STORMWATER RUNOFF INTO SANTA MONICA BAY: SOURCES AND IMPACTS

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Stormwater Runoff: Sources and Impacts

CHAPTER 112

SURFACE WATER MONITORING UNDER THE COUNTRY'S LARGEST MUNICIPAL STORMWATER PERMIT

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Abstract

The Los Angeles County Department of Public Works and its predecessor Flood Control District have been actively engaged in stormwater quality monitoring for many years. As the principal permittee of the new Los Angeles County Municipal Stormwater NPDES Permit, the Department is undertaking one of the most comprehensive water quality monitoring programs of any municipal stormwater program in the country. The program features water quality monitoring of storm and dry weather flows from both mass emission and land-use specific drainage areas, an illegal connection elimination program, a critical source monitoring program, and a receiving waters impact study. The list of constituents sampled is extensive, including metals, hydrocarbons, pesticides, solids, nutrients, semi-volatile organics, and selected minerals.

The information collected from the monitoring program will be used to: track water quality status, trends, and loads and identify pollutants of concern; monitor and assess land use and watershed pollutant loads; identify and assess significant water quality problems in watersheds; identify sources of pollutants in runoff; identify and eliminate illicit connections and discharges; evaluate the effectiveness of best management practices, and; assess impacts on receiving waters.

Introduction

Los Angeles County is one of the largest governmental jurisdictions in the country. At more than 10,200 square km (4000 square miles) with a population of over 8.8 million, it is larger than two states in size and 42 states in population. Roughly three fourths of the land surface drains to the Pacific Ocean; only the northeast corner of the county drains to the Mojave Desert at the edge of the Great Basin. The downtown Los Angeles area averages about 380 mm (15") of rainfall a year, most of it falling in the six months between October and April. Higher elevations in the San Gabriel Mountains can expect up to 1143 mm (45") of rain a year.

Ever since its inception in 1915, the Los Angeles County Flood Control District has been concerned with inland surface water quality. Because of its mandate to recharge stormwater runoff into underground aquifers, the District has always been concerned with conventional water quality parameters like turbidity and suspended solids. In 1967, the District expanded water quality monitoring into a regularly scheduled activity of dry weather and wet weather grab sampling. In 1985, the Los Angeles County Flood Control District was integrated, along with the County's Road and Engineering Departments, into the newly formed Los Angeles County Department of Public Works. Over the years, the water quality monitoring program has been revised and modified a number of times to support infrastructure and operational needs and meet regulatory requirements.

The latest regulatory requirements derive from the 1990 and 1996 Municipal Stormwater NPDES permits issued by the State Regional Water Quality Control Board under the federal Clean Water Act amendments of 1987. Recognizing that nonpoint source pollution was at least as much a threat to water quality as point source pollution, the amendments focused on controlling pollutants associated with stormwater and urban runoff. The regulations apply to urban areas with a population of at least 100,000. Since the Department of Public Works is the major owner and operator of the storm drain system, it became the "principal permittee." The other 85 incorporated cities within the portion of the county that drains to the Pacific Ocean, including the City of Los Angeles, became "copermittees."

The total drainage area covered by the stormwater permit comprises some 7900 square km (3100 square miles) and includes tributary area from three adjacent counties (see map). The population is distributed on some 2 million parcels served by roughly 4000 km (2500 miles) of storm drains, channels, and rivers. The permit area also contains some 150,000 licensed businesses.

The 1990 NPDES Municipal Stormwater Permit

The 1990 permit, one of the first in the nation under the newly revised federal Clean Water Act, called for the development of a comprehensive monitoring plan, an illegal connection and discharge elimination program, and implementation of in-stream monitoring in three distinct phases. The plan that the Department developed departed from the historical program already in place. The largest departure was in characterizing runoff quality in terms of the land use of the drainage area. Under this approach, the Department would focus on runoff from seven land use types developed from information compiled by the Southern California Association of Governments (SCAG), namely:

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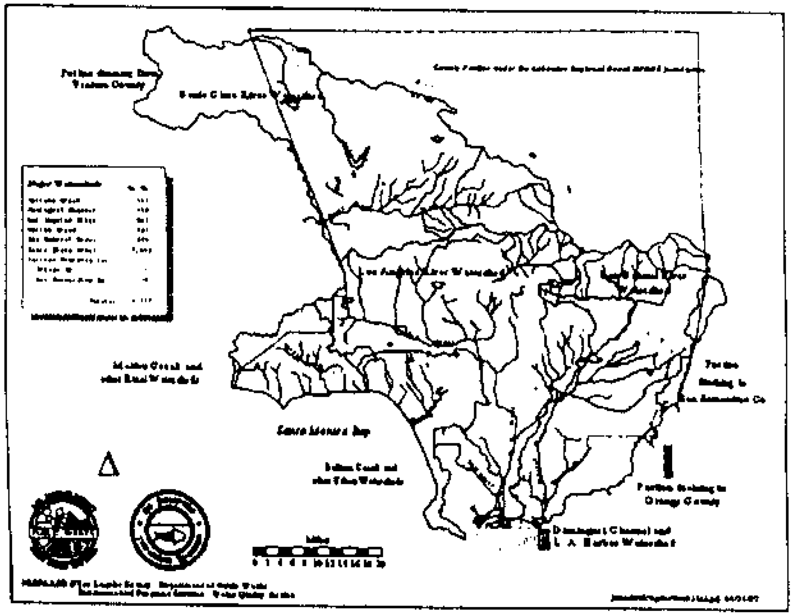

Figure 1 Map of Los Angeles County and Watershed Management Areas

- open space/recreational
- low density residential
- high density residential
- multifamily
- commercial
- industrial
- transportation

The seven land use types, aggregated according to similar imperviousness characteristics, closely resembled the types already in use by the Department's peak rainfall/runoff model. In addition, the plan included monitoring "mass emission" runoff from large drainage areas that have a wide variation of land use types

To begin implementing the in-stream monitoring phases of the plan, Department staff manually overlaid land use transparencies over watershed and drain alignment maps to identify the best candidates for nonpoint source monitoring. Siting was accomplished by answering the following questions:

- Is the chosen land use type predominant and homogeneous throughout the tributary area?
- Are the design flow rate and drain hydraulics known for the tributary area so that the drain will not flow surcharged in a moderate storm? Are there tidal or backwater influences that would affect flow rate measurements?
- Is there usually water in the drain during periods of no rain? If so, what is the flow rate?
- Is the site near a source of electrical power? For underground drains, is there a nearby manhole?
- Is the site in a relatively safe neighborhood?
- Does additional right of way need to be purchased?

Once these questions were answered, and the individual designs and construction permits completed, the installation of Phase I stations began in the Spring of 1994 Phase I covered all of the surface drainage area tributary to Santa Monica Bay, some 1100 square km (414 square miles) Through the land use analysis process, the Department chose five land use sites monitoring a total of 26 square km (10 square miles) of drainage area, and four mass emission monitoring sites covering 530 square km (209 square miles) of drainage area. Fifty three percent of the monitored area would be undeveloped while the balance would be urbanized coastal basin. By Jan. 15, 1995, all nine stations were installed.

Included as a requirement in the 1990 plan was the estimation of total pollutant loading to the ocean. The estimation would be accomplished by the application of a spreadsheet model that converts rainfall to runoff via the use of imperviousness values for each of the seven land use types. The Department had been using such impervious values for years in its peak rainfall/runoff modeling. The volume of runoff derived from recorded rainfall amounts would then be multiplied by an "event mean concentration" for a number of "pollutants of concern" identified in the permit. The result, multiplied by an appropriate conversion factor, would represent total loading, in pounds per event, discharging to the ocean.

Event mean concentrations would be derived from flow-weighted compositing of samples. The scope of the program meant that the only feasible method of collecting composited flows was with automated refrigerated sampling equipment. The samplers, with 38 liter (10 gallon) water collection capacity, could be programmed in advance to cover a wide range of storm sizes without requiring one or more bottle changes during a rainfall event. A pressure transducer in the bottom of the storm drain would sense the depth of flow once a predetermined triggering level is exceeded. Converting the depth to a flow rate for the drain's size and slope, the processor would start measuring the volume of flow going past the station. After a predetermined volume of flow ensued, the sampler would begin its cycle of purge and collection. Programming for each station would take into account the size and overall imperviousness of the drainage area so that runoff from a storm of 10 mm (0.4") rainfall would fill one 10 liter (2-1/2 gallon) sample bottle in increments of 400 ml aliquots. Similarly, runoff from a storm of 40 mm (1.6") would develop 38 liters (10 gallons) of sample.

The 1990 monitoring plan identified a wide range of constituents to be tested, including:

- bacteria
- general minerals
- biochemical oxygen demand
- total organic carbon
- total petroleum hydrocarbons
- volatile organic compounds
- semi-volatile organic compounds

Those constituents requiring short holding times or not amenable to compositing would be collected via manual grab samples. If safe and convenient, open channels would be sampled from nearby bridges. Underground drains would have to be sampled manually with the automatic sampler's pump already in place.

Finally, the plan called for monitoring five storms per year. Dry weather sampling would also be conducted every other month. For the dry weather case, compositing would be time weighted.

The 1994-95 storm sampling season, the first under the new stormwater permit plan, was the last season of the historic sampling program. By the advent of the next storm season, 1995-96, the Department had identified and installed an additional 15 land use and mass emission stormwater monitoring stations under Phases II and III of the 1990 NPDES permit, bringing the total to 24 sites in the permit area. These additional stations monitored runoff in the Los Angeles River, San Gabriel River, and Santa Clarita River watersheds. All told, the Department was monitoring runoff from 14 land use sites and 10 mass emission sites; 11 were open channel and 13 were underground drains. Mass emission monitoring covered 4240 square km (1657 square miles), and land use monitoring 59 square km (23 square miles).

The need for collecting meaningful storm grab samples meant arriving at the sampling site before the peak flow occurred, any time of day. This requirement introduced a logistical task of mobilizing a squad of up to 26 people into teams, each with a dozen bottles and sample collection paraphernalia. A command and coordination system was thus set up to train personnel, assign people to collection sites, follow weather forecasts, notify the contract laboratory, and send out samplers in the event of rain. Storm event coordinators were able to track weather forecasts and actual rainfall in real time through the Department's real time remote sensing system, otherwise known as ALERT. At the first sign of sustained rainfall, the coordinator would activate the sampling teams to fan out across the county to collect grab samples at the predetermined locations. By virtue of the refrigerated units, composited samples could be kept at each site until personnel could retrieve the samples during normal working hours.

An extra monitoring requirement imposed by the Regional Water Quality Control Board was a toxics runoff sampling program. The program called for sampling runoff from a municipal corporation yard and two industrial sites to detect the presence of toxics of concern as set forth in EPA's NPDES Stormwater Sampling Guidance Document. In both the 1994-95 and 1995-95 storm seasons, runoff was sampled at the Department's road maintenance yard in Westchester. In the 1995-96 season, the program expanded to include sampling of stormwater runoff at an auto dismantling site and a heavy industrial site.

The 1996 NPDES Municipal Stormwater Permit

As the original stormwater permit was drawing to a close in 1995, negotiations began on the succeeding permit. The new document issued in 1996 varied in a number of ways from its predecessor. One of the differences was a statement of objectives to be attained by the monitoring program. Those objectives are to:

- track water quality status, trends, and loads and identify pollutants of concern;
- monitor and assess land use and watershed pollutant loads;
- identify and assess significant water quality problems in watersheds,
- identify sources of pollutants in runoff;
- identify and eliminate illicit connections and discharges
- evaluate effectiveness of Best Management Practices;
- assess impacts on receiving waters.

To achieve these goals, the new permit separated the monitoring program into five basic elements:

- Continued land use monitoring
- Continued mass emission monitoring
- Continued storm drain inspection
- New "critical source" monitoring
- New receiving waters study

The permit further divided the 7900 square km (3100 square mile) drainage area into six management areas based on natural watershed boundaries. Those management areas are:

- Malibu Creek and neighboring rural watersheds
- Ballona Creek and neighboring urban watersheds
- Los Angeles River watershed
- San Gabriel River watershed
- Santa Clara River watershed
- Dominguez Channel and Los Angeles Harbor watershed

While stormwater monitoring under the original permit was designed to collect runoff after an initial rainfall of 10 mm (0.4"), the new permit called for collection of runoff from as little as 6 mm (0.25") of rainfall. In addition, a pilot study would be set up on one station to evaluate the feasibility of collecting runoff from a storm of 2.5 mm (0.1") rainfall. The basic list of constituents would stay the same, but volatile organic compounds would be dropped in favor of the herbicides diazinon, chlorpyrifos, diuron, and malathion.

Land Use Monitoring

While keeping with the primary objective of "developing and supporting effective programs towards reduction of pollutants to the maximum extent practicable," the new permit refocussed the land use monitoring program. It described in detail an 8 step process by which the Department would reassess its ongoing program. The object of the reassessment was to identify and then monitor types of land uses believed to cause the greatest mass loading of pollutants. The loading calculation would take into account not only land use type but also areal extent and rainfall distribution.

Starting with an initial list of 104 land use types arranged in 45 groups identified by the Southern California Association of Governments (SCAG), Department staff aggregated and split the land use types into a list of 37 categories. Of these, the top 12 urban uses based on total area were chosen for field survey. For each of the 12 types, 8 representative areas no larger than a city block were chosen for field survey during the spring of 1996.

With field-derived estimates of imperviousness, a loading model was run for four hypothetical constituents (copper, phosphorus, COD, and TSS) and the results ranked according to a marginal benefit analysis. The top seven land use types that had marginal benefits above or equal to the maximum and were chosen for monitoring. They were

- Vacant
- High Density Single Family Residential
- Light Industrial
- Transportation
- Retail/Commercial
- Multifamily Residential
- Educational Facilities

As it turned out, the first 5 land use types listed above were already being monitored under the 1990 stormwater permit. The Department would be able to keep one site from each land use for continued sampling; the excess sites could be abandoned under the terms of the 1996 permit. New stations to monitor the last two land use types, multifamily and educational, would be installed by the end of the 1996-97 storm season.

In addition to the loading analysis, land use was also ranked by total area in each of the six individual watershed management areas. Four land use types not already on the list were then identified, namely

- heavy industrial
- rural residential
- utility facilities
- mixed residential

By the start of the 1997-98 storm season, two of these four land uses will also be chosen for monitoring, bringing the total to nine land use monitoring stations.

Lastly, in the 1996-97 storm season, the permit requires the Department to sample up to 100 "station events." That is, the number of sampling stations multiplied by the number of sampled storms would not exceed 100. In 1997-98 and subsequent years of the permit's duration, the Department would sample up to 200 station events.

