POLLUTANT MASS EMISSIONS TO THE COASTAL OCEAN OF CALIFORNIA:

Initial Estimates and Recommendations to Improve Stormwater Emission Estimates

Final Report to:

State Water Resources Control Board
Sacramento, CA

From:

Southern California Coastal Water Research Project
Westminster, CA

San Francisco Estuary Institute
Richmond, CA

Moss Landing Marine Laboratory
Moss Landing, CA

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FOREWORD

This project was initiated in response to Assembly Bill 1429 (Chapter 899, Statutes of 1997), which focused on stormwater runoff and coastal water quality monitoring, and suggested the use of pollutant mass emission estimates as a potential tool for management decision-making. Assembly Bill 1429 directed the State Water Resources Control Board to propose a program that will improve its ability to estimate mass emissions from all sources discharged to the California coastline and assess what proportion of the total load originates from stormwater runoff versus other sources. This report makes first-order estimates of mass emissions from a variety of sources, including stormwater runoff, to the State's coastline. It draws on the experience of making those estimates to recommend steps needed to improve the reliability and completeness of our knowledge of pollutant loads to the coastline.

This document represents a multi-group effort and includes stand-alone appendices for southern California, San Francisco Bay, and the central/northern California coasts. Each region has developed detailed load estimates using local agency involvement and provided regional recommendations based upon their specific needs. Although each region was given adequate flexibility to use the most appropriate techniques for their areas, a common approach was utilized statewide so that sufficient comparability existed to compile data into a larger-scale assessment. The cumulative statewide mass emissions estimates, a critique of the estimates, and recommendations for a comprehensive program, including a budget, appear in this report. The technical approaches for developing mass emission estimates from the three regions are contained within each regional appendix.

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I. INTRODUCTION

There are numerous sources of pollutants from land- and ocean-based activities that represent potential risks to the coastal ecosystems throughout the State. These include over 200 point sources such as publicly owned treatment works (POTWs), industrial dischargers, oil platforms, and power generating stations. There are also a large variety of non-point sources, such as stormwater runoff from more than 300 coastal watersheds in the State, dredged material disposal at five designated dumpsites in State waters, and atmospheric deposition from some airsheds with amongst the poorest air quality in the nation.

One tool used by environmental managers to evaluate potential ecosystem risk is an estimate of pollutant mass emissions. Mass emission estimates measure the total pounds (tons) of pollutants discharged to the ocean. Mass emission estimates help ecosystem managers make decisions about stewarding coastal resources in at least two manners. First, mass emission estimates assist environmental managers by comparing the mass of a specific pollutant discharged among two or more sources. Managers may wish to compare two different types of sources or two different sources of the same type. For example, managers may wish to assess if more pollutants are released from POTWs that discharge treated sewage effluents, or from a creek that receives stormwater runoff from an urbanized watershed. Alternatively, the manager may wish to assess whether more pollutants are arising from one watershed versus another watershed. In either scenario, managers are using mass emission estimates to evaluate potential risk.

The second manner that mass emission estimates aid environmental managers for decision-making is assessing trends. For example, a small source may become a priority if it has a significantly increasing trend. Alternatively, once a source starts to be controlled, measuring mass emissions over time will demonstrate if the management actions taken were effective at reducing pollutant contributions.

One goal of this report was to estimate mass emissions from a variety of point and non-point sources to the coastal waters of the State. The objective was to assess what proportion of the total load is comprised by stormwater runoff. Stormwater runoff is defined as the runoff induced by rainfall and reaching a stream or drain during and within hours of a rainstorm. The second goal was to provide recommendations for improving runoff mass emission estimates and stormwater monitoring. This report presents a statewide synthesis of results, conclusions, and recommendations. Subsequent appendices present detailed findings in different regions of the State.

II. METHODS

There were three principles used for estimating mass emissions statewide. The first principle was that this study relied upon existing data; no new data collection was performed. The second principle was that regionalization was an important component to estimating loads since different areas of the State have significantly different watershed characteristics. Thus, the state was divided into three regions corresponding to the Southern California Bight (US/Mexico Border to Pt. Conception), the San Francisco Bay, and the Central/North Coast (Pt. Conception to California/Oregon Border). The third principle focused on developing a common statewide approach so that estimates from each region were comparable, but with sufficient flexibility to incorporate region-specific characteristics and needs.

We estimated inputs from six different types of sources. These sources included urban and non-urban stormwater runoff, POTWs, industrial facilities (i.e. oil refineries, etc.), power generating stations, dredged material disposal, and oil platforms. We focused on annual estimates, but the target years for each source ranged from 1995 to 1998 enabling us to capture the most recent information available. We characterized all point sources that discharge to the coastal waters starting at the head of tide and extended to the edge of the continental shelf (ca. 200 m depth). For runoff, we estimated all loads from coastal watersheds downstream of significant dams.

Stormwater runoff mass emissions were estimated using a simple model utilizing rainfall, watershed area, land use within the watershed, and water quality for each of the land uses defined in the watershed. While the generalized model oversimplifies many watershed processes in its assumptions, it was the best tool for the data types available and the large variety of watershed conditions encountered throughout the state. Runoff loads were estimated for a typical rain year averaged over 30 years (1961-1990). The long-term rainfall averaging minimized year-to-year bias in runoff volume. Average water quality concentrations from 1990-1999 were used. The primary sources of water quality data were compiled from the large municipalities that have National Pollutant Discharge Elimination System (NPDES) permits for municipal stormwater discharges (which began ca. 1990). The sensitivity of the model was tested by using the 10^{th} and 90^{th} percentiles of rainfall and water quality data sets. Base data sets of rainfall, watershed area, and land use were adopted statewide. However, loads were calculated using local data sets where improved information was available. For example, many counties have well-defined, current land use information that was substituted for the statewide data. Regional water quality data sets were also used where available. When data were unavailable regionally, water quality data were shared statewide.

