September 2002. 40pp.

Schubel, J.R., R. Berger, J. Conomos, P. Herrgesell, A. Mearns, and S. Weisberg. 2004. Report of the 2003 Program Review, Regional Monitoring Program for Trace Substances in the San Francisco Estuary. SFEI Contribution 303. San Francisco Estuary Institute, Oakland, CA.

Sowers, J.M., 1999. Creek and watershed map of Fremont & Vicinity. Oakland Museum of California, Oakland, CA.

Sowers, J.M., 2004. Creek and watershed map of Palo Alto & Vicinity. Oakland Museum of California, Oakland, CA. 1:25,800 scale.

Sowers, J.M. and Thompson, S.C., 2005. Creek and watershed map of Milpitas and northern San Jose. Oakland Museum of California, Oakland, CA. 1:25,800 scale.

Topping, B.R. and Kuwabara, J.S., 2003, Dissolved nickel and benthic flux in south San Francisco Bay: A potential for natural sources to dominate. Bulletin of Environmental Toxicology and Chemistry, v. 71, p. 46-51.

Topping, B.R., Kuwabara, J.S., Marvin-DiPasquale, M.C., Agee, J.L, Kieu, L.H., Flanders, J.R., Parchaso, F., Hager, S.W., Lopez, C.B. and Krabbenhoft, D.P., 2004, Sediment Remobilization of Mercury in South San Francisco Bay, California. U.S. Geological Survey Scientific Investigations Report 2004-5196, 60p. http://pubs.water.usgs.gov/sir2004-5196.

Tsai, P., and Hoenicke, R., 2001. San Francisco Bay atmospheric deposition pilot study Part 1: Mercury. San Francisco Estuary Institute, Oakland Ca, July, 2001. 45pp. http://www.sfei.org/rmp/reports/air_dep/mercury_airdep/ADHg_FinalReport.pdf

Tsai, P., Hoenicke, R., Hansen, E., and Lee, K., 2001. San Francisco Bay atmospheric deposition pilot study Part 2: Trace metals. San Francisco Estuary Institute, Oakland Ca, September, 2001. 53pp. http://www.sfei.org/rmp/reports/air_dep/tracemetals/AD_TMFinalReport.pdf

Tsai, P., Hoenicke, R., Yee, D., Bamford, H.A., and Baker, J.E., 2002. Atmospheric concentrations and fluxes of organic compounds in the northern San Francisco Estuary. Environmental Science and Technology 36, 4741-4747.

Wittner, E., and McKee, L., 2002. Mapping urbanized and rural drainages in the Bay Area: A tool for improved management of storm water contaminants derived from small tributaries. A Technical Report of the Watershed Program, San Francisco Estuary Institute, Oakland, CA. 41pp.