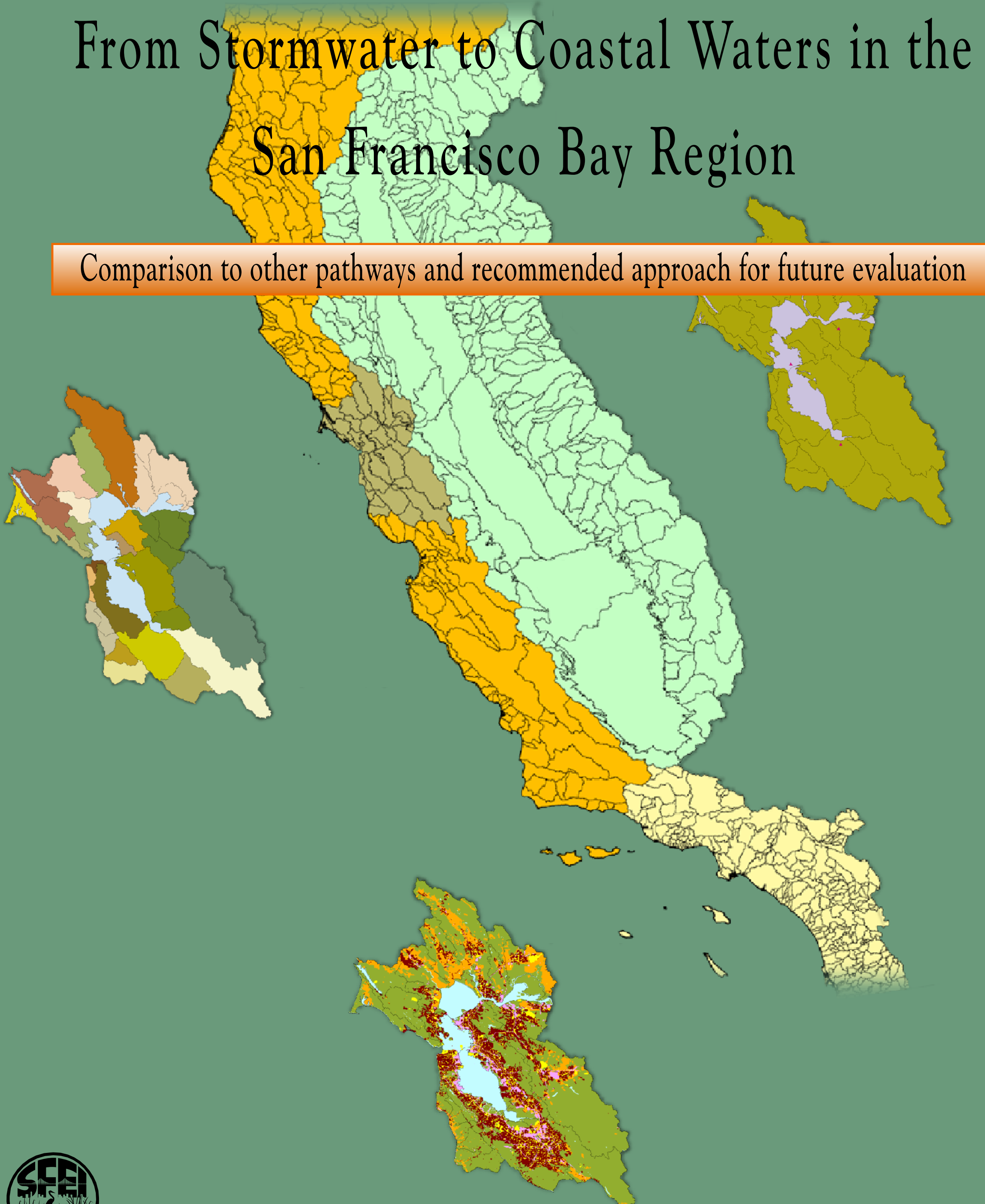
CONTAMINANT LOADS

From Stormwater to Coastal Waters in the San Francisco Bay Region

Comparison to other pathways and recommended approach for future evaluation



Published by the San Francisco Estuary Institute, September 2000

AUTHORS

J.A. Davis, L.J. McKee, J.E. Leatherbarrow, and T.H. Daum

San Francisco Estuary Institute

September 2000

TABLE OF CONTENTS

ACKNOWLEDGMENTS

The Sources, Pathways, and Loadings Workgroup of the Regional Monitoring Program for Trace Substances in the San Francisco Estuary provided oversight for this project and generated some of the ideas presented in this report. Members of the Workgroup that participated in discussion and review of this report included: Don Yee, Rainer Hoenicke, Bruce Thompson, and Pam Tsai, SFEI; Tom Mumley and Fred Hetzel, San Francisco Bay Regional Water Quality Control Board; Jim Kuwabara, U.S. Geological Survey, Trish Mulvey; Andy Gunther, Applied Marine Sciences; Jim McGrath, Port of Oakland; Terry Cooke and Peter Mangarella, URS Corporation; Geoff Brosseau, Bay Area Stormwater Management Agencies Association, and Dan Cloak, Santa Clara Valley Urban Runoff Pollution Prevention Program.

Cristina Grosso and Zoltan Der of SFEI prepared the GIS-based figures.

Tom Dunne of U.C. Santa Barbara provided particularly valuable comments on a draft of the report.

I. INTRODUCTION

The California Legislature, through Assembly Bill 1429, mandated that action be taken to address gaps in knowledge of contaminant discharge to California's coastal waters. The Coastal Watershed Loading Project provides the framework for this effort. SFEI, the Southern California Coastal Water Research Project (SCCWRP), and the California State University Moss Landing Marine Laboratories (MLML) were directed by the legislation to collaborate and produce the following products for the State Water Resources Control Board (SWRCB):

1) To the extent possible, an estimate of the total discharge of pollutants from state coastal watersheds to bays, estuaries, and coastal waters, from all sources;
2) The identification of the relative contribution of storm-water to the total discharge of contaminants to coastal waters;
3) A description of methodologies for improved monitoring of the mass discharge of contaminants from storm-water into coastal waters, including the appropriate frequency of monitoring for each pollutant; and
4) An estimate of the costs of implementing such a monitoring program and a proposed schedule of implementation.

The coastal hydrologic regions shown in Figure II-1 defined the geographic scope of this project. The areas of responsibility were as follows: North and Central Coasts – MLML; San Francisco Bay – SFEI; South Coast – SCCWRP. The Central Valley Region also drains to the coast through San Francisco Bay and was included in the analysis for the Bay region. SFEI, MLML, and SCCWRP collaborated to apply uniform methods for estimating contaminant loads throughout coastal California.

Estimation of contaminant loads from stormwater runoff was a particular focus of this project. The estimation of total loads from all sources provides context needed for understanding the significance of stormwater loads. A lack of data presently constrains our ability to accurately estimate stormwater loads. For some regions of coastal California data are almost completely lacking. We selected a simplistic modeling approach with minimal data requirements that could produce estimates that intended to be comparable across all of the coastal regions. There were two principal objectives of performing these calculations. One objective was to develop preliminary estimates that indicate the possible order of magnitude of stormwater loads. Models that account for non-linear hydrological and in-stream contaminant processes supported by more extensive input data would be required to develop more precise estimates with well defined accuracy bounds. The second primary objective was to identify and prioritize gaps in the information needed to estimate stormwater loads.

This report, while following the general format of the reports for the other regions, is tailored to the needs and conventions of the Bay region. One aspect of this is an attempt to focus on contaminants that are currently of high priority in this region. Contaminants currently on the 303(d) list of substances impairing beneficial uses in the Bay include mercury, PCBs, copper, nickel, diazinon, DDT, chlordane, dieldrin, chlorinated dioxins, chlorinated dibenzofurans. Unfortunately, a lack of raw data precludes estimation of regional stormwater loads for many of these substances using the selected modeling approach.

Another regional convention is the use of the term “sources”. “Sources” in this report are defined as activities leading to the release of contaminants into the environment, such as combustion of gasoline in a car engine or application of a pesticide to an agricultural crop. Sources are distinct from “pathways”, which include the routes through which contaminants enter the Bay, such as stormwater runoff, local tributaries, or municipal effluents. Pathways are sometimes misconstrued as sources.

Also unique to this region was the loading of contaminants from another large region: the Central Valley. The drainage basin of the Sacramento and San Joaquin Rivers (referred to as “the rivers” below) comprises about 37% of the land area of California and the Rivers carry between 40 and 50% of the freshwater runoff in the State. These rivers discharge into the Bay region. Since contaminant loads from the Central Valley region are attributable to a similar mixture of sources and pathways as exist for the Bay region, Central Valley loads are considered separately from the loads of regional origin in the Bay Area. Since modeling and cataloging data for the entire Central Valley was beyond the scope of this project, a different approach was taken to estimate loads from this region that employed empirical concentration and flow data.

Another emphasis in this region was developing recommendations for ways of obtaining improved estimates of stormwater mass loads. This was accomplished through literature review and discussions with regional experts on stormwater.

The first sections (II-V) of this report present estimates of contaminant mass loads from each of the major pathways for the Bay region. Methods and results are presented separately for each pathway. This is followed by a comparison of the estimated loads from each pathway in the Bay region (section VI). Loads from the Central Valley region are estimated in section VII. Conclusions from the mass load analysis are presented in section VIII. Section IX presents recommendations for improved approaches to estimating stormwater mass loads in the future.

II. STORMWATER RUNOFF

Description of Pathway

Stormwater runoff is considered to be a potentially significant pathway for the entry of many contaminants to San Francisco Bay, including contaminants of current concern such as PCBs, PAHs, registered pesticides (e.g., diazinon and chlorpyrifos), mercury, copper, and nickel (Davis et al. 2000). For the purposes of this report, stormwater is defined as all water that enters the Bay from local watersheds (defined by the boundary of the study area (Figure II-1)) that results from the residual of incident precipitation and flows through natural, modified or constructed drainage lines. The volume of stormwater was predicted using estimated runoff coefficients from discretized land uses categories, incident rainfall, and the area of each land use. It does not predict the volume of stormwater that flows through an individual drainage line but instead assumes that all such generated stormwater will find its way to San Francisco Bay. At present, contaminant loading from the stormwater pathway is relatively poorly characterized. The lack of information on stormwater loads is partially due to the technical difficulty and expense of measuring the highly variable processes that result in contaminant transport to the Estuary by stormwater, and partially due to a relative lack of attention compared to effluent discharges.

This report describes the application of a simple model to estimate contaminant mass loads from stormwater runoff in the Bay Area. There were two primary objectives of this modeling effort. One objective was to produce order of magnitude estimates of stormwater loads. This information is intended to indicate the importance of managing stormwater mass loads. The second primary objective was to identify and prioritize gaps in the information needed to estimate stormwater loads.

The Model

Stormwater loads were estimated using a simple rainfall/runoff model (Maidment 1993; Gunther, et al. 1987; BCDC 1991). The model hypothesizes, as an approximation of complex reality, a linear relation between actual total stormwater volume, annual rainfall depth, and land use. Further, it hypothesizes, as an approximation of complex reality, a linear relation between load and stormwater volume using an average concentration for each distinct land use type. The model is expressed mathematically as follows:

$$W = \sum_{j=1}^{n} (C_j * r_j * i * A_j) \qquad \text{Equation (1)}$$

W	=	Contaminant load from a hydrologic unit
C	=	Stormwater contaminant concentration for land use *j*
r	=	Runoff coefficient for land use *j*
i	=	Average rainfall for the hydrologic unit
A	=	Area of land use *j* in the hydrologic unit

The advantages of this model for estimating stormwater loads are its minimal data requirements and its ease of implementation. As applied in this study, the model relies on input data that are highly simplified representations of temporally dynamic processes and spatially heterogeneous features. Although runoff coefficients and contaminant concentrations are a function of many complex climatic processes as well as chemical, biological and physical processes on watershed surfaces, here we make the simplifying assumption that runoff and contaminant concentrations are a function of land use only. The estimates presented are therefore only approximate and highly simplified representations of the actual load of each contaminant. They are presented as a first step toward quantifying stormwater loads to the San Francisco Bay region of the California coast.

Input Data and Sensitivity Analysis

<u>Watershed and Water-body Delineations</u>

Data from CALWATER (version 2.0) were used for delineation of the major hydrologic regions and watersheds (WITS 1999). This is a State Water Resources Control Board (SWRCB) watershed delineation with further subdivisions of smaller watershed units, and is the most standardized delineation that is currently available. It is a geographic information system (GIS) database in ARCINFO® format. CALWATER has become the standard watershed definition for a number of local, state and federal agencies, and is used in the CALFED project among others.

A hierarchical set of groupings was used in this project. The hydrologic region is the most general grouping and defines the areas of responsibility for the three collaborating agencies in the project (Figure II-1). The hydrologic area is the most detailed level of delineation overall, but hydrologic sub-areas are defined in certain places with the most detailed delineations (note the Tomales Bay, Fairfield, Concord, and San Mateo Coastal hydrologic areas are divided into sub-areas). The watershed delineations and names for the San Francisco Bay region are shown on Figure II-2. CALWATER is a work in progress, and is currently being updated and refined on a hydrologic area basis. For this analysis the most resolute available CALWATER delineations were utilized.

The CALWATER map is sufficient for developing regional stormwater load estimates. Having consistent resolution throughout the study area would be helpful. The scale of the CALWATER map would be insufficient for study of smaller watersheds.

The project steering committee decided to remove drainage areas greater than 20 mi^2 behind dams from the analysis (Figure II-3). The rationale was that significant retention of particles and chemical transformation will occur in reservoirs, significantly reducing transport to coastal waters. It is acknowledged that arguments can also be made that these areas should be included, as the reservoirs are not perfect traps for contaminants, especially during high flow events that transport large masses of contaminants. A significant amount of land area was excluded from the analysis based on this decision: 180,000 ha, 21% of the total area included in the analysis (855,000 ha). A more rigorous approach could be taken to account for the effect of dams on stormwater loads. For example, design information for each dam could be reviewed to evaluate transport of wash-load during storms of varying magnitude. Detailed evaluation of such data was beyond the scope of this project.

California statewide hydrography data, commonly referred to as the "river reach" dataset, was used to delineate rivers and open freshwater within the study area. This data layer consists of flowing waters (rivers and streams), standing waters (lakes and ponds), and natural and created wetlands (CDFG 1997). For this study only the stream and standing waters data were used; wetland areas were included within the open space land use category. The California Department of Fish and Game (CDFG) dataset was originally published by the United States Geological Survey (USGS) as Digital Line Graph (DLG) files at 1:100,000 scale, and was updated under the auspices of the US EPA to ARCINFO® format.

As with the CALWATER map, the scale of this dataset is sufficient for regional estimates. The level of detail would be insufficient for studies of smaller watersheds. For instance, Wildcat Creek is not included in this layer. Although storm drains are flowing waters and are important conveyances of stormwater runoff, there were no storm drains included in this data layer, and a regional map of storm drain outfalls (and associated catchments) has yet to be created. This is a critical data gap that needs to be addressed for more accurate calculations of contaminant loading to the Bay. An SFEI project that will map storm-drains and their drainage areas in the Bay Area is beginning this summer.

<u>Land Use</u>

Good quality land use data were available for most of the San Francisco Bay region. The 1995 Association of Bay Area Governments (ABAG) land use data set was used for the classifications in this study (ABAG 1995). The general land use map encompassing the study region is shown in Figure II-4. This is the most up to date and accurate land use data available for the Bay Area on a regional scale, and is in ARCINFO® format at 200 meters resolution. There were approximately 160 detailed classifications, which were generalized into five categories: agricultural, commercial, industrial, open, residential, and water (Table II-1). The protocols for generalizing these detailed land uses were developed from the San Francisco Estuary Project land use study (Perkins et al. 1991) and in collaboration with SCCWRP and MLML.

This generalization was done for several reasons, the primary one being that land use-based storm water contamination data are not available at the level of detail which the specific classifications would require, in this or most other areas which have been studied (see NOAA 1987; Gunther et al. 1987; Wong et al. 1997). A watershed, even a very small one, will usually contain multiple specific land uses within a general use. For example, the commercial land use classifications of schools, retail outlets, and hospitals may all be found within a single watershed. Use of these general categories makes it possible to employ data on runoff coefficients and contaminant concentrations from studies throughout the Bay Area and from other regions.

The California Gap Analysis Program (GAP) dataset, which is a detailed atlas of plant communities, vertebrate species, and vertebrate species richness (CDFG 1998), also contains more generalized urban land use classifications, and was used for a small portion of the Pescadero Creek hydrologic area which was not included in the ABAG dataset. The GAP data layer is in ARCINFO® format. The areas not covered by the ABAG data were all classified as open space within the GAP data set, so no detail was lost in the land use classification. Land use percentages, using the ABAG classifications, were generated for each hydrologic area or sub-area. This was accomplished using spatial overlay functionality found in the ARCINFO® GIS, in which the hydrologic units in the CALWATER data layer were overlaid on the ABAG land use data layer. The resulting summary consisted of the area (square meters) and percent area of each land use for each hydrologic area or sub-area (Table II-2). A source of error inherent in this spatial overlay operation was that open waters were defined slightly differently in some areas in the CALWATER data layer than in the ABAG land use data layer. However this discrepancy is insignificant, accounting for less than 0.5 percent of the total hydrologic area and sub-area.

Rainfall

Rainfall is one of the driving variables in stormwater models (EPA 1997; Trommer et al. 1996) although it is usually used in time steps of less than a day. The simple model used here used an annual time step, as explained previously. For the simple annual time step model it was important to select rainfall data that were compiled and generated in a consistent way throughout the study area. The Parameter-elevation Regressions on Independent Slopes Model (PRISM) is the underlying data set from which the rainfall data layer was created (OCS 1999). PRISM is an analytical model that uses rainfall data at specific points and a digital elevation model (DEM) to generate estimates of annual rainfall expressed as isohyets (Figure II-5). PRISM provided good quality data for use in the runoff model: data were available for all of the modeled watersheds and its resolution was adequate to assign an average rainfall for each watershed.

The majority of data used to generate the PRISM isohyets in the San Francisco Bay hydrologic area come from the Cooperative Summary of the Day (Co-op data) monthly average rainfall values (NCDC 1998). We compiled monthly values from Co-op rain gauges that were within the study area for the years 1961 - 1990. For selected areas, First Summary of the Day (FSOD) daily rainfall values (NCDC 1994) were used to characterize individual storms for model calibration.

Since the hydrologic areas all have variable amounts of rainfall, an annual average value for each hydrologic area was determined by calculating the location of the geometric center ("centroid") of each polygon, using ARCINFO®, and using the value of the isohyet where the centroid was located. This approach was selected by the statewide steering committee. A more representative approach would have been to calculate an area-weighted average for each hydrologic area; this approach is recommended for future applications of this type of model. The rain gauges within each hydrologic area were used for that area, and where no Co-op data were available, the nearest gauges were used.

Rainfall in the Bay Area exhibits high inter-annual and spatial variation. Using two hydrologic areas as examples, annual rainfall from 1961-1990 varied between 19 and 35 inches in the Napa River hydrologic area and between 15 and 30 inches in the East Bay Cities hydrologic area (Figure II-6a and b). Rainfall is also highly variable among locations in the Bay Area. Average rainfall in the hydrologic areas ranged from a low of 15 in for Fremont Bayside to 41 in for Tomales Bay (Sub-area 112) (Figure II-5, Table II-3). Up to 60 in of rainfall is estimated by PRISM for some of the highest elevations in the Coast Range however it should be emphasized that these are model predictions that have not been verified by empirical field collected rain gauge data.

The high variability of rainfall necessitates careful consideration of summary data to use in the runoff model. The objective of this modeling effort was to estimate stormwater loads for an average year. Therefore, the annual average rainfall for each hydrologic area for the period 1961 to 1990 (Table II-3) was selected as the best index of rainfall. In addition to the long term average rainfall, the 10^{th} and 90^{th} percentiles of the set of 30 annual average rainfall values for each hydrologic area were used to assess the sensitivity of the runoff model to inter-annual variation in rainfall. Co-op data were used to calculate 10th and 90th percentiles (Table II-3).

The sensitivity of the load estimates to this inter-annual variation in rainfall is shown for each modeled constituent in Tables II-4 to II-13. Total suspended solids (TSS) loads are important because they are an index of potential loads of many contaminants that associate with particles. Estimated TSS loads varied by approximately ± 50% when the 10^{th} and 90^{th} percentile rainfall values from the 30-year period were used instead of the average (Table II-4). The estimates using 10^{th} and 90^{th} percentile rainfall values are indicative of loads during a dry year and a wet year, respectively. Estimates for other contaminants showed a similar magnitude of variation based on the different rainfall values (Tables II-5 to II-13). These calculations indicate that inter-annual variation in rainfall causes loads to vary by approximately ± 50%.

Research in the River Creedy, a temperate watershed in Devon, UK shows an inter-annual variation in sediment transport of 10 times for a 7-year period (Webb and Walling 1982). The minimum sediment transport was 80% less than the mean and the maximum sediment transport was 200% greater than the mean. Given that the coefficient of variation in rainfall for temperate watersheds is typically much less than for Mediterranean climate watersheds such as in the Bay area, the estimates of variation reported in the current work (± 50%) would appear to be a minimum. The cumulative effect of variability and uncertainty in rainfall and the other model parameters is discussed below in the section "Estimated Mass Loads from Stormwater Runoff".

Runoff Coefficients

A runoff coefficient is a simple number that describes a highly variable process: the transfer of rainfall into surface runoff. A runoff coefficient represents the fraction of incident rainfall that flows off of a land surface or through the groundwater systems to the drainage lines of the watershed. Spatial and temporal variability in the properties of the land surface and underlying unsaturated zones, and in rainfall, combine to influence the amount of runoff that occurs. Land surface properties that can influence runoff coefficients include soil characteristics, slope, vegetation, soil saturation, temperature, and the presence of impervious or fractured layers. These properties are heterogeneous across the landscape. Some of these properties also vary considerably over time. In this assessment we have taken a highly simplified approach to capturing this heterogeneity: estimating long term average runoff coefficients for each of the five broad categories of land use.

Rainfall and runoff data from the Wildcat Creek watershed illustrate the variability of runoff coefficients for individual storms (Table II-14). The primary land uses in the Wildcat Creek watershed are open (67%) and residential (26%), with small percentages of commercial (4%) and industrial (2%) use. Observed runoff coefficients for a number of storms in this watershed from 1978 to 1993 varied between 0.18 and 1.00. The average runoff coefficient for the 10 storms was 0.57, but this average value by itself is not a very good descriptor of the observed distribution of runoff coefficients for individual storms.