Point source estimates were calculated based upon annual average flow and annual average concentration. The flow and concentration data were taken from each discharger's self-monitoring program mandated under their NPDES permit. Dredged material disposal data were obtained from the US Army Corps of Engineers.

III. RESULTS

Stormwater runoff is a significant contributor of pollutant mass emissions to the coastal waters of the State (Table 1). Runoff contributed over 90% of the nitrate, cadmium, and lead relative to other sources. Stormwater runoff also contributed the majority of the cumulative load for suspended solids and four other trace metals including chromium, copper, nickel, and zinc. There were insufficient data from all sources to compare loads for additional nutrients or organic constituents such as pesticides, herbicides, and petroleum hydrocarbons.

Table 1. Estimates of total mass emissions to the coastal waters of the State of California and percent of load by source. mt = metric tons; - = no data

	units	Total Load	Percent of Load					
			Runoff	POTWs	Industrial	Dredge	Platform	Power Plants
Suspended Solids	mt x 10^6	302	78.8	2.8	0.04	18.0	0.34	<0.01
Nitrate-N	mt x 10^3	52	93.5	6.5	<0.01	0.0	-	<0.01
Cadmium	mt	15	91.8	6.0	0.10	2.1	<0.01	<0.01
Chromium	mt	400	73.4	1.8	0.18	24.6	<0.01	<0.01
Copper	mt	756	57.3	39.2	0.12	3.3	<0.01	<0.01
Lead	mt	214	91.3	1.8	0.05	6.9	<0.01	<0.01
Nickel	mt	494	74.0	8.6	0.27	17.2	0.01	<0.01
Zinc	mt	1,672	68.6	27.0	0.33	4.1	<0.01	<0.01

Although the loads delivered by stormwater appear large, our estimates of runoff loads are uncertain due to variability in rainfall and water quality (Table 2). We modeled an average rainfall year and average water quality to estimate stormwater runoff loads. We also conducted sensitivity analysis by modeling the 10^{th} and 90^{th} percentiles of rainfall and water quality to assess variability due to these factors. Variability in rainfall and water quality can alter our estimate of statewide loads several-fold for most constituents. The range of loads based upon changes in rainfall varied from 50 to 150% of the average load. The range of loads based upon changes in water quality varied from 30 to 600% of the average load. The large variability due to water quality was expected and is due to several factors including differences in antecedent rainfall (time between storms) and pollutant build-up/wash-off phenomenon (i.e. first flush, particle mobilization, etc.), as well as differences in monitoring design and sample collection used by the various stormwater agencies throughout the State. The proportion of variability due to build-up/wash-off versus that due to sampling design is unknown.

Our estimates of runoff are also confounded by variability in detection limits among monitoring programs (Table 3). The effect of non-detectable (NDs) quantities can significantly bias results based upon how NDs are treated. We evaluated NDs using three scenarios; ND=0, ND=1/2 the reporting limit, and ND=reporting limit. Depending upon which approach was used the mass emission estimates could increase orders of magnitude. For constituents that were nearly always detected (e.g. suspended solids), the difference in load estimates were relatively small (0.05%) using the two scenarios. For constituents in trace quantities that were rarely detected, however, the difference in mass emission estimates between the two scenarios was much more dramatic. For example, chlorpyrifos was detected in 1% of the 459 samples collected and, depending upon how NDs were treated, the mass emission estimates ranged from 15 kg to 1,500 kg. It is important to recognize that this phenomenon was not restricted to runoff monitoring, but is a problem that pervades every source investigated.

Table 2. Sensitivity analysis for mass emission estimates of selected constituents based upon variability in rainfall and water quality. Sensitivity analysis focused on the 10th and 90th percentiles of each data type for stormwater runoff to coastal waters of the State.

	Variance Due to Rainfall (% of mean)		Variance Due to Water Quality (% of mean)	
	10th Percentile	90th Percentile	10th Percentile	90th Percentile
Suspended Solids	53	147	34	403
Nitrate	56	142	16	228
Phosphate	47	157	55	440
Cadmium	54	145	37	434
Chromium	54	145	36	416
Copper	54	145	21	412
Lead	50	150	45	634
Nickel	55	143	36	418
Zinc	52	149	32	488

Table 3. The effects of different methods of averaging non-detects on the estimated stormwater load to the southern California Bight. mt = metric tons; kg = kilograms; ND = non-detects; RL = reporting limit

				Averaging Scheme		
	Unit	Total Number of Samples	Number of ND	ND = 0	ND = ½ RL	ND = RL
Suspended Solids	mt	1,869	67	264,668	264,736	264,805
BOD	mt	852	42	20,558	20,712	20,867
COD	mt	951	217	61,467	62,192	62,916
Nitrate	mt	2,493	95	2,720	2,724	2,728
Nitrite	mt	797	292	68.0	124	181
Phosphate	mt	1,063	28	508	509	510
Cadmium	kg	2,132	1,659	598	951	1,303
Chromium	kg	2,143	1,354	11,088	12,575	14,062
Copper	mt	2,177	279	35.7	36.1	36.5
Mercury	kg	963	918	819	1,242	1,665
Nickel	mt	2,133	1,033	11.54	13.1	14.6
Lead	mt	2,139	684	12.31	13.7	15.1
Selenium	kg	997	858	458	2,793	5,128
Zinc	mt	2,124	205	161	166	172
Chlordane	kg	637	636	-	108	216
Chlorpyrifos	kg	459	454	15.1	770	1,526
Diazinon	kg	465	435	13.9	398	783
Dieldrin	kg	601	599	-	45.82	91.6
PCB	kg	599	599	-	313	626
DDT	kg	636	615	21.3	64.4	107
MTBE	kg	8	8	-	467	934