The constituents of concern to be monitored under the land use program are

Total PAH
Copper
Chromium
Selenium
Total phosphorus
Chlorpyrifos
Total DDT
Chlordane
Nickel
Silver
Mercury
TSS
Malathion
Total PCB's
Cadmium
Lead
Zinc
Total nitrogen
Diazinon
Simazine

Elimination of the time dependent constituents has allowed the Department a respite in responding personnel to land use stations to collect grab samples during storms.

Mass Emission Monitoring

In addition to monitoring the runoff from specific land uses, the Department of Public Works is also monitoring the major drainage areas near their outfall to the ocean. Five of the mass emission monitoring stations installed under the original 1990 permit would be retained under the new permit, namely Los Angeles River, San Gabriel River, Coyote Creek, Ballona Creek, and Malibu Creek. Four of the original mass emission sites would be abandoned, while one would be kept to continue the calibration of the SWMM model begun under the 1990 permit. Amounting to some 4200 square km (1654 square miles) of drainage area, the monitoring stations would produce information used to calculate total loading to the ocean.

Constituents tested for mass emissions include those under the land use program plus bacteria, oil and grease, total phenols, cyanide, and TPH. Because these additional constituents could only be collected by grab, the storm response coordinating task continued, although at a reduced scale

The new permit also allowed sampling at mass emission stations to total five events per year--dry weather, storm, or a combination of both. In addition, the Ballona Creek station is the site of a one-year "wide channel" study designed to determine if there is any variation of pollutant concentrations across the width of a large channel. Results of this study will define what measures, if any, need to be taken in modifying results in this situation.

Critical Source Monitoring

The toxics evaluation of runoff from the three industrial sites under the original stormwater permit expanded into an enhanced "critical source" monitoring program under the 1996 permit. Similar to the land use monitoring evaluation process described above, the Department of Public Works undertook a five step process to identify and prioritize a list of critical industries within the county that may contribute significant pollutants to stormwater runoff. Standard Industrial Codes, or SIC's, played a major role in the selection process. Once selected, appropriate sites would be monitored over a two year period for the duration of the permit to measure runoff quality with and without remedial cleanup actions. These remedial actions are called Best Management Practices, or BMP's.

The first step was to develop an initial list of candidate industries. This list contained industries both included and excluded under the State's General Industrial Activities Stormwater permit process. Initial candidate selection was based on prevalence in the county and the extent of outdoor activities. The resulting list yielded a group of 30 candidate industries ranked by the number of facilities.

The next step involved developing a set of criteria to prioritize the list. A number of empirical factors were used to assign levels of significance to each SIC category. Loading (Q) would be addressed by the number of sources at a site and the likelihood of release. Imperviousness (R) of a site would be represented by the percent of paved area. Pollutant toxicity (T) would be denoted by the number of toxic pollutants and inherent toxicity of the mix. An exposure factor (E) signifies if activities are exposed to rainfall. And finally, number (N) would represent the total number of sites in the county. Each variable would be assigned a qualitative number from 1 to 10, with 10 representing the worst condition. The pollutant potential (P) used to rank the results would thus be the product of all the factors, or

$$P = Q \times R \times T \times E \times N$$

Based on this ranking scheme, the top five "critical source" industries were:

- Wholesale Trade (scrap and auto dismantling)
- Automotive Repair/Parking
- Fabricated Metal Products
- Motor Freight

Chemical Manufacturing

A literature search was simultaneously conducted to identify what "critical source" industries, if any, have already been analyzed. The search reveled that similar stormwater studies have yet to be performed.

After the identification and prioritization, the Department then had the task of finding six companies of any one of the top five industries to enlist for monitoring runoff from five storms during the 1996-97 storm season. For the subsequent season, half of the chosen sites would be fitted with the same structural or nonstructural BMP at the Department's expense. The other half would remain as controls in order to evaluate BMP effectiveness. At the same time, stormwater monitoring of six companies of the next critical source industry would begin. This scenario would continue for six years until five critical source industries and remedial BMP's are tested and evaluated, or until another search reveals similar studies underway in some other part of the country.

Constituents tested would include:

Total petroleum hydrocarbons (diesel and gasoline)
pH
Electrical conductivity
Oil and grease
Semivolatile organics
Chemical oxygen demand
MBAS
Total suspended solids
Total dissolved solids
Total organic carbon
Total and dissolved aluminum
Total and dissolved cadmium
Total and dissolved chromium
Total and dissolved copper
Total and dissolved iron
Total and dissolved lead
Total and dissolved nickel
Total and dissolved zinc

Illegal Connection Program

Begun under the 1990 permit, the illegal connection and discharge elimination program was instituted by the Department to identify, investigate, and eliminate illegal connections and discharges to the municipal storm drain system. The program is centered around a geographic data base and a field inspection operation.

Compilation of the geographic data base began in 1990 with the monumental task of inventorying the entire County 4000 km (2500 mile) storm drain system. The foundation of the inventory is a CADD depiction of all of the Department drain alignments. Department staff from the beginning have been superimposing over each CADD alignment information extracted from the drain's construction drawings. The data collected relate to each storm drain's name, size, material, and stationing. In addition, all catch basin and manhole locations are entered on the CADD drawing. Along with the CADD entry, staff is entering the identical data into a tabular data base.

A second tabular data base has also been compiled that enumerates all of the connection permits granted by the Department to other agencies and private parties over the years allowing their connection to the Department's storm drains. Permitted connection information includes receiving drain name, permit applicant, drain material, and station. To date, more than 86,000 connection records have been entered and approximately 3500 km (2200 mi.) of storm drain attribute data have been plotted and tabulated. A geographic information system soon to be installed in-house for the NPDES Stormwater Permit program will greatly enable staff to compile and analyze these kinds of data.

The field inspection operation is conducted by the Department's storm drain maintenance division. The maintenance division develops its own inspection schedule and requests the storm drain connection maps and data tables in advance. Since the beginning of the inspection program in January 1996, 75 drains have been inspected, yielding a total of 984 undocumented connections. Office staff will then determine if the undocumented connections are legal or illegal and issue permits or orders to seal the outlet accordingly.

Receiving Waters Monitoring

Perhaps the most eagerly awaited study is the receiving waters study being performed in Santa Monica Bay off the mouths of rural Malibu Creek and urban Ballona Creek. The Department of Public Works, pulling together ongoing works in progress, is funding a half-million dollar 3-phased ocean monitoring program. The participants are the University of Southern California Sea Grant Program, Southern California Coastal Waters Research Project, and U C Santa Barbara. The work plan is comprised of:

- a plume dispersion study that will deal with stormwater spreading, mixing, and impacts at the ocean interface;
- a benthics study that will assess stormwater impacts on the sediments and benthic invertebrate community,
- a toxics effects study that will determine if water column or sediment toxicity results from stormwater discharge;

The plan calls for the collection of data for the ocean studies to end after the 1996-97 storm season. However, if either the benthics or toxicity studies need further investigation, they will be extended into the 1997-98 storm season.

On the fresh water side, three samples will be collected at the Los Angeles River and San Gabriel River monitoring sites in 1997-98 and 1998-99 to conduct a sea urchin toxicity assay to be funded by the Department.

Ever since the first nonpoint source regulations were proposed, stormwater management agencies nationwide have argued that not enough scientific evidence exists to quantify a cause-and-effect relationship between stormwater runoff and receiving water impacts. Already in its second year, this study will go a long way in defining those impacts.

Conclusion

The Los Angeles County Department of Public Works is actively executing the terms of the latest NPDES Municipal Stormwater permit, which includes a comprehensive monitoring program. The permit applies to more than 7900 square km (3100 square miles) of area that eventually drains to the Pacific Ocean. The drainage area is the largest such permitted area in the nation.

In 1990, the Department modified its historic sampling program under the terms of one of the nation's first stormwater permits. The new program included in-stream monitoring of runoff from specific land use types, an illicit connection elimination program, an industrial runoff toxics study, and an estimation of total loads to the Ocean.

In 1996, under the terms of the succeeding stormwater permit, the Department added a critical source monitoring element and a study of possible stormwater impacts on ocean receiving waters.

The Department of Public Works has committed and will continue to commit significant resources to develop and support effective programs towards the reduction of stormwater pollutants to the receiving waters in and adjacent to Los Angeles County.

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World Almanac, 1993

CHAPTER 113

An Epidemiological Study of Possible Adverse Health Effects of Swimming in Santa Monica Bay

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Abstract

An epidemiological study of possible adverse health effects of swimming was conducted in Santa Monica Bay during the summer of 1995. The study was conducted in response to wide public perception and evidence that there may be health risks associated with swimming in beach areas contaminated by runoff. Higher risks of a broad range of symptoms (gastrointestinal and upper respiratory) were observed for subjects swimming close to storm drains (0 versus 400 yards). Higher risks of several symptoms were also observed for subjects swimming in water with high levels of single bacterial indicators and in water where enteric viruses were detected. Low ratio of total to fecal coliforms was found to be associated with higher risks of a broad range of symptoms. In response to the study results, an action agenda has been adopted and implemented by the local community to reduce the exposure to the risk and the sources of contamination.

Introduction

As one of the 28 National Estuary Programs, the Santa Monica Bay Restoration Project (SMBRP) is charged with assessing the Bay's pollution problems and with producing a Bay Restoration Plan to serve as a blueprint for the Bay's recovery. Since its genesis in 1988,, a primary focus of energy has been to find the answer to a fundamental human health question: "How safe is it to swim in Santa Monica Bay?" Nearly fifty million tourists and local residents come to Santa Monica Bay's public beaches each year to enjoy its recreational resources, but there has been wide public perception and some scientific evidence that there may be health risks associated with swimming in beach areas contaminated by runoff.

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In previous investigations conducted by the SMBRP (SMBRP, 1992, 1991, 1990), human pathogens were detected in summer runoff, an unexpected result since sewer and storm drain systems in Los Angeles are completely separate. Possible sources of pathogens contamination into the storm drain system include illegal sewer connections, leaking sewer lines, malfunctioning septic systems, illegal dumping from recreational vehicles, or direct human sources such as campers or transients. Other potential sources of human pathogens in near shore areas include sewage spills into storm drains, small boat waste discharges and swimmers themselves.

The members of the SMBRP therefore decided that the definitive step necessary to answer this question of swimming-related health risks was an epidemiological study. The study was launched in the summer of 1995 under the auspices of the SMBRP, with a wide support of governmental agencies, dischargers, and environmental communities. It was hoped that the study would provide a scientific basis for addressing the wide public perception about the health risks associated with swimming in urban runoff-impacted beach areas, for developing pollutant control measures if necessary, and ultimately for promoting the local tourism-based economy.

Study Overview

During the course of the study (June to September 1995), 15,492 beachgoers who swam at three Santa Monica Bay beaches located near flowing storm drain outlets were interviewed. Nine to 14 days after the beach interviews, 13,278 follow-up telephone interviews were conducted to ascertain the occurrence of 16 symptoms (including fever, chills, eye discharge, earache, ear discharge, skin rash, infected cut, nausea, vomiting, diarrhea, diarrhea with blood, stomach pain, coughing, coughing with phlegm, nasal congestion, sore throat), and a group of symptoms indicative of "highly credible gastrointestinal illness" (HCGI)[2] and significant respiratory disease" (SRD)[3].

Water samples were collected daily in ankle depth at various distances from the drains (0, 100 yards north and south, and at 400 yards[4]) and analyzed for

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[2] Two definitions of HCGI were used in this study and grouped as HCGI-1 (vomiting, diarrhea and fever, stomach pain and fever) or HCGI-2 (vomiting and fever).

[3] Symptoms including fever and nasal congestion, fever and sore throat, and cough with sputum.

[4] Previous studies have showed that indicator bacteria levels at 400 yards are generally low, therefore comparisons could be made between rates of illness in swimmers at this distance and at 0 yards.

total and fecal coliforms, enterococci, and *E. coli*. In addition, water samples were collected at storm drain sites every Friday, Saturday, and Sunday and analyzed for enteric viruses.

Persons who bathed and immersed their heads in the ocean water were potential subjects for this study. There were no restrictions based on age, sex or race. Persons who had bathed at the study beaches within seven days of the survey date (before and after) were excluded, as were subjects who bathed on multiple days. Since a primary research question was whether the risk of illness was associated with levels of particular indicator organisms in the water (which could vary from day to day), it would have been impossible to link subjects' experiences with specific counts on a given day if they were in the water on numerous days.

Summary of Findings[1]

Fifty-five percent of the subjects surveyed were male, 45 percent female. Forty-eight percent of the subjects were children (under 12 years of age); 13-to-25 year-olds comprised 26 percent of the survey population and the remaining 26 percent were aged 26 and over. The ethnicity of the survey population was 45 percent white, 43 percent Latino, 3 percent black, 3 percent Asian, 3 percent multi-ethnic, and 2 percent "other." Children and Latino subjects tended to swim closer to the drain. Sixty-three percent of subjects swimming at the drain were children under 12. Eighty-eight percent of the surveyed subjects were residents of California.

The analyses conducted in this study addressed two questions: a) What are the risks of illness relative to the distance one swims from a flowing storm drain? and b) Are the risks of illness associated with measures of water quality? The major findings resulting from these analyses are as follows:

1. **There is an increased risk of illness associated with swimming near flowing storm drain outlets in Santa Monica Bay.** Statistically significant increases in risks for a broad range of adverse health effects were found for subjects that swam in front of storm drains in comparison to those who swam over 400 yards away (Table 1). These increases in risk appeared to be limited to the 0 yard distance, as a significant drop-off effect was observed at other distances from the drain (Figure 1).

   The estimated number of excess cases of illness attributable to swimming at the drain reached into the 100's per 10,000 exposed subjects (greater than 1 percent, Table 1) suggesting that significant numbers of beachgoers swimming near storm drain outlets are subject to increased health risks.

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[1] See SMBRP 1996 for detailed summary.

Table 1. Comparative health outcomes for swimming in front of drains versus 400+ yards away.

Health Outcome	Relative Risk (0 vs. 400+ Yds)	Estimated No. of Excess Cases per 10,000 Persons
Fever	57%	259
Chills	58%	138
Ear Discharge	127%	88
Vomiting	61%	115
Coughing w/ Phlegm	59%	175
Any of the above symptoms	44%	373
HCGI-2	111%	95
SRD	66%	303
HCGI-2 or SRD	53%	314

The results did not change when adjusted for age, beach, gender, race, California versus out-of-state resident, socioeconomic status, or worry about potential health hazards at the beach. Distance results also did not change substantially when controlled for each bacterial indicator.