There is a relative lack of published information that would enable accurate estimation of the appropriate runoff coefficients to use. Further there is a high degree of difficulty associated with the definition of an average year. For example, the upper gauging station in the Napa River watershed was analyzed for its annual variability (Figure II-7). This analysis shows that the annual runoff coefficient for this predominantly rural watershed varies on an annual basis from about 15% to about 70%. These crude estimates are probably an overestimate of runoff coefficients given that the rainfall input was estimated at the same point that discharge was measured. In the absence of a better estimate of rainfall input, these analyses provide an example of the variability of runoff coefficients in relation to annual rainfall rather than the absolute magnitude of the runoff coefficient.

Where possible, total annual runoff coefficients reported from local studies were used to estimate stormwater loads to the Bay. BASMAA (1996), citing Maidment (1993), presented values for residential, commercial, industrial, and open land uses (Table II-15). No published local estimate for agricultural land was available. A value reported by SCCWRP (this report) for Southern California (0.10) was the best available estimate for agricultural land. The use of point estimates of annual average runoff coefficients for broad land use categories is clearly a great oversimplification, and a primary reason that load estimates derived from the simple model are considered to be accurate only within an order of magnitude.

Rainfall and flow data were available for some local watersheds (Wildcat Creek, 11 sub-watersheds in Alameda County, and two sub-watersheds in Contra Costa County) that allowed for comparison of measured runoff with runoff predicted from the model. These data are plotted on linear scales in Figures II-8a, II-8c, and II-8d. The largest empirical dataset was generated for Alameda County. Good agreement between predicted and measured runoff was observed for the Alameda dataset. Linear regression on these untransformed data yielded an R^2 of 0.90, and a regression line with a slope close to 1 and an intercept close to 0. Given the lognormal distribution of the data, a regression on the log-transformed data is more appropriate and also reveals a strong linear relationship (Figure II-8b). Too few data points for a sound statistical analysis are available for Wildcat Creek (Figure II-8c) and Contra Costa County (Figure II-8d). These limited data suggest that the model predictions match the Contra Costa data well, but that the model does not accurately predict runoff from the Wildcat Creek watershed. The reason that the data fit poorly in the Wildcat Creek Watershed is because Wildcat has large areas of vegetated lands and only relatively small areas of impervious surfaces. Open lands and agricultural lands have much lower runoff coefficients than do paved urban surfaces. Furthermore, the runoff coefficients are more variable in open or agricultural lands due to seasonal and inter-annual variations in soil moisture. In contrast, runoff coefficients are more predictable in urban areas and much less variable. In summary, the simple model has failed to predict accurate discharge from areas with high soil permeability and predicted discharge well in highly impervious areas of San Francisco Bay. In follows that estimates of pollutant loads will also be bias in the same manner.

Uncertainty surrounds these estimated average runoff coefficients because of the variability of runoff. This uncertainty is a key contributor to the overall uncertainty in the estimated stormwater loads. The sensitivity of the model to changes in runoff coefficients was assessed by using values representative of the ranges of values reported for each land use (Table II-15) as model input (Tables II-4 to II-13). In general, load estimates were less sensitive to changes in runoff coefficients than to rainfall or concentration.

The TSS load was relatively sensitive to changes in the runoff coefficient for agricultural land (Table II-4), even though only 14% of the region is agricultural land (Table II-2). The best estimate of TSS concentration in agricultural stormwater runoff was high relative to the concentrations for other land use categories. The agricultural TSS concentration, however, is from a different region (southern California) and is based on only 14 station events at two stations. This information suggests that obtaining better information on concentrations in runoff from agricultural lands is a priority. Varying individual runoff coefficients one at a time within the range of values reported in the literature caused estimated total loads to vary from –26% to +53%.

Runoff coefficients, rainfall, and land use data were used to generate estimated flow volumes for each land use within each hydrologic area (Table II-16). These flow data were combined with land use specific concentration data to generate the load estimates.

<u>Contaminant Concentrations</u>

Contaminant concentrations that are characteristic of stormwater runoff from each land use were the final ingredient needed for input to the simple model. The project Steering Committee identified which contaminants to include in the analysis (Table II-17).

Many factors influence the concentration of contaminants in stormwater runoff. Precipitation itself contains a significant quantity of contaminants and in some urban areas and for certain contaminants precipitation may deliver more pollutants than other sources within the watershed (Randall et al. 1981). Contaminants can be stored either temporarily or permanently on the land surfaces or transported, over a relatively short period of time, to the drainage system. These changes in forms or timing are holistically described as transfer functions (Figure II-9).

Many activities can lead to varying degrees of contamination of specific land areas. Some of these sources of contaminants include petroleum hydrocarbons, PAHs, and metals that are emitted, leak, or wear from motor vehicles, fertilizers and pesticides applied to gardens and lawns, pesticides used in structural pest control, animal waste, decaying vegetation, geologic sources in the watershed, industrial chemical use, roof materials, and many others. The distribution of some chemicals such as organophosphate pesticides or PCBs may be dependent on specific use and disposal practices of individual businesses or households, making for a heterogeneous spatial distribution even within a given land use category.

The individual pollutants derived from each source as well as the pollutants derived from rainfall can undergo chemical, physical, or biological transformations at any time as water travels across the watershed surface to the creek or storm drain. An example of a chemical transformation is the oxidation of ammonium to nitrate or the oxidation of organic debris such as animal waste or lawn clippings. Some chemicals adsorb or desorb from particles rapidly and others can be incorporated into organic material and others change from non-volatile to volatile forms. As a result, care must be taken not to assume that pollutants that are in one form in the urban area are in the same form once they arrive in the receiving water body at some later time. It also follows that pollutants that were not bio-available at their source may become bio-available (or vice versa) after transport through the various transfer functions.

Like runoff volumes, rates of contaminant transport off the land surface are highly variable temporally and spatially. They also vary from contaminant to contaminant. Some contaminants, like mercury and PCBs, have a strong tendency to bind or adsorb to soil or sediment particles. Sediment movement therefore governs movement of these particle-associated contaminants. Other contaminants are soluble in water and transported primarily in a dissolved form. Contaminant transport is therefore driven by water and sediment transport, and is at least as variable as these two processes. All of the factors that cause variability in runoff volumes and sediment transport also cause variability in contaminant concentrations in stormwater. A family of curves illustrates several possible trajectories of change in contaminant concentration during the course of a storm (Figure II-10).

Contaminant concentrations can also exhibit longer-term temporal fluctuations. One factor that can cause long-term fluctuations is long-term variation in rainfall. During drought periods urban and even more so rural landscapes build up and store contaminants because there are fewer floods, less intense floods, and floods of less total volume during drought. Subsequently during an average flow year or the period just after the break in the drought, flow-weighted mean concentrations will be higher as this stored material is transported off the landscape. As the storage is depleted concentrations decrease. The stormwater studies in the late 1980s and early 1990s were conducted during a dry period (Figure II-11). The data collection programs in Alameda and Santa Clara counties show a bias towards storm events of equal to or less than a 1:2 year return (Figure II-12a and b). Data collection in Contra Costa County appears to have covered a range of storm events from less than 1:2 year return interval to greater than a 1:25 year return interval (Figure II-12c). A plausible hypothesis is that these dry conditions caused concentrations measured during this period to be higher than they would have been in a period with average rainfall. Available data were reviewed to evaluate this hypothesis (analysis not shown), but were insufficient to either confirm or contradict the existence of a positive bias in the measured concentrations.

Contaminant concentrations can also vary spatially due to many factors. Spatial variation in rainfall is one of these factors. The majority of urban water quality data collected in the San Francisco Bay region has been collected in the low rainfall / runoff areas of the east and south Bay. As discussed above in the context of a persistent drought, drier conditions may 1) increase the annual storage of materials on watershed surfaces and decrease the mass loads entering the receiving water bodies, and 2) result in greater first flush effects and therefore greater flow-weighted mean concentrations. It is therefore possible that data collected in the south and east Bay may not be suitable for extrapolation to urban and rural areas in other hydrologically contrasting areas of the Bay such as those of the west and north.

In addition to uncertainty due to the variability of contaminant concentrations, chemical analysis introduces variability into measured concentrations. Acceptable amounts of uncertainty associated with individual measurements are in the range of ± 25%. As concentrations being measured approach the detection limits of the method the associated uncertainty increases further. Insensitive analytical methods generate data that are of little use in a mass loading analysis.

As for runoff coefficients, contaminant concentrations are variable in space and in time, and a single average is an imperfect descriptor of the distribution of contaminant concentrations associated with a specific land use. Uncertainty surrounding estimates of average, land use-specific concentrations is a major source of uncertainty in the stormwater loading estimates.

Where possible, concentration data from local studies were used to estimate stormwater loads to the Bay. Total (dissolved plus particulate) concentrations were used in the model. BASMAA (1996) assembled available local concentration data into a coherent database and generated contaminant concentrations for each land use. Two general categories of stations were sampled in the BASMAA studies: land use sites, intended to allow characterization of concentrations for specific land uses, and mass emission sites, intended to allow estimation of mass loads to downstream water bodies. Data from the land use sites were used to generate land use specific concentrations and are summarized in this report. Contaminant concentrations were also measured at many mass emission stations, but these data were not collected for use in estimating land use-specific concentrations, so they are not summarized in Tables II-17 and II-18. Trace organics, including PCBs and the organochlorine pesticides, were measured at mass emission stations only.

Since the concentration data were collected from land use stations that actually represented mixed land uses, multiple linear regression was used to estimate average total concentrations (dissolved + particulate) for each specific land use (BASMAA 1996). Site mean concentration (based on flow-weighted event mean concentrations from individual storms) from approximately 20 land use stations was the dependent variable in the regression; the independent variables were the proportion of total flow contributed by each land use within the watershed. Given this method of generating estimated average concentrations, it was not possible to calculate conventional summary statistics (e.g., standard deviations or percentiles) for concentrations for each land use. The inability to estimate standard deviations for the concentration data interfered with error propagation analysis of the model.

For the most frequently sampled contaminants, approximately 150 station events were collected and the vast majority of results were above detection limits (Table II-17). These data provided a firm basis for quantitative analysis, including multiple regression to estimate land use specific concentrations. BASMAA's (1996) estimated average concentrations for these contaminants are provided in Table II-18, along with concentrations reported from other studies for comparison. Results reported as below detection limits (BDL) were prevalent for mercury and selenium, and BASMAA (1996) did not estimate concentrations for these elements. Data were very sparse or nonexistent for many of the contaminants identified for inclusion in this study. No local data were available for concentrations associated with agricultural land use. Concentrations measured in southern California were the best data available, although even these concentrations were based on relatively few measurements and cannot be considered very precise estimates.

The effect of treatment of BDL results (i.e., whether they were assigned a value of zero, half the detection limit, or the detection limit) on estimated concentrations of mercury and selenium could be investigated by alternately substituting these values in the raw data and then repeating the multiple regression. Results of these analyses are summarized in Table II-19. Treatment of BDL results affected both the number of statistically significant concentrations and the magnitude of the concentrations. The prevalence of BDL values for mercury and selenium introduced a large amount of uncertainty in their estimated concentrations that did not affect the other contaminants that were consistently detected. Consequently, stormwater load estimates were not generated for mercury and selenium and other contaminants with even weaker data (i.e., PCBs, PAHs, organochlorine pesticides, dioxins) in this modeling exercise.

The derivations of the BASMAA concentration data preclude calculation of percentiles and the use of percentiles of the distributions in a sensitivity analysis. As an alternative, the sensitivity of the model to variation in contaminant concentrations was evaluated by using a range of values for each contaminant that spanned one order of magnitude and was centered (on a log scale) around the mean (Tables II-4 to II-13). Given the many sources of variation in mean land use specific concentrations, this was considered a realistic range of values to use.

Loads of many contaminants were relatively sensitive to these ranges of concentrations. Estimated total TSS loads were sensitive to varying concentrations for agricultural land (Table II-4). The upper bound agricultural TSS concentration increased the total load by over two-fold, from 310,000,000 kg to 660,000,000 kg. The uncertainty surrounding the agricultural TSS concentration was described in the previous section. The estimated total TSS load was also sensitive to changes in the TSS concentration for open space. Estimated total loads of many contaminants increased by over 50% when the upper bound concentration for a particular land use was used (Tables II-5 to II-13): for residential, a >50% increase was observed for every metal, BOD, and phosphate; for commercial, lead and zinc; for industrial, cadmium, lead, zinc, and phosphate; for agricultural, TSS, chromium, copper, BOD, and nitrate; and for open, TSS, chromium, nickel, BOD, and phosphate. In summary, the range of input values used for concentrations (varied one at a time) caused total contaminant loads to vary from –36% to +116%.

Estimated Mass Loads from Stormwater Runoff

The "best estimate" total stormwater loads of modeled contaminants are presented in Table II-20. The first thing to note in this Table is that existing data were only sufficient to support estimates of a few contaminants using the selected modeling approach. Loads could not be estimated using this approach for most contaminants of current priority in the region, including mercury, PCBs, selenium, DDT, chlordane, dieldrin, dioxin, and diazinon. Estimates could be generated for these other priority contaminants using other approaches or by extrapolating from existing data in an even more liberal manner than is done in this report. This type of analysis is best done on a case-by-case basis with the support of a detailed literature review, and was beyond the scope of this project. The analysis presented in the draft mercury TMDL for the Bay region is a good example of this type of analysis (SFBRWQCB 2000).

The estimates that are presented in Table II-20 should really be considered ranges, rather than reliable point estimates. Variability and uncertainty limit our ability to describe stormwater loads with point estimates.

Limitations of the input data make it impossible to present a rigorous quantitative analysis of the aggregate uncertainty in the final load estimates. As discussed above, standard errors for the runoff coefficients and concentration data were not available. These standard errors would be needed to conduct an error propagation analysis. Also, more sophisticated methods for calculating errors were not chosen because even these would not determine the true variability. For example, the error propagation associated with addition may be calculated by summing the squares of the individual errors associated with each parameter and taking the square root (McKee and Eyre 2000; Winter 1981):

$$s_x = \sqrt{s_a^2 + s_b^2 + s_c^2 + \ldots}$$

(Equation 2)

For calculation of error propagation during multiplication and division the formula becomes:

$$s_x = x \cdot \sqrt{\left(\frac{s_a}{a}\right)^2 + \left(\frac{s_b}{b}\right)^2 + \left(\frac{s_c}{c}\right)^2 + \ldots}$$

(Equation 3)

The model we used calculates loads for a region as the sum of loads in each hydrologic unit. Loads within each hydrologic unit are the sum of loads from each of the five land use categories within the hydrologic unit. Loads for each land use is the product of rainfall, runoff coefficient, and concentration. A rigorous error propagation analysis would therefore apply equation 4 to the loads for each land use within the hydrologic unit, equation 3 to the sum of the loads from each land use within the hydrologic unit, and equation 3 again to the sum of the loads from all hydrologic units.

Estimates from the simple model suggest that inter-annual variability in rainfall will cause loads in any one year to vary by ± 50%, and actual inter-annual variability in loads due to variation in rainfall is probably far larger than this. Uncertainty and variability associated with individual annual average runoff coefficients caused estimated loads to range from –26% to +53%. Uncertainty and variability associated with individual contaminant concentrations for each land use caused estimated loads to range from –36% to +116%. The combined effect on the regional load estimates of all of this variability and uncertainty in the input data make a point estimate of a long-term average regional load a misleading descriptor for any one year.

Inter-annual variability in pollutant transport is likely to vary from one watershed to another as a function of its physical characteristics. It is hypothesized that the true inter-annual load variability for suspended sediments in some Bay area watersheds is in the vicinity of 1000 times (McKee, unpublished data), however this has yet to be verified. Even the use of these error propagation methods would probably not capture a 1000 times variation.

The objective of the modeling effort was to produce estimates that are accurate to within one order of magnitude. Given this objective, the estimates are presented in Table II-20 as ranges that span one order of magnitude. Confidence intervals reported for stormwater load estimates in other studies employing similar models suggest that the range presented is reasonable (Gunther et al. 1991, Hoos and Lizarraga 1996).

The stormwater load estimates for each hydrologic area indicate which of these areas are likely to exhibit the largest total loads (Table II-21). The largest loads of TSS and many other contaminants were estimated for the Napa River hydrologic area. This was the largest hydrologic area (Figure II-2) and had the highest estimated runoff volume (Table II-16). Other, more urbanized, areas with high estimated runoff volumes, including East Bay Cities, Palo Alto, Alameda Creek, and San Mateo Bayside, also contributed relatively large proportions of the total loads, especially for cadmium, lead, zinc, and the other trace metals. Hydrologic areas with a large percentage of agricultural use (Sonoma Creek, Petaluma River, and Fairfield 220723) had relatively high estimated loads of TSS and nitrate.

Loads from each hydrologic unit can also be expressed on a per hectare basis to indicate places with relatively high potential loading rates (Table II-21b). Hydrologic units with relatively high percentages of agricultural land (i.e., Sonoma Creek, Fairfield 220723, Petaluma River, and San Mateo Coastal 2202223) had the highest estimated loads of TSS and nitrate. The hydrologic units with the highest area-normalized loads of trace metals and phosphate were San Rafael, Berkeley, San Francisco Bayside, and Concord 220734; these units generally have high percentages of commercial and industrial development. Suspended sediment discharge calculated using three years of data collected from many watersheds in California indicated a range from 40 kg/ha/year to 21,000 kg/ha/year (Anderson 1981). Anderson's analysis shows a suspended sediment discharge of 2,150 kg/ha/year for Napa and 1,620 kg/ha/year for Sonoma watersheds. This indicates that the magnitude of sediment loads in Table II-21b may be underestimated by a factor of 3 to 4 times. This illustrates the potential errors associated with using a simple model for calculating stormwater loads especially for particles whose concentrations vary as a complex non-linear function of flow.

Stormwater load estimates indicate the potential for varying contributions from each land use category (Table II-22). Agricultural land is a potentially large contributor of TSS and nitrate. Residential land appears to be a large contributor of all of the metals. In spite of their small contributions to total land area, commercial and industrial area still appear to generate substantial loads of phosphate, cadmium, lead, zinc, and other contaminants. Open space accounts for the largest land area and potentially contributes a relatively large proportion of TSS, BOD, phosphate, chromium, and nickel.

The load estimates generated in this study are in good agreement with regional estimates previously reported for the Bay (Table II-23).

The use of more realistic modeling approaches could generate more accurate estimates of stormwater loads. A major shortcoming of the simple model is its linearity. Research in the U.S. and other parts of the world clearly demonstrate the non-linear processes associated with the transmission of sediments and pollutants from their watershed sources to down stream receiving water bodies during runoff associated with storm events. Typically relationships between mass loads follow a power function when regressed against discharge. Although this relationship usually accounts for >90% of the variation in a single watershed for some pollutants, when comparisons are made among watersheds it becomes clear that other descriptors are important in the transport processes. In the case of suspended sediments, watershed area, topography, and annual rainfall play an important role (e.g., Milliman and Syvitski 1992; Milliman 1995). The simple method employed during the AB1429 study clearly fails to take these accepted hydrological principles into account.

A comparison of sediment discharge for the Guadalupe River watershed, presented in the draft mercury TMDL (SFBRWQCB 2000), found that the simple model predicted much lower sediment discharge than USGS calculations based on flow data and sediment transport curves. As with the Napa and Sonoma comparisons presented before, this comparison also suggests that the simple model estimates presented in this report may be substantially lower than actual loads especially for particle related pollutants.

FIGURE II-1. Delineation of coastal hydrologic regions and hydrologic areas and sub-areas. From WITS (1999). A color version of this figure can be viewed at the SFEI website: www.sfei.org under Contaminant Monitoring and Research.

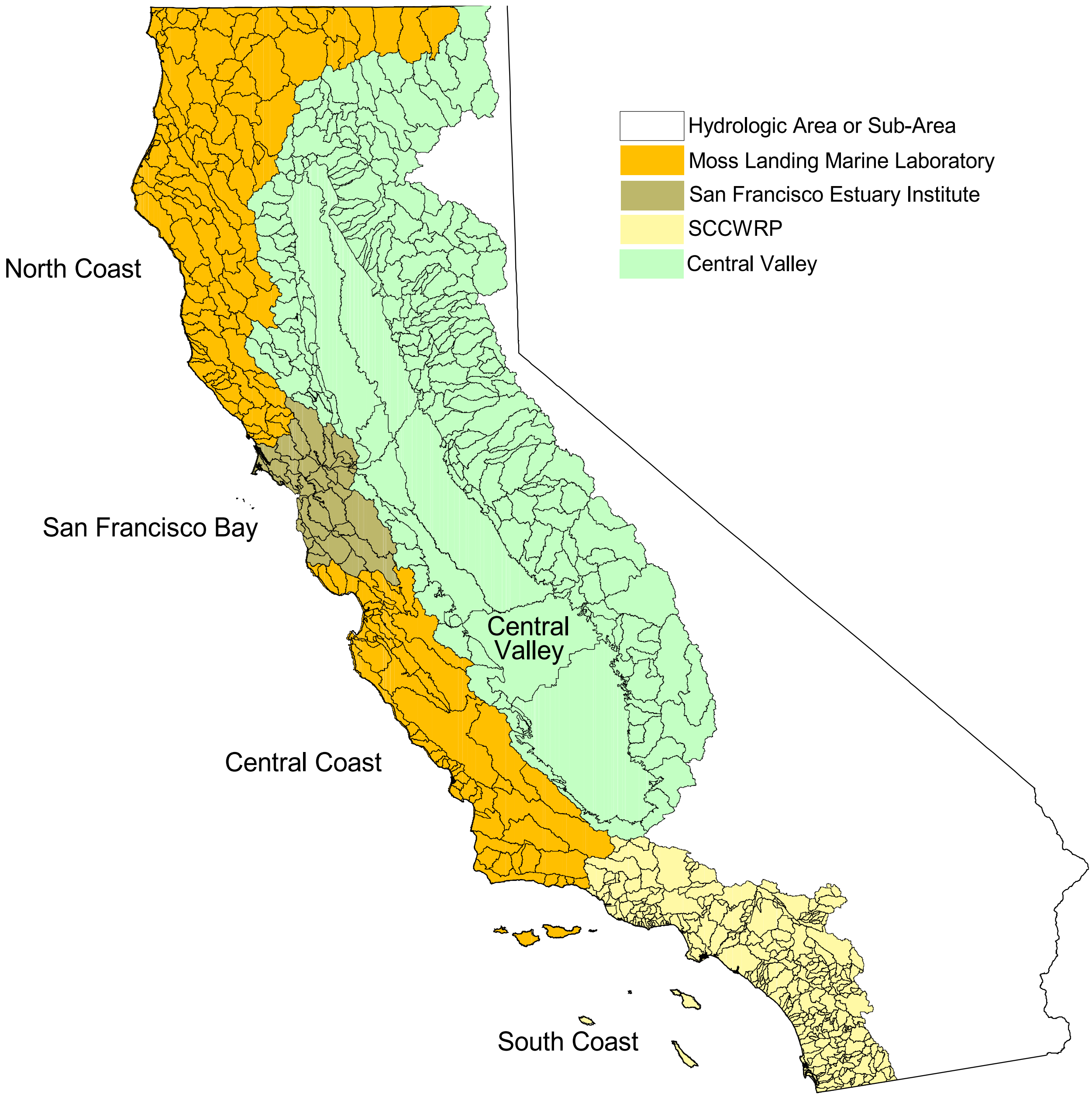


FIGURE II-2. Hydrologic area for the San Francisco Bay region.
A color version of this figure can be viewed at the SFEI website: www.sfei.org under Contaminant Monitoring and Research.

FIGURE II-3. Drainage area greater than 20 mi^2 upstream of dams. These areas were excluded in the load calculations. A color version of this figure can be viewed at the SFEI website: www.sfei.org under Contaminant Monitoring and Research.

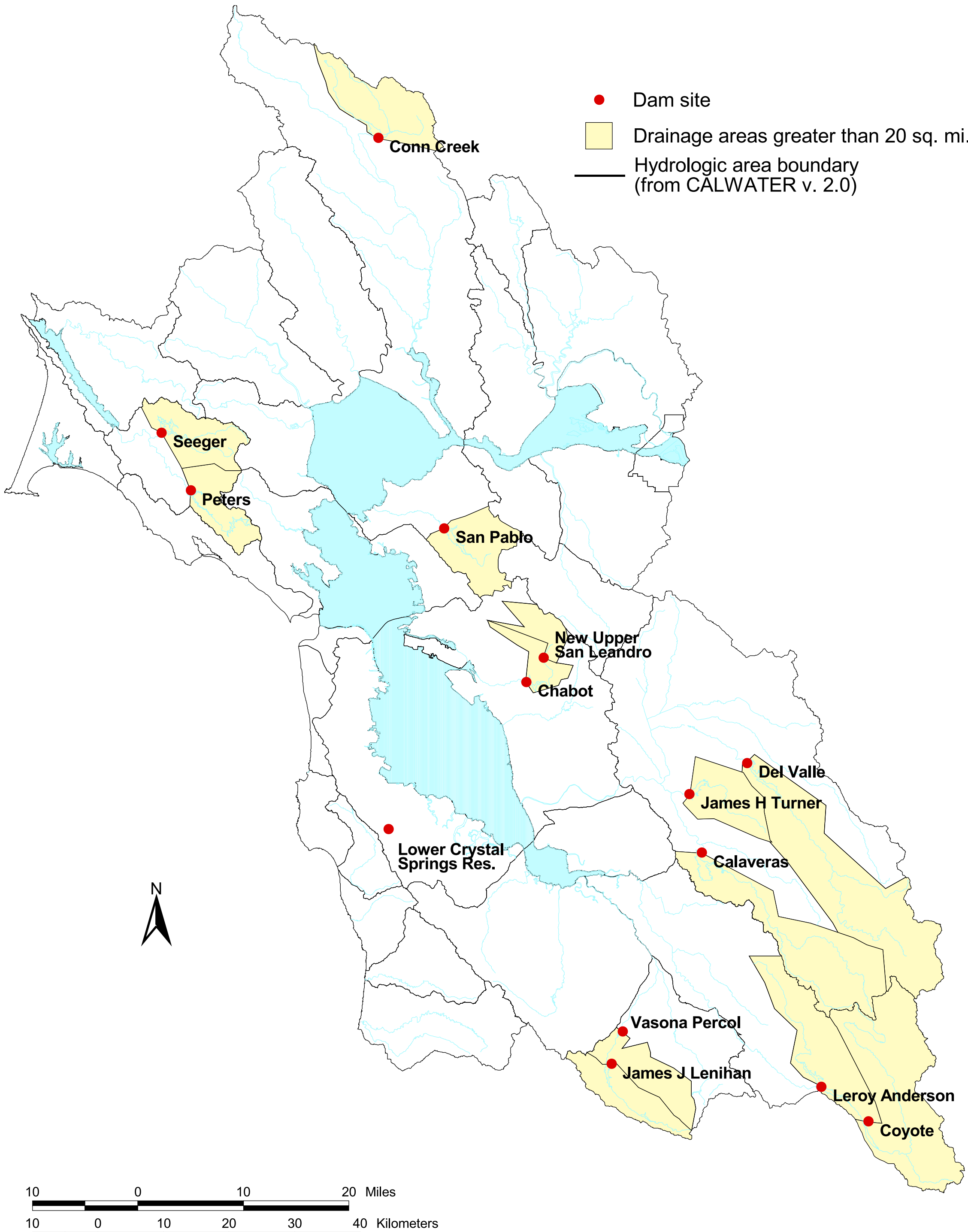


FIGURE II-4. General land use in the Bay Area. From ABAG (1995).
A color version of this figure can be viewed at the SFEI website: www.sfei.org under Contaminant Monitoring and Research.

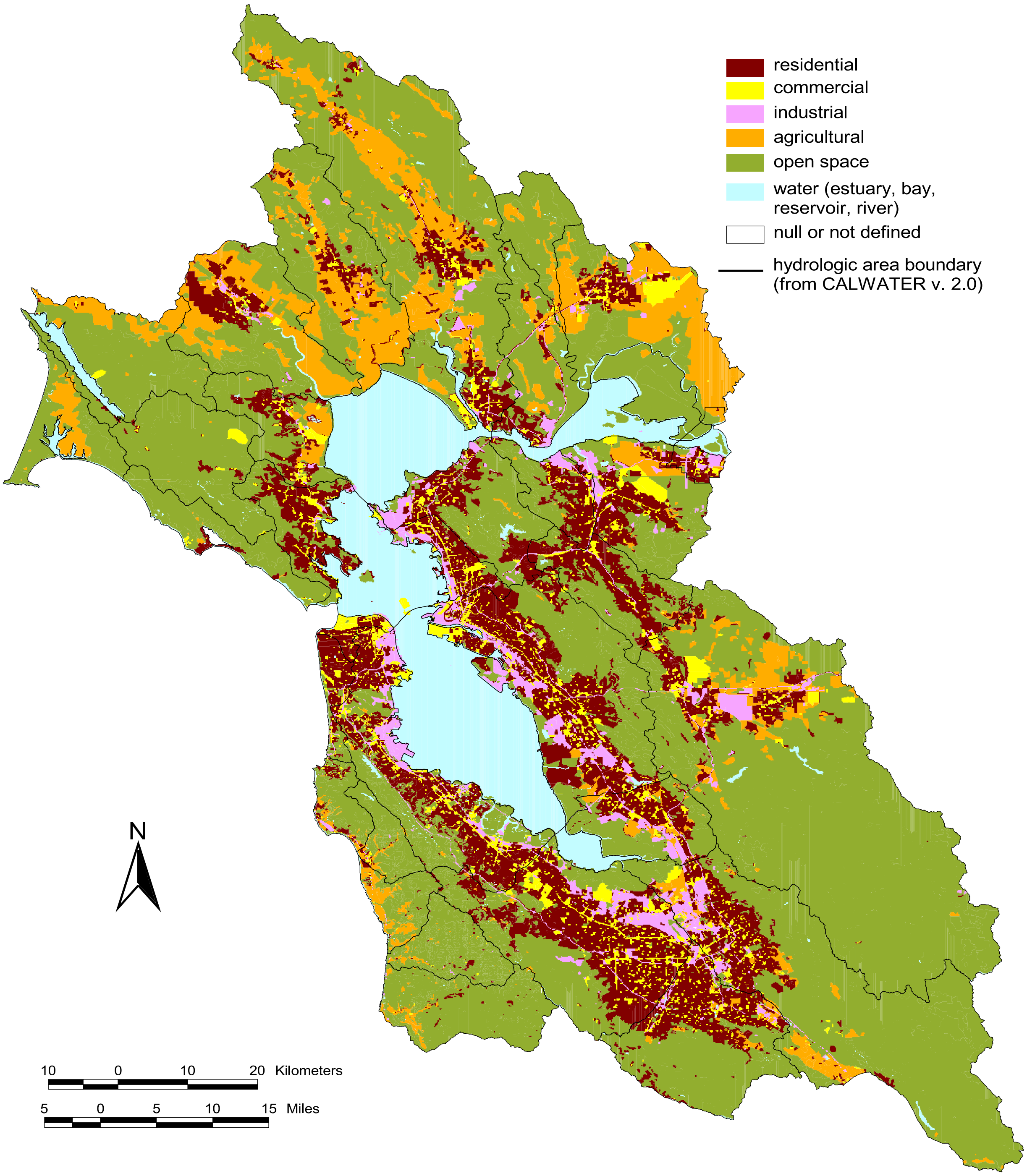


FIGURE II-5. Average annual rainfall in inches, 1961-1990. From PRISM (1998). A color version of this figure can be viewed at the SFEI website: www.sfei.org under Contaminant Monitoring and Research.

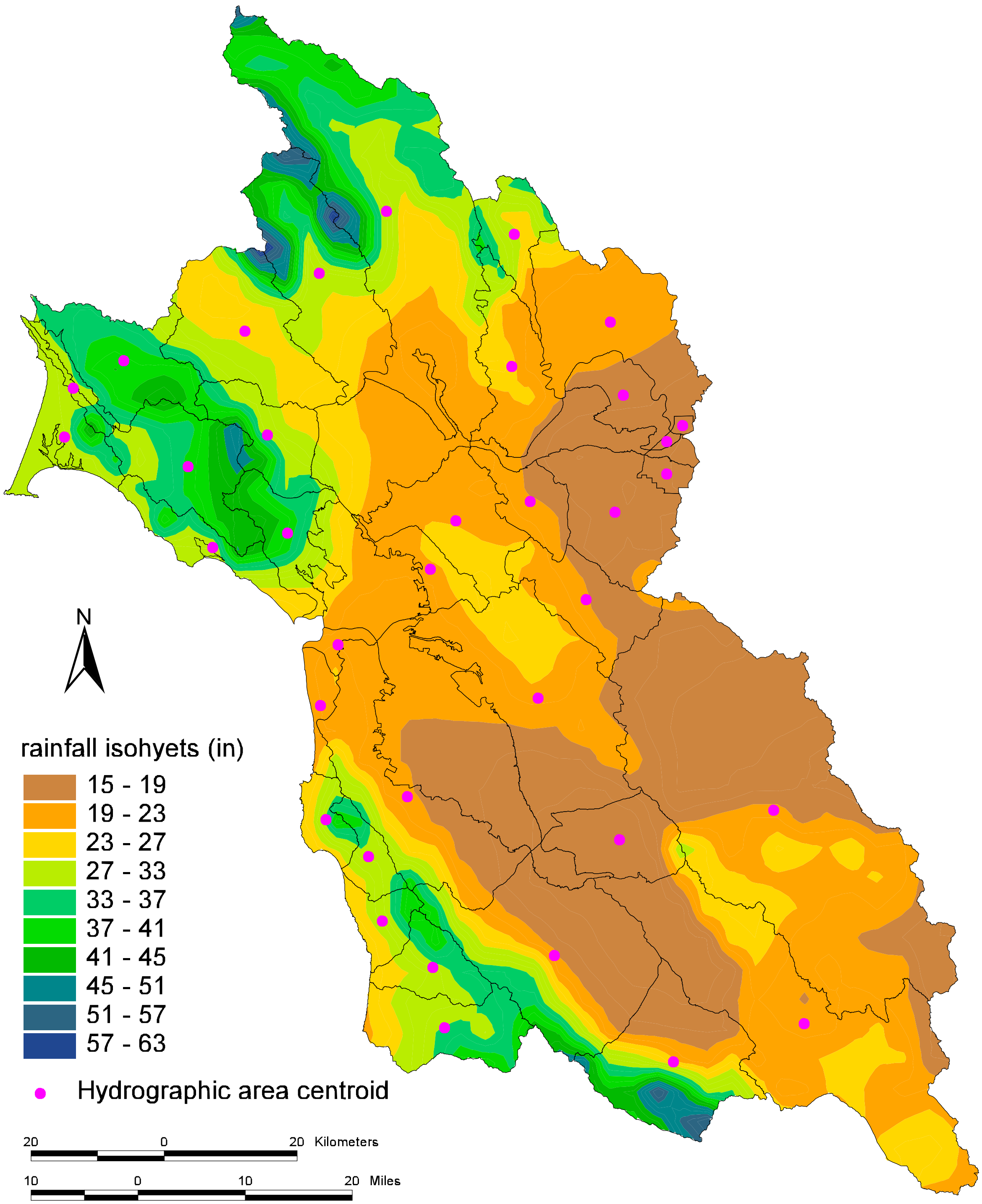


FIGURE II-6 a. Interannual variation of rainfall in the Napa River, 1961-1990.

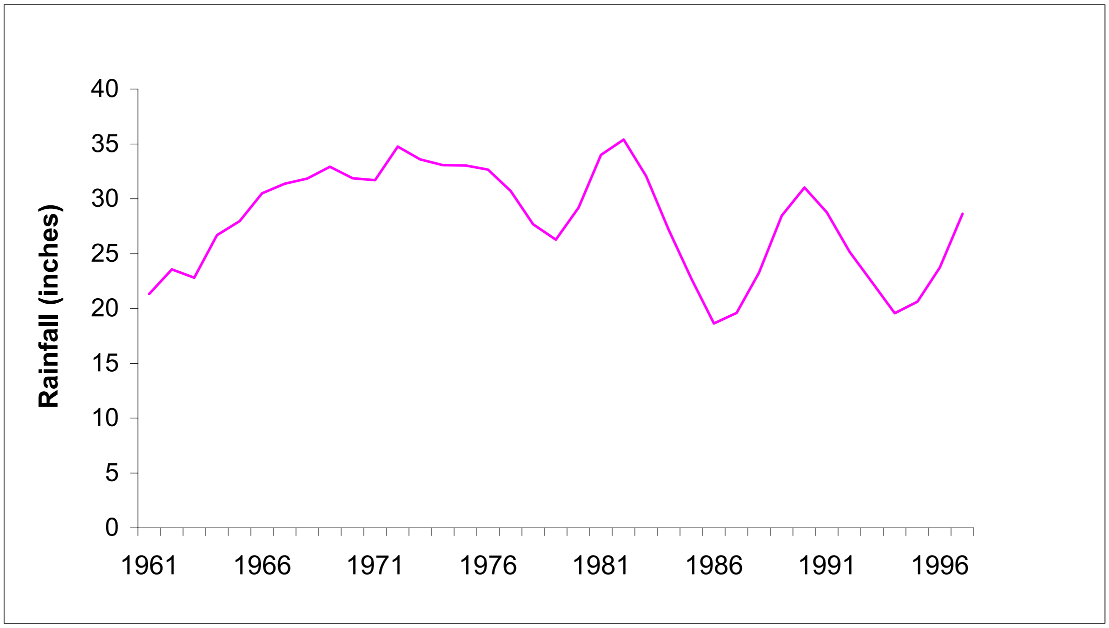


FIGURE II-6 b. Interannual variation of rainfall in the East Bay Cities, 1961-1990.

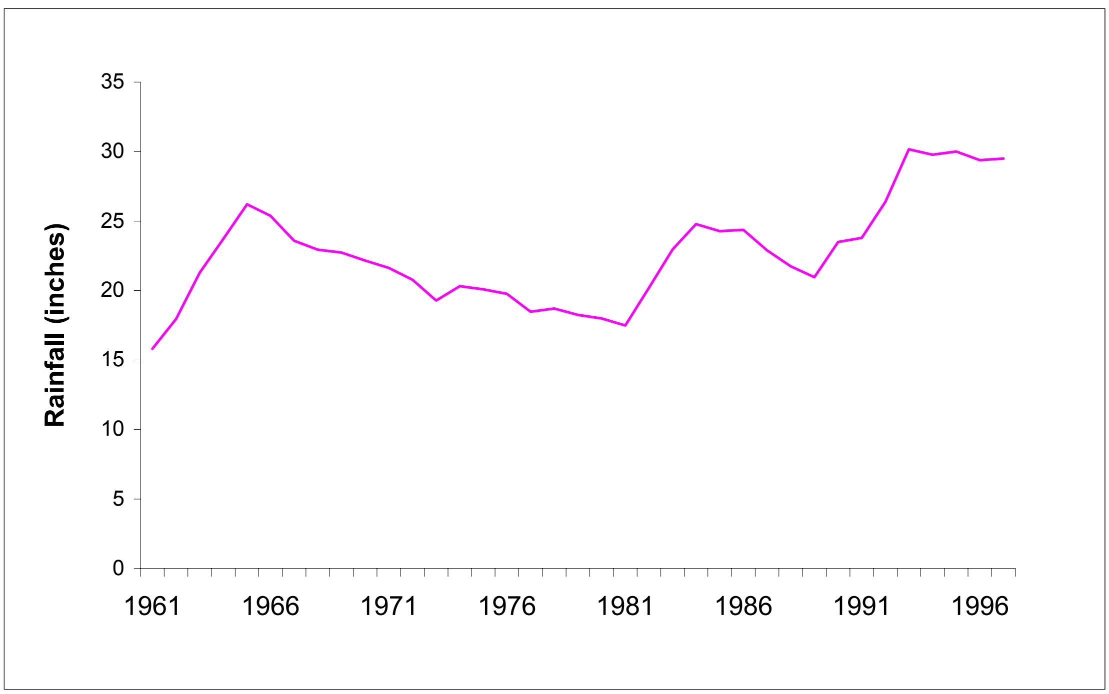
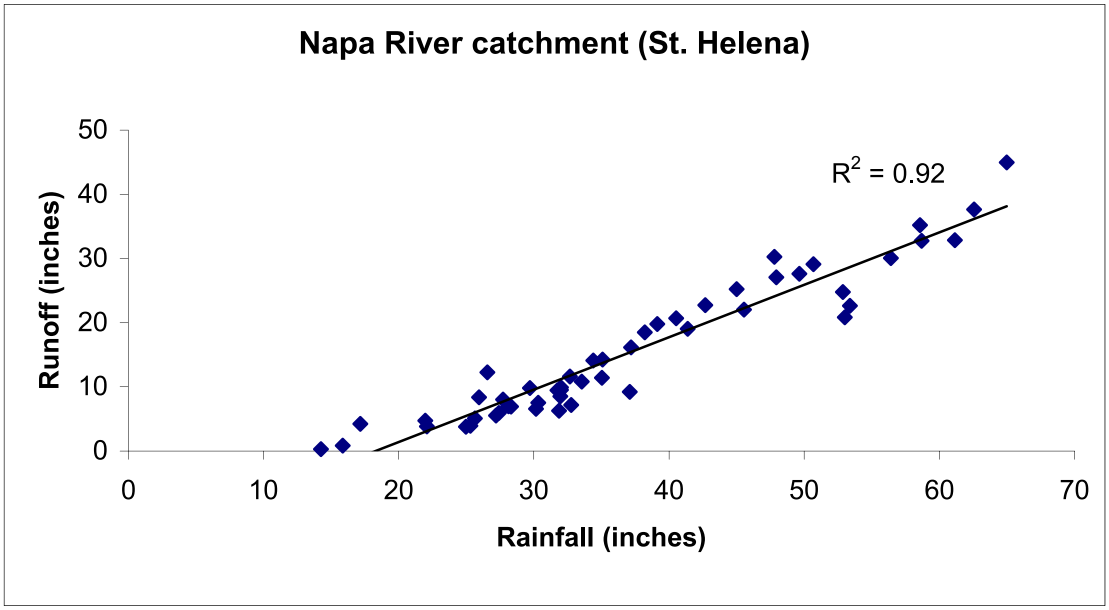
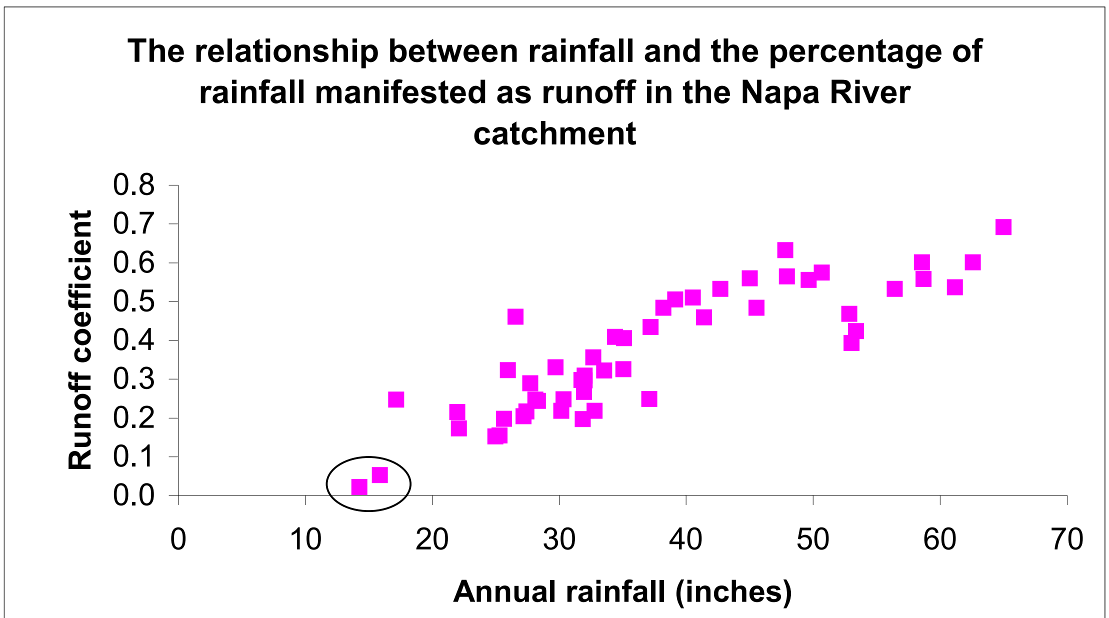


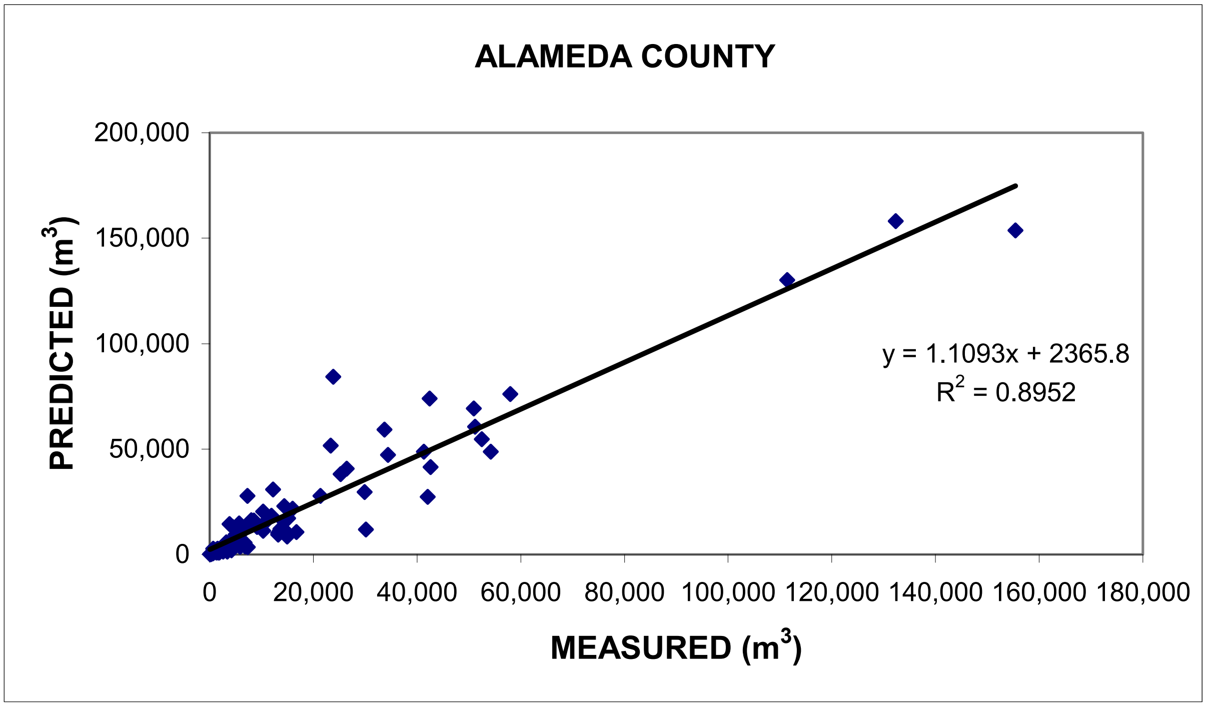
FIGURE II-7. Rainfall and measured runoff coefficients in the Napa River watershed. Ignoring two outliers from the 1976/77 drought, the runoff coefficients varied from approximately 15% to 70% of the annual rainfall, with an average of 38%.





<u>**Catchment statistics (1932 - 1994 excluding 12 incomplete data years)**</u>
Area = 210.8 sqkm (81.4 sq.miles)
Mean annual precipitation (MAP) = 944mm (37 inches) CV = 0.33
Mean annual runoff (MAR) = 387mm (15 inches) CV = 0.73
Mean flow rate = 2.6 cms (91.4 cfs)
Mean Annual runoff coefficient = 38%
Some regulation by Bell Canyon Reservior since 1959

FIGURE II-8. Comparison of measured and predicted runoff volumes for three regions in the Bay Area.



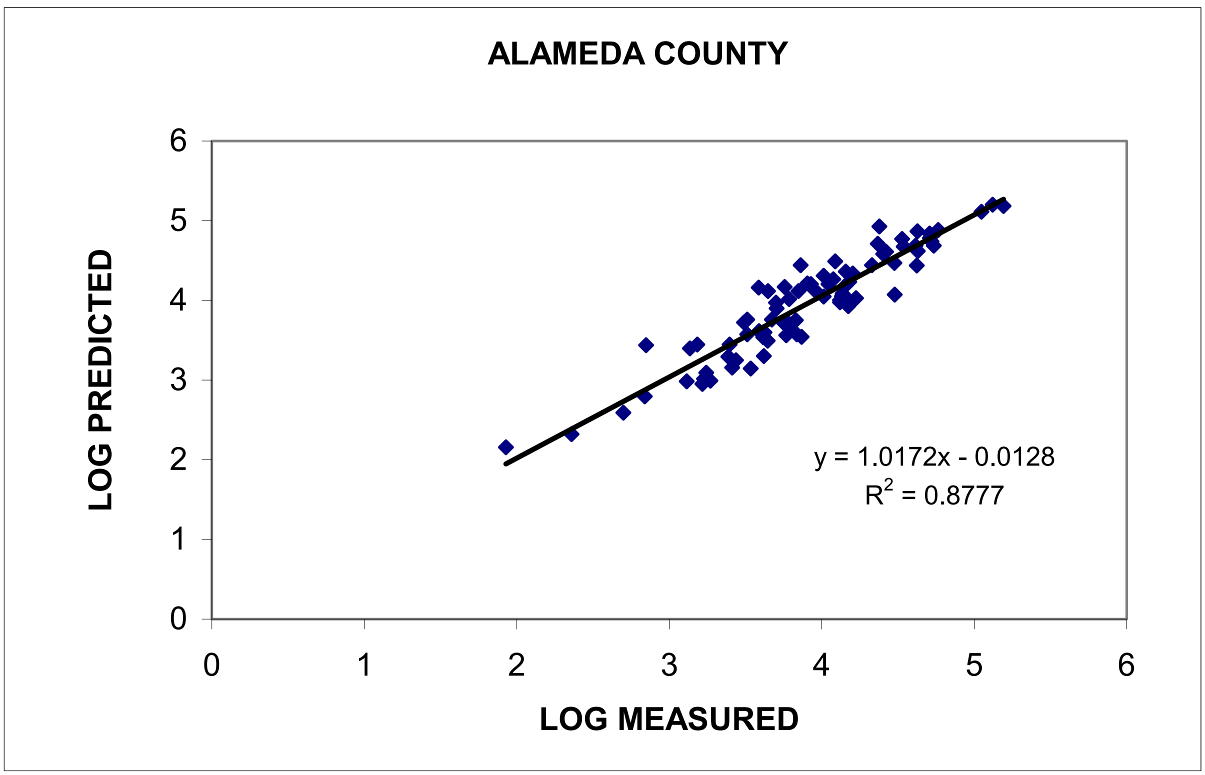
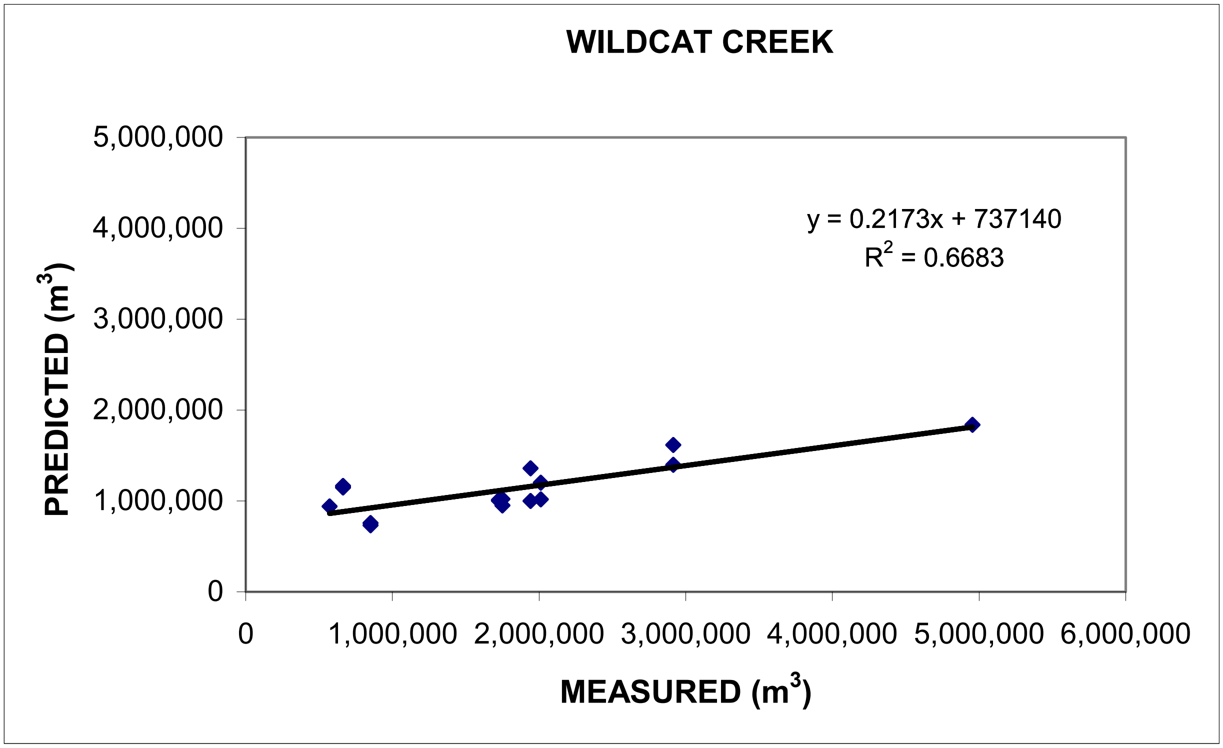


FIGURE II-8 (cont.) Comparison of measured and predicted runoff volumes for three regions in the Bay Area.



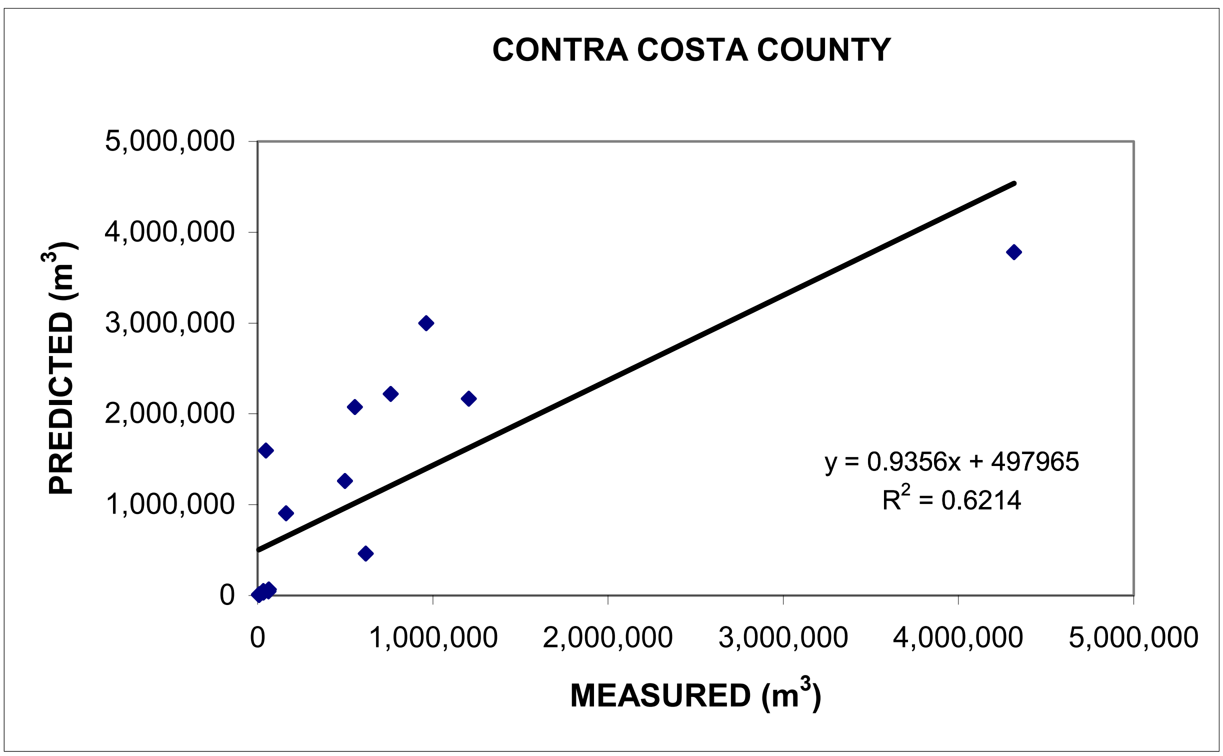


FIGURE II-9. Conceptual model of contaminant transport via stormwater runoff.

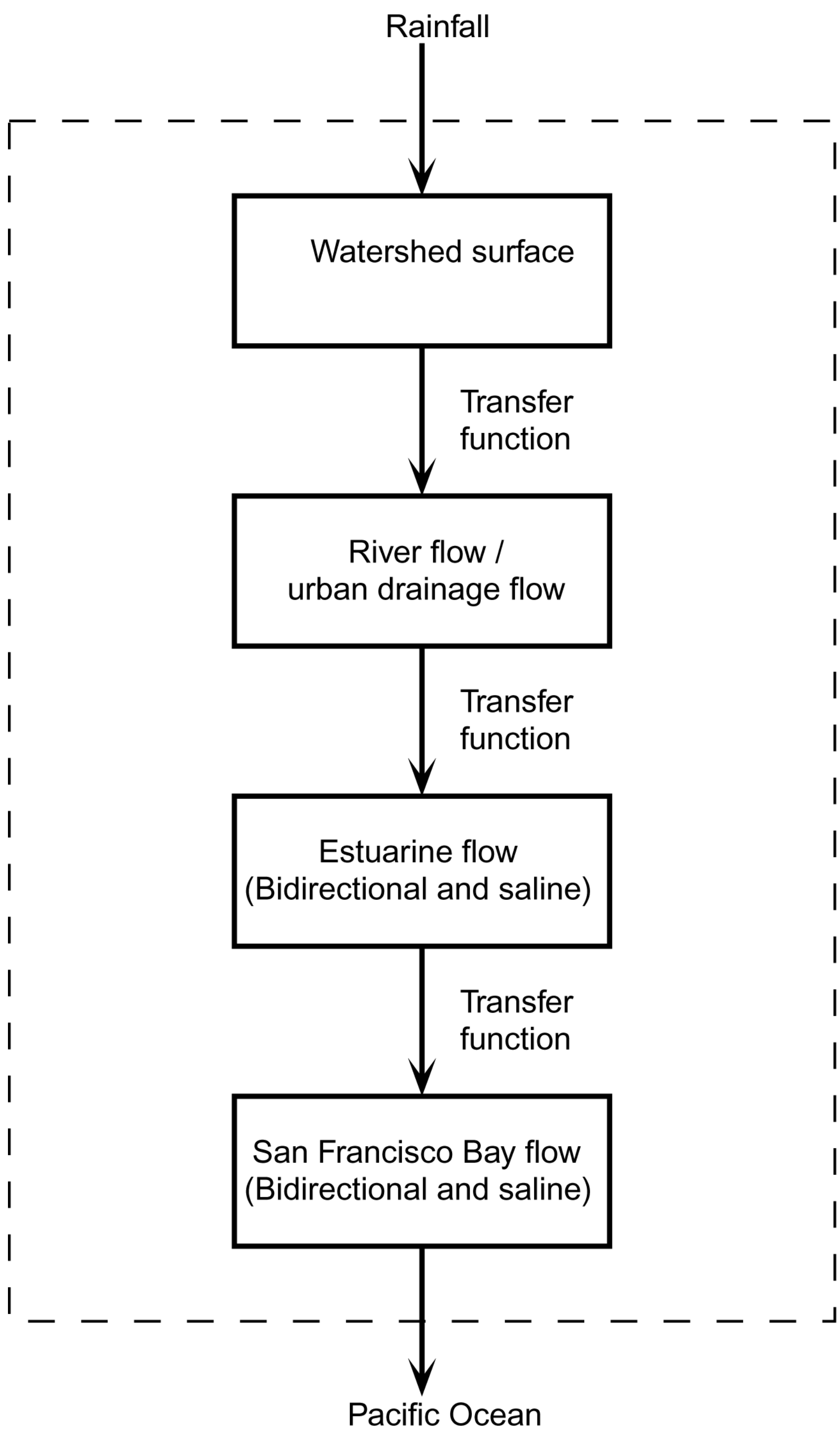


FIGURE II-10. Curves illustrating several possible trajectories of change in contaminant concentration during the course of a storm. Q = flow. C = concentration.

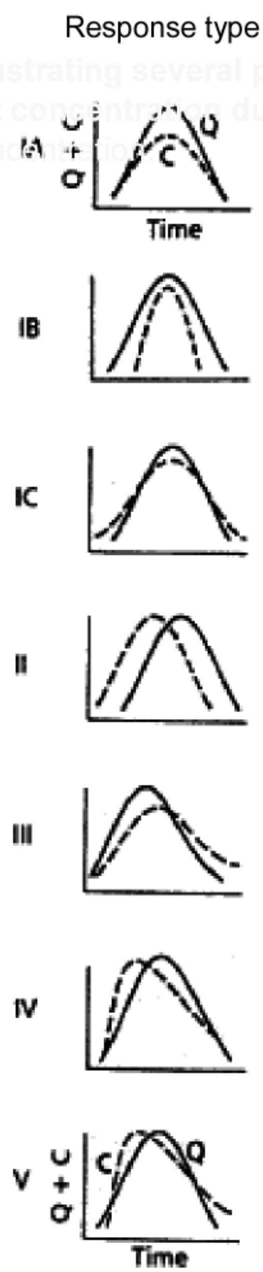


Figure II-10. Curves illustrating several possible trajectories of change in contaminant concentration during the course of a storm. Q = flow. C = concentration.

FIGURE II-11. Long-term record of rainfall at San Jose. Second graph shows accumulative deviation from the mean and the persistent belowaverage rainfall from 1984-1991.

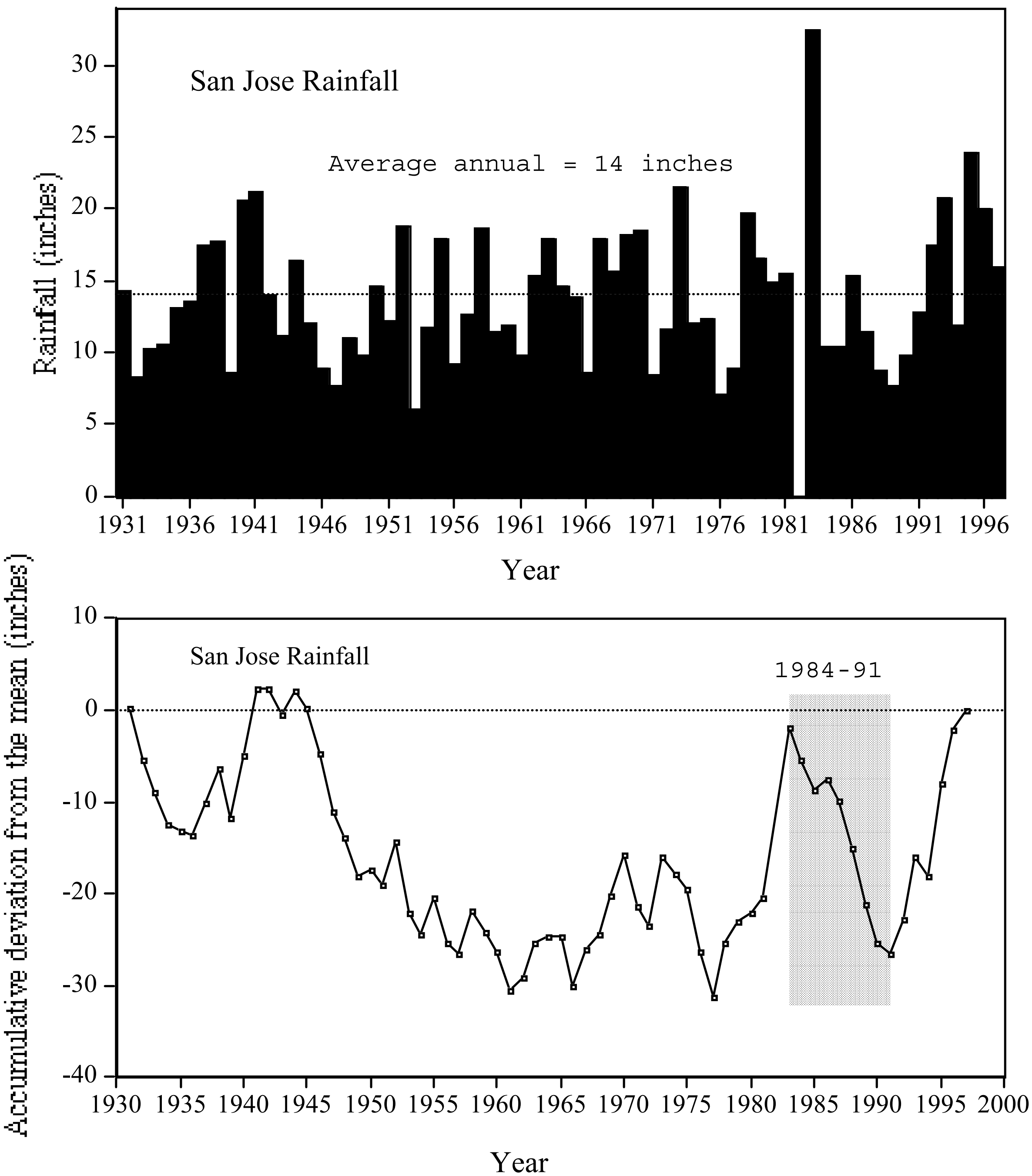


FIGURE II-12 a. Comparisons of data collected during stormwater monitoring in Alameda county with the return frequencies of storms for rain gauges in or adjacent to the study area that have suitable data available.

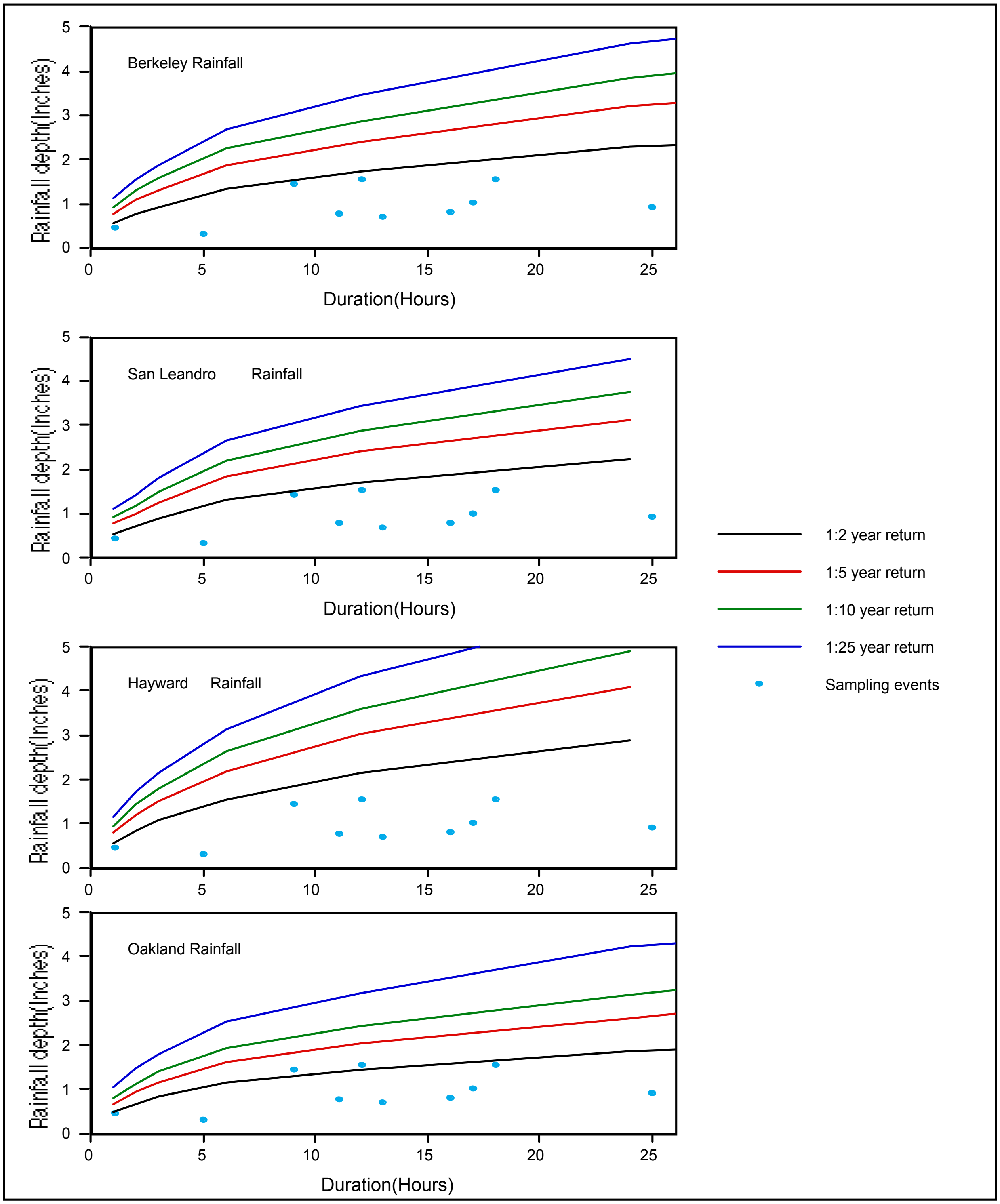


FIGURE II-12 b. Comparisons of data collected during stormwater monitoring in Santa Clara county with the return frequencies of storms for rain gauges in or adjacent to the study area that have suitable data available.

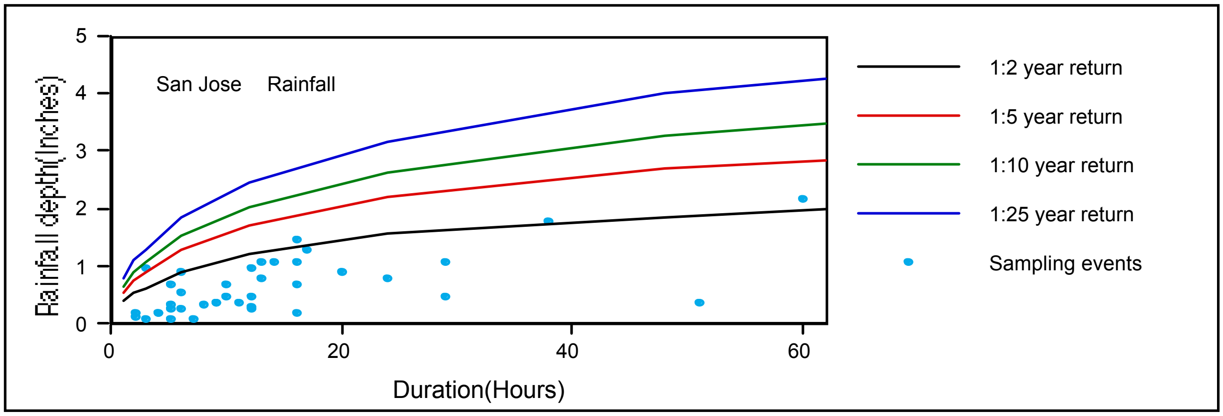


FIGURE II-12 c. Comparisons of data collected during stormwater monitoring in Contra Costa county with the return frequencies of storms for rain gauges in or adjacent to the study area that have suitable data available.

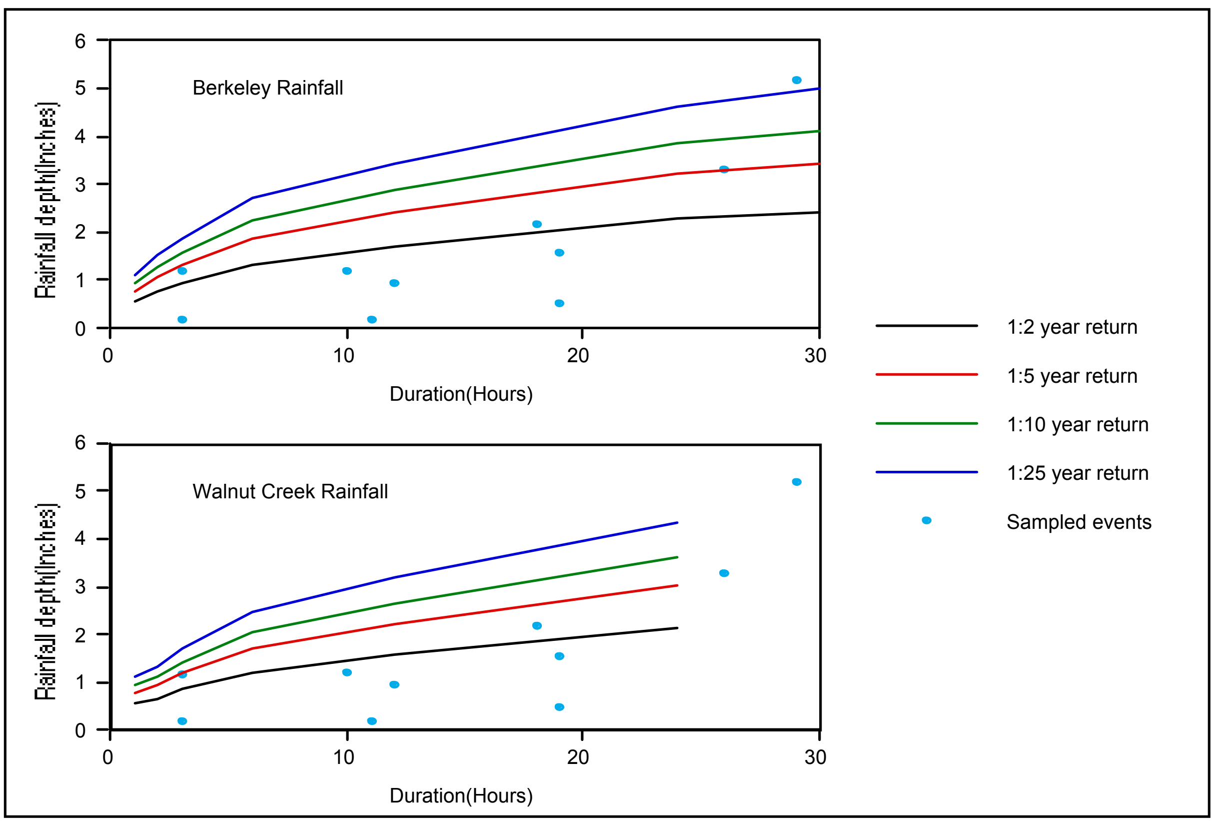


TABLE II-1. Land use classifications used by ABAG (1995) and their assigned categories for this report.

General Land Use	Land Use Identification Code number	Land Use Description
agricultural	23	Confined Feeding (large poultry farms, hog and cattle feedlots, with many
agricultural	211	Cropland
agricultural	21	Cropland and Pasture
agricultural	24	Farmsteads and Other Agriculture (the largest component of this land use is inactive farm land)
agricultural	223	Greenhouses and Floriculture
agricultural	2111	Irrigated
agricultural	2112	Non-Irrigated
agricultural	221	Orchards or Groves
agricultural	22	Orchards, Groves, Vineyards, Nurseries and Ornamental Horticulture Areas
agricultural	212	Pasture
agricultural	222	Vineyards and Kiwi Fruit
commercial	1262	Churches and Synagogues
commercial	1265	City Hall or County Government Center
commercial	1232	Colleges and Universities
commercial	12	Commercial and Services
commercial	122	Commercial Outdoor Recreation
commercial	148	Communication Facilities
commercial	1481	Communications, Network Tower
commercial	1482	Communications, Tower
commercial	1242	Community Hospitals (not designated trauma centers)
commercial	1268	Convention Centers
commercial	123	Education
commercial	1231	Elementary and Secondary Schools
commercial	1263	Fire Station
commercial	1253	General Military Use
commercial	1245	Home Health Care Facilities (not used)
commercial	1241	Hospital Trauma Centers (designated centers)
commercial	124	Hospitals, Rehabilitation Centers and Other Public Facilities
commercial	129	Hotels
commercial	1266	Local Government Emergency Operations Center (EOC)
commercial	1267	Local Jails or Rehabilitation Centers
commercial	1483	Media Communications Facilities
commercial	1244	Medical Clinics (not used)
commercial	1243	Medical Long-Term Care Facilities
commercial	1256	Military Airport
commercial	1252	Military Commercial/Services
commercial	1255	Military Communications
commercial	1254	Military Hospital
commercial	125	Military Installations
commercial	1257	Military Open Areas
commercial	1258	Military Port
commercial	1251	Military Residential
commercial	16	Mixed Residential and Commercial Use
commercial	162	Mixed Use In Buildings
commercial	146	Municipal Wastewater Facilities
commercial	147	Municipal Water Supply Facilities
commercial	126	Other Public Institutions and Facilities
commercial	1246	Out-Patient Surgery Centers
commercial	1264	Police Station
commercial	1249	Psychiatric Facilities

TABLE II-1 (cont.). Land use classifications used by ABAG (1995) and their assigned categories for this report.

General Land Use	Land Use Identification Code number	Land Use Description
commercial	127	Research Centers
commercial	121	Retail and Wholesale
commercial	1233	Stadium
commercial	1261	Stadium (when not associated with a college or university)
commercial	1248	State Mental Health and Developmentally Disabled Facilities
commercial	1247	State Prisons
commercial	161	Transitional (mixed use of land areas)
commercial	1234	University Housing
commercial	1462	Wastewater Pumping Station
commercial	1463	Wastewater Storage
commercial	1461	Wastewater Treatment Plant
commercial	1472	Water Pumping Station
commercial	1473	Water Storage (covered)
commercial	1474	Water Storage (open)
commercial	1471	Water Treatment (Filtration) Plant
industrial	143	Airports
industrial	1455	Building (currently not used)
industrial	1412	Bus Transit Centers
industrial	1415	City, County or Utilities Corporation Yard (for the maintenance of their vehicles)
industrial	1436	Commercial Airport - Other (including parking, buffers, and other land related to airport operations)
industrial	1432	Commercial Airport Air Cargo Facility
industrial	1433	Commercial Airport Airline Maintenance
industrial	1431	Commercial Airport Passenger Terminal
industrial	1434	Commercial Airport Runway
industrial	1435	Commercial Airport Utilities (water, communications, power)
industrial	1444	Commercial Port - Other Terminal and Ship Repair
industrial	1442	Commercial Port Container Terminal
industrial	1443	Commercial Port Oil and Liquid Bulk Terminal
industrial	1441	Commercial Port Passenger Terminal
industrial	1445	Commercial Port Storage Facility or Warehouse
industrial	1453	Electricity, Other (including power lines meeting a 55-yard (50-meter) minimum mapping specification)
industrial	1451	Electricity, Power Plant
industrial	1452	Electricity, Substation (not associated with industrial activities, covering the minimum mapping size requirement of 2 acres or 1 hectare)
industrial	1447	Ferry Terminal (including associated open areas and parking)
industrial	131	Heavy Industry
industrial	1411	Highways and Interchanges (meeting a 55-yard, or 50-meter, minimum mapping specification)
industrial	13	Industrial
industrial	132	Light Industry
industrial	1423	Light Rail Stations (typically too small to meet the 2 acre, or 1 hectare, minimum)
industrial	1424	Light Rail Yards (typically too small to meet the 55-yard, or 50-meter, minimum)
industrial	1448	Marina
industrial	144	Marine Transportation Facilities
industrial	133	Metal Salvage or Recycling
industrial	15	Mixed Commercial and Industrial Complexes
industrial	1413	Park and Ride Lots (for car pools)
industrial	145	Power Facilities
industrial	1438	Private Airfield (note - not all private airfields are identified)
industrial	1437	Public (General Aviation) Airfield

TABLE II-1 (cont.). Land use classifications used by ABAG (1995) and their assigned categories for this report.

General Land Use	Land Use Identification Code number	Land Use Description
industrial	1421	Rail Passenger Stations (including Amtrak, BART and CalTrain)
industrial	142	Rail Transportation Facilities
industrial	1422	Rail Yards (included are switching, classification and maintenance yards, as well as terminals)
industrial	141	Road Transportation Facilities
industrial	761	Sanitary Land Fills
industrial	1454	Service Center (currently not used)
industrial	75	Strip Mines, Quarries and Gravel Pits
industrial	1446	Tow Boat Facility (usually too small to meet the minimum mapping size requirement of 2 acres or 1 hectare)
industrial	14	Transportation, Communication and Utilities
industrial	1414	Truck or Bus Maintenance Yard
open	74	Bare Exposed Rock
open	72	Beaches
open	172	Cemeteries
open	321	Chaparral
open	322	Coastal Shrub
open	41	Deciduous Forest
open	42	Evergreen Forest
open	423	Evergreen Mix
open	171	Extensive Recreation
open	61	Forested Wetlands
open	1711	Golf Courses
open	31	Herbaceous Rangeland
open	43	Mixed Forest
open	33	Mixed Rangeland
open	77	Mixed Sparsely Vegetated Land
open	62	Nonforested Wetlands
open	174	Open Space--Urban
open	762	Other Transitional
open	173	Parks
open	422	Pine
open	1712	Racetracks
open	421	Redwood and Douglas Fir
open	63	Salt Evaporation Ponds
open	73	Sand Other than Beaches
open	32	Shrub and Brush Rangeland
open	76	Transitional Areas
residential	114	Mobile Home Parks (technically a part of 113 but listed separately)
residential	113	Nine and Over DUs per Hectare (less than 1/3 acre lots)
residential	111	One and Under Dwelling Units (DUs) per Hectare (approx. 2 to 5 acre lots)
residential	17	Other Urban and Built-Up Land (affected by urban development but with minimal paving and buildings)
residential	11	Residential
residential	112	Two to Eight DUs per Hectare (approx. 1/3 to 1 acre lots)
residential	175	Urban Vacant Land
water	54	Bays and Estuaries (receiving water, not counted)
water	64	Land on USGS Base Maps but Water on USGS Land Use Maps (receiving water, not counted)
water	53	Reservoirs (receiving water, not counted)
water	51	Streams and Canals (receiving water, not counted)
water	56	Water on USGS Base Maps but Land on USGS Land Use Maps

TABLE II-2. Land use for each hydrologic unit and for the region.
Drainage areas greater than 20 mi^2 above dams excluded.

Hydrologic Area Name	Drainage Area (m^2)	Residential (%)	Commercial (%)	Industrial (%)	Agricultural (%)	Open (%)
Tomales Bay (220112)	252,752,539	0	1	0	19	80
Tomales Bay (220113)	101,380,447	1	0	0	0	99
Tomales Bay (220114)	27,225,811	3	0	0	3	94
Point Reyes	132,814,776	0	0	0	27	73
Bolinas	133,885,937	5	1	0	1	93
San Francisco - Coastal	55,907,889	62	12	2	0	24
San Mateo - Coastal (220221)	74,818,178	11	1	2	8	77
San Mateo - Coastal (220222)	74,170,346	2	1	0	7	89
San Mateo - Coastal (220223)	84,572,334	3	0	0	30	67
San Gregorio Creek	134,552,376	2	0	0	3	95
Pescadero Creek	219,210,666	1	0	0	5	93
San Rafael	157,659,876	50	8	1	0	41
Berkeley	87,585,261	57	16	18	0	9
San Francisco - Bayside	28,764,911	58	39	2	0	1
East Bay cities	537,837,394	44	9	12	1	34
Alameda Creek	940,853,470	10	3	3	11	73
San Mateo - Bayside	426,680,239	41	10	12	0	37
Fremont Bayside	191,146,170	26	6	11	8	49
Coyote Creek	473,402,458	23	6	7	10	53
Guadalupe River	215,171,511	47	8	5	5	35
Palo Alto	593,745,251	43	10	8	1	39
Novato	183,975,415	23	7	1	13	56
Petaluma River	377,643,849	14	1	2	35	48
Sonoma Creek	429,766,542	8	1	1	36	54
Napa River	937,888,979	10	3	1	24	62
Pinole	152,427,916	33	5	12	0	49
Fairfield (220721)	226,198,776	12	1	5	12	70
Fairfield (220722)	131,685,843	0	0	0	13	86
Fairfield (220723/26)	410,248,260	8	6	2	48	36
Fairfield (220724/25)	109,760,473	0	0	0	1	99
Concord (220731)	283,955,162	25	10	7	9	49
Concord (220732)	212,544,012	44	4	1	1	50
Concord (220733)	121,715,016	39	6	7	0	47
Concord (220734)	30,053,627	46	9	26	6	12
TOTAL	8,552,001,708	21	5	4	13	56

TABLE II-3. Rainfall statistics for each hydrologic unit for the period 1961-1990.
Averages from PRISM (1998). 10th and 90th percentiles from NCDC (1998).

Hydrologic Area Name	Average rainfall (in)	10th percentile from gauges (in)	90th percentile from gauges (in)
Tomales Bay (220112)	41	27	66
Tomales Bay (220113)	39	27	66
Tomales Bay (220114)	33	16	51
Point Reyes	31	16	51
Bolinas	31	16	51
San Francisco - Coastal	23	12	26
San Mateo - Coastal (220221)	35	17	34
San Mateo - Coastal (220222)	33	17	35
San Mateo - Coastal (220223)	31	17	38
San Gregorio Creek	33	17	38
Pescadero Creek	35	19	41
San Rafael	39	27	66
Berkeley	21	13	35
San Francisco - Bayside	21	13	29
East Bay cities	22	12	32
Alameda Creek	21	10	26
San Mateo - Bayside	21	11	29
Fremont Bayside	15	9	20
Coyote Creek	21	9	20
Guadalupe River	25	15	57
Palo Alto	21	10	41
Novato	33	16	51
Petaluma River	27	15	34
Sonoma Creek	29	19	44
Napa River	31	16	51
Pinole	23	13	26
Fairfield (220721)	25	13	29
Fairfield (220722)	29	13	29
Fairfield (220723)	21	13	29
Fairfield (220724)	19	13	29
Concord (220731)	17	12	28
Concord (220732)	21	14	35
Concord (220733)	21	14	28
Concord (220734)	17	12	28

TABLE II-4. Sensitivity analysis for TSS. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

	Input data			Total stormwater TSS load		
	Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Rainfall	10th %	Mean	90th %	-45	310,000,000	46

		Input data			Total stormwater TSS load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-5	310,000,000	5
	Commercial	0.60	0.90	0.95	-2	310,000,000	0
	Industrial	0.60	0.90	0.95	-3	310,000,000	1
	Agricultural	0.05	0.10	0.20	-26	310,000,000	51
	Open	0.10	0.25	0.50	-13	310,000,000	22
Concentrations (mg/L)	Residential	28	90	286	-7	310,000,000	23
	Commercial	30	98	312	-5	310,000,000	15
	Industrial	49	157	502	-7	310,000,000	21
	Agricultural	646	2068	6618	-35	310,000,000	112
	Open	27	85	272	-15	310,000,000	49

TABLE II-5. Sensitivity analysis for cadmium. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

	Input data			Total stormwater cadmium load		
	Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Rainfall	10th %	Mean	90th %	-45	2,300	49

		Input data			Total stormwater cadmium load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-11	2,300	11
	Commercial	0.60	0.90	0.95	-6	2,300	1
	Industrial	0.60	0.90	0.95	-8	2,300	1
	Agricultural	0.05	0.10	0.20	-8	2,300	15
	Open	0.10	0.25	0.50	-9	2,300	15
Concentrations (µg/L)	Residential	0.52	1.7	5.3	-18	2,300	58
	Commercial	0.61	1.9	6.2	-13	2,300	40
	Industrial	1.0	3.1	10	-17	2,300	55
	Agricultural	1.5	4.7	15	-11	2,300	34
	Open	0.13	0.43	1.4	-10	2,300	33

TABLE II-6. Sensitivity analysis for chromium. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater chromium load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	40,000	48

		Input data			Total stormwater chromium load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-10	40,000	10
	Commercial	0.60	0.90	0.95	-4	40,000	1
	Industrial	0.60	0.90	0.95	-4	40,000	1
	Agricultural	0.05	0.10	0.20	-14	40,000	27
	Open	0.10	0.25	0.50	-16	40,000	27
Concentrations (µg/L)	Residential	7.6	24	77	-15	40,000	49
	Commercial	6.6	21	68	-8	40,000	26
	Industrial	7.8	25	80	-8	40,000	26
	Agricultural	44	141	451	-19	40,000	60
	Open	4.1	13	42	-18	40,000	59

TABLE II-7. Sensitivity analysis for copper. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater copper load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	66,000	49

		Input data			Total stormwater copper load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-12	66,000	12
	Commercial	0.60	0.90	0.95	-6	66,000	1
	Industrial	0.60	0.90	0.95	-5	66,000	1
	Agricultural	0.05	0.10	0.20	-13	66,000	26
	Open	0.10	0.25	0.50	-8	66,000	14
Concentrations (µg/L)	Residential	16	51	162	-19	66,000	62
	Commercial	16	51	162	-12	66,000	37
	Industrial	17	53	169	-10	66,000	33
	Agricultural	70	225	720	-18	66,000	58
	Open	3.4	11	35	-9	66,000	30

TABLE II-8. Sensitivity analysis for lead. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater lead load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	81,000	51

		Input data			Total stormwater lead load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-10	81,000	10
	Commercial	0.60	0.90	0.95	-14	81,000	2
	Industrial	0.60	0.90	0.95	-8	81,000	1
	Agricultural	0.05	0.10	0.20	-3	81,000	6
	Open	0.10	0.25	0.50	-4	81,000	7
Concentrations (µg/L)	Residential	16	52	166	-16	81,000	52
	Commercial	47	151	483	-28	81,000	90
	Industrial	30	97	310	-16	81,000	50
	Agricultural	19	60	192	-4	81,000	13
	Open	2.2	7.0	22	-5	81,000	15

TABLE II-9. Sensitivity analysis for nickel. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater nickel load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	49,000	49

		Input data			Total stormwater nickel load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-11	49,000	11
	Commercial	0.60	0.90	0.95	-5	49,000	1
	Industrial	0.60	0.90	0.95	-5	49,000	1
	Agricultural	0.05	0.10	0.20	-9	49,000	17
	Open	0.10	0.25	0.50	-15	49,000	25
Concentrations (µg/L)	Residential	11	36	114	-18	49,000	59
	Commercial	11	34	109	-11	49,000	34
	Industrial	13	41	131	-11	49,000	35
	Agricultural	34	109	349	-12	49,000	38
	Open	4.7	15	48	-17	49,000	55

TABLE II-10. Sensitivity analysis for zinc. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater zinc load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	280,000	50

		Input data			Total stormwater zinc load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-11	280,000	11
	Commercial	0.60	0.90	0.95	-10	280,000	2
	Industrial	0.60	0.90	0.95	-8	280,000	1
	Agricultural	0.05	0.10	0.20	-5	280,000	9
	Open	0.10	0.25	0.50	-6	280,000	10
Concentrations (µg/L)	Residential	59	188	602	-17	280,000	54
	Commercial	124	397	1270	-21	280,000	68
	Industrial	116	371	1187	-17	280,000	55
	Agricultural	108	345	1104	-7	280,000	21
	Open	11	34	109	-7	280,000	22

TABLE II-11. Sensitivity analysis for BOD. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater BOD load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	16,000,000	48

		Input data			Total stormwater BOD load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-10	16,000,000	10
	Commercial	0.60	0.90	0.95	-5	16,000,000	1
	Industrial	0.60	0.90	0.95	-5	16,000,000	1
	Agricultural	0.05	0.10	0.20	-10	16,000,000	21
	Open	0.10	0.25	0.50	-16	16,000,000	26
Concentrations (mg/L)	Residential	3.1	10	32	-16	16,000,000	52
	Commercial	3.1	10	32	-10	16,000,000	31
	Industrial	4.1	13	42	-11	16,000,000	35
	Agricultural	13	42	134	-14	16,000,000	46
	Open	1.6	5.0	16	-18	16,000,000	57

TABLE II-12. Sensitivity analysis for nitrate. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater nitrate load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	1,500,000	47

		Input data			Total stormwater nitrate load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-8	1,500,000	8
	Commercial	0.60	0.90	0.95	-4	1,500,000	1
	Industrial	0.60	0.90	0.95	-3	1,500,000	0
	Agricultural	0.05	0.10	0.20	-26	1,500,000	53
	Open	0.10	0.25	0.50	-7	1,500,000	11
Concentrations (mg/L)	Residential	0.22	0.70	2.2	-12	1,500,000	39
	Commercial	0.22	0.70	2.2	-7	1,500,000	23
	Industrial	0.19	0.60	1.9	-5	1,500,000	17
	Agricultural	3.1	10	32	-36	1,500,000	116
	Open	0.063	0.20	0.64	-8	1,500,000	24

TABLE II-13. Sensitivity analysis for phosphate. For rainfall, input data were 10th percentiles (low), averages (best), and 90th percentiles (high). For runoff coefficients, input values for each land use bracket the range of reported values (see Table 15). For stormwater concentrations, input values span one order of magnitude around the mean values selected for each land use (see Table 18).

		Input data			Total stormwater phosphate load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
	Rainfall	10th %	Mean	90th %	-45	510,000	48

		Input data			Total stormwater phosphate load		
		Low	Best	High	Decrease with low value (%)	Best (kg)	Increase with high value (%)
Runoff coefficients	Residential	0.20	0.35	0.50	-9	510,000	9
	Commercial	0.60	0.90	0.95	-4	510,000	1
	Industrial	0.60	0.90	0.95	-9	510,000	1
	Agricultural	0.05	0.10	0.20	-4	510,000	9
	Open	0.10	0.25	0.50	-18	510,000	30
Concentrations (mg/L)	Residential	0.094	0.30	0.96	-15	510,000	48
	Commercial	0.094	0.30	0.96	-9	510,000	29
	Industrial	0.22	0.70	2.2	-18	510,000	57
	Agricultural	0.18	0.57	1.8	-6	510,000	19
	Open	0.059	0.19	0.61	-21	510,000	67

TABLE II-14. Runoff coefficients from the Wildcat Creek watershed for a range of individual storms.

Station	Year	Date	Rainfall, Leopold gauge (inches)	Flow in Wildcat Creek (inches)	Runoff Coefficient
Wildcat Creek at Richmond	1978	Jan 9 to 19	5.57	3.52	0.63
Wildcat Creek at Richmond	1979	Jan 7 to 15	6.38	1.16	0.18
Wildcat Creek at Richmond	1980	Jan 9 to 17	5.53	3.02	0.55
Wildcat Creek at Richmond	1981	Jan 20 to 30	5.16	1	0.19
Wildcat Creek at Richmond	1983	Jan 21 to Feb 1	5.59	3.06	0.55
Wildcat Creek at Richmond	1987	Feb 11 to 16	4.02	1.49	0.37
Wildcat Creek at Vale Rd.	1982	Jan 1 to 4	7.65	5.69	0.74
Wildcat Creek at Vale Rd.	1986	Feb 1 to 11	10.99	10.97	1
Wildcat Creek at Vale Rd.	1986	March 7 to 15	7.44	3.79	0.51
Wildcat Creek at Vale Rd.	1993	Jan 6 to 24	10.08	9.67	0.95

TABLE II-15. Average annual runoff coefficients from selected studies.
Values in boxes were selected as the "best estimate" input data for the model.

		BASMAA (1996)	BCDC (1991)	NOAA (1987)	Wong et al. (1997)	SCCWRP (2000)
	single family			0.2	0.39	
Residential	multi-family				0.58	
	undiff	0.35	0.38			0.23
Commercial		0.9	0.85	0.65	0.74	0.57
	light	0.7			0.74	
Industrial	heavy	0.9				
	transportation	0.95				
	undiff		0.72	0.3		0.58
Agricultural						0.1
Open		0.25	0.12	0.06	0.1	0.08
Other	mixed			0.23	0.66	0.38

BASMAA (1996) Monitoring Data analysis 1988 - 1995
BCDC (1991) Land use Change report
NOAA (1987) National Coastal Pollutant Discharge Inventory
Wong et. al. (1997) GIS to estimate storm-water pollutant mass loadings
SCCWRP (this report)

TABLE II-16. Annual stormwater runoff volumes for each hydrologic unit and land use category.

Hydrologic Area Name	Total (m^3/yr)	Residential (%)	Commercial (%)	Industrial (%)	Agricultural (%)	Open (%)
Tomales Bay (220112)	60,000,000	0	3	0	8	88
Tomales Bay (220113)	25,000,000	1	1	0	0	97
Tomales Bay (220114)	5,700,000	4	0	0	1	95
Point Reyes	22,000,000	0	0	0	13	87
Bolinas	27,000,000	7	4	0	0	89
San Francisco - Coastal	13,000,000	54	26	6	0	15
San Mateo - Coastal (220221)	18,000,000	14	5	8	3	70
San Mateo - Coastal (220222)	16,000,000	3	4	1	3	89
San Mateo - Coastal (220223)	14,000,000	4	2	2	14	78
San Gregorio Creek	28,000,000	2	1	1	1	95
Pescadero Creek	48,000,000	2	1	0	2	95
San Rafael	56,000,000	49	19	3	0	29
Berkeley	25,000,000	38	28	30	0	4
San Francisco - Bayside	8,800,000	35	61	3	0	0
East Bay cities	130,000,000	35	20	25	0	20
Alameda Creek	140,000,000	12	10	11	4	64
San Mateo - Bayside	99,000,000	33	21	24	0	21
Fremont Bayside	27,000,000	25	15	26	2	32
Coyote Creek	87,000,000	24	15	20	3	39
Guadalupe River	51,000,000	44	20	12	1	23
Palo Alto	130,000,000	36	22	18	0	23
Novato	47,000,000	27	20	4	4	46
Petaluma River	60,000,000	21	5	6	15	52
Sonoma Creek	68,000,000	14	4	2	17	63
Napa River	180,000,000	14	10	5	10	62
Pinole	35,000,000	29	12	28	0	31
Fairfield (220721)	41,000,000	15	3	16	4	62
Fairfield (220722)	23,000,000	0	1	1	6	92
Fairfield (220723)	52,000,000	12	24	6	20	38
Fairfield (220724)	13,000,000	0	0	0	0	100
Concord (220731)	45,000,000	24	24	17	3	33
Concord (220732)	37,000,000	47	11	4	0	38
Concord (220733)	24,000,000	36	15	17	0	32
Concord (220734)	6,700,000	31	16	46	1	6

TABLE II-17. Frequency of detection of contaminants in stormwater in Bay Area investigations. Data are for land use stations only. Data from BASMAA (1996). - indicates data is not available.

	Total # of Samples	# Below Detection Limits	Frequency of Detection (%)
Suspended solids	183	0	100
BOD	64	0	100
COD	-	-	-
CBOD	-	-	-
Nitrate-N	54	0	100
Nitrite-N	9	1	89
Ammonia-N	54	19	65
Total phosphorus	-	-	-
PO4-P	54	0	100
Cadmium	155	2	99
Chromium	152	1	99
Copper	152	1	99
Lead	153	2	99
Mercury	148	111	25
Nickel	153	6	96
Selenium	150	103	31
Zinc	154	1	99
Total PCB	-	-	-
Total PAH	19	0	100
Total DDT	-	-	-
Total Chlordane	-	-	-
Dieldrin	-	-	-
Chlorpyrifos	-	-	-
Diazinon	-	-	-
Dioxins	-	-	-
Total coliform	92	0	100
Fecal coliform	-	-	-
Enterococcus	-	-	-
MTBE	-	-	-

TABLE II-18. Stormwater contaminant concentrations from various studies. Concentrations in boxes were best estimates selected for use in the model. Concentrations are totals (dissolved plus particulate).

TSS (mg/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential	192	76	90			102
commercial	192	76	98			118
industrial						174
light industrial	114	152	113			
heavy industrial	114	152	157			
transportation	192					
open	11	85				371
urban						
agriculture						2068

Cadmium (ug/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential	0.9	1.7	1.7	1.3		0.3
commercial	0.9	1.7	1.9	1.8		0.4
industrial				5.0		0.7
light industrial	1.4	5.9	1.7			
heavy industrial	1.4	5.9	3.1			
transportation	0.9		2.7			
open	0.2	0.6	0.4	0.6		0.5
urban			1.9		1.8	
agriculture						4.7

Chromium (ug/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential	14	21	24	19		4
commercial	14	21		12		7
industrial				40		6
light industrial	20	39	21			
heavy industrial	20	39	25			
transportation	14		35			
open	2	10	13	9		7
urban			22		9	
agriculture						141

TABLE II-18 (cont.). Stormwater contaminant concentrations from various studies. Concentrations in boxes were best estimates selected for use in the model. Concentrations are totals (dissolved plus particulate).

Copper (ug/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential	31	51		33		25
commercial	31	51		28		33
industrial				49		46
light industrial	44	53				
heavy industrial	44	53				
transportation	31					
open	3	9	11	11		23
urban			45		43	
agriculture						225

Lead (ug/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential	73	61	52	48		13
commercial	73	61	151	45		12
industrial				125		17
light industrial	77	134	143			
heavy industrial	77	134	97			
transportation	73		137			
open	4	4	7	3		5
urban			108		182	
agriculture						60

Nickel (ug/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential	20	41	36	21		6
commercial	20	41	34	29		9
industrial				38		10
light industrial	13	54				
heavy industrial	13	54	41			
transportation	20		77			
open	1	18	15	6		8
urban			34			
agriculture						109

TABLE II-18 (cont.). Stormwater contaminant concentrations from various studies. Concentrations in boxes were best estimates selected for use in the model. Concentrations are totals (dissolved plus particulate).

Zinc (ug/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential	246	251	188	180		141
commercial	246	251	397	280		233
industrial				875		326
light industrial	367	1471	358			
heavy industrial	367	1471	371			
transportation	246		279			
open	34	10		9		45
urban			284		202	
agriculture						345

BOD (mg/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential		10				20
commercial		10				26
industrial						21
light industrial		13				
heavy industrial		13				
transportation						
open		5				20
urban						
agriculture						42

TABLE II-18 (cont.). Stormwater contaminant concentrations from various studies. Concentrations in boxes were best estimates selected for use in the model. Concentrations are totals (dissolved plus particulate).

Nitrate-N (mg/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential		0.7				3.3
commercial		0.7				2.1
industrial						1.9
light industrial		0.6				
heavy industrial		0.6				
transportation						
open		0.2				2.7
urban						
agriculture						10

Phosphate-P (mg/L)	Alameda (WCC 1991)	Santa Clara (WCC 1991)	BASMAA (1995)	BCDC (1991)	NOAA (1987)	SCCWRP (2000)
residential		0.3				0.6
commercial		0.3				0.6
industrial						0.4
light industrial		0.7				
heavy industrial		0.7				
transportation						
open		0.2				
urban						
agriculture						0.6

TABLE II-19. Effect of treatment of below detection limit (BDL) values on concentrations of mercury and selenium estimated through multiple regressions. HDL=BDL values set to half the detection limit. DL=BDL values set to the detection limit.

	Hg (μg/L)			Se (μg/L)		
	Zero	HDL	DL	Zero	HDL	DL
Open/ Open Forest	0.19	0.27	0.35	0.39	0.48	0.56
Light Industrial	0.11	0.18	0.25	0.26	0.42	0.58
Heavy Industrial	0.20	0.27	0.34	0.31	0.38	0.45
Residential	0.30	0.38	0.45	0.79	0.91	1.03
Commercial	0.14	0.19	0.25	-0.02	0.13	0.29
Transportation	0.04	0.13	0.22	0.27	0.29	0.30

Boxes indicate coefficient was significant at p<0.10.

TABLE II-20. Estimated annual contaminant mass emissions from stormwater runoff.
Data in kg/yr. - indicates data are insufficient to estimate loads.

	Lower Bound	Best Estimate	Upper Bound
Suspended solids	170,000,000	310,000,000	670,000,000
BOD	8,600,000	16,000,000	25,000,000
COD	-	-	-
CBOD	-	-	-
Nitrate-N	810,000	1,500,000	3,200,000
Nitrite-N	-	-	-
Ammonia-N	-	-	-
Total phosphorus	-	-	-
PO4-P	280,000	510,000	850,000
Cadmium	1,300	2,300	3,700
Chromium	22,000	40,000	64,000
Copper	36,000	66,000	110,000
Lead	44,000	81,000	150,000
Mercury	-	-	-
Nickel	27,000	49,000	78,000
Selenium	-	-	-
Zinc	150,000	280,000	470,000
Total PCB	-	-	-
Total PAH	-	-	-
Total DDT	-	-	-
Total Chlordane	-	-	-
Dieldrin	-	-	-
Chlorpyrifos	-	-	-
Diazinon	-	-	-
Dioxins	-	-	-
Total coliform	-	-	-
Fecal coliform	-	-	-
Enterococcus	-	-	-
MTBE	-	-	-

TABLE II-21 a. Estimated annual stormwater mass emissions from each hydrologic unit. Data in percent except as noted.

	TSS	Cd	Cr	Cu	Pb	Ni	Zn	BOD	Nitrate	Phosphate
REGION TOTAL (kg/yr)	310,000,000	2,300	40,000	66,000	81,000	49,000	280,000	16,000,000	1,500,000	510,000
Tomales Bay (220112)	4.8	2.1	3.6	2.7	1.2	2.9	1.5	3.1	4.2	2.6
Tomales Bay (220113)	0.7	0.5	0.9	0.5	0.3	0.8	0.4	0.8	0.4	1.0
Tomales Bay (220114)	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.2
Point Reyes	2.4	0.9	1.6	1.3	0.4	1.2	0.6	1.4	2.2	1.0
Bolinas	0.8	0.7	1.0	0.7	0.5	1.0	0.6	1.0	0.5	1.1
San Francisco - Coastal	0.4	0.9	0.7	0.9	1.2	0.9	1.1	0.8	0.6	0.8
San Mateo - Coastal (220221)	0.9	0.8	0.9	0.8	0.6	0.9	0.7	0.9	0.8	0.9
San Mateo - Coastal (220222)	0.7	0.5	0.7	0.5	0.3	0.6	0.4	0.7	0.6	0.7
San Mateo - Coastal (220223)	1.6	0.7	1.1	0.9	0.4	0.9	0.5	1.0	1.6	0.7
San Gregorio Creek	1.0	0.7	1.1	0.6	0.4	1.0	0.5	1.0	0.6	1.1
Pescadero Creek	2.0	1.2	1.9	1.2	0.6	1.7	0.8	1.8	1.4	1.9
San Rafael	1.6	3.4	2.9	3.3	4.1	3.4	3.8	3.1	2.1	3.1
Berkeley	0.9	2.2	1.4	1.8	2.8	1.8	2.6	1.7	1.1	2.0
San Francisco - Bayside	0.3	0.7	0.5	0.7	1.2	0.6	1.0	0.6	0.4	0.5
East Bay cities	4.7	10	7.1	8.6	12	8.7	11	8.1	5.4	9.7
Alameda Creek	7.7	7.2	7.6	7.0	6.8	7.5	6.9	7.6	7.1	8.0
San Mateo - Bayside	3.4	7.6	5.3	6.4	9.1	6.5	8.6	6.1	3.9	7.3
Fremont Bayside	1.3	2.0	1.6	1.7	2.2	1.8	2.1	1.7	1.3	2.0
Coyote Creek	4.5	5.9	5.0	5.4	6.2	5.4	6.1	5.3	4.5	5.9
Guadalupe River	2.0	3.6	2.9	3.4	4.2	3.4	4.0	3.1	2.4	3.3
Palo Alto	4.4	9.4	6.9	8.2	11	8.3	11	7.8	5.1	8.8
Novato	2.6	2.7	2.8	2.8	3.1	2.8	2.9	2.8	2.8	2.6
Petaluma River	7.4	4.0	5.4	5.1	2.8	4.4	3.3	4.7	7.5	3.6
Sonoma Creek	9.1	4.2	6.2	5.6	2.5	4.8	3.1	5.3	9.0	3.8
Napa River	17	10	13	12	8.4	11	9.0	12	16	10
Pinole	1.2	2.6	1.8	2.1	2.7	2.2	2.7	2.1	1.3	2.6
Fairfield (220721)	2.3	2.2	2.3	2.1	1.7	2.2	1.9	2.3	2.1	2.4
Fairfield (220722)	1.4	0.7	1.2	0.8	0.4	1.0	0.5	1.1	1.2	1.0
Fairfield (220723)	8.2	4.3	5.6	5.6	4.0	4.5	4.1	4.9	8.5	3.4
Fairfield (220724)	0.4	0.3	0.4	0.2	0.1	0.4	0.2	0.4	0.2	0.5
Concord (220731)	2.2	3.2	2.6	2.9	3.8	2.9	3.6	2.8	2.3	3.0
Concord (220732)	1.1	2.1	1.9	2.0	2.2	2.1	2.1	2.0	1.3	2.0
Concord (220733)	0.8	1.6	1.2	1.4	1.8	1.5	1.7	1.4	0.9	1.6
Concord (220734)	0.3	0.7	0.4	0.5	0.7	0.5	0.7	0.5	0.3	0.6

TABLE II-21 b. Estimated annual stormwater mass emissions from each hydrologic unit. Data in kg/ha.

	TSS	Cd	Cr	Cu	Pb	Ni	Zn	BOD	Nitrate	Phosphate
Tomales Bay (220112)	580	0.0020	0.057	0.071	0.039	0.056	0.17	20	2.5	0.53
Tomales Bay (220113)	210	0.0012	0.034	0.030	0.024	0.039	0.10	13	0.56	0.49
Tomales Bay (220114)	230	0.0011	0.032	0.032	0.020	0.035	0.092	12	0.73	0.42
Point Reyes	550	0.0016	0.049	0.063	0.023	0.045	0.12	16	2.4	0.40
Bolinas	190	0.0012	0.030	0.032	0.032	0.036	0.12	12	0.60	0.42
San Francisco - Coastal	220	0.0038	0.051	0.10	0.17	0.076	0.54	23	1.5	0.72
San Mateo - Coastal (220221)	370	0.0024	0.048	0.069	0.070	0.058	0.26	19	1.6	0.64
San Mateo - Coastal (220222)	300	0.0014	0.037	0.043	0.035	0.041	0.14	14	1.1	0.45
San Mateo - Coastal (220223)	600	0.0019	0.053	0.074	0.034	0.050	0.16	18	2.8	0.43
San Gregorio Creek	230	0.0011	0.031	0.032	0.022	0.036	0.097	12	0.72	0.42
Pescadero Creek	280	0.0012	0.035	0.037	0.022	0.039	0.10	13	1.0	0.44
San Rafael	320	0.0049	0.073	0.14	0.21	0.10	0.67	31	2.0	1.0
Berkeley	310	0.0059	0.065	0.14	0.26	0.10	0.83	31	1.9	1.2
San Francisco - Bayside	290	0.0057	0.069	0.15	0.35	0.11	0.98	32	2.2	0.96
East Bay cities	270	0.0044	0.053	0.11	0.18	0.079	0.59	24	1.5	0.92
Alameda Creek	260	0.0018	0.033	0.049	0.058	0.039	0.21	13	1.1	0.43
San Mateo - Bayside	250	0.0041	0.050	0.099	0.17	0.074	0.56	23	1.4	0.87
Fremont Bayside	210	0.0024	0.033	0.060	0.092	0.045	0.31	14	1.0	0.53
Coyote Creek	290	0.0029	0.042	0.075	0.11	0.056	0.36	18	1.4	0.63
Guadalupe River	290	0.0039	0.054	0.10	0.16	0.077	0.52	23	1.7	0.78
Palo Alto	230	0.0036	0.047	0.092	0.16	0.069	0.50	21	1.3	0.76
Novato	440	0.0034	0.060	0.10	0.14	0.075	0.44	24	2.2	0.71
Petaluma River	610	0.0025	0.057	0.089	0.060	0.057	0.24	20	3.0	0.49
Sonoma Creek	660	0.0022	0.058	0.087	0.047	0.055	0.20	20	3.2	0.45
Napa River	550	0.0025	0.056	0.085	0.072	0.059	0.27	20	2.6	0.55
Pinole	250	0.0039	0.048	0.091	0.15	0.071	0.50	22	1.3	0.88
Fairfield (220721)	320	0.0022	0.040	0.060	0.062	0.048	0.24	16	1.4	0.55
Fairfield (220722)	340	0.0012	0.036	0.042	0.022	0.036	0.10	13	1.4	0.38
Fairfield (220723)	620	0.0024	0.055	0.090	0.080	0.054	0.28	19	3.1	0.43
Fairfield (220724)	110	0.0005	0.016	0.014	0.009	0.019	0.042	6	0.30	0.23
Concord (220731)	240	0.0026	0.037	0.067	0.11	0.050	0.35	16	1.2	0.54
Concord (220732)	170	0.0022	0.035	0.063	0.085	0.049	0.28	15	0.95	0.49
Concord (220733)	200	0.0031	0.041	0.077	0.12	0.060	0.40	18	1.1	0.67
Concord (220734)	320	0.0051	0.056	0.11	0.19	0.084	0.66	26	1.7	1.1

TABLE II-22. Estimated annual stormwater mass emissions from each land use category.
- indicates data are insufficient to estimate loads.

	Total (kg/yr)	Residential (%)	Commercial (%)	Industrial (%)	Agricultural (%)	Open (%)
Suspended solids	310,000,000	11	7	9	51	22
BOD	16,000,000	24	14	16	21	26
COD	-	-	-	-	-	-
CBOD	-	-	-	-	-	-
Nitrate-N	1,500,000	18	11	8	53	11
Nitrite-N	-	-	-	-	-	-
Ammonia-N	-	-	-	-	-	-
Total phosphorus	-	-	-	-	-	-
PO4-P	510,000	22	13	26	9	30
Cadmium	2,300	26	18	25	15	15
Chromium	40,000	22	12	12	27	27
Copper	66,000	28	17	15	26	14
Lead	81,000	24	41	23	6	7
Mercury	-	-	-	-	-	-
Nickel	49,000	27	15	16	17	25
Selenium	-	-	-	-	-	-
Zinc	280,000	25	31	25	9	10
Total PCB	-	-	-	-	-	-
Total PAH	-	-	-	-	-	-
Total DDT	-	-	-	-	-	-
Total Chlordane	-	-	-	-	-	-
Dieldrin	-	-	-	-	-	-
Chlorpyrifos	-	-	-	-	-	-
Diazinon	-	-	-	-	-	-
Dioxins	-	-	-	-	-	-
Total coliform	-	-	-	-	-	-
Fecal coliform	-	-	-	-	-	-
Enterococcus	-	-	-	-	-	-
MTBE	-	-	-	-	-	-

TABLE II-23. Comparison of load estimates for stormwater from this study with estimates from other studies.
Estimates for other studies include the Delta, which was not included in this study. Data in metric tones/yr.

	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
BCDC (1991)	3.8	48	67	71	44	370
Gunther et al. (1987)	0.3-3	3-15	7-59	30-250	-	34-270
NOAA (1988)	2	13	53	222	-	239
Gunther et al. (1991)	1.2-2.3	20-44	33-65	50-107	25-71	280-740
This study	1.3-3.7	22-64	36-110	44-150	27-78	150-470

III. EFFLUENT DISCHARGES

Description of Pathway

The term "effluent discharges" as used in this report includes both publicly owned treatment works (POTWs) and industrial effluents. POTWs are facilities that receive and treat sanitary waste from the surrounding municipality. The sources of sanitary waste include inputs from domestic and industrial sewerage systems. Industrial facilities also employ processes that generate wastewater. Most industries discharge their wastewater to POTWs via the sewer system. A smaller number of industrial facilities treat their own wastewater and discharge it to the Bay.

In the San Francisco Bay region, effluent discharges are currently considered to be a potentially significant pathway for only two high priority contaminants: selenium and organophosphate pesticides (Davis et al. 2000). Contaminant loading from effluent discharges is relatively well characterized, as effluent monitoring under the NPDES program has been in place for decades. Other pollutants of concern in effluents have largely been effectively managed by pollution prevention and wastewater treatment.

The effluent discharges included in the analysis account for more than 85% of the flow from all discharges in the region (Table III-1). Fourteen POTWs and six industrial discharges were included. The largest dischargers, especially San Jose/Santa Clara, East Bay MUD, San Francisco Southeast, and Central Contra Costa Sanitation District, account for most of the effluent flow and contaminant loads.

Methods

Compliance monitoring data from 1998 were used to estimate mass loads. Final effluent samples are collected just prior to discharge and, depending upon the constituent, were measured between daily and annual intervals. We obtained the effluent monitoring data from NPDES annual reports submitted by each discharger to the Regional Water Quality Control Board.

Mass loads were calculated according to Equation 4:

$$ME = \sum_{k=1}^{n} (C_k * Q_k * T_k) \qquad \text{Equation (4)}$$

where:

ME	=	Annual mass loads
C	=	mean constituent concentration for month k
Q	=	mean daily effluent flow for month k
T	=	number of days in month k
n	=	months of the year.

The influences of the BDL results on the estimated loads were evaluated by also performing the calculations with these results set to the detection limit.

Results and Discussion

Estimated total loads of contaminants from effluent discharges are presented in Table III-2. The influence of BDL values is illustrated by calculating loads with these values set either to zero or the detection limit. A prevalence of BDL values had a significant effect on estimates for cadmium, lead, PCBs, PAHs, and DDTs. For comparison with other pathways we used estimates with BDL values set to zero.

TABLE III-1. List of effluent discharges included in the analysis and their average daily discharge volumes for 1998.

Facility	Flow (MGD)	Treatment
San Jose/Santa Clara WPCP	133	Advanced
East Bay MUD	92	Secondary
City & Co. of S.F., Southeast	87	Secondary
Union Sanitary District-Alvarado	31	Secondary
Central Contra Costa S.D	52	Secondary
City & Co. of S.F., Oceanside	23	Secondary
City of Palo Alto	29	Advanced
City of Sunnyvale	18	Advanced
So. Bayside System Authority	21	Secondary
Fairfield Suisun Sewer Dist.	17	Secondary
Vallejo Sanitation & Flood Cont.	14	Secondary
LAVWNMA, Livermore-Amador Valley WMA	NA	Secondary
City of San Mateo	15	Advanced
So. S.F./ San Bruno WQCP	11	Secondary
C&H Sugar	1	Activated sludge
Tosco Corp. at Avon	5	Pond/RBC/carbon
Tosco Corp. at Rodeo	3	Pond/RBC/carbon
Shell Oil Company	6	Activated sludge/carbon
EXXON	3	Activated sludge/carbon
Chevron U.S.A.	8	Activated sludge/wetland

TABLE III-2. Estimated mass emissions from effluent discharges for 1998. The influence of BDL values is illustrated by calculating emissions with BDL values set either to zero or the detection limit. Data in kg/yr. - indicates data are insufficient to calculate loads.

Constituent	BDL = 0	BDL = Detection limit
Suspended solids	7,500,000	7,500,000
BOD	900,000	910,000
COD	1,500,000	1,500,000
CBOD	830,000	830,000
Nitrate-N	3,000,000	3,000,000
Nitrite-N	110,000	110,000
Ammonia-N	2,000,000	2,000,000
Total phosphorus	55,000	55,000
PO4-P	970,000	970,000
(Arsenic)	750	1,800
Cadmium	83	280
Chromium	1,300	1,700
Copper	5,900	6,200
Lead	700	1,300
Mercury	23	30
Nickel	4,800	5,200
Selenium	1,700	1,800
(Silver)	440	960
Zinc	34,000	34,000
Total PCB	0	16
Total PAH	200	1,100
Total DDT	0	1
Total Chlordane	0	0
Dieldrin	0	0
Chlorpyrifos	0	0
Diazinon	-	-
Dioxins	0	0
Total coliform	-	-
Fecal coliform	-	-
Enterococcus	-	-
MTBE	-	-

IV. ATMOSPHERIC DEPOSITION

Description of Pathway

Contaminants in the atmosphere deposit on both land and water surfaces. Deposition to the land results in transfer to the Bay in stormwater runoff, and is accounted for in the estimates for that pathway. Direct deposition to the Bay is another potentially significant loading pathway. Available information suggests that direct atmospheric deposition may be a significant pathway for loading of PAHs, PCBs, and mercury (Davis et al. 2000). Atmospheric deposition may also be a significant component of the dioxin mass budget for the Bay.

The Regional Monitoring Program initiated an Atmospheric Deposition Pilot Study in 1999 to address the lack of local data on this pathway. Preliminary results from sampling in 1999 are provided in this section. These data are used to estimate the possible magnitude of loads to the Bay as a whole from direct atmospheric deposition.

Methods

Atmospheric deposition data from the three SFEI Air Deposition Pilot Study sites (Figure IV-1) (SFEI 2000) was used to estimate dry deposition loadings of copper, nickel, cadmium, and chromium to the open Bay waters. The dry deposition values were measured in $ug/m^2/day$ between August 31 and December 22 (Table IV-1). Total loads from dry deposition were obtained by calculating an average daily rate for each contaminant and multiplying by the number of days in a year. Cumulative wet deposition for the time period September 14 to December 21 was measured in units of ug/m^2 for the same suite of metals. Wet deposition of mercury was measured in units of ng/m^2 for the time period September 14 to November 9 (Table IV-1). Total wet deposition loads were extrapolated from the measured data based on the fraction of the annual average rainfall for the Bay (21 in, estimated from Figure II-5) that fell during the sampling period.

Results and Discussion

Estimated rates of dry, wet, and total atmospheric deposition of copper, nickel, cadmium, and chromium are presented in Table IV-2. Dry and total rates of mercury deposition are not available. Notably absent from the table are PAHs, PCBs, and dioxins; direct atmospheric deposition may be significant for these contaminants but local data are very limited for PAHs and nonexistent for PCBs and dioxins.

FIGURE IV-1. Sampling locations for estimation of loads from the rivers and from atmospheric deposition. A color version of this figure can be viewed at the SFEI website: www.sfei.org under Contaminant Monitoring and Research.

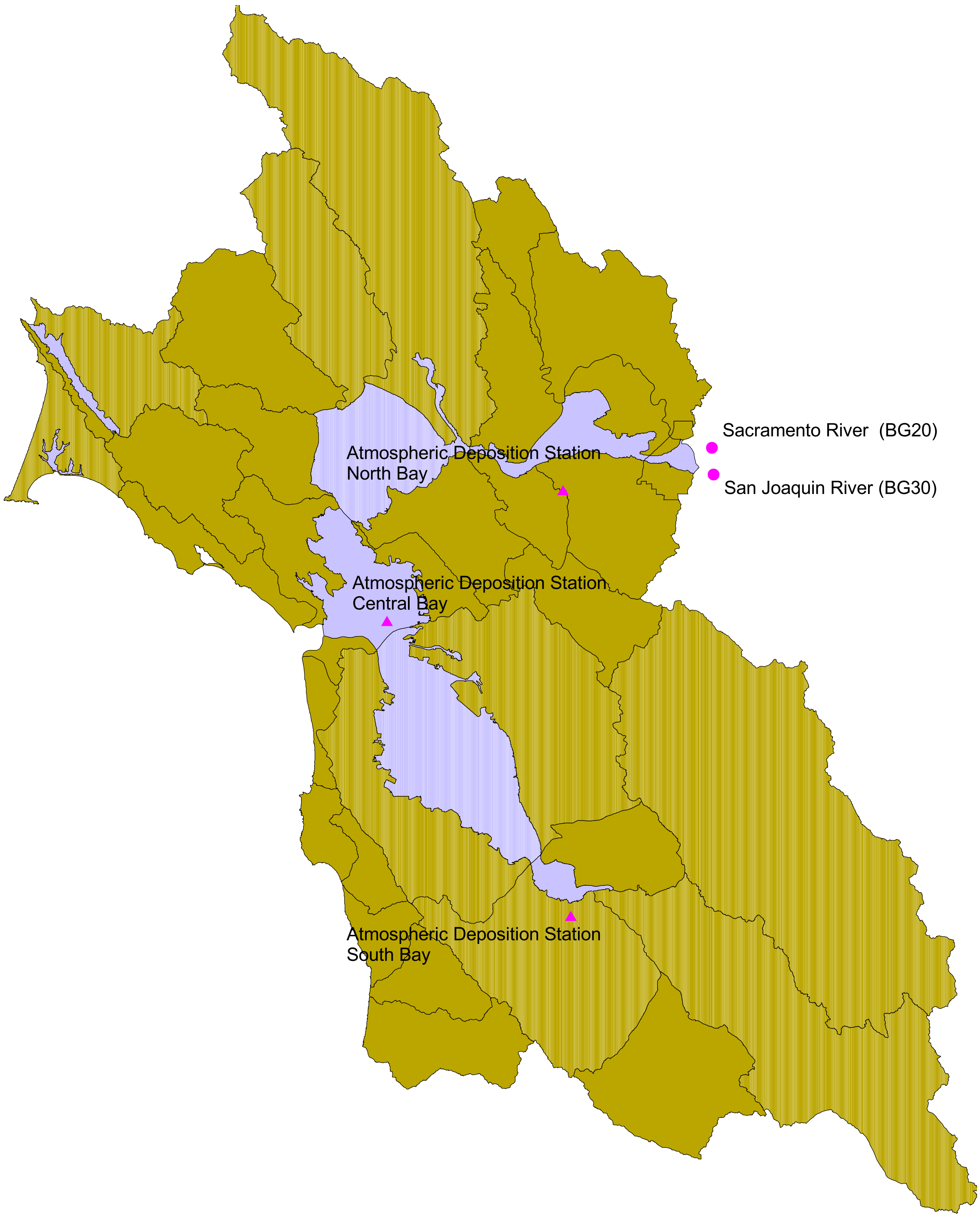


TABLE IV-1. Measured rates of direct atmospheric deposition to the Bay.
Initial results of the RMP Atmospheric Deposition Pilot Study.

Direct Dry Deposition of Trace Metals (ug/m2/day) (August 31 to December 22, 1999)					
		South Bay	Central Bay	North Bay	MDL
Cu	Sept	2.55	3.48	2.87	0.18
	Oct	0.95	0.54	1.03	
	Nov	2.04	3.81	2.42	
	Dec	2.28	1.2	1.68	
		South Bay	Central Bay	North Bay	MDL
Ni	Sept	2.17	2.22	2.55	0.18
	Oct	0.6	0.33	1.22	
	Nov	0.85	0.94	0.78	
	Dec	1.08	1.04	0.99	
		South Bay	Central Bay	North Bay	MDL
Cd	Sept	0.05	0.06	0.06	0.06
	Oct	0.07	0.09	0.13	
	Nov	0.06	0.06	0.09	
	Dec	0.03	0.06	0.16	
		South Bay	Central Bay	North Bay	MDL
Cr	Sept	2.51	3.06	2.47	0.96
	Oct	1.28	1.9	1.89	
	Nov	1.23	1.11	1.25	
	Dec	1.71	1.4	1.7	

Wet Deposition of Trace Metals (Cumulative Deposition from September 14 to December 21, 1999)			
	South Bay	Central Bay	North Bay
Cu (ug/m2)	13.74	40.49	32.86
Ni (ug/m2)	7.05	14.66	20.89
Cd (ug/m2)	0.39	0.99	0.72
Cr (ug/m2)	14.54	27.2	30.75
Rainfall (cm)	3.15	8.46	4.52

Wet Deposition of Mercury (Cumulative Deposition from September 14 to November 9, 1999)			
Hg (ng/m2)	172.59	451.46	496.19
Rainfall (cm)	1.93	4.14	1.47

NOTES:
1. Dry deposition: 24-hour cumulative sampling every 14 days.
   Each data set represents the average deposition rate during the month.
2. Wet deposition: 14-day cumulative rain sampling
   Each data set represents the cumulative wet deposition for the entire duration noted.

TABLE IV-2. Preliminary estimates of direct atmospheric deposition to the Bay. Based on initial results of the RMP Atmospheric Deposition Pilot Study. - indicates data not available.

	Average dry deposition (kg/yr)	Average wet deposition (kg/yr)	Total atmospheric deposition (kg/yr)
Cu	856	207	1064
Ni	509	101	611
Cd	32	5	37
Cr	741	173	914
Hg	-	5.5	-

V. DREDGED MATERIAL DISPOSAL

Description of Pathway

Dredged materials are any bottom sediments excavated from the navigable waterways of the United States. Dredged materials are derived from coastal development, such as the construction or modification of ports and marinas, referred to as "new work dredging". Dredging is also used to maintain the navigable channels for shipping ("maintenance dredging"). In the Bay area, dredged material is disposed of at aquatic sites in the Bay or offshore and at upland disposal sites. Contaminants derived from shipping and boating activities, stormwater runoff, effluent discharges, atmospheric deposition, and other pathways become incorporated into these bottom sediments. Disposal of dredged material can introduce these accumulated contaminants to new environments.

Dredged material disposal is considered to be a minor pathway for the loading of contaminants to the Bay (Davis et al. 2000). Copper is the only contaminant where this pathway may be significant (Davis et al. 2000). With regard to loading to the Bay, maintenance dredging and dredged material disposal either serve to redistribute sediments within the Bay (for in-Bay disposal), which doesn't affect a Bay-wide mass budget, or to remove sediment from the Bay (ocean or upland disposal), which represents a loss term in a mass budget. In-Bay disposal was not evaluated for this project. On the other hand, offshore disposal in the Bay region does represent a potentially significant pathway for new inputs to the offshore environment, and this pathway was evaluated.

Methods

The quality of dredged materials is determined by chemical analysis and toxicity testing according to the USEPA and the USACE guidance (1991). The USACE maintains a database (the Ocean Disposal Dataset) that includes information on chemical concentrations and disposal volumes.

Data were obtained from the Ocean Disposal Dataset from the San Francisco Region for 1995. There were two Bay area dredging sites using offshore disposal, the Port of San Francisco and Oakland Harbor. Dredged materials from the San Francisco site were disposed of at the San Francisco Channel Bar, and the Oakland Harbor dredged materials were disposed of at the San Francisco Deep Ocean site. Contaminant loads for dredged sediment volumes were calculated based on a sediment density value of 1.087 g/cm^3. Concentrations of most contaminants were not reported for the Oakland Harbor material.

Results and Discussion

Total reported loads for these two sites in 1995 are presented in Table V-1.

TABLE V-1. Estimated annual contaminant loads to the Bay from dredged material disposal. Based on data from 1995. Data in kg/yr. - indicates data are insufficient to estimate loads.

	San Francisco (SF Channel Bar)
Total solids	18,000
BOD	-
COD	-
CBOD	-
Nitrate-N	-
Nitrite-N	-
Ammonia-N	-
Total phosphorus	-
PO4-P	-
(Arsenic)	-
Cadmium	0
Chromium	15,000
Copper	1,200
Lead	1,300
Mercury	6
Nickel	9,700
Selenium	0
(Silver)	0
Zinc	8,100
Total PCB	-
Total PAH	210
Total DDT	0
Total Chlordane	0
Dieldrin	0
Chlorpyrifos	-
Diazinon	-
Dioxins	-
Total coliform	-
Fecal coliform	-
Enterococcus	-
MTBE	-

VI. COMPARISON OF PATHWAYS IN THE BAY REGION

The relative magnitudes of loads from the pathways discussed in this report are compared in Table VI-1. The uncertainty associated with the estimate for each category must be kept in mind as these data are evaluated. Estimates for effluent discharges are the most accurate because they are based on a relatively large amount of quantitative data. The estimates for stormwater runoff are preliminary, are acknowledged to be underestimates, and only intended, at best, to be accurate within one order of magnitude. The values listed for runoff in the table should be considered as indicative of the order of magnitude range that contains the actual value. Estimated rates of atmospheric deposition are also preliminary and uncertain, based on extrapolation of a very limited dataset.

Meaningful comparisons among pathways could only be made for two contaminants that are currently high priority concerns in the Bay: copper and nickel. Insufficient data were available for other priority contaminants (including mercury, PCBs, diazinon, chlorpyrifos, DDT, chlordane, dieldrin, and dioxins) to allow comparisons using the modeling approach employed in this report.

The estimates that could be generated with the selected approach, even though they underestimate actual loads of particle-associated contaminants, suggest that metal loads from stormwater runoff are greater than those from effluent discharges. Loads of copper and nickel from Bay Area stormwater runoff are 11-fold and 10-fold greater, respectively, than loads from Bay Area effluents (Table VI-1). Although data were insufficient to evaluate other priority contaminants with the model, other sources of information suggest that stormwater runoff is also a significant pathway for mercury, PCBs, PAHs, organophosphate pesticides, organochlorine pesticides, and dioxins (Davis et al. 2000).

As mentioned in the previous discussion of concentration data used in the stormwater model, estimates could be generated for other priority contaminants using other approaches. The draft TMDL report for mercury is a good example of this type of analysis (SFBRWQCB 2000). In the TMDL report suspended sediment load data generated from this report and other sources were combined with regional data on concentrations of mercury in suspended sediment to generate estimated loads from the regional watershed. A best estimate watershed load of mercury was 170 kg/yr; this included 50 kg from one particularly contaminated sub-watershed (the Guadalupe River). Watershed loads of mercury were higher than the best estimate for loads from effluent discharges (44 kg/yr).

Preliminary data from the RMP Atmospheric Deposition Pilot Study for copper, nickel, and two other metals suggest that atmospheric deposition is a minor pathway for these contaminants.

TABLE VI-1. Comparison of pathways of contaminant loads to the Bay.
- indicates data are insufficient to calculate loads.

Constituent	Total Load (kg/yr)	Runoff (%)	Effluent discharges (%)	Atmospheric deposition (%)	Dredged material disposal (%)
Suspended solids	320,000,000	98	2.4	-	0
BOD	-	-	-	-	-
COD	-	-	-	-	-
CBOD	-	-	-	-	-
Nitrate-N	4,500,000	33	67	-	-
Nitrite-N	-	-	-	-	-
Ammonia-N	-	-	-	-	-
Total phosphorus	-	-	-	-	-
PO4-P	1,500,000	34	66	-	-
Cadmium	2,400	95	3.4	1.5	0.0
Chromium	57,000	70	2.3	1.6	26
Copper	74,000	89	8.0	1.5	1.6
Lead	-	-	-	-	-
Mercury	-	-	-	-	-
Nickel	64,000	76	7.5	0.9	15
Selenium	-	-	-	-	-
Zinc	320,000	87	11	-	2.5
Total PCB	-	-	-	-	-
Total PAH	-	-	-	-	-
Total DDT	-	-	-	-	-
Total Chlordane	-	-	-	-	-
Dieldrin	-	-	-	-	-
Chlorpyrifos	-	-	-	-	-
Diazinon	-	-	-	-	-
Dioxins	-	-	-	-	-
Total coliform	-	-	-	-	-
Fecal coliform	-	-	-	-	-
Enterococcus	-	-	-	-	-
MTBE	-	-	-	-	-

VII. LOADS FROM THE CENTRAL VALLEY REGION

Description

The drainage basin of the Sacramento and San Joaquin Rivers (referred to as "the rivers" below) comprises about 37% of the land area of the State of California and the Rivers carry between 40 and 50% of the freshwater runoff in the State. Contaminant loading from the rivers to coastal waters is considered to be significant for mercury, selenium, nickel, silver, and registered pesticides, and possibly significant for PCBs, PAHs, copper, and cadmium (Davis et al. 2000). Our existing understanding of contaminant loading from the rivers is generally weak because few data are available on contaminant transport during the individual storms that transport large proportions of total annual loads.

The Central Valley region contains its own array of contaminant pathways, including stormwater runoff, effluent discharges, and others. Preparing an inventory of loads from every pathway in the upper watershed was beyond the scope of this project. As an alternative, empirically measured concentrations obtained in the Regional Monitoring Program for two stations at the point where the rivers enter the Bay were used to estimate total loads from the upper watershed. The estimates for the rivers represent total loads - a mixture of contaminants from stormwater runoff and all other pathways. A population-based estimate of the loads from effluent discharge in the upper watershed was used to attempt to separate the contributions of point vs. non-point loads.

Methods

RMP sampling sites at the Sacramento and San Joaquin Rivers near their confluence were chosen in order to represent the Delta drainage (Figure IV-1). Freshwater inflow to the Bay in this area is a complex function of river flows, tidal circulation, and water export from the Delta. Water quality data from the two RMP stations were averaged, and then multiplied by the Delta outflow volume on the date of sample collection. These values were calculated for each sampling event. The average of these values for the period 1993-1998 was then calculated to obtain average daily loads. The annual estimates are based on extrapolation of these average daily loads. Delta outflow values were from the DAYFLOW program (DAYFLOW 1998).

An advantage of using RMP data is that all priority contaminants are quantified in most samples. Consequently, BDL values are not an impediment to using these data.

Results and Discussion

Actual loads to the Bay from the rivers are probably greater than estimated in this analysis (Table VII-1). As mentioned previously, a large proportion of the annual transport of many contaminants will occur after specific storms, such as those that result in significant transport of contaminated particles or that coincide with pesticide applications on agricultural lands. The RMP data used in the calculations were not designed to characterize these events. Event-based sampling would be required to accurately characterize transport of contaminants by the rivers.

Cataloging all of the NPDES discharges in the Central Valley was beyond the scope of this study. As an alternative, Table VII-1 presents a crude estimate of effluent discharge loads in the Valley based on the data gathered for the Bay region. The 1998 population of the Bay region, using the boundaries as defined by the Project, was 6.3 million (ABAG 2000). The population of the Central Valley region in 1998 was 5.9 million (California Department of Finance 2000). Effluent contaminant discharge rates from the Bay area were extrapolated to the Central Valley region using these population figures. This is obviously an imperfect comparison, as the effluent discharges in the Central Valley may have different chemical composition than Bay area effluents, but it does give a gross indication of how much of the total input from the Central Valley may come from effluents. In general, the effluents are a minor fraction of the total estimated load from the Central Valley. Exceptions are the nutrients ammonia and phosphate, silver, PAHs, and selenium. The selenium estimate is probably not appropriate for the Valley as it is influenced by the several refinery discharges in the Bay region. Overall, this comparison suggests that most of the total estimated riverine contaminant transport is not attributable to effluent discharges. Since the riverine estimates are considered to be too low, effluents in the upper watershed are probably even smaller contributors than indicated by these calculations.

The contribution of stormwater runoff to riverine loads was not estimated, but probably is substantial. Recent studies of riverine transport of mercury (Larry Walker Associates 1997, Foe and Croyle 1998), organophosphate pesticides (Kuivila and Foe 1995), and organochlorine pesticides (Kratzer 1998) indicate that stormwater runoff is a major pathway for loading of many priority contaminants from the Central Valley.

TABLE VII-1. Estimated contaminant loads to the Bay from the Central Valley Region and estimated contribution of effluent discharges to the total loads.
- indicates data are insufficient to calculate loads.

Constituent	Central Valley (kg/yr)	Estimated contribution of effluent discharges in the upper watershed (%)
Suspended solids	3,500,000,000	0
BOD	-	-
COD	-	-
CBOD	-	-
Nitrate-N	43,000,000	6
Nitrite-N	2,200,000	5
Ammonia-N	5,100,000	38
Total phosphorus	-	-
PO4-P	6,400,000	14
Cadmium	1,600	5
Chromium	550,000	0
Copper	270,000	2
Lead	64,000	1
Mercury	710	3
Nickel	410,000	1
Selenium	9,700	16
Zinc	3,800,000	1
Total PCB	11	1
Total PAH	410	44
Total DDT	44	0
Total Chlordane	9	0
Dieldrin	8	0
Chlorpyrifos	28	0
Diazinon	1,100	0
Dioxins	-	-
Total coliform	-	-
Fecal coliform	-	-
Enterococcus	-	-
MTBE	-	-

VIII. CONCLUSIONS

- Bay Area stormwater runoff accounts for a large proportion of regional loading of some contaminants to the Bay in spite of the probable under estimation using the simple model. Stormwater loads of copper and nickel, the two priority contaminants with sufficient data to apply the model, were approximately 10 times higher than combined loads from municipal and industrial effluents.

- A lack of concentration data for many priority contaminants precluded modeling these contaminants with the approach selected. Other sources of information indicate that stormwater loadings of many priority contaminants are probably significant components of Bay-wide mass budgets.

- Stormwater load calculations are sensitive to variability (real fluctuations in time or space) and uncertainty (the imprecision of measurement) in rainfall, runoff coefficients, and in the concentration data used as input. Average annual total stormwater emissions to coastal waters in the Bay region can be expected to be extremely variable and difficult to estimate with precision.

- Contaminant loads from the Central Valley region to the coast are significant, and stormwater probably accounts for a substantial portion of these loads.

IX. RECOMMENDATIONS FOR IMPROVING STORMWATER EVALUATION IN THE SAN FRANCISCO BAY REGION

Stormwater runoff is a potentially significant pathway for many priority contaminants and there is a clear need for better information on stormwater loads to coastal waters of the San Francisco Bay region. Discussions with Bay region technical experts led to the development of a general strategy for obtaining, in a cost-effective manner, the knowledge needed for well-informed management of stormwater loads.

The development of explicit statements of management needs was beyond the scope of this project. The implementation of these recommendations should be preceded by a process in which the appropriate stakeholders develop an adaptive management framework including goals, management questions or information needs, data assessment methods, data use agreements, and public information and participation. Development of such a framework will help ensure that implementation of the recommendations is purposeful, useful, and ultimately successful in improving the results of watershed management.

The simple model used in this report was intended only to provide preliminary estimates of emissions, and does not provide a sound basis for stormwater management decisions at the regional level. More sophisticated models and monitoring approaches will be needed to decide how to manage stormwater emissions in the Bay region. Stormwater monitoring is technically challenging and expensive, and it would be prohibitively expensive to monitor stormwater emissions in every Bay Area coastal watershed. A more pragmatic approach to stormwater evaluation is to gather information from carefully selected watersheds that are representative of other watersheds, and to extrapolate results from the monitored watersheds to the unmonitored watersheds. A general strategy with the following series of steps is recommended.

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.

More specific recommendations to implement this general strategy are presented below.

Recommended Elements Of Stormwater Load Evaluation Strategy

a. Watershed Characterization

1) It is recommended that we characterize and classify our watersheds with regard to the basic properties that determine stormwater transport of priority contaminants. Some of these properties include the distribution of contaminant sources, climate, land use, geology, human demographics, and stormwater conveyances. A good example of this type of compilation has just been completed for the Wildcat Creek watershed (SFEI 2000a). We recommend that a classification system be developed to incorporate these, and other important factors, into a watershed 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. This information should be used to select representative Observation Watersheds for detailed, long-term evaluation. A review of existing information on locations and magnitudes of various possible sources will be essential in this characterization process.

b. Conceptual Model Development

2) It is recommended that conceptual models be developed for stormwater flow and for each priority contaminant in stormwater runoff that includes, to the extent possible, qualitative or quantitative description of processes that are important in stormwater transport. These conceptual models can be developed at different scales depending on management needs, should help to direct the allocation of resources and time, and should be easily understood by decision makers.

3) It is recommended that conceptual models of contaminant processes and transport by stormwater should be coupled with conceptual models and mass budgets for contaminant fate and effects in the Estuary. Fate models are essential for TMDLs, for placing estimated loadings in the context of regional mass budgets, and for assessing the response time of the Estuary to changes in contaminant inputs resulting from stormwater management.

c. Develop Evaluation Strategies

4) It is recommended that we characterize contaminants into broad classes based on their physical and chemical properties and uses. Possible classifications include those that are dominated by effluent discharges, those that are strongly associated with sediment, those that are banned and therefore are related to historical uses and distributions, those that are organic, and those that have volatile pathways. Another important classification will be those for which distributions can be predicted with land use-based models versus those with stochastic distributions that cannot be reliably predicted based on land use. The spatial distribution of

some contaminants (such as copper and perhaps PAHs) can be predicted based on land use patterns. The spatial distribution of other contaminants (PCBs are a likely example) may be unrelated to land use - alternative approaches should be developed for these kinds of contaminants.

d. Detailed Study of Observation Watersheds

5) More detailed stormwater loading evaluations should be done on selected watersheds in a strategic manner that is tailored to management needs (e.g., TMDLs) and the distribution and properties of each contaminant. Improved estimates are NOT needed of the annual average regional stormwater contaminant loadings for management of stormwater in the Bay region. The current effort and previous efforts have estimated annual average loads on an order of magnitude basis adequately. More data and the use of more sophisticated modeling methods are unlikely to substantially improve annual average region-wide estimates relative to the time and cost. Improved estimates ARE needed of stormwater emissions from selected, representative watersheds, which can be monitored and modeled in a manner that does not oversimplify the complexities of contaminant transport in stormwater, that is cost-effective, and that yields technically sound results.

6) Conduct long-term studies in a number of Observation Watersheds in the region that represent different urban landscapes, different hydrological, climatological, and geological types. The number and locations of Observation Watersheds should be carefully considered in the context of the overall stormwater evaluation strategy. These 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. Eventually, the region should have several Observation Watersheds that capture the range of variability among watersheds in the region. In this way, high quality data will be obtained, a firm basis for long term trend analysis will be established, and results will be generated that can be extrapolated to other watersheds in each region that are sampled less intensively. This would provide a cost effective approach to obtaining the technically sound information needed for management of stormwater over the long term.

7) Once sources have been identified and management techniques have been put in place, it is recommended that long term monitoring within specific areas of Observation Watersheds can provide evidence of the effectiveness of management techniques with the caveat that the signal to noise ratio for determining temporal trends may only be high for certain BMPs. For some contaminants, a trend may never be seen due to confounding factors such as annual variations in the timing, quantity, spatial heterogeneity and intensity of rainfall, atmospheric deposition of pollutants, naturally occurring substances, or the BMPs only having a small positive effect.

8) Stormwater loading evaluations based on reliable concentration data for priority pollutants (mercury, PCBs, PAHs, registered pesticides, and selenium) are needed in Observation Watersheds. Future field studies for these priority contaminants should employ analytical methods that are sensitive enough to yield quantitative data that are useful in load estimation.

9) It is recommended that data be collected for specific land uses in agricultural sectors so that a better understanding can be gained for the likely relationships between land use in the farming sector and contaminant transport to the Estuary. Data on runoff coefficients and contaminant concentrations are currently lacking for agricultural land use in the Bay area, which may account for a significant fraction of loads. Specifically, storm event sampling needs to be done in carefully selected stream locations that drain small homogeneous agricultural watersheds of specific land use types (e.g., vineyards). This recommendation has direct consequence to the TMDL process and possible implementation of BMPs.

10) It is recommended that better data be collected for the open space land use category using an event-based sampling approach in carefully selected representative homogeneous portions of Observation Watersheds. The open space data available from studies to date are from a few locations during only a few storm events. The available data are insufficient for meaningful extrapolation to other areas of the region. Without such data, compliance concentrations in receiving water bodies or TMDL listed areas of the region may be set lower than background "natural concentrations" and thus compliance may be unattainable.

11) Stormwater contaminant transport is just one component of beneficial use assessment. Water quality studies in Observation Watersheds should be integrated with other watershed assessment efforts so that resources allocated for watershed assessment are used in the most efficient manner possible.

e. Extrapolate to Other Watersheds

12) For priority contaminants with distributions that can be predicted based on land use, it is recommended that future load estimation use more sophisticated modeling approaches that recognize the non-linearity of pollutant processes in the environment. The model may be an empirical spreadsheet / graphical style model or a computer model with more complex algorithms for soil loss, routing, concentration fluctuations and in-stream processes (see Nix 1991 and Trommer et al. 1996 for discussion). Specific models include but are not limited to SWMM, HSPF, STORM, QQS, USGS regional regression with local calibration (e.g. (Driver and Troutman 1989; Barks 1994; Hoos and Patel 1996), or non-linear (annual, seasonal or monthly time-step) regression calculations. Modeling should be coupled with comparisons to empirical data from monitoring to determine the most cost-effective approaches to both modeling and monitoring.

Other Recommendations

13) It is recommended that we continue building institutional structures that enhance collaboration, management questions / hypotheses, standardized data collection, standardized data reporting and interpretation on a regional basis so that duplication is decreased and information is enhanced. All data should follow National Hydrological Data (NHD) format conventions, be subject to agreed-upon QA/QC procedures, and be readily accessible.

14) It is recommended that the current management initiatives (Creek inventories and pilot watersheds) that have been issued to the counties in the San Francisco Bay region be enhanced by the following processes:
   a. Revisit and redefine a set of management questions that will direct the watershed inventory in relation to recommendation 1.
   b. Revisit and redefine a stringent set of management questions that direct the Observation Watershed assessment program in relation to recommendation 6.
   c. Set up a scientific review committee to oversee the design, collection, observation, reporting, and interpretation of data collected (recommendations 1 and 6).
   d. Set up the protocols for observations in the Observation Watersheds so that the data can be collected rigorously, efficiently, and using appropriate methods with oversight from the scientific review committee.
   e. Decide which Observation Watersheds to use ensuring a holistic regional framework.
   f. Carry out data collection / observation of the Observation Watersheds and interpretation presentation of the results.
   g. Have the results independently peer reviewed by qualified scientists.
   h. Develop and maintain a data management approach that provides access to datasets and results.
   h. Instigate further modeling to address new management questions arising from the pilot studies.

15) Investigate the use of, or continue the use of the following indicators of urban sources and loadings in the context of recommendations 6 and 7:
   a. Clam tissue and sediment particles as indicators of urban stormwater contaminant enrichment over the background and trends (RMP special studies).
   b. Tracking BMPs by monitoring street sweeping dirt (e.g., copper is likely to increase due to increased copper use in brake pads of vehicles). Another approach would be to monitor contaminants captured in sediment retention basins.
   c. Assessment of urban stream sediment particle enrichment for various contaminants. These enrichment factors could be monitored over time to

assess BMP effectiveness or spatially to assess influence of natural versus anthropogenic inputs.

16) The Sacramento and San Joaquin rivers are a significant pathway for contaminant loading from the Central Valley region to the coast. Recent studies of mercury, organophosphate pesticides, and organochlorine pesticides indicate that stormwater contributes a large proportion of loads of these contaminants. Stormwater loads from the Central Valley region should be characterized along with loads from other coastal regions.

X. REFERENCES

ABAG. 1995. Description of land use classification categories. Association of Bay Area Governments (ABAG), Oakland, CA.

Anderson, H.W. 1981. Sources of sediment induced reductions in water quality appraised from catchment attributes and land use. Journal of Hydrology 51, 347-358.

Barks, S.C. 1994. Verification and adjustment of regional regression models for urban storm-runoff quality using data collected in Little Rock, Arkansas. U.S. Geological Survey Water Resources Investigations Report 94-4216

BASMAA, 1996. San Francisco Bay Area Stormwater Runoff Monitoring Data Analysis 1988 - 1995. Bay Area Stormwater Management Agencies Association; prepared by URS Greiner Woodward-Clyde.

BCDC. 1991. The effects of land use change and intensification on the San Francisco Estuary. Prepared for the San Francisco Estuary Project, EPA Region IX. 186 pp.

CDFG. 1997. California Department of Fish and Game GIS metadata. California statewide hydrography.
http://www.gislab.teale.ca.gov/meta/hydrogra.txt

CDFG. 1998. California GAP analysis program. California Department of Fish and Game. 1997.
http://www.dfg.ca.gov/whdab/gap.htm

California Department of Finance. 2000. http://www.dof.ca.gov/html/fs_data/stat-abs/tables/b3.xls (17 April 2000).

Davis, J.A., K. Abu Saba and A.J. Gunther. 2000. Technical Report of the Sources, Pathways, and Loadings Workgroup. San Francisco Estuary Institute, Richmond, CA.

Driver, N.E. and B.M. Troutman. 1989. Regression models for estimating urban storm-runoff quality and quantity in the United States. Journal of Hydrology 109, 221- 236.

EPA, 1997. Compendium of tools for watershed assessment and TMDL development. Environmental Protection Agency. EPA841-B-97-006, May 1997.

Foe, C. and W. Croyle. 1998. Mercury Concentrations and Loads from the Sacramento River and from Cache Creek to the Sacramento-San Joaquin Delta Estuary. California Regional Water Quality Control Board, Central Valley Region, Rancho Cordova, CA.

Gunther, A., J. Davis and D. Phillips. 1987. An assessment of the loading of toxic contaminants to the San Francisco Bay Delta. Aquatic Habitat Institute, Richmond, CA. 330 pp.

Hoos, A.B. and A.R. Patel. 1995. Adjustment of regional regression models of urban-runoff quality using data for Chattanooga, Knoxville, and Nashville, Tennessee. U.S. Geological Survey Water Resources Investigations Report 95-4140.

Hoos, A.B. and J.S. Lizarraga. 1996. Procedures for adjusting regional regression models of urban-runoff quality using local data. U.S. Geological Survey Water-supply Paper 2428.

Kratzer, C.R. 1998. Transport of Sediment-Bound Organochlorine Pesticides to the San Joaquin River, California. USGS Open-File Report 97-655. U.S. Geological Survey, Sacramento, CA.

Kuivila, K.M. and C.G. Foe, 1995. Concentrations, transport and biological effects of dormant spray pesticides in the San Francisco Estuary, California. Environ. Tox. and Chem., 14:1141-1150.

Larry Walker Associates. 1997. Sacramento River Mercury Control Planning Project: Final Project Report. Larry Walker Associates, Davis, CA.

Maidment, D.R. (Ed.) 1993. Handbook of hydrology. McGraw-Hill, New York.

Malkovich, J. 1999. Peak storms and error propagation analysis. CRC Press, Auckland, New Zealand.

McKee, L. and B. Eyre. 2000. Nitrogen and phosphorus budgets for the sub-tropical Richmond River catchment, Australia. Biogeochemistry **50**, 207-239.

Milliman, J.D. and J.P.M. Syvitski. 1992. Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. Journal of Geology 100, 525-544.

Milliman, J.D. 1995. Sediment discharge to the ocean from small mountainous rivers: the New Guinea example. Geo-marine Letters 15, 127-133.

NCDC. 1994. Surface land daily cooperative, summary of the day. TD-3210. National Climatic Data Center, Federal Building, Asheville, North Carolina. October 1994.

NCDC. 1998. Surface land daily cooperative, summary of the day. TD-3200. National Climatic Data Center, Federal Building, Asheville, North Carolina. 21 January 1998.

Nix, S.J. 1991. Applying urban runoff models. Water environment and Technology 3, 47-49.

NOAA. 1987. National coastal pollutant discharge inventory: urban runoff methods document with west coast addendum. Strategic Assessments Branch, Ocean Assessments Division, National Oceanic and Atmospheric Administration, Rockville, MD. 20852.

OCS. 1999. Climate mapping with PRISM. Oregon Climate Service. http://www.ocs.orst.edu/prism/prism_new.html

Perkins, J.B., S. Potter and L. Stone. 1991. Status and trends report on land use and population. Prepared by the Association of Bay Area Governments for the San Francisco Estuary Project. U.S. EPA. San Francisco, CA. 186 pp.

Randall, C.W., D.R. Helsel and D.M. Griffin, Jr. 1981. Comparison of pollutant mass loads in precipitation and runoff in urban areas. Second International Conference on Urban Storm Drainage, Urbana, Illinois, USA. June 14-19, 1981. p29-38

SFBRWQCB. 2000. Watershed Management of Mercury in the San Francisco Bay Estuary: Draft Total Maximum Daily Load Report to U.S. EPA. San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

SFEI. 2000a. Draft Version: Wildcat Creek Landscape Change - A History of Sediment-Water Relations and the Role of People in the Wildcat Watershed, Contra Costa County, California. San Francisco Estuary Institute, Richmond, CA.

SFEI. 2000b. 1998 annual report: San Francisco Estuary Regional Monitoring Program for Trace Substances. San Francisco Estuary Institute, Richmond, CA.

Trommer, J.T., J.E. Loper and K.M. Hammett. 1996. Evaluation and modification of five techniques for estimating stormwater runoff for watersheds in west-central Florida. Water-Resources Investigation Report 96-4158. U.G. Geological Survey.

Walling, D.E. and B.W. Webb. 1992. Water quality physical characteristics. In Carlow, P. and Petts, G.E. (Eds.) The Rivers Handbook. Blackwell Science. p48-72.

Webb, B.W. and D.E. Walling. 1982. The magnitude and frequency characteristics of fluvial transport in the Devon drainage basin and some geomorphological implications. Catena 9, 9-23.

Winter, T.C. 1981. Uncertainties in estimating the water balance of lakes. Water Resources Bulletin 17, 82-115.

WITS. 1999. Watershed Information Technical System. California Environmental Resources Evaluation System (CERES), California Resources Agency.

http://ceres.ca.gov/watershed/

Wong, K, E. Strecker and M. Stenstrom. 1997. GIS to estimate storm-water pollutant mass loadings. Journal of Environmental Engineering. August, 1997.