IV. DISCUSSION

This study demonstrated that stormwater runoff is a large pathway of potential pollutants that needs to be investigated further. Even given the uncertainty in the mass emission estimates due to variations in rainfall, water quality concentrations, and detection limits, contributions from runoff are large. The calculations presented herein are screening level estimates that should provide the rationale and justification for more comprehensive monitoring, evaluation, and assessment.

Although not designed for trends, results from this project were used to show changes in mass emissions over time (Table 4). We compared estimates for POTWs and stormwater runoff from southern California with mass emissions measured in 1971 (SCCWRP 1973). Although discharge volumes increased after 25 years, the combined mass emissions declined an average 95% for trace metals and more than 99% for total DDT. The majority of these declines were the result of decreased mass emissions from POTWs, which spent over $5 billion in increased treatment, pretreatment, source control, and reclamation. On the other hand, loads from stormwater runoff were similar or increased from the early 1970s to the mid-1990s. Hence, stormwater runoff's proportion of the combined load increased from 5%, or less, to the majority of most trace metal emissions. In fact, the only constituents that have been substantially reduced in runoff discharges over time have been those targeted for source reduction by programs other than stormwater agencies, including lead and total DDT.

Table 4. Comparison of the combined mass emissions from publicly owned treatment works (POTWs) and stormwater runoff from 1971-72 to 1995-96 to the southern California Bight. mt = metric tons; kg = kilograms; L = liters

		Early 1970s			Mid-1990s		
		Combined	Percent of Load		Combined	Percent of Load	
		Total	Runoff	POTW	Total	Runoff	POTW
Flow	L x 10^9	1,359	5.5	94.5	2,660	35.1	64.9
Susp Solids	mt x 10^3	552	49.6	50.4	340	77.8	22.2
Nitrate	mt	1,510	64.9	35.1	3,137	86.7	13.3
Phosphate	mt	13,710	3.0	97.0	2,310	22.0	78.0
Cadmium	mt	55	2.2	97.8	2	30.0	70.0
Chromium	mt	674	3.7	96.3	20	56.9	43.1
Copper	mt	585	3.1	96.9	96	37.4	62.6
Lead	mt	301	29.9	70.1	17	71.9	28.1
Nickel	mt	330	5.2	94.8	44	26.1	73.9
Zinc	mt	1781	5.7	94.3	263	61.2	38.8
Total DDT	kg	19,119	0.6	99.4	24	87.7	12.3

Part of the reason that stormwater runoff mass emissions might have increased over time is the increased urbanization within coastal watersheds. Water quality datasets in the San Francisco Bay region showed that residential, commercial, and industrial land uses had substantially higher concentrations of cadmium, chromium, copper, lead, and zinc than open land uses. Modeling analysis in southern California demonstrated that highly and moderately developed watersheds contributed disproportionately greater quantities of flow and mass emissions of nutrients (nitrate, nitrite, phosphate, ammonia), trace metals (copper and zinc), and pesticides (diazinon) relative to open land uses.

There were three categories of limitations that hindered our ability to estimate loads in this report. The first type of limitation was the availability of data such as land use, flow, and water quality. This problem was most pronounced along the central/northern coast region of the State. Typically, the most urbanized regions of the State had intergovernmental organizations that have developed land use planning strategies and maps of land use distributions. However, the less-developed regions had exceptionally poor documentation of land use distributions. In a similar regard, Regional Water Quality Control Boards (RWQCBs) in the urbanized areas of the State have issued stormwater NPDES permits for municipal areas, but no such permits have been issued for less urbanized areas. In fact, the implementation of stormwater monitoring programs has generated some large and robust data sets; there are more data in southern California alone than in 30 municipal NPDES monitoring programs nationwide. In central and north coast regions, however, there are no large NPDES stormwater monitoring programs and this region was forced to extrapolate concentrations from southern California and the San Francisco Bay region for every constituent. Flow data were crucial in this project for validating our runoff models. Unfortunately, only 67 of the States' more than 300 watersheds representing approximately 25% of the estimated total runoff volume had flow gaging sites prior to discharging into coastal waters. To make matters worse, many existing flow gages throughout the State have been discontinued rather than repaired, maintained, or upgraded in recent years.

Incomparability of existing monitoring programs, both regionally and statewide, impaired our ability to estimate stormwater runoff loads. We found that the greatest source of variability in load estimates was due to variability in water quality measurements. Part of this variability is likely due to phenomenon such as pollutant build-up and wash-off, but a certain fraction of the variability is due to differences in sampling design and methods. For example, some monitoring programs conduct flow-paced composite sampling, while others conduct time-paced composite sampling, while others conduct individual grab sampling. Studies have shown that these differences can exacerbate variance estimates many-fold (Leecaster *et al.* 2000). A second example of incomparability among programs was the inconsistency in target analytes. For instance, organophosphate pesticides such as diazinon and chlorpyrifos have been shown to cause aquatic toxicity in both urban and agricultural watersheds (Bailey *et al.* 2000), but were rarely measured statewide. In fact, no pesticides or herbicides were measured in common among monitoring programs so that point and non-point sources comparisons could be made. A third example of incomparability among stormwater monitoring programs was detection limits and reporting levels. The effect of reporting levels biased mass emission estimates up to a factor of 100, depending if non-detects were counted as zero, or at the reporting level. After careful examination, we found that non-detects occurred most frequently in monitoring programs with the highest reporting levels. Point sources in central/north coast region were a good example of reporting level bias. These point sources exhibited the highest reporting levels of point sources statewide. The point sources in this region were the smallest contributors statewide when non-detects were set to zero, but became amongst the largest point source contributors when non-detects were set at the reporting level.