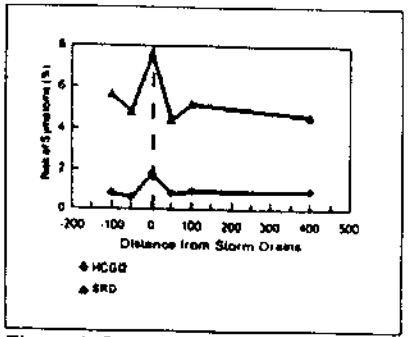

Figure 1. Reports of HCGI-2 and SRD relative to distance from drains.

2. **There is an increased risk of illness associated with swimming in areas with high densities of bacterial indicators.** "Cutoff points" were used to determine whether there were differences in the incidence of illness for those who swam in waters with bacterial densities "greater than" versus "less than" certain cutoff levels. Symptoms were found to be associated with swimming in areas where bacterial indicator counts were greater than the cutoff points that are used as part of federal and state water quality standards (Table 2). However, effects were noted for only few symptoms for the three bacterial indicators analyzed in this study.

Table 2. Health outcomes associated with swimming in areas with high bacterial indicator counts.

Indicator (cutoff)	Health Outcomes	Increased Risk
E. coli (>320 cfu)	Earache	46%
	Nasal congestion	24%
Enterococcus (>106 cfu)	Diarrhea w/ blood	323%
	HCGI-1	44%
Total coliform (>10,000 cfu)	Skin rash	200%
Fecal coliform (>400 cfu)	Skin rash	88%

cfu: colony forming unit.

3. **The total coliform to fecal coliform ratio was found to be one of the better indicators for predicting health risks.** When analyses were restricted to time when total coliforms exceeded 1,000 cfu, significant associations were observed, with incidence of illness generally increasing as the ratio of densities of total coliforms to fecal coliforms decreased (Figure 2). The strongest effects were generally observed when the total-to-fecal coliform ratio of 2:1 was used for comparison.

None of the bacterial results changed when adjusted for age, beach, gender, race, California versus out-of-state resident, socioeconomic status or worry about potential health hazards at the beach.

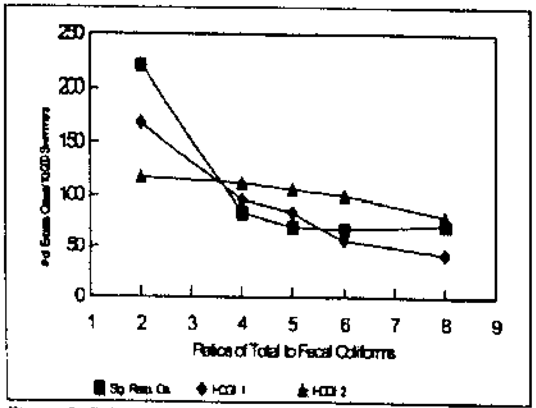

Figure 2. Relationship of excess cases of illness and total-to-fecal coliform ratios (when total coliform exceeded 1,000 cfu).

4. **Illnesses were reported more often on days when the samples were positive for enteric viruses.** Seventeen samples were positive for enteric viruses. Although based on small numbers, a comparison of subjects who were swimming within 50 yards of the drain on days when samples were tested for viruses indicates that a number of outcomes were reported more often on days when the samples were positive for viruses versus days when samples were negative. Symptoms for which increased risks were noted include: fever (53% increase), vomiting (89% increase), HCGI-1 (74% increase), and HCGI-2 (126% increase). Results remained essentially unchanged when adjusted for covariates or for each bacterial indicator.

5. **High densities of bacterial indicators were measured on a significant number of survey days, particularly in front of drains.** A great deal of day-to-day variability in bacterial indicator counts was recorded, however, high bacterial densities in water samples were detected most frequently directly in front of drains (at 0 yards). High densities of *E. coli*, fecal coliforms, and enterococcus occurred on over 25 percent of survey days. Total coliform levels were exceeded less frequently (8.6 percent of days). Total-to-fecal coliform ratios of less than 5 occurred on 12 percent of survey days.

Follow-Up Actions

This epidemiological study was the first large-scale study in the nation to investigate possible adverse health effects associated with swimming in ocean waters contaminated by urban runoff. The results of this health risk investigation provided both good news and cause for concern. The good news is that, of the Bay's 50-plus mile coastline, less than 2 miles are problematic. However, the study has also confirmed that there is a risk of illness associated with swimming immediately adjacent to flowing storm drains. Although it is not yet known what specific pathogens cause illness, the study confirms that the distance from storm drains and the bacterial indicators that are being monitored do help to predict risk. In addition, the total-to-fecal coliform ratio has been found to be a useful predictor of illness and could be used as a new analytical tool.

The scientific findings documented through this study laid the foundation to develop new policies and actions that will improve our ability to protect the public's health. The SMBRP has identified an "Epi Study Action Agenda" to respond to the findings of this study. This Action Agenda included steps to be taken in five areas: education and advisories to the public, implementation of source control measures, identification and prevention of pathogen sources, modification of water quality standards and monitoring programs, and financing. Since adoption of the Action Agenda in May 1996, significant progress has been made in its implementation. New warning signs with stronger language have been posted near flowing storm drains in Santa Monica Bay. Dry-weather flows of eight problematic drains have been scheduled for diversion or on-site treatment. In addition, given the results of this study, the SMBRP recommends that the US EPA and the State health agencies develop national and state-wide bathing beach water quality standards/criteria.

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CHAPTER 114

AN INTEGRATED STRATEGY FOR MANAGING URBAN RUNOFF POLLUTION IN LOS ANGELES COUNTY

Dr. Xavier Swamikannu[1]

Abstract

Contaminated urban runoff can harm important water resources, including estuaries, coastal waters, and wetlands. Urban runoff typically contains the same types of pollutants that are found in wastewater and industrial discharges. The enormous volume of runoff discharges transport significant mass loads of pollutants.

California issued the first urban runoff permit program to eighty-four municipalities (now eighty-six) in Los Angeles County in 1990. A countywide approach was used because of the complexity and networking of the urban drainage system. The permit program was revised in July 1996 to promote watershed management. Staff utilized consensus-building techniques and worked with a committee of stakeholders (the "negotiating group") comprised of representatives of selected municipalities and environmental groups. Separate discussions were also held with other interested parties to resolve areas of disagreement.

The municipal storm water and urban runoff program in Los Angeles County offers a unique challenge to protecting the coastal environment because of the large number of municipal jurisdictions participating to implement an innovative and cost-effective approach. This paper describes the process followed to reach agreement on this landmark effort, the progress to date, and imminent challenges that lie ahead.

Introduction

Storm water and urban dry weather runoff pollution can damage important water resources, including streams, lakes, estuaries and wetlands, and ground water (USEPA 1994). Many recent studies have shown that runoff from urban areas typically contains significant quantities of the same general types of pollutants that are found in wastewater and industrial discharges and often causes similar water quality problems (CRWQCB-LA 1988; Pitt and Field 1990; SCCWRP 1993). These pollutants include heavy metals (e.g., chromium, cadmium, copper, lead, mercury, nickel, zinc), pesticides, herbicides, nutrients, bacteria, and synthetic organic compounds such as fuels, waste oils, solvents, lubricants, and grease.

In addition, large impervious surfaces in urban areas increase the quantity and peak flows of runoff, which in turn cause hydrologic impacts such as scoured streambed channels, instream sedimentation, and loss of habitat (TI 1994; CWPR 1996; Arnold and Gibbons 1996). Furthermore, because of the enormous volume of runoff discharges mass loads of pollutants in storm water can be significant (SMBRP 1994). There are multiple sources of pollution that contaminate storm water, including land use activities, operation and maintenance activities, illicit discharges and spills, atmospheric deposition, and vehicular traffic conditions (USEPA 1992A). While the impacts on the beneficial uses of water bodies are site-specific and vary due to differences in local land use conditions, geography, geology, hydrologic conditions, and the type of receiving water, the characteristics of urban storm water are similar.

Amendments to the Clean Water Act (CWA) in 1987 established new statutory requirements to control industrial and municipal storm water discharges to waters of the United States [CWA Section 402 (p)]. Storm water from municipal separate storm sewer systems (MS4s) are required to be managed with, "controls to reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and systems, design and engineering.." (40 CFR Pt. 122.26)

Urban Runoff Pollution in Southern California

Urban runoff and storm water contamination in the Southern California Bight, which includes the Los Angeles region, was identified as a regionwide problem by the National Research Council (NRC 1990). Further, water quality assessments conducted by the California Regional Water Quality Control Board - Los Angeles Region (CRWQCB-LA) identified urban runoff as a leading cause of impairment of a number of water bodies in Los Angeles County (CRWQCB-LA 1993). Pollutants associated with the

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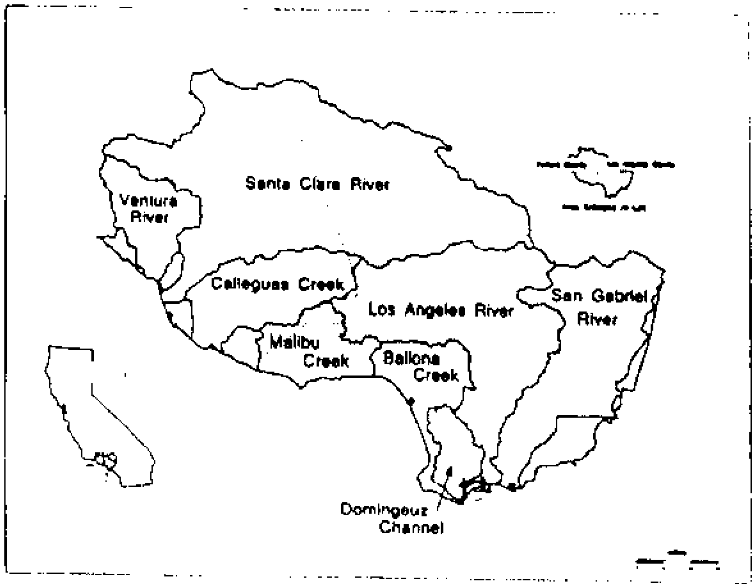

Figure 1. Map of the watershed management areas in Los Angeles and Ventura counties that are under the regulatory authority of the California Regional Water Quality Control Board - Los Angeles Region.

impairment include: heavy metals, coliform, enteric viruses, pesticides, nutrients, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, organic solvents, sediments, trash, debris, algae, scum, and odor.

More recently, an epidemiological study demonstrated the increased risk of acute illness associated with swimming near flowing storm drain outlets in Santa Monica Bay (SMBRP 1996B). Human pathogens have also been identified in summer urban runoff (SMBRP 1992). Possible sources of human pathogen contamination include pet and livestock feces, illicit sewer connections to the storm drains, leaking sewer lines, malfunctioning septic systems, improper waste disposal by recreational vehicles, campers or transients. Additional potential sources of human pathogens in nearshore waters include sewage overflows into storm drains, small boats waste discharges, and bathers themselves.

The Los Angeles County Storm Water Program

Los Angeles County, California, is the most densely populated county in the State of California. The storm water program area includes eighty-five cities as well as the unincorporated areas of the County within the jurisdiction of CRWQCB-LA. The storm drain system serves a population of about 9 million who live on approximately 7,000 km^2 (3,100 mi^2) of land area. Nearly a third of statewide industry is included within the program boundary. There are six major watershed management areas (Figure 1).

The CRWQCB-LA is the National Pollutant Discharge Elimination System (NPDES) permitting authority for the Los Angeles region under delegation provisions of the Federal Clean Water Act and the Porter-Cologne Act (California Water Code). This delegation authorizes it to regulate and control the discharge of pollutants into waters of the U.S. and the State of California.

Pursuant to changes to the CWA, the CRWQCB-LA issued the first storm water permit (Order No. 90-079) in June 1990, to the municipalities in Los Angeles County. Because of the complexity and networking of the storm drain system and drainage facilities within and tributary to the County of Los Angeles, a countywide approach in permitting storm water and urban runoff discharges was adopted. The County of Los Angeles was designated as Principal Permittee under that permit. As Principal Permittee, the County of Los Angeles is responsible for the general administration of the permit and facilitates cooperation among municipalities. The first permit term expired in 1995.

Program Restructuring

The first step in restructuring the storm water permit program was to convene a stakeholder group to work with CRWQCB-LA staff to develop permit requirements and implementing language. Since direct discussions with eighty jurisdictions was not practical, the CRWQCB-LA asked the County of Los Angeles to assemble a representative group of city delegates. Besides the County, three small city representatives and the City of Los Angeles were chosen from the membership of the Storm Water Executive Advisory Committee, a pre-existing group that occasionally met to coordinate implementation of the first storm water permit. These parties comprised the stakeholder group, along with Heal the Bay, an advocacy organization which was asked to participate and provide the environmental perspective on this issue. This organization's involvement was important in order to reduce the likelihood of third party citizen lawsuits or appeals. This advisory committee, often called the "negotiating group," met approximately

60 times over an 18-month period to identify areas of agreement and narrow areas of disagreement.

In addition to holding meetings of the negotiating group, CRWQCB-LA staff held numerous meetings with the cities, watershed committees, stakeholder attorneys, industry spokespeople and individual city representatives. Working with the negotiating group's input, staff sent out a first partial draft permit in September, 1995. A first full draft was distributed for comments in December, 1995. A Public Service Announcement video was made available to elected officials and decision makers to facilitate understanding of the objectives and the benefits of the effort (SMBRP 1996A). In large part due to the involvement and buy-in of the majority of participants, the permit was ultimately approved by the CRWQCB-LA Board in July, 1996 (CRWQCB-LA 1996).

Storm Water Program Elements

The permit requires municipalities to implement comprehensive pollution prevention and management programs to reduce storm water pollution. The Storm Water Management Program (SWMP) must include controls necessary to reduce the discharge of pollutants from the MS4 to the Maximum Extent Practicable (MEP). These controls consist of a combination of best management practices, control techniques, system design and engineering methods.

Specifically, municipalities are required to develop and implement programs to control storm water pollution in the following areas: (1) Illicit connections and illicit discharges elimination; (2) Development planning and construction controls; (3) Public agency activities management; and, (4) Public information and participation initiatives. The development and implementation are scheduled over a period of thirty six months.

The requirements of Section 6217(g) of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) were also reviewed to ensure consistency with guidelines for urban runoff pollution management. CZARA requires coastal states with approved coastal zone management programs to address nonpoint pollution impacting or threatening coastal water quality (USEPA 1993)

Monitoring is performed by Los Angeles County to characterize sources, evaluate water resource impacts, and to assess the effectiveness of pollution control methods. Preliminary results on the impact of storm water pollution on selected receiving waters are reported in the Conference Proceedings (Bay 1997; Schiff 1997).