The final limitation of our stormwater runoff mass emission estimates was the type of model that was selected. The simple model was the best model based upon the data available, but lacks some of the necessary characteristics that would make it a useful tool for watershed planning and total maximum daily load (TMDL) development. The simple model is static and makes several assumptions negating its use by managers for more detailed examinations. For example, annual load estimates calculated using the simple model were adequate for this study, but managers may need to evaluate loadings and concentrations on smaller time scales such as seasonally, by storm, or within storms. In addition, the simple model assumes that pollutants generated at greater distances inland are transported to the ocean with equal efficiency as pollutants that are generated nearest the coast. We know this is not always the case, particularly for constituents that can degrade or transform such as bacteria or nutrients.

Managers need to be able to assess if large loads result in receiving water impacts. This study demonstrated that mass emissions from stormwater runoff are large and could be considered a potential threat to receiving waters. However, large mass emissions alone do not automatically infer environmental degradation. A second element needs to be considered including concentration of the discharge and the receiving water environmental characteristics. Very little monitoring has been accomplished around the State to assess whether stormwater runoff loads or concentrations result in receiving water impacts. The largest receiving water studies to date have been conducted in Santa Monica Bay (Bay and Schiff 1997) and in Coyote Creek (Pitt *et al.* 1982). Both studies identified impacts to water and sediment quality, as well as aquatic biota. While no stormwater agencies have integrated receiving water monitoring programs, several have begun toxicity testing as part of their effluent characterization studies to begin addressing these questions. In particular, toxicity identification evaluations that help to identify a constituent of concern have helped to focus management actions. Assessing receiving water impacts helps both regulators and dischargers justify a need to take management action and provide benchmarks for improvements once actions have been taken.

While receiving water data were not available for this study, the concentrations of fecal indicator bacteria (e.g. total and fecal coliforms, enterococcus) in wet weather discharges were uniformly high and frequently exceeded shoreline water quality thresholds. The most bacteria monitoring data were generated in southern California where over 90% of all samples, including more than 63% of the open land uses, exceeded thresholds adopted by the State Department of Health Services (Health and Safety Code §115880 [Assembly Bill 411, Statutes of 1997, Chapter 765]). The prevalence of fecal indicator bacteria in stormwater runoff discharges is not a new phenomenon and has been observed regionally in southern California (Schiff 1997) and nationally (US EPA 1983). Moreover, the beach water quality by storm drains exceeds AB 411 thresholds up to 60% of the time during dry weather, which is an order of magnitude more frequently than beaches distant from storm drains (Noble *et al.* 2000). Epidemiological studies in Santa Monica Bay during the summer demonstrated that swimming-related illnesses increase next to storm drains compared to swimmers at distances of 400 yds (Haile *et al.* 1999). However, the health risk of swimming due to wet weather discharges is unknown.

V. CONCLUSIONS ABOUT MASS EMISSION ESTIMATES

- *Stormwater runoff is a large pathway of potential pollutants to the coastal waters of the State*

  Stormwater runoff discharges comprised the majority of the pollutant load to the coastal waters of the State. Stormwater runoff contributed over 90% of the nitrate, cadmium, and lead relative to other point sources. Stormwater runoff also contributed the majority of the cumulative load for suspended solids and four other trace metals including chromium, copper, nickel, and zinc. There were insufficient data from all sources to compare loads for additional nutrients or organic constituents such as pesticides, herbicides, and petroleum hydrocarbons.

- *Modeled stormwater runoff mass emission estimates are uncertain due to the tremendous natural variability inherent to rainfall and water quality*

  Differences in water quality and rainfall can alter our modeled estimates of stormwater runoff mass emissions by more than 600%, depending upon the constituents. It appears that variability in water quality is more significant than variability in rainfall. There are several factors that contribute to the variability in water quality including pollutant build-up and wash-off, as well as dramatic differences in sampling and analysis among the numerous stormwater monitoring programs around the State.

- *Although combined mass emission estimates have decreased over the last 25 years from southern California, stormwater runoff mass emission estimates have remained the same or increased. No long-term trend information exists for other regions of the State.*

Combined mass emission estimates to coastal waters in the mid-1990s are significantly lower compared to the early 1970s. For example, trace metal mass emissions to the southern California Bight have decreased by more than 90% and mass emissions of many pesticides have decreased by more than 99%. This reduction has been primarily the result of POTWs who have implemented strict management actions such as increased treatment, pretreatment, source control and reclamation. Runoff emissions on the other hand, have remained similar or increased over this same time period. The only significant reductions observed in stormwater emissions were for lead, total DDT and total PCB, all of which were controlled by mechanisms other than stormwater management actions. The result has been that stormwater runoff has become a proportionally larger contributor as POTW emissions have been reduced.

- *Our estimates of mass emissions from stormwater runoff, particularly for the North and Central Coastal Regions, are hindered by lack of data*

Lack of data, particularly in the central and northern coastal regions, severely hindered our ability to estimate mass emissions. We chose a model to estimate stormwater runoff mass emissions statewide because there are so few monitoring sites at the mouths of major watersheds statewide. However, finding reliable data to run the model was also difficult and extrapolations from southern California or San Francisco Bay were required for the central and north coasts. The missing data fell into three categories; flow data, land use data, and water quality data.

- *Bacteria densities in wet weather runoff were uniformly high regardless of land use or watershed type*

Bacterial measurements were uniformly high with 90% of the samples exceeding water quality thresholds established by the State Department of Health Services. Although stormwater monitoring agencies are not responsible for monitoring beaches and do not make beach closure or posting decisions, other investigators have found that beach water quality is significantly worse near storm drains throughout southern California (Noble *et al.* 2000). An epidemiological study in Santa Monica Bay found an increased incidence of illness in swimmers that swam near storm drains during the summer (Haile *et al.* 1999). However, the health risk of swimming near wet weather discharges is unknown.

VI. RECOMMENDATIONS FOR ESTIMATING LOADS AND STORMWATER RUNOFF MONITORING

There are 14 recommendations that have been grouped into three general concepts. The first group of recommendations addresses how to fill data gaps identified in this report. The goal of this subsection is to identify additional data sets that need to be collected if the objective were to repeat this project using the same approach and technique in the future. The second group of recommendations addresses how to improve runoff load estimates beyond what was attempted in this report. We identified several limitations in this study that managers may want to overcome in future efforts. Hence, the recommendations in this subsection focus on new approaches and techniques for advancing stormwater runoff mass emission estimates. The third group of recommendations focuses on how to improve stormwater monitoring for managers to fully utilize mass emission information. Although the recommendations in this subsection were beyond the scope of this project, the goal is to provide the tools stormwater managers need to improve assessments of emissions and impacts, then communicate these results when evaluating stormwater discharges. Implementation of the recommendations in this section should be coordinated with the appropriate managers and stakeholders to ensure that the endproducts are purposeful, useful, and ultimately successful in improving the results of watershed management.

Each of the recommendations are presented in terms of projects that can be selected, designed, and implemented as needs in stormwater runoff management are prioritized and resources allocated. The format of each recommendation first introduces the need for that project, provides example projects where available, then provides a preliminary cost estimate and budget rationale. Each recommendation is costed separately, but it is important to note that substantial cost savings can be realized if multiple recommendations are funded and implemented simultaneously; many of the recommendations follow a logical sequence building upon the previous study.

Recommendations to Fill Data Gaps Identified in this Report

- *A large body of regional water quality data needs to be collected from northern and central California coastal watersheds before reliable estimates of mass emissions from these regions can be made.*

  Land use information, water flow and associated water quality data were essentially non-existent from northern and central California coastal watersheds. This was particularly disconcerting because the large watersheds and coastal agricultural areas in these portions of the state represent two/thirds of California's coastline. Although large regional differences in land use and stormwater runoff from northern and central

California coastal watersheds exist, modeled stormwater mass emission estimates were based on data from southern California and San Francisco Bay. Effort must be dedicated toward developing a regional database for northern and central California for reliable mass emission estimates. This effort needs to include improved and consistent measures of stormwater flow, water quality concentrations, and land use information.

The cost estimate for developing and implementing a stormwater monitoring program for the central and north coasts of California is $3,000,000 the first year and $1,500,000 annually thereafter. This cost estimate is based upon existing costs for monitoring programs in southern California. Of the four Phase 1 Municipal NPDES Stormwater Monitoring Programs along the southern California coastline, monitoring and reporting costs range from $250,000 to $750,000 per year. The cost estimate for this recommendation assumes a median cost of $500,000 and that an equivalent of three such programs (ca. 30 sites total) would need to be implemented. First year costs of double the ongoing annual cost estimate are provided to account for capital expenditures, site selection, and installation.

- *Monitor a variety of agricultural land use sites to assess representative runoff concentrations statewide*

We used water quality results from categories of land uses (i.e. residential, industrial, and commercial) for modeling runoff mass emissions. One land use that was noticeably undersampled was agricultural land uses. For example, there were more than 300 station events at 25 residential land use sites throughout the State, but only 12 station events at two agricultural land use sites statewide. The loading of certain constituents, including several pesticides, was disproportionately large from agricultural land use relative to the other land uses modeled. A large variety of agricultural activities occur in coastal watersheds statewide and the monitoring data we compiled were not adequately representative. Different types of crops will apply varying quantities and types of nutrient amendments, pesticides, or herbicides. A project needs to be conducted that will monitor different agricultural activities throughout the state to obtain representative constituent concentrations from this land use. These data can be used to evaluate the potential risk from this land use relative to other land uses, prioritize particular crops or agricultural activities that contribute most to mass emissions, and evaluate the effect of various best management practices.

The estimated cost for conducting agricultural land use monitoring statewide is $4,000,000. This cost estimate assumes that five different crops in each of the six coastal RWQCBs will need to be monitored. Each crop will require at least three replicates and should be sampled for at least three storms. The cost to collect each sample was assumed to be $3,000 and the laboratory analytical costs for each sample was assumed to be $4,000.

- *Monitor for organophosphate pesticides*

  Organophosphate pesticides (OP pesticides) have recently been identified as pollutants of concern in urban and agricultural watersheds throughout the State. OP pesticides have been positively identified as the constituent that caused aquatic toxicity in seven of the nine RWQCB jurisdictions (deVlaming *et al.* 2000, deVlaming *personal communication*). OP pesticides include constituents such as diazinon and chlorpyrifos. Over 2.2 million pounds of diazinon and 1.6 million pounds of chlorpyrifos are sold annually statewide (deVlaming *et al.* 2000), but are not routinely monitored in stormwater runoff. In addition, when these constituents were monitored, the methods used for analysis were not sensitive enough to detect concentrations that could result in aquatic toxicity and potential receiving water impairments. A special study needs to be conducted that will sample a variety of land uses and the mouths of several watersheds to assess what the extent of OP pesticide contributions are statewide. Measuring the concentrations of OP pesticides in runoff from different land uses will enable better modeling of these constituents and measurements from large watershed will facilitate validation of the OP mass emission model. The survey should use detection limits of sufficient sensitivity that concentrations at biologically relevant levels can be quantified.

  The estimated cost of monitoring OP pesticides statewide is approximately $1,700,000. This cost estimate assumes that 60 sites would be sampled by existing monitoring programs and split samples could be obtained at no extra cost. It also assumes that 30 additional sites would need to identified and sampled at a cost of $3,000 per sample. The final assumption is that 10 samples for each of the 90 sites at a laboratory cost of $400 per sample would need to be collected.

- *Install additional flow gages at the mouths of coastal watersheds*

  Flow gages, particularly on large rivers and creeks, provide crucial information for runoff management. Most gages are installed for flood management and water supply, but flow measurements are also crucial for water quality management. In this report, we utilized data from flow gages to calibrate and validate our runoff model by comparing measured to modeled volumes. Unfortunately, there were only 67 watersheds with gages located at their mouth representing less than 25% of the volume entering coastal waters statewide. Since volumes from coastal watersheds exceed all other coastal point sources by more than a factor of two, managers need to accurately determine runoff volumes to assess changes in mass emissions. This will be particularly true as new development occurs in undeveloped watersheds and runoff volumes increase due to increased imperviousness, or alternatively, in developed watersheds where stricter controls are being implemented (i.e. numeric sizing criteria or SUSMPs) and reduction in loads or volumes are expected.

The estimated cost of installing and maintaining additional flow gages would be $3,000,000 the first year with an ongoing annual budget of $500,000 for operation and maintenance (O&M). This cost estimate assumes that an additional 28 gages are needed statewide. Initial year costs were assumed to be $75,000 per site and O&M would cost $15,000 per year per site based on discussions with the US Geological Survey. Site selection would require an additional $100,000 as a one-time cost.

- *Determine the contributions from other potentially large sources whose pollutant loads are unknown. Atmospheric deposition is one such source.*

  One finding from this study was that stormwater runoff and POTWs are the greatest contributors of pollutants to the coastal oceans of the six sources we surveyed. This finding is apparent only because these sources have existing monitoring programs to assess their inputs. We recommend that additional studies be conducted that will assess inputs from unmonitored sources, which may contribute large quantities of potential pollutants. In southern California and San Francisco Bay, atmospheric deposition is a potentially large, unmonitored source because it falls between the jurisdictions of the Regional Water Quality Control Boards and the Air Quality Management Districts (AQMD). The mission of the AQMD is to protect human health (primarily from inhalation) and therefore focuses on air concentrations. Atmospheric deposition, which is the mechanism that impacts aquatic ecosystem health, is not routinely monitored and special studies are few. Pilot studies in Los Angeles and San Francisco have shown that atmospheric deposition potentially contributes significant fractions of trace metal and organic pollutants to receiving waters. Moreover, atmospheric deposition does not just deposit directly onto water surfaces. Atmospheric deposition also collects on urban surfaces and is washed off during subsequent rain events and could be a significant fraction of stormwater runoff loads.

  The estimated cost for instituting an atmospheric deposition program would be $1,500,000. This cost estimate is based upon the Santa Monica Bay and San Francisco Bay atmospheric deposition pilot studies. Each of these projects cost approximately $250,000. The cost estimate assumes a pilot study of comparable magnitude will be initiated in each of the six coastal RWQCBs jurisdictions.

- *Develop minimum standards for detection limits statewide. Consistently low detection limits for trace elements and organic compounds are technically feasible and should be achieved during periodic surveys.*

  A data gap identified in all three regions of the state was the bias introduced by varying detection limits. In southern California, increasingly higher detection limits were correlated with an increasing frequency of non-detectable samples (NDs). Depending upon how NDs were mathematically treated, mass emission estimates varied by orders of magnitude for many constituents. For example, the highest detection limits were found in the central and north coast regions. The bias of how NDs are mathematically treated switches the central and north coast POTWs from the smallest to largest contributors of many pollutants.

In an effort to eliminate bias introduced through estimating low-level chemical concentrations, a concerted effort needs to be dedicated toward improving analytical capabilities of participating laboratories. Minimum standards for detection limits should be established for all NPDES permits (POTW and stormwater programs) to allow for statewide consistency in data reporting when data is used for mass emission calculations. Minimum detection limit standards should occur during periodic surveys where chemical concentrations regularly fall below detectable levels. Current analytical methods are available for meeting this need and only require implementation at participating facilities on a non-routine basis and participation in a suitable quality assurance (QA) program.

The cost estimate for developing standardized detection limits statewide is $750,000 the first year and $100,000 each year thereafter on an ongoing basis. This cost estimate assumes that the first year will require data review to establish minimum analytical requirements needed to detect individual chemicals of concern and develop an implementation program. Ongoing work will require oversight of participating laboratories, continuing QA, and data reporting.

Recommendations to Improve Load Estimates

- *Create a statewide watershed classification system*

  Stormwater monitoring is technically challenging and costly; this is why so few watersheds are monitored within the State. Consequently, a pragmatic approach to stormwater evaluation is to gather information from carefully selected watersheds that are representative of other watersheds, and extrapolate measurements from monitored watersheds to unmonitored watersheds. Watersheds can be classified into similar groups based upon key attributes level of development, land use distribution, precipitation, geology, and others. We recommend that a classification system be developed to incorporate these, and other important factors, into a statewide classification system. This classification scheme could be utilized in a variety of applications. For example, TMDL approaches and tools that are developed from one watershed type may be extrapolated to another watershed, if the watershed properties were similar. The classification system should be used for selecting representative observation watersheds for detailed, long-term evaluation (see next recommendation).

The cost estimate for establishing a statewide watershed classification system is $12,000,000. This estimate is based upon initial scoping assessments of $4,000,000 in the San Francisco Bay region that includes a component for geographical information system (GIS) coverages. It was assumed that additional coastal watersheds could be gathered at triple the cost, albeit GIS coverages would likely be less complete.

- *Establish a Statewide network of observation watersheds for intensive study and monitoring of long-term trends in stormwater emissions*

We recommend that long-term studies be conducted in a number of observation watersheds that represent different urban landscapes, different hydrological, climatological, and geological types. These observation watersheds can be testing grounds for development of improved monitoring and modeling techniques. They can also be a testing ground for management actions and strategies to detect the effect of management actions on long-term trends in loads. For example, several of the recommendations provided in this report (i.e. additional data collection, advanced modeling, efficiency and effectiveness studies, receving water monitoring, etc.) could be accomplished within the observation watershed and the results could be extrapolated to similar, but less-intensively monitored watersheds.

Long-term monitoring in nine watersheds around the State would cost an estimated $1,000,000 per year with an additional $200,000 the first year. This cost assumes that the ongoing monitoring at the mouth and selected locations within the watershed would cost approximately $110,000 per year per watershed. This cost includes sampling and laboratory analysis based on estimated monitoring program costs in the San Francisco Bay region. The additional first year costs would include resources necessary for monitoring design, site selection, and equipment installation.

- *Evaluate more complex watershed models that integrate pollutant fate and transport processes. These may be especially useful for TMDL development.*

We recommend that more complex watershed models be evaluated that incorporate fate and transport processes within the watershed. These models are more complex, but account for hydrodynamic processes, as well as water quality dynamics including pollutant transformations, degradation rates, deposition, and sequestering. The disadvantage of applying these models is the large amount of data necessary to generate reliable results. The advantages include their vastly improved predictive capability. The simple models such as the one used in this study can generate load estimates, but altering model parameters to predict future management actions is the fundamental feature that will enable many managers to improve TMDLs. Rerunning the predictive model with an array of management actions will help regulators and stakeholders evaluate which actions have the most potential for effectively reducing loads and/or concentrations.

The study does not require creating a complex model. Existing complex watershed models, such as SWMM, HSPF, and others were developed and have been applied predominantly in the eastern U.S. by the USEPA. These models have not been used extensively in California, and their predictive capabilities have not been rigorously validated. It is imperative that these models be evaluated in our environments where flows are not uniform and many streams are effluent dominated waterways. It is possible that these previously developed models could be modified for our unique water quality situations. However, the model modifications, calibrations, and verifications need to occur before management can use them with confidence.

The evaluation and implementation of more complex models would cost an estimated $3,000,000. This cost assumes that the development of one model would cost approximately $750,000 per watershed based upon upcoming studies on the Los Angeles River. At least four watersheds should be targeted around the State.

- *Conduct the necessary studies to improve the effectiveness and cost-efficiency of current stormwater runoff monitoring programs.*

Stormwater monitoring programs throughout the State were designed independently and comparability among programs is lacking. Part of the problem is that many programs are relatively new and have typically focused on characterizing stormwater discharges. However, there has been very little attempt to critically determine what the most effective and cost-efficient monitoring program ought to be. We recommend a study be initiated that assesses what the optimum monitoring design should be for answering specific management questions.

An example of this type of study has been conducted on the Santa Ana River watershed (Tiefenthaler *et al.* 2000, Leecaster *et al.* 2000). Near-continuous monitoring of flow and water quality was conducted for an entire water year. Then the appropriate statistical analysis was applied to determine what the optimum within storm sampling frequency, timing and number of storm events, and data analysis were to critically address management questions with specified levels of confidence and certainty. The results identified that the confidence and bias in mass emission estimates and power to detect trends could be vastly improved over current designs with minimumal effort. Unfortunately, the results from this study have not been tested in any other watershed within the state. We recommend that a similar study be conducted in different watersheds to improve the monitoring designs of current programs. This becomes particularly important as many agencies (municipal, industrial, and construction) renew or receive new NPDES permits for stormwater discharges.

The cost of implementing a study to assess the effectiveness and efficiency of stormwater runoff monitoring would be $1,000,000. This cost estimate assumes that four watersheds around the state would be targeted at a cost of $250,000 per watershed based upon the Santa Ana River project. The Santa Ana River Study focused on suspended solids. Incremental cost increases can be added for additional constituents or constituent classes.

Recommendations to Improve Stormwater Monitoring for Managers to Fully Utilize Load Information

- *Form regional stormwater monitoring networks to increase comparability among monitoring programs, pool resources to address common needs, and effectively share information.*

  Many of the issues that face stormwater agencies and regulators are not watershed specific, but are regional in nature. Several of the recommendations in this report are good examples (e.g. monitoring for OP pesticides, tool development, and improving monitoring program effectiveness and efficiency). One mechanism to address these large-scale issues is to form regional stormwater monitoring networks. These networks can serve several roles including addressing regional research issues in a cost-effective manner by enhancing cost-sharing, information exchange, and shared management activities such as public education. We recommend the formation of regional monitoring networks around the state. The SWRCB should support and encourage these networks to assist in regional comparability and cost-effectiveness.

  Two stormwater agency networks currently exist within the State. The first is the State Stormwater Quality Task Force, which is an excellent vehicle for addressing statewide issues and focuses on policy matters. The second is the Bay Area Stormwater Management Agency Association (BASMAA). The BASMAA represents an example that ought to be duplicated in different regions throughout the state. This association of stormwater managers, which is attended by permittees and regulators, represents a forum that provides positive dialogue unlike any in the nation. Collectively, BASMAA has been able to move individual monitoring programs forward, redirected existing effort to address regional concerns, and developed management actions that can be shared by all.

  The cost of supporting four stormwater networks around the State would be approximately $800,000 per year. This cost estimates assumes that each monitoring network would require $200,000 per year based upon current operating budgets for BASMAA.

- *Conduct receiving water studies that link stormwater discharges and beneficial use impacts*

  Mass emission estimates are only a tool to identify potential risk to aquatic habitats. We identified that stormwater mass emissions were reasonably large from coastal watersheds. We recommend that studies be conducted in sensitive receiving water bodies to assess if stormwater discharges are resulting in beneficial use impairments. Only ambient monitoring will be able to tell managers if the potential risk is resulting in real water quality impacts. The advantages to this study are four-fold. First and foremost, documenting receiving water impairments will provide managers and regulators the justification they need to take further actions in reducing loads. Second, the extent and magnitude of the impact will guide the level of response necessary to correct the discharge. Third, if the receiving water study is designed appropriately, it will help to identify the cause of impact. Finally, receiving water monitoring will provide managers and regulators the information they need to assess if the management actions they take are effective at improving or restoring the beneficial use. Receiving water studies conducted to date have found habitat and ecological impacts including chemical contamination in water column and sediment samples, aquatic toxicity, benthic community alterations, and bioaccumulation resulting from storm drain discharges.

  The cost estimate for conducting receiving water studies that link stormwater discharges with receiving water impacts would be $3,000,000. This cost estimate assumes that four receiving water bodies would be studied at a cost of $750,000 each based upon similar studies in Santa Monica Bay.

- *Refine current tools that assess anthropogenic versus natural loads in stormwater discharges*

  Direct comparisons of stormwater and point sources provide managers incomplete information since the types of discharges are so different. For example, trace metals from POTW discharges are almost exclusively from human contributions while trace metals in stormwater runoff are a combination of natural and anthropogenic contributions. We recommend that a study be conducted to refine a tool(s) that will assess what fraction of stormwater is natural versus what fraction is anthropogenic. This is particularly important as TMDLs for trace metal become more prominent; there are more than 170 waterbodies on the State's 303(d) for trace metals. This tool will enable stormwater managers, regulators, and stakeholders to distill some variability out of the current mass emission estimates, improve their ability to assess BMPs, and enable realistic target reduction goals as TMDLs are developed and implemented.

Scientists have begun developing these tools and they need refining and validation to make them useful for regulators and management. Two approaches are currently being pursued in different parts of the State. In the San Francisco Bay region, scientists are evaluating techniques that target the fine-grained fraction of solids that are discharged; trace metals are more prominent in silt- and clay-sized particles than coarser-grained sand. In the southern California region, scientists are using conservative elements, such as iron, to quantitatively determine the anthropogenic and natural fractions.

The cost estimate for developing a tool to assess natural versus anthropogenic fractions of trace metals in stormwater discharges would be $1,000,000. This cost estimate assumes that the desired tool would need to be developed and refined in four regions around the state at a cost of $250,000 per region based upon a similar study conducted in southern California.

- *Refine current tools that assess the biological impacts in receiving waters near stormwater discharges.*

One tool that monitoring agencies and regulators desperately need is a way to assess if stormwater discharges are impacting aquatic biota in receiving waters. Unfortunately, very little effort has been expended on receiving water monitoring and the science to make these assessments is still in its infancy. We recommend that a study be conducted that will refine tools that help managers make assessments of biological integrity.

There are two approaches that attempting to develop these tools to assess biological integrity. The first focuses on marine habitat and is located in southern California. The benthic response index, jointly developed by regulators and dischargers, has been an extremely useful in determining how much area near deepwater ocean outfalls are impacted by POTW discharges. The second effort focuses on freshwater habitat and has been most active in northern California. The index of biological integrity has been successfully applied in Ohio to show improvements in receiving waters after reducing combined sewer overflows. Both approaches need to be refined and validated near storm drains before management can use them with confidence.

The cost estimate for developing a tool to assess biological impacts would be $1,800,000. This estimate assumes that half of the project cost will be sample collection and processing and at least 150 samples within each of the six coastal RWQCB jurisdictions will be necessary. Individual sample collection and processing costs are approximately $1,000 per sample based on estimates from the California Department of Fish and Game.

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APPENDIX A

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/335_AppendixA.pdf

APPENDIX A1

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/335_AppendixA1ofAppendixA.pdf

APPENDIX B

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APPENDIX C

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