No	Land Use	Cu Load	Cum Pcent
0			0
1	High Density SFR	7912	0.31
2	Vacant	5405	0.52
3	Light Industrial	2415	0.61
4	MF Residential	1678	0.68
5	Transportation	2416	0.77
6	Retail and Commercial	1311	0.83
7	Low Density SFR	557	0.85
8	Mixed Residential	507	0.87
9	Educational Facilities	494	0.89
10	Nat Resource Extraction	338	0.90
11	Heavy Industrial	307	0.91
12	General Office Use	245	0.92
13	Open Space and Rec	219	0.93
14	Institutions	217	0.94
15	Utility Facilities	191	0.95
16	Mobile Homes	173	0.95
17	Other Commercial	165	0.96
18	Mixed Transport/ Utility	158	0.96
19	Floodways and Structures	117	0.97
20	Under Construction	114	0.97
21	Remaining (21-37)	678	1.00
	Total	25815	1

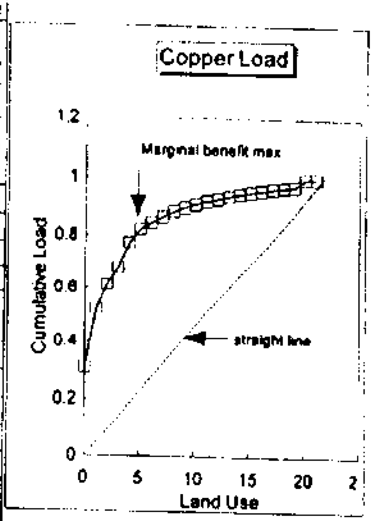

Figure 2. Modelled pollutant loads for copper (Cu) based on thirty seven landuse types in Los Angeles County. The inflexion point of the cumulative load curve indicates the cut-off point for diminishing marginal benefit. Additional landuse type sampling for the pollutant beyond the cut-off point is of marginal benefit. The copper EMC for the transportation landuse was calculated using storm water data provided by the California Department of Transportation.

Prioritizing Actions

A scientifically defensible approach is essential to prioritizing pollution control efforts. Consequently, predominant landuses that contribute significant pollutant loads, and the numerical dominance of certain types of industrial and commercial activities in Los Angeles County have been selected for further study.

Landuse selection: Landuse for special monitoring were selected in a multi-step process as follows, (i) selection of eight representative locations from selected landuse categories identified from an initial landuse list compiled from landuse overlays and landuse data from the Southern California Association of Governments (SCAG); (ii) performing a site survey at representative locations; (iii) evaluation of the use of aerial photographs as an alternative measure of imperviousness for each survey location; (iv) modelling of mass emissions based on landuse categories using Event Mean Concentrations (EMCs) from past landuse monitoring, and (vi) performing a marginal benefit analysis to select landuses for monitoring. The marginal benefit analysis was conducted for representative pollutant categories: solids (total suspended solids, heavy metal (total copper); nutrient (total phosphorous; and organics (chemical oxygen demand), for all Los Angeles County and also by watersheds.

Seven landuses out of thirty seven were selected for monitoring and characterization because their landuse-mass emissions were equal to or greater than the maximum marginal benefit for at least one pollutant category. The seven are: (i) High density single family residential; (ii) vacant; (iii) light industrial; (iv) transportation; (vi) retail and commercial; multi-family residential; and (vii) educational facilities. The marginal benefit analysis for Cu for Los Angeles County is shown in Figure 2. Just seven landuses contribute 85% of the Cu pollutant load in storm water. Cu is a priority pollutant in storm water and Cu concentrations in many estuaries exceed water quality criteria (Moran 1997).

Figure 3 illustrates modelled pollutant loads for Cu by dominant landuses in the two watersheds that drain to Santa Monica Bay: (i) Ballona Creek and urban; and, (ii) Malibu Creek and rural. The Source Significance Index (SSI) which is the ratio of pollutant load percent to land use percent is also shown. The SSI is influenced directly by pollutant concentrations and inversely by landuse area percent, and thus may be utilized as an indicator of transient in-stream effects such as toxicity or to evaluate cost benefit of control measures implementation. Currently, there is no evidence that Cu in storm water has any measurable impact on Santa Monica Bay (Schiff 1997).

Critical Pollution Sources Selection: The County identified a list of candidate industrial sources based on the numerical prevalence countywide, designation under USEPA Phase I storm water regulations, and storm water pollution characteristics (LACDPW 1996). These industrial facilities were then ranked based on a semi-quantitative measure. The Pollution Potential (P) was computed as a product of several criteria and normalized to fall between 0 and 100

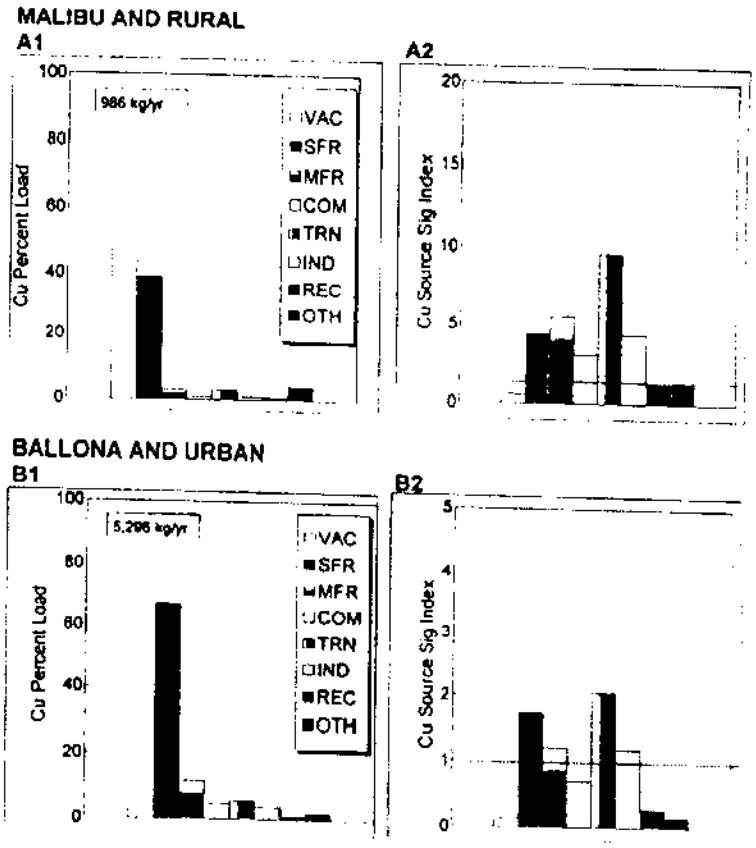

Figure 3. Modelled percent load for copper (Cu) in two watersheds which differ in the dominant type of landuses. A1- Malibu and rural; B1- Ballona and urban. A2 and B2 are their respective Source Significance Index (SSI) which is the ratio of percent load to percent area for a particular landuse. The dashed line indicates SSI value of 1, the theoretical value were pollutant concentrations all equal. (VAC - Vacant; SFR - Single Family Residential; MFR - Multi Family Residential; COM - Commercial; TRN - Transportation; IND - Industrial; REC - Recreational; and OTH - Other)

Pollution Potential $(P) = Q \times R \times T \times E \times N$,
where Q is pollutant quantity; R is the runoff amount; N is number of facilities; T is pollutant toxicity, and E is the rain exposure factor.

Table 1. Ten highest ranking industrial facility types selected for storm water characterization and pollution control assessment in Los Angeles County. (SIC - Standard Industrial Classification Major Group number)

SIC (1)	Industry (2)	Number of Facilities (3)	Pollution Rank (4)
50	Scrap / Auto Dismantling	587	1
75	Automotive Repair / Parking	6,067	2
35	Fabricated metal Products	3,283	3
42	Motor Freight	872	4
28	Chemicals / Allied Products	1,069	5
55	Automotive Dealers / Gas Retail	2,744	6
33	Primary Metal Products	703	7
49	Electric / Gas / Sanitary	2,001	8
45	Air Transportation	319	9
30	Rubber / Miscellaneous	1,034	10

The top ten ranks from the thirty industrial types that were analyzed for Pollution Potential (P) are shown in Table 1. Los Angeles County selected the first five ranking industry types for further study to characterize storm water pollution and evaluate potential best management practices (BMPs) to control pollution. In each industry type, six facilities will be evaluated over a five year period. In the first year of the study, a baseline characterization of each industry type will be completed by sampling storm water discharges from all six facilities. Three of the facilities in each industry type will then be augmented with appropriate BMPs and monitored in subsequent years to measure reductions in storm water pollution.

Challenges Ahead

Numerous challenges lie ahead both for the municipalities and the CRWQCB-LA. The large size of the Los Angeles Storm Water Program ensures that the gamut of environmental participation - from pro-activism and passivity to active resistance - is well represented among municipal participants. Any inherent inertia on the other hand is adequately counterbalanced by a vocal and vigilant environmental community represented by nationally active groups. The CRWQCB-LA must reconcile competing interests and be fully engaged in program implementation. This will be difficult to do if staff resources become limited by State budget constraints. Similarly, municipalities face competing budget priorities in an era of voter and legislative fiscal conservatism.

Los Angeles County is in the process of preparing countywide model components . These models will be submitted to CRWQCB-LA for approval over the next three years. The integrated cooperative approach offers the opportunity to cut costs from economies of scale, cost sharing, pooling of resources and coordination of implementation actions. No doubt some of the municipalities will make modifications to the models to reflect conditions within their municipal areas. Balancing municipal flexibility with countywide consistency will offer a challenge to the CRWQCB-LA.

The Watershed Area Management Plans (WMAPs) are the long-term blue prints to aggressively protect water resources, human health, and aquatic habitats in the proximate geographic subunit of the cities. Watershed committees are required to develop WMAPS in order to focus priority actions once countywide baseline programs have been established. The critical financial mechanism to fund development of the WMAPs has not be identified.

Los Angeles County is required to identify and develop performance standards for SWMP components by the year 20001 to quantify level of effort, program effectiveness and provide BMP baselines. The candidate parameters for the performance standards must be identified and evaluated during model development in order to ascertain meaningful indicators of storm water pollution reduction.

The monitoring program conducted by Los Angeles County must be sustained long-term and integrated with other regional monitoring programs to track the condition of water resources and assess the effectiveness of BMPs. In addition, watershed monitoring programs may need to be diversified to assess the needs and status of other watersheds beyond the present two. Such undertakings will need the financial participation and resources support from the other eighty-five municipalities.

Conclusion

The efforts to control urban storm water pollution is a huge undertaking. The current implementation agreement in Los Angeles County reflects the benefits of taking a consensus seeking approach to protecting coastal environments when there are a large number of stakeholders. In order for the storm water management program to be successful, the full participation of divergent interests - the municipalities, business, environmental advocates and the public - is essential to ensure effective implementation of a storm water programs to achieve a healthier coastal environment. In addition, both the State and the Federal governments must expend adequate resources to ensure continuous engagement with the implementing community. In this new environment of openness and responsiveness any perceived governmental apathy will erode public trust.

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CHAPTER 115

Storm water Runoff into Santa Monica Bay Identification, Impact and Dispersion

Burton H. Jones[1] and Libe Washburn[2]

Abstract.

Storm water runoff into the coastal ocean can have major impacts on a variety of oceanographic properties and processes that include coastal currents, coastal nutrient and optical characteristics, and contamination from heavy metals, organic compounds and microbial input. Off southern California these inputs are low for most of the year, but during the winter season, large rainstorms result in large inputs of freshwater and the associated contaminants from storm water runoff. These inputs have both event and seasonal scale effects on Santa Monica Bay. Towyo and surface mapping were used to map the three-dimensional distribution of dissolved and particulate components associated with storm water runoff into Santa Monica Bay during the winter of 1996. Results from this study indicate that the plume can extend offshore approximately 5 km from the coast and alongshore at least 5 km. The freshwater generally forms a thin surface layer that is initially less than 5 m thick, although the influence of the plume (salinity < 33.0 pss) can be detected to nearly 10 m depth. Three major particle groups are observed during these periods: 1) particles within the storm water runoff, 2) phytoplankton in the water column, and 3) resuspended sediments. These particles have a large effect on the water column optics, and may carry a measurable load of absorbed contaminants including heavy metals and organic compounds which may be toxic to marine organisms. Following the plume over the course of 2-3 days at the end of a storm indicates that the plume remains in the coastal area for at least 3 days with gradual dilution during this period. Dinoflagellate blooms can develop after the rain event providing a secondary particulate field associated with the plume. It is likely that the stratification and nutrient input provided by the freshwater inflow contribute to the presence and development of this dinoflagellate population.

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Introduction.

The storm water component of urban runoff into the coastal ocean can have major impacts on a variety of oceanographic properties and processes that include coastal currents, coastal nutrient and optical characteristics, and the presence of toxic materials such as heavy metals and organic compounds. Storm water runoff is a small part of urban runoff in southern California during most of the year. But during the winter season, November through March, large rainstorms result in large inputs of freshwater and the associated contaminants from storm water runoff (SCCWRP, 1992). At the least, these inputs have both event and seasonal scale effects on Santa Monica Bay. Two major drainage systems, the Ballona Creek and Malibu Creek watersheds, contribute nearly 60 percent of the freshwater inflow into Santa Monica Bay (Table 1). The Ballona Creek watershed is highly urbanized with only 17 percent open land. In contrast, the Malibu Creek watershed is comparatively rural with 88 percent open land.

Table 1. Comparison of land use characteristics for the two watershed systems Ballona Creek and Malibu Creek

Land Use	Ballona Creek	Malibu Creek
Single Family	46%	8%
Multiple Family	18%	1%
Commercial	8%	1%
Public	4%	0%
Industrial - Light	4%	1%
Urban - other	4%	2%
Open	17 %	88%
Total Percent	100%	100%
Total Acres ($*10^3$)	83.3	70.3
Pct of FW Inflow	31%	27%

The impact of these storm water inputs on the coastal receiving waters has been poorly understood until recently, because there has been little research on the freshwater impacts on the coastal zone in southern California. In contrast, other inputs, such as treated sewage outfalls, have been well studied, partly because of environmental regulation, engineering interests, and community concern. In other regions where freshwater input from rivers is a continous process there have been studies of the physics (e g. Garvine, 1982, Muchow and Garvine, 1992), nutrient chemistry, and biological impacts on the coastal region (e g. Malone, 1982, Lohrenz et al , 1990)

Methods.

Field sampling consists of several types of measurements to study the distribution of freshwater inputs from river sources during winter storms. Continuous mapping of physical and optical properties was performed with a towyo system that we have developed and used successfully for sewage outfalls (Washburn et al., 1992; Jones et al., 1993; Wu et al., 1994). The towed platform carries a conductivity-temperature-depth instrument (CTD) that is used to measure temperature, salinity, and density of seawater. Seawater turbidity is measured with a transmissometer having a path length if 0 25 m and a 660 nanometer (nm) light source and detector. The presence of chlorophyll in seawater, which can derive from ocean and terrestrial sources, is quantified with a fluorometer. The light distribution in the water column is measured with a Photosynthetically Available Radiation (PAR) sensor. The platform is moved through the water column along a zigzag tow path by winching the platform up and down as the ship steams ahead at about 4 knots. Vertical sections obtained in this way are referred to as towyo sections. The upper limit of the towyo sections is the sea surface; we tried to break through the sea surface in order to sample to the top of the water column. The lower limit is generally within about 5 m of the sea floor, although on a few occasions the platform made contact with the bottom

Continuous surface sampling is accomplished using the same set of instruments through which near-surface water is pumped continuously while towyo sampling is occurring. An instrument which measures spectral absorption and attenuation at 9 visible wavelengths is also incorporated in the near-surface measurements. Ship's position is recorded at 10 second intervals from a GPS receiver

Ocean currents are measured with an electromagnetic current sensor that also measures temperature and instrument depth were also measured by the current meter. The current meter, deployed by SCCWRP, was mounted on a mooring that was located at 33° 56 172' N, 118° 30 103' W in a water depth of 40 m. The depth of the current meter was about 15 m from the surface. The current meter was configured to sample as follows: 1) raw current speed and direction were obtained at a rate of 2 samples per second, 2) raw current samples were averaged over 10 seconds and 30 of these 10-second averages were stored in memory every 30 minutes. That is a 5-minute segment of 10-second averages was recorded every 1/2 hour.

Observations:

The study region for the impact of storm water runoff on the receiving waters of Santa Monica Bay is shown in Figure 1. The two major focus areas are the regions off of the mouths of Ballona Creek and Malibu Creeks. Not all track lines are sampled each time. Rather, the track lines are chosen according to the direction that the plume is flowing and the wave and wind patterns

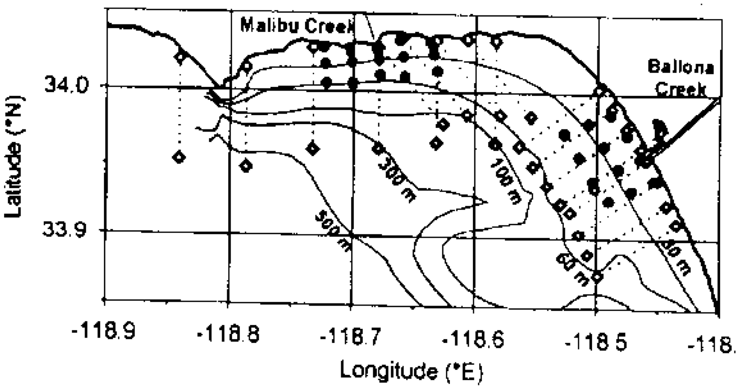

Figure 1. Map of northern Santa Monica Bay showing the way points (diamonds) and sampling tracks (dashed lines) for towyo mapping and benthic sampling sites (black circles used by SCCWRP for studying the benthic impacts from the storm water runoff

The storm water study that is described below occurred during the period of March 5-7, 1996. The rainfall began on March 4 and ended early on March 5, yielding more than 0 8 inches of precipitation (Figure 2). The integrated flow from Ballona Creek for the period of the storm was about 1 2x10^6 m^3 over the period of 24 hours between 0730 on March 4 and 0730 on March 5. We sampled for 3 days sequentially during this study, permitting a longer study of the temporal evolution of the coastal ocean following the storm event.

On March 5, we obtained four towyo transects near Malibu Creek and five towyo sections near the mouth of Ballona Creek. From the towyo tracks near the mouth of Ballona Creek we were able to construct the near-surface maps of temperature, salinity, chlorophyll fluorescence and beam attenuation coefficient (Figure 3). It is evident in these maps that there is a significant freshwater plume that extends between 2 and 4 km offshore from the beach. The plume is evident from the warmer (lighter) and fresher (darker) water that was present near the mouth of Ballona Creek. Both suspended particulate matter, as indicated by the beam attenuation coefficient, and chlorophyll fluorescence were high within the Ballona Creek plume and decreased seaward.

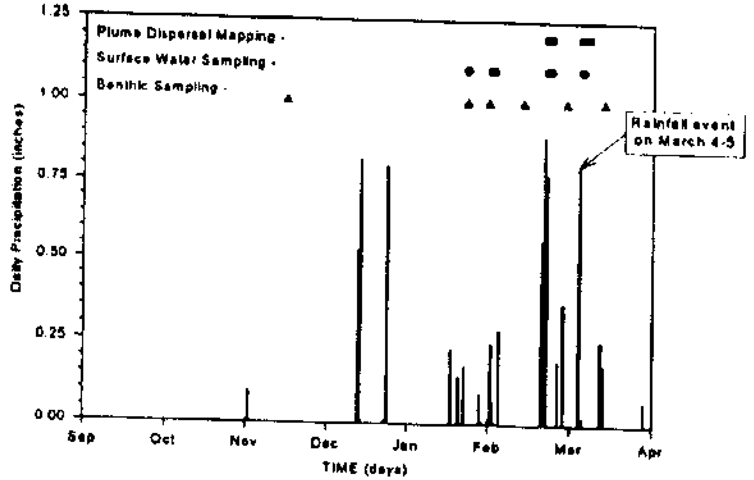

Figure 2 Rainfall events during the winter of 1995-96. Sampling events are indicated across the top of the figure squares indicate plume mapping, circles indicate water column toxicity sampling, and triangles indicate benthic sampling

Towyo 9 extended seaward from the south end of the Marina Del Rey breakwater and reveals the subsurface structure associated with the plume across the shelf. When the sampling began, the flow from the storm had already subsided significantly. As seen in the surface map, the plume characteristics of fresher, warmer, and more turbid water were evident in the nearshore, near-surface layer (Figure 3) This layer was less than 5 meters near the coast and thinned offshore extending to a distance of about 4 km from the coast The subsurface water on the shelf was cool (<14 °C) and saline (>33.4 pss) as shown in Figure 4. High particle concentrations, indicated by beam c, were observed in the near-surface layer associated with the storm water plume and in the bottom boundary layer (Figure 4). In the nearshore 0.5-1 km of the transect the particle concentration was high (beam c > 1 m^{-1}) throughout the water column, perhaps resulting from a combination of bottom resuspension and sinking from the runoff plume. The near-bottom layer is similar to near-bottom layers that we have often observed off of Palos Verdes (e.g. Washburn et al , 1992) Deeper water appeared to intrude up the shelf near the bottom as evidenced by the cool (<12 5°C), salty (>33 45), low chlorophyll water

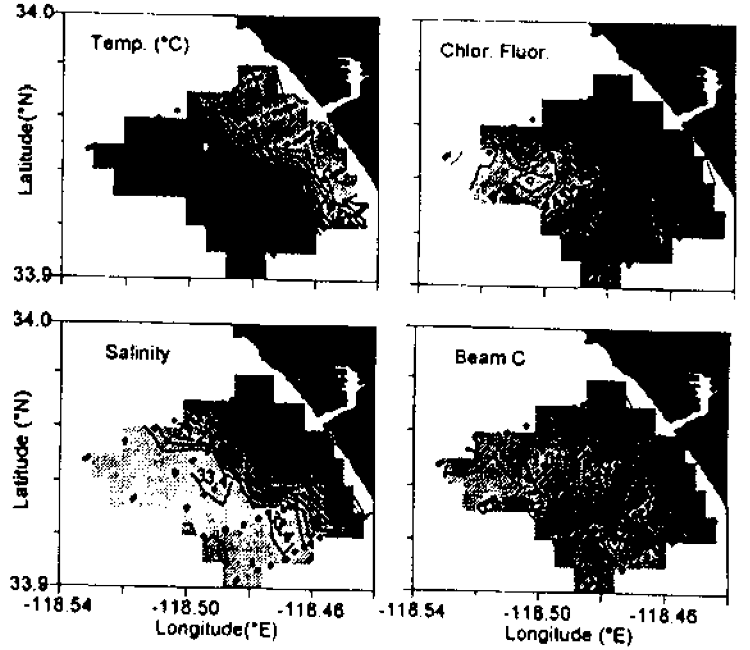

Figure 3 Surface maps constructed from the near-surface observations of the towyo indicated by the diamonds, which indicate locations where the towyo was within 2-3 m of the surface. This map is from March 5, 1996 Chlorophyll fluorescence is in relative units (the voltage output of the sensor, where 1 volt corresponds to about 0.6 µg/l chlorophyll); beam attenuation is in the units of m^{-1}; salinity is expressed in the units of practical salinity scale (pss), essentially parts per thousand.

Subsurface chlorophyll fluorescence at ~20 dbar between 2 5 and 4.5 km is likely to be evidence of phytoplankton rather than terrigenous plant material.

Two days later on March 7, a larger scale map of the area was obtained with transects extending from south of Marina del Rey to Point Dume, west of Malibu Creek. Low salinity water, evidence of the storm water runoff, was still present nearshore throughout the area (Figure 5). However, salinities were not as low as observed on March 5. Nearsurface particle concentrations were highest in the low salinity water and corresponded somewhat with higher chlorophyll fluorescence in the surface layer. The highest chlorophyll fluorescence values were observed both nearshore and south of Malibu Creek. The largest values found between Point Dume

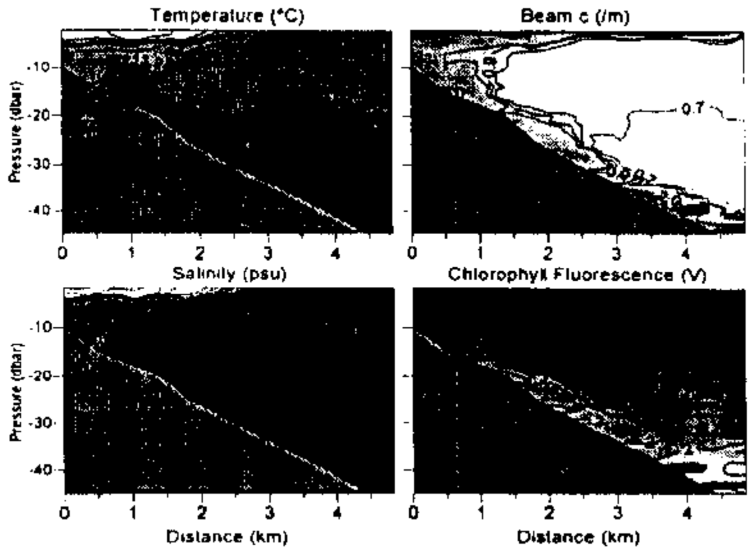

Figure 4 Towyo section extending southwestward from the southern end of the Marina del Rey breakwater Corresponds to the central transect shown in Figure 3 Units are the same as in Figure 3

and Malibu Creek were associated with reddish brown water typical of dinoflagellate blooms

The transect extending offshore from the southern end of the Marina del Rey breakwater was again profiled with the towyo on March 7 (Figure 6) As seen in the surface map, there was still evidence for the presence of runoff in the inner 2 5 km of the transect where salinities of <33 4 penetrated to >10 dbar Particle concentrations, as indicated by beam c, were still high in the upper layer, but did not show the extreme values observed on previous transects Chlorophyll fluorescence were no longer high the low salinity, turbid water near the surface, but showed subsurface maxima that were independent of the higher particle concentrations in the surface layer and near the bottom

An unusual feature was observed within this transect Between 2 5 and 4 km there was a dynamic feature that was apparent in all of the variables (Figure 6) It is most noticeable in the elevation of the contour lines of temperature and salinity But there is also evidence in chlorophyll fluorescence with the bifurcation of the subsurface chlorophyll maximum and in beam c with the elevation of particles to more than 15 dbar above the bottom This narrow uplifting is probably the result of an internal wave passing through the region Examining the surface map in Figure 5 it appears that the cool spot in the center of this transect may be the surface expression of this feature and provides no indication of this feature in any of the other transects

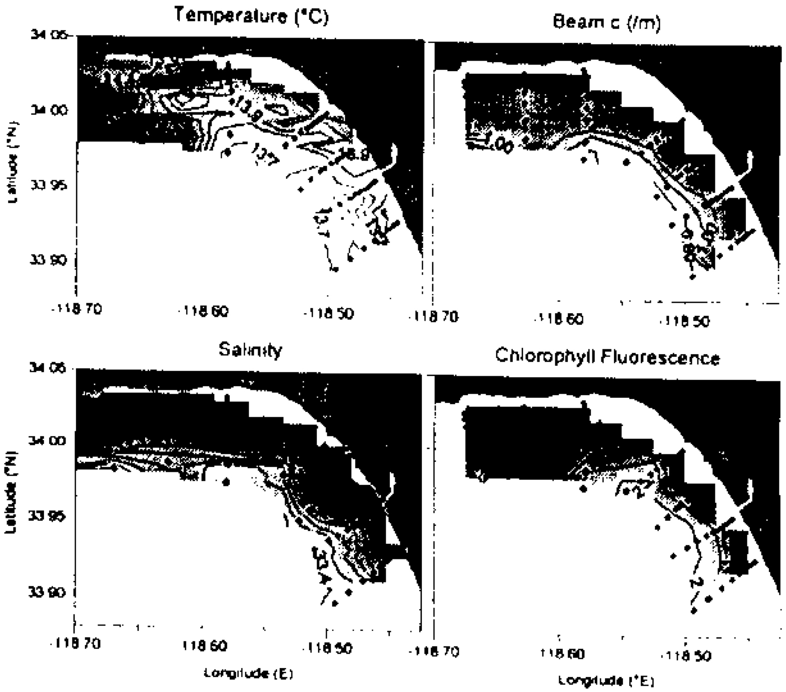

Figure 5 Surface maps from the towyo mapping on March 7, 1996 Units are the same as in Figure 3

Moored sampling

The current time series at 15 m reveals that ocean currents near the Ballona Creek outflow are highly variable A summary of some basic statistics of the current data are presented in Table 2 For both the eastward and northward components of current, the standard deviation exceeds the mean which confirms the variable nature of currents in this region The mean current speed is 8 9 ± 6 2 cm s^{-1} in the direction of 162° ± 83° true Thus the mean current direction is toward the southwest and is oriented alongshore, more or less parallel to lines of constant depth (isobaths)

Because these data are effectively sampled at a rate of 2 points per hour, they resolve fluctuations in currents on a minimum time-scale of about 1 hour The total

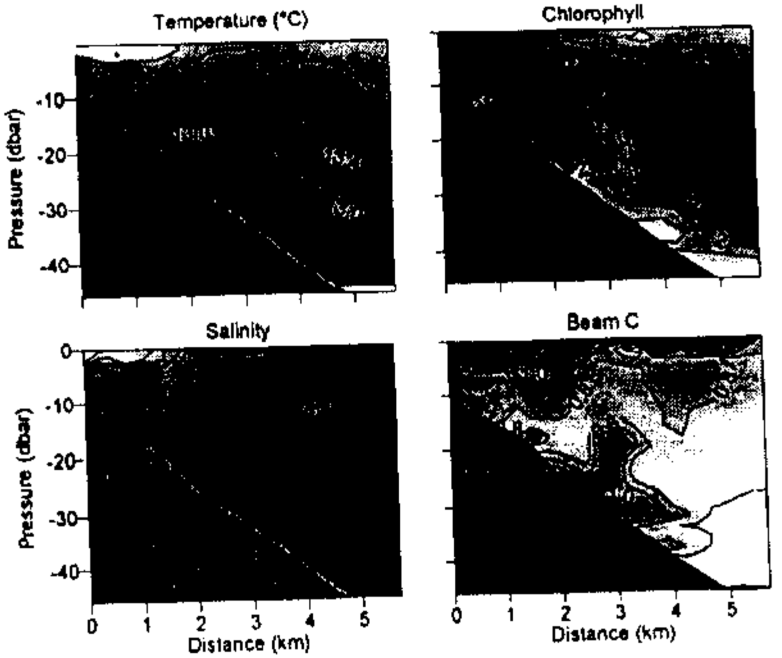

Figure 6. Towyo section obtained on March 7, 1996. As in Figure 4, this section extends southwestward from the southern end of the Marina del Rey breakwater. This transect corresponds to the second line from the south in Figure 5. Units are the same as in Figure 3

Table 2 Basic current statistics

Parameter	Mean	Standard deviation
eastward velocity (cm s^{-1})	1 0	6 8
northward velocity (cm s^{-1})	-1 7	7 7
speed (cm s^{-1})	8.9	6 2
direction (degrees true)	162	83

length of the time series is about 70 9 days, so the maximum resolved time scale of current fluctuations is about 2 months Several physical oceanographic processes produce variability over this range of time scales including tides, wind forcing, coastal-trapped waves, and eddies. All of these processes may be important for dispersing storm water runoff plumes from Ballona and Malibu Creeks.

It is important to determine the dominant time scales of currents during runoff events to understand the dynamic processes which disperse the storm water runoff plume. To aid in identifying these time scales, power spectra are computed for the eastward (u) and northward (v) velocity components. A clear peak is found in the spectra at frequencies corresponding to the lunar and solar semi-diurnal tides (periods in the range 11 97 to 12.42 hours). A smaller peak is associated with the lunar and solar diurnal tides (periods in the range 23.93 to 26.87 hours). In addition to the tidal peaks in the spectra, current fluctuations occur over a continuum of time scales from 12 hours to about 11 days, the longest period which is resolved by the spectra.

Other important quantities measured by the moored current meter are temperature and pressure. The temperature time series shows a 2.5° temperature oscillation over a period of about 30 days. A full period of the oscillation was observed, but it is not known it continued beyond the observation period High frequency temperature fluctuations with a period of about 12 hr are clearly due to the diurnal tides The pressure time series measures the water depth with respect to the current meter. Peak-to-trough variations of 2 m in water depth occur on time scales of 12 hours and are due to the semi-diurnal tide. The low frequency "envelope" of fluctuations with a period of about 14 days results from the spring-neap cycle of the tides. Clearly tides are a dominant source of current fluctuations are likely to be very important in transporting the storm water plumes over periods of several hours.

Discussion.

Towyo mapping along with nearsurface continuous pumping has been used to successfully map the distribution of the storm water runoff into Santa Monica during several storm events. Results from a single smaller event in March 1996, demonstrate several aspects of the impact of storm water runoff into the coastal ocean

Initially the plume spreads as a thin layer over the surface extending offshore 2-5 km and alongshore for larger extents depending on the alongshore advection During the initial stages, when there is still significant discharge from the creek, the plume is demarcated at its offshore boundary by a sharp front which is apparent visibly (i e , optical properties), in salinity and temperature During this period the plume is often less than 5 m deep, and the most intense part of the plume is probably less than 2 m deep, as seen in Figure 4

Over time the plume becomes more dilute and the particle concentrations decrease in the upper layer This can be seen by comparing the surface maps (Figures 3 and 5) and the towyo sections (Figures 4 and 6) from March 5 and 7, 1996. Other factors indicate that the impact of the plume is greater than just the initial input of dissolved and particulate material The development of the dinoflagellate bloom seen on March 7 near Malibu indicates that the nutrients and stratification provided by the runoff plume contribute to the biological productivity of the region. In other areas, river plumes are a significant factor in coastal primary and secondary production through the transport of buoyancy and nutrients into the coastal ocean (Malone, 1982, 1984; Lohrenz et al., 1990). Initially, primary production may be inhibited or limited in the region of the storm water due to the rapid attenuation of light by the high particle concentrations in the storm water, and perhaps by the toxic components that may be present (e.g. SCCWRP, 1992).

There are several deleterious effects that can result from runoff plumes. The most obvious factors are the introduction of pathogenic bacteria and viruses which affect the human population, and toxic elements and compounds which can affect marine life. It is likely that these effects are intially directly correlated with the proportion of storm water in the sea water. Bay et al. (this volume), as part of this project, have shown that toxicity to indicator organisms correlates well with salinity. They found that toxic metals are most likely to be the toxic component in the storm water runoff. These toxic effects can be apparent when runoff concentrations are as little as 5% (salinity $\leq$~32) in the surface seawater. Therefore, the distribution of the storm water in the surface layer, as measured by salinity, is an important tool for mapping the dispersion of toxicity effects in the coastal ocean.

Coastal currents are highly variable in this region and therefore prediction of the direction and speed of dispersion of the plume will be difficult. The mean current speed during the current meter deployment was about $3.4\ \mathrm{cm \cdot s^{-1}}$, or <0.1 knots, suggesting very low mean advection. However, because of the strong tidal variation of currents, the actual dispersion can be more than 10 km alongshore during a single phase of the tidal cycle. The circulation within Santa Monica Bay is complex (Hickey, 1993) and the maps that we have obtained indicate that the frontal boundaries are spatially variable (e.g. Figure 3). Therefore, although the predominant direction of advection will be alongshore, eddy systems within the Santa Monica Bight could result in significant offshore transport of storm water runoff.

The results presented here provide an initial look at the impacts of storm water runoff on the receiving waters of Santa Monica Bay. Plume mapping, combined with toxicity and benthic sampling, provide a powerful technique for assessing the spatial impact of storm water and for evaluating the influence of physical dynamics on the dispersion of the storm water. More detailed analysis of the data set is ongoing and is expected to yield additional insight into the interaction of storm water runoff with the coastal ocean off of southern California.

Acknowledgments:

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CHAPTER 116

Stormwater Runoff Effects on Santa Monica Bay: Toxicity, Sediment Quality, and Benthic Community Impacts

Steven Bay[1], Kenneth Schiff[1], Darrin Greenstein[1], and Liesl Tiefenthaler[1]

ABSTRACT

Results from the initial year of a three year study of the effects of stormwater in Santa Monica Bay are described. Surface water and sediment samples were collected for analysis following four significantly-sized storm events in January through March, 1996. Toxicity was present in water samples offshore of Ballona Creek and was proportional to the concentration of runoff in the plume. Changes in sediment characteristics, such as grain size and TOC, were evident offshore of both Ballona and Malibu Creeks. Not only were the changes in sediment characteristics temporally stable (similar patterns observed after storms and during dry weather periods), but there was a gradient of change decreasing both upcoast and downcoast away from each creek mouth. Sediment contaminants, such as lead, total DDT, total PCB, and total PAH, were elevated at stations directly offshore Ballona Creek compared to sediments at similar depths offshore Malibu Creek. The first year's results have not detected significant stormwater-related changes in benthic infaunal community assemblages or sediment toxicity in the vicinity offshore the discharge of either creek.

INTRODUCTION

Urban runoff has been shown to discharge large quantities of contaminants (Schiff and Stevenson 1996; SCCWRP 1990, 1994a) and can be toxic to marine organisms (Bay *et al.* 1996). Unlike municipal wastewater, stormwater runoff enters the nearshore marine environment, often through estuaries or wetlands, wholly untreated. New regulations and increased monitoring efficiency are enhancing in-channel measurements, yielding better information on characterization of wet weather inputs and effectiveness of best management practices (LACDPW 1996). However, virtually no information exists on contaminant fates and their biological effects once wet weather discharges enter the marine environment.

The fate and effects of contaminants on the receiving environment cannot be predicted from in-channel measurements alone. The mixing of the freshwater plume with ambient seawater alters the chemical state and solubility of some contaminants; particle aggregation and settling are also affected in complex ways. Furthermore, the nearshore environment is very dynamic with waves and currents having a strong influence on the deposition and distribution of stormwater contaminants. Moreover, much of what we know about the effects of contaminants in the benthic environment has been learned from studies of ocean wastewater outfalls. These systems differ greatly from stormwater discharges in terms of discharge composition and variability, mixing and dispersion, as well as the receiving environment characteristics. Therefore, directed studies of stormwater discharge are needed in order to identify the contaminants of concern and their biological effects.

The research described in this report represents the initial results of a three year program to investigate the linkage between stormwater discharge and environmental effects. This study, conducted in collaboration with the University of Southern California (USC), USC Sea Grant, and the University of California at Santa Barbara (UCSB), had three principal objectives. The first objective was to measure the dispersion and mixing of stormwater plumes in Santa Monica Bay; this work was conducted by our collaborators and is presented in an accompanying article. The second objective was to examine the magnitude and characteristics of water column and sediment toxicity near stormwater discharges. This work element examines potential contaminant effects and provides an important link with similar data from measurements within the watershed. The final objective of this project was to measure the impacts to benthic communities in the immediate vicinity of the discharge. This article presents the results from the toxicity and benthic studies for the first wet season of sampling.

METHODS

The Ballona Creek and Malibu Creek watersheds were selected for evaluation in this study. Both watersheds are roughly similar in size (Figure 1), and together they encompass over half of the entire Santa Monica Bay drainage area (Stenstrom and Strecker 1993). The Ballona Creek drainage basin is highly urbanized, 83% of the watershed is developed and comprised of predominantly residential land use. Almost the entire channel is concrete-lined. Conversely,

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Malibu Creek is predominantly undeveloped; 88% of the watershed is open land and the channel is almost entirely earthen. These differences in watershed characteristics, combined with localized diversity in rainfall, lead to large variations in flow and pollutant loading to the ocean, even for the same storm event (LACDPW 1996). By comparing impacts associated with each watershed type, we hope to distinguish between effects arising from urban and non-urban stormwater runoff.

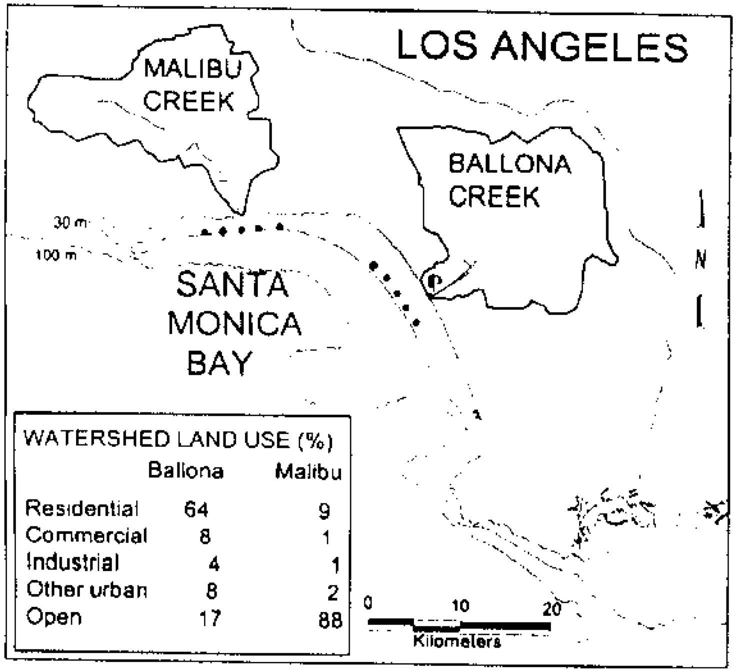

Figure 1. Watershed characteristics and sediment sampling sites for the two study locations. All stations were located along the 25 m isobath. Circles (•) indicate stations sampled after multiple storms for chemistry and infaunal community analyses. Sediment from all 10 stations were collected for toxicity tests following the February 1996 storm event.

Sampling and Sample Handling

Wet season sampling was accomplished after four 1996 storm events of variable magnitude: January 21 (1.52 cm rain at Los Angeles Civic Center), January 31 (0.51 cm), February 19-21 (10.16 cm), and March 4 (1.78 cm). Wet season sampling was coordinated with plume dispersion studies conducted by USC and UCSB. Water samples for toxicity were collected as soon as possible following a storm (8-48 hours), while sediment samples were collected up to 14 days following target storms in order to allow suspended particles to settle.

Surface water samples (upper meter) were collected during each of the four storm events. Five water samples were obtained from the Ballona Creek area during each event. Fewer samples were collected off Malibu Creek, due to difficulties in accessing the study area and the relatively small amount of runoff found in the surface water. Water sampling methods varied because of the necessity to use different boats for some sampling. Surface water samples were either collected by dipping a glass jar attached to the end of an aluminum pole or from a submersible pump deployed from a boom amidships of the boat. Samples were stored under refrigeration at SCCWRP and tested within 48 hours.

Locations of the water sampling stations were determined during each cruise and varied between events. Salinity measurements were used to select locations that represented a gradient of runoff concentration, usually aligned along a transect running between the creek mouth and a reference station containing no measurable runoff, located up to 6 km offshore.

Four stations offshore of each creek mouth were targeted for post-storm sediment chemistry, toxicity, and infauna measurements (Figure 1). All eight stations were located at roughly 25 m, a depth indicated by a pre-season spatial survey to show strong gradients of change across the area of stormwater influence (Bay and Schiff 1997). One additional sediment sample at each site was collected for sediment toxicity and chemistry following the February storm.

Sediments were collected using a 0.1 m^2 modified Van Veen grab. For contaminant analysis, only surficial sediments (top 2 cm) from undisturbed, representative grabs were collected. Sediment samples were placed in separate containers for grain size, TOC/TN, trace organics, and metals analyses. Samples were either stored under refrigeration (grain size) or frozen until analyzed. Samples for sediment toxicity tests were taken from replicate grabs and stored under refrigeration.

For benthic invertebrate community (infaunal) analysis, entire sediment grab samples were gently washed through a 1.0 mm mesh stainless steel screen on the boat. The organisms retained on the screen were "relaxed" using $MgSO_4$ (Epsom salts) in seawater. After 30 minutes the sample was fixed with 10% borax buffered formalin and returned to the laboratory. After 24 hours, samples were rinsed with freshwater to remove formalin and preserved in 70% ethanol.

Analytical Chemistry

Grain Size Analysis. Sediment grain size was measured using a Horiba Model LA-900 laser scattering particle size distribution analyzer. Sediment samples were first homogenized, then a representative aliquot was passed through the instrument and the particle sizes determined by detection of scattered (refracted and reflected) laser light.

Total Organic Carbon, Total Nitrogen and Total Volatile Solids Analysis. Total organic carbon and total nitrogen (TOC/TN) measurements were conducted using a Carlo Erba 1108 CHN Elemental Analyzer, according to methods developed by SCCWRP (1993b). Sediment samples were homogenized, dried, and then digested with acid to remove inorganic carbon. Samples were then oxidized by combustion in the analyzer and the evolved carbon and nitrogen quantified using a thermal conductivity detector.

Total Volatile Solids (TVS) was measured using a Thermolyne Model 62700 muffle furnace. Sediments were dried at 60 °C overnight, combusted at 500 °C, and then weighed after cooling. TVS was determined from the net loss in weight after combustion. While not as specific a measure as TOC, TVS has been shown to be significantly correlated with TOC measurements in reference areas of the Southern California Bight (Thompson *et al.* 1993).

Metal Analysis. Samples were prepared for metal analysis (aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc) in accordance with EPA Method 3051 (EPA 1996). Dried sediment samples were digested using a nitric acid:hydrochloric acid mixture. Metal concentrations were determined using a Hewlett Packard Model 4500 inductively coupled plasma-mass spectrometer (ICP-MS) according to EPA Method 200.8 (EPA 1991).

Pesticides and Polychlorinated Biphenyls (PCB). Analytical methods for chlorinated pesticides and polychlorinated biphenyls followed EPA protocols (EPA 1986 or EPA 1983). Six DDT isomers and metabolites (o,p'-DDT, p,p'-DDT, o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE) and 27 individual PCB congeners (congeners 8, 18, 28, 29, 44, 50, 52, 66, 77, 87, 101, 104, 105, 118, 126, 128, 138, 153, 154, 170, 180, 187, 188, 195, 201, 206, 209) were quantified. Samples were also examined for twelve additional chlorinated pesticides (isomers of chlordane and lindane, hexachlorobenzene, and derivatives of endosulfan), but none of these compounds were detected for any sample in this study.

Specific methodological details for the analyses can be found in SCCWRP (1994b) or Zeng and Khan (1995), but a general description of the procedure follows. Samples for DDT and PCB analysis were homogenized and then centrifuged to remove pore water. Following sediment extraction by methylene chloride, the extracts were cleaned of interfering compounds using activated copper addition and preparative columns of alumina and silica. Extracts were concentrated to 1 mL and injected into a Hewlett Packard Model 5890 II gas chromatograph equipped with a 60m x 0.25 mm ID (0.25 µm film thickness) DB-5 fused silica capillary column and a ^{63}Ni electron capture detector (GC-ECD) for analyte measurement.

Polynuclear Aromatic Hydrocarbons (PAH). PAH analyses were conducted using EPA protocols (EPA 1986 or EPA 1983) which quantify 28 different PAHs. Specific methodological details can be found in Zeng and Khan (1995) or SCCWRP (1995a). Analysis was accomplished by injecting a portion of the same solvent extract used for the chlorinated hydrocarbon measurements into a Hewlett Packard Model 5890 II gas chromatograph equipped with a DB-5 column (60m x 0.25 mm ID x 0.25 µm film thickness) and a Hewlett Packard Model 5870 Mass Selective Detector in electron impact ionization mode.

Infaunal Community Analysis

Each infaunal sample was sorted into six different taxonomic groups - annelids, molluscs, arthropods, ophiuroids, miscellaneous echinoderms, and "other phyla". A minimum of 10% of each sample was resorted by another person to detect missed organisms. If sorting efficiency was less than 95%, then the entire sample was resorted. Biomass measurements were obtained by weighing each group of organisms to the nearest 0.01 g (wet weight).

Each organism was identified to the lowest taxon possible, using standardized nomenclature developed for the Southern California Bight (SCAMIT 1996). Species level identifications were assigned by scientists who were experts in their taxonomic group and were active members of the Southern California Association of Marine Invertebrate Taxonomists (an interagency quality assurance group). Ten percent of all samples were re-identified and enumerated by a second taxonomist for quality assurance. All new species encountered were maintained in a voucher collection which is located at SCCWRP.

Toxicity Measurement

Three types of environmental samples were tested for toxicity: surface water, sediment interstitial water, and whole sediment. Surface water samples were not filtered or centrifuged before testing. Brine (prepared by the partial freezing of seawater) was added to samples with a salinity below 30 g/kg to adjust the salinity to 34 g/kg. Each water sample was tested at a single concentration, 100% sample or the maximum concentration after salinity adjustment. Four replicates of each sample were tested. The percentage of runoff present in each toxicity test sample was calculated from the initial salinity value and included dilution resulting from salinity adjustment. This calculation assumed that the percent of runoff present in the original sample was inversely proportional to the relative salinity, expressed as a percentage of the background value (outside of plume).

Interstitial water was extracted from the sediment samples by centrifugation twice at 3,000 x g for 30 minutes. Laboratory seawater was added to the samples to produce three test concentrations containing 100, 50, and 25% interstitial water. Three replicates of each concentration were tested.

Water quality measurements conducted during each toxicity tested consisted of salinity, dissolved oxygen, pH, and total ammonia content. Measurements were made using electrodes that were calibrated daily. Measurements were made at the start of each test and also at the end of the 10-day amphipod survival test. Electronic thermometers were used to measure water temperature continuously during each experiment.

Sea Urchin Fertilization. All samples of surface water and interstitial water were tested for toxicity using a sea urchin fertilization test (Chapman *et al.* 1995). The test consisted of a 20 minute exposure of sperm to the samples at 15 °C. Eggs were then added and given 20 minutes for fertilization to occur. The eggs were preserved and examined later with a microscope to assess the percent fertilized. Toxic effects are expressed as a reduction in fertilization percentage.

Purple sea urchins (*Strongylocentrotus purpuratus*) used in the tests were collected from intertidal areas in northern Santa Monica Bay. The tests were conducted in glass vials containing 10 mL of solution. A negative control (0.45 µm and activated carbon filtered natural seawater from Redondo Beach) and a brine control (distilled water containing 50% brine) were included in each test series for quality assurance purposes.

Amphipod Survival. The toxicity of sediment samples was assessed by measuring the survival of amphipods following a 10 day exposure period. Test methods followed standard guidelines (ASTM 1991). A one liter sediment sample was removed from storage and homogenized with a plastic spoon. A 2 cm layer of sediment was added to five replicate one-quart glass canning jars for each station. Approximately 750 mL of lab seawater, adjusted to a salinity of 30 g/kg, was added to each jar. The jars were fitted with aeration tubes and allowed to equilibrate overnight before addition of the amphipods.

Twenty amphipods (*Rhepoxynius abronius*) were added to each jar. The test animals were collected from Puget Sound (Washington). A sample of collection site sediment was also included in the test, as a negative control. The test was conducted at 15°C, under constant illumination. Surviving animals were removed from the sediment at the end of the exposure by sieving and counted to determine the percent survival. Reburial success was not determined.

RESULTS

Surface Water Toxicity

Toxicity was present in surface water samples collected near the mouth of Ballona Creek during three of the four sampling events. No toxicity was detected in water samples collected one day following the January 21 storm. Water samples from this event contained less than 4% runoff, below the concentration range of Ballona Creek runoff (>6 %) shown to produce toxicity in related studies (Bay et al. 1997). The relatively small amount of runoff present in the January 22 samples may have been due to a delay in collection following the storm.

A map of the results for water samples collected following the January 31 and February 19-21 storms shows that toxicity was usually present near the mouth of Ballona Creek. Toxic water samples were restricted to a relatively small area (≤1 km offshore of Ballona Creek) following the January 31 (Figure 2) and March 4 storms (Bay and Schiff 1997). A greater area of toxicity appeared to be present on February 21, with toxic water present up to 4 km from the mouth of Ballona Creek. No toxicity was detected in water samples collected near the mouth of Malibu Lagoon in January and March. Toxicity was not expected in the Malibu samples, since all samples from the area contained less than 2% runoff. Too few samples were collected to examine the longshore distribution of toxic surface water.

The magnitude of toxicity was proportional to the amount of Ballona Creek runoff present in the sample (Figure 3). This relationship was also similar to the dose response pattern measured for Ballona Creek stormwater samples collected during the same storm (Figure 3).

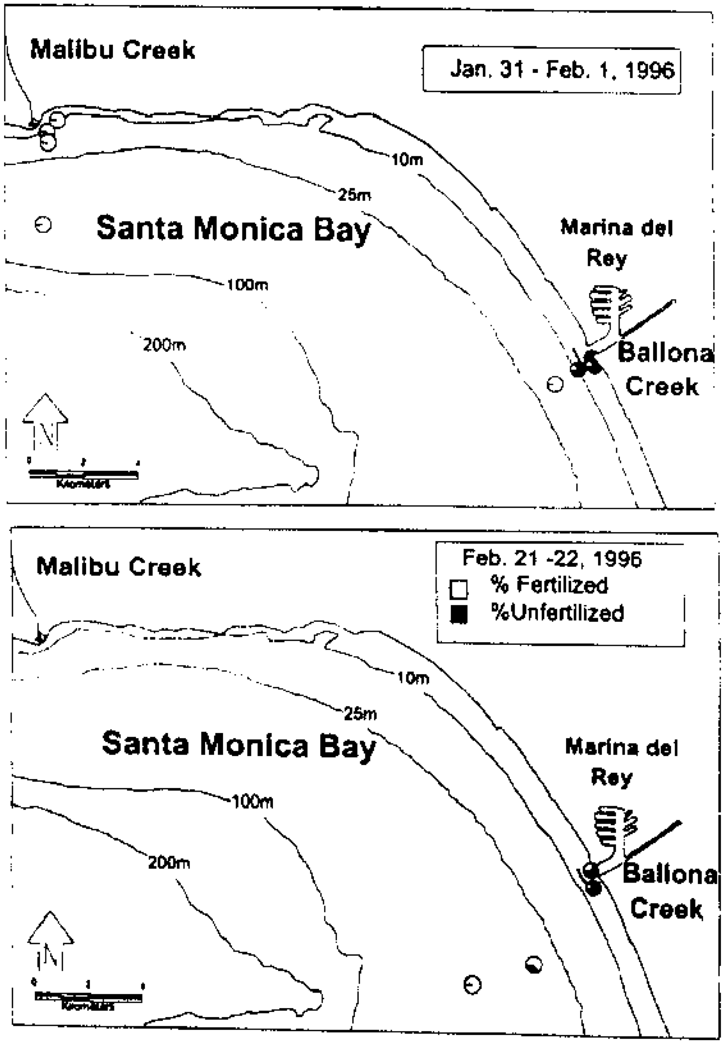

Figure 2. Surface water toxicity results for stations sampled after two storms. Pie diagrams show results of sea urchin fertilization test.

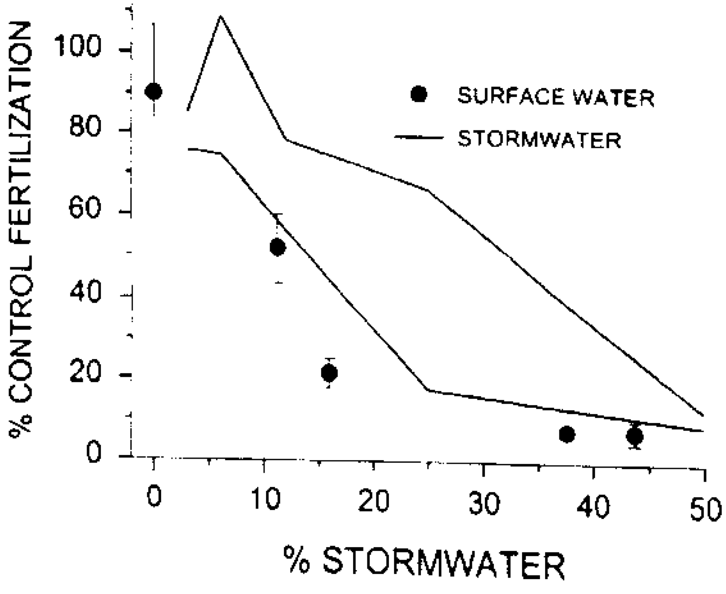

Figure 3. Comparison of sea urchin fertilization test results for February 21-22, 1996 samples of Ballona Creek stormwater (upstream) and nearby surface water (mean and standard deviation). Stormwater dose response lines are for two samples that represent the range of toxicity measured during the storm (Bay *et al.* 1997). All values have been normalized to the control response.

Effects on Sediment

Sediment Concentrations. The analytical results from the four sets of post-storm sediment samples were used to determine the wet season average concentrations of sediment characteristics and contaminants directly offshore the mouths of Ballona and Malibu Creeks. Sediments sampled at Malibu Creek contained twice the fines, 50% more TOC, and 25% greater TN than Ballona Creek (Table 1). Of the 14 different inorganic/metal constituents, seven were substantially greater in sediments offshore of Malibu Creek (Al, Be, Cd, Cr, Fe, Ni, Se), three were substantially greater in sediments offshore of Ballona Creek

(Pb, Hg, Ag), and the remaining three constituents were roughly similar in the sediments offshore of the two drainages (As, Cu, Zn). Ballona Creek was significantly greater in sediment concentrations of total DDT, total PCB, and total PAH than Malibu Creek.

Table 1. Mean (± 95% confidence intervals) sediment characteristics and pollutant concentrations offshore a highly urbanized (Ballona Ck) and less urbanized (Malibu Ck) watershed. Sediment samples were taken directly offshore each creek mouth at roughly 25 m depth following storm events.

	Ballona Creek (n=4)		Malibu Creek (n=3)	
	Mean	95% CI	Mean	95% CI
General Characteristics (% dry wt)				
Fines	30.5	1.2	53.6	8.2
TOC	0.662	0.263	0.912	0.106
TN	0.064	0.012	0.080	0.008
Inorganic Contaminants (ug/dry g)				
Aluminum	14075	258	21500	898
Arsenic	4.9	0.7	5.0	1.3
Beryllium	0.39	0.03	0.57	0.10
Cadmium	0.45	0.07	0.68	0.15
Chromium	41.8	3.1	57.5	13.7
Copper	11.2	2.0	13.0	2.6
Iron	15575	123	22933	2103
Lead	26.8	2.2	10.3	1.2
Mercury	0.17	0.02	0.10	0.01
Nickel	14	1	29	4
Selenium	0.49	0.05	0.69	0.04
Silver	0.93	0.13	0.31	0.05
Zinc	56	3	58	7
Organic Contaminants (ng/dry g)				
Total DDT	26.5	6.7	17.5	3.3
Total PCB	26.0	11.0	3.6	2.1
Total PAH	289.3	185.3	73.5	2.2

Gradients of Stormwater Influence. Sediment characteristics offshore of Ballona Creek followed a distinct pattern across the gradient of stormwater influence (Figure 4). The proportion of sedimentary fine-grained materials (silt + clay) was greatest directly offshore the creek mouth and declined both upcoast and downcoast. Grain size was significantly higher directly offshore Ballona Creek (31% fines) relative to sediments 4 km upcoast (19% fines). Similarly, a spatial pattern in sediment TOC and TN content was associated with Ballona Creek discharges. Sediment organic carbon content doubled directly offshore Ballona Creek (0.66% TOC) compared to sediments 4 km upcoast (0.30% TOC).

The spatial pattern in sediment characteristics offshore Malibu Creek was less distinct than at Ballona Creek, but was still discernible (Figure 4). Fine-grained sediments at 25 m depth directly offshore the creek mouth were 15% greater than in sediments collected at similar depths 4 km upcoast. In general, background conditions at Malibu Creek, as indicated by sediment characteristics such as grain size, were substantially different compared to background conditions offshore Ballona Creek.

Inorganic contaminants offshore of Ballona Creek followed a pattern across the gradient of stormwater influence which was similar to the pattern observed in sediment characteristics. Stormwater associated metals such as lead, copper, and zinc were significantly higher in sediments sampled directly offshore of the creek mouth and concentrations declined both upcoast and downcoast (Figure 4). Wet season averages at distant stations 4 km upcoast were between 41% (for copper) and 70% (for zinc) of average concentrations directly offshore of Ballona Creek mouth.

The pattern of inorganic sediment contamination across the gradient of stormwater influence offshore Malibu Creek was small or non-existent compared to the patterns observed offshore Ballona Creek (Figure 4). As with the sediment characteristics, where patterns did exist the magnitude of changes were smaller than at Ballona Creek. Wet season averages at distant stations 4 km upcoast were between 58% (for copper) and 80% (for zinc) of values measured directly offshore of the Malibu Creek mouth. Average metal concentrations were highest in sediments sampled 2 to 4 km downcoast from the Malibu Creek mouth.

Organic contaminants offshore of Ballona Creek followed a distinct pattern across the gradient of stormwater influence (Figure 4). Total DDT, total PCB, and total PAH were highest in sediments directly offshore of the creek mouth and concentrations declined both upcoast and downcoast. Wet season averages at distant stations 4 km upcoast were between 6% (for total PAH) and 41% (for total DDT) of average concentrations directly offshore of Ballona Creek mouth

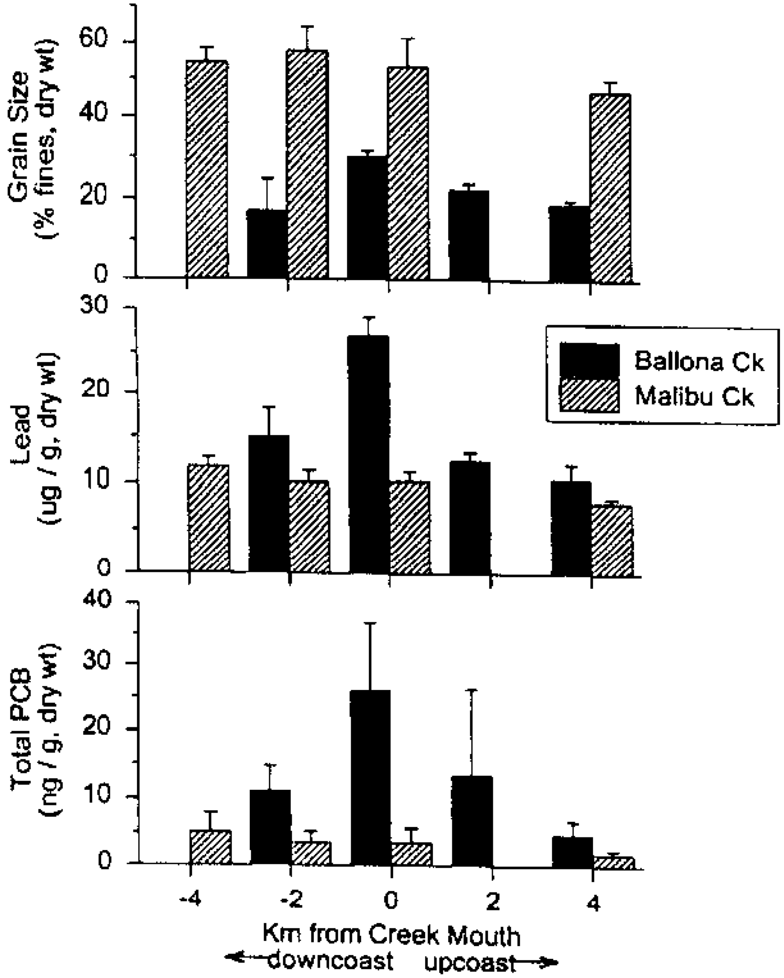

Figure 4. Grain size, lead, and total PCB concentrations in surficial sediments offshore of Ballona and Malibu Creeks. Values are mean (+95% CI) of 3-4 storms during the 1995-96 wet season. Distance from creek mouth refers to the upcoast (+) or downcoast (-) direction at a depth of 25 m.

Organic contaminants offshore of Malibu Creek generally did not follow a pattern across the gradient of stormwater influence (Figure 4). There was no consistent trend to the data and organic contaminant concentrations were very low overall. The greatest wet season concentrations of total PCB and total PAH were not directly offshore of Malibu Creek, but 4 km downcoast instead. However, the lowest values for all three organic compound classes were regularly observed 4 km upcoast from the Malibu Creek mouth.

Toxicity. Amphipod survival was high (89-98%) and indicative of no toxicity in all sediment samples (Table 2). The concentration of ammonia in the water overlying the sediment was slightly higher for stations within 2 km of either creek, possibly reflecting the organic enrichment identified by chemical analyses. These ammonia concentrations were not toxic and were within the range typically found in sediment toxicity tests.

Interstitial water from nine of ten sediment samples was nontoxic to sea urchin sperm (Table 2). Only interstitial water from the Ballona Creek station located 6 km upcoast was toxic, reducing fertilization by about 60% (relative to the control).

Table 2. Summary of toxicity test results for whole sediment (amphipod survival) and interstitial water (sea urchin fertilization). Sediment samples were collected February 28, 1996. Distances refer to the upcoast (+) or downcoast (-) direction at a depth of 25 m.

Distance from creek (km)	Amphipod survival		Sea urchin fertilization	
	% Survival mean (SD)	Ammonia [a] (mg/L)	% Fertilized mean (SD)	Ammonia [b] (mg/L)
Ballona Creek				
-2	93 (4)	2.0	98 (2)	4.2
0	95 (6)	3.1	98 (2)	6.2
2	89 (11)	2.6	95 (4)	4.1
4	97 (4)	1.5	96 (1)	3.4
6	98 (3)	1.7	42 (5)	9.8
Malibu Creek				
-4	93 (6)	1.1	98 (1)	2.1
-2	91 (8)	1.6	99 (1)	2.0
0	90 (7)	2.8	95 (1)	2.7
2	93 (6)	2.0	99 (1)	1.5
4	89 (10)	0.6	99 (2)	1.7

Infaunal Community Structure. A total of 30 samples were sieved, sorted, weighed and identified for infaunal community structure analysis. A total of 8,531 individuals were identified comprising 389 different taxa. About 90% of the total abundance at each creek represented species common to both sites. The dominant species recorded at each creek site included the polychaetes, *Spiophanes missionensis* and *Paraprionospio pinnata*, the mollusc, *Tellina modesta*, and the amphipods, *Amphideutopus oculatus* and *Ampelisca brevisimulata*. Interestingly, the Malibu Creek site also contained some organisms (e.g., *Amphiodia urtica*) which are typical of fine-grained habitats common in deeper water (Bergen 1995).

For the entire wet season, stations directly offshore of Ballona Creek and Malibu Creek at 25 m depth had similar diversity (Shannon-Wiener H'), evenness (Pielou's J), and species richness (Table 3). Abundance was slightly reduced offshore of Ballona Creek relative to Malibu Creek.

Table 3. Summary of infaunal results for the 1995-96 wet season. Distances refer to the upcoast (+) or downcoast (-) direction at a depth of 25 m.

Distance from creek mouth (km)	Mean (95% Confidence Interval)			
	Abundance[a]	Species Richness	Diversity[b]	Eveness[c]
Ballona Creek (n=4)				
-2	324 (46)	94.5 (12.4)	1.73 (0.08)	0.88 (0.03)
0	244 (18)	80.0 (4.4)	1.70 (0.04)	0.89 (0.01)
2	216 (33)	66.5 (4.4)	1.60 (0.05)	0.88 (0.02)
4	145 (47)	67.3 (13.1)	1.68 (0.08)	0.93 (0.02)
Malibu Creek (n=3)				
-4	374 (66)	94.0 (10.4)	1.70 (0.10)	0.86 (0.03)
-2	378 (325)	85.3 (57.1)	1.60 (0.30)	0.90 (0.08)
0	333 (38)	95.7 (9.1)	1.74 (0.02)	0.88 (0.02)
4	303 (52)	91.3 (10.4)	1.71 (0.08)	0.87 (0.04)

[a] Number of individuals/0.1 m^2

[b] Shannon-Wiener H'

[c] Pielou's J

Examination of trends across the gradient of stormwater influence did not reveal any significant relationships to stormwater discharges (Table 3). Instead, mean abundance decreased moving upcoast offshore of both creeks. Similarly, species richness was highest downcoast and lowest upcoast of the Ballona Creek mouth. Species richness was fairly constant across the gradient of stormwater influence at Malibu Creek, but the station 2 km downcoast showed high variability. Diversity and eveness measures showed no strong trends between stations.

DISCUSSION

Results from the first year of this study, though preliminary, have already helped address several important questions regarding runoff effects in receiving waters. Stormwater runoff in Southern California is extremely variable between storms and years. We cannot be sure that the patterns or magnitudes of effects discussed below are representative without conducting similar measurements over a longer time span, as planned for the subsequent years of this study.

- **Do stormwater discharge plumes contain toxic materials?**

The results indicate that surface water toxicity in the Ballona Creek area may occur when discharge plumes contain greater than about 10% runoff. Malibu Creek discharge plumes did not contain toxic concentrations of runoff, primarily because of greater dilution. Differences in runoff concentrations in the surface water samples prevent a direct comparison of the results for Malibu and Ballona plumes. Less concentrated runoff plumes off Malibu are probably the result of several factors, including much lower flow rates (up to two orders of magnitude difference) due to the more permeable watershed and additional dispersion resulting from delays in obtaining samples from the Malibu area.

The surface water toxicity results are consistent with tests of stormwater (sampled upstream of the creek mouth) conducted as part of a project funded by the Santa Monica Bay Restoration Project (Bay *et al.* 1997). Toxicity of Malibu Creek stormwater is usually less than similar samples from Ballona Creek, with concentrations of ≥ 25% usually needed to produce toxic effects. Extending these results to surface waters, it is likely that less toxicity will be present offshore of Malibu Creek.

- **Do stormwater discharges produce long-lasting alterations in Santa Monica Bay sediments?**

Discharges from Ballona and Malibu Creeks appeared to alter the general characteristics (e.g. grain size and organic content) of offshore sediments. The spatial pattern of altered sediment characteristics was persistent (present in dry weather) and could be observed at least 2 km distant. Some alterations in sediment characteristics were observed at depths of 40 m, but were not seen in depths of less than 10 m (Bay and Schiff 1997). These changes are not unexpected sine the combined loads of suspended solids from these two channels were estimated to be greater than 21 x 10^3 mt during the 1994-95 water year (LACDPW 1996). Moreover, these results are consistent with other studies which observed increases in sediment fines at distances ≥ 2 km offshore of the Santa Clara River following large winter storms (Kolpack and Drake 1985).

Runoff from urbanized watersheds appear to have some effect on the receiving water benthic environment. Sediments offshore of Ballona Creek were higher in concentrations of organic contaminants such as total DDT, total PCB, and total PAH as well as lead, a stormwater-associated metal, compared to sediments offshore of the less urbanized Malibu Creek watershed. This contamination covaried with sediment characteristics across the gradient of Ballona Creek stormwater influence. Sediment concentrations of organic and inorganic pollutants were highest offshore of the Ballona Creek mouth and then decreased upcoast and downcoast. Similarly, other researchers have shown that runoff from watersheds with as little as 15 to 25% urbanized land use(i.e. imperviouseness) have altered freshwater ecosystems (Yoder and Rankin 1996, Schueler 1994).

It is unlikely that the changes in sediment contaminants measured near Ballona and Malibu Creeks represent most of the many tons of contaminants entering Santa Monica Bay from stormwater each year. More research is needed to define the range of influence and eventual deposition of storm discharged particles in Santa Monica Bay. This work is continuing at SCCWRP, and is part of the effort being conducted with our collaborators at USC and UCSB.

- **Is sediment toxicity affected?**

Results from the sediment toxicity tests indicate that the altered sediment characteristics and increased contaminants resulting from stormwater discharge did not result in increased sediment toxicity. Amphipod survival was not reduced by exposure to sediment from any station. These results are similar to sediment toxicity data from the Southern California Bight Pilot Project (SCBPP), a regional study of coastal sediment quality conducted in 1994 (SCCWRP 1996). Sediment from 72 stations in Southern California (in depths of 10-200 meters), including 13 sites in Santa Monica Bay, were collected and tested for toxicity using a similar amphipod survival test. No significant amphipod mortality was found at any of the SCBPP stations.

Amphipod survival tests do not always provide a highly sensitive measure of sediment toxicity. Recent amphipod survival tests on much more highly contaminated sediments located near Southern California wastewater outfalls failed to detect toxicity in samples that caused sublethal effects on other toxicity test species (SCCWRP 1995b) or contained altered benthic communities (SCCWRP 1993c). The 10 day amphipod survival test was used in this program because it is a reliable method commonly used in sediment quality studies, and toxic effects observed with this test are often associated with adverse benthic community changes.

Interstitial water toxicity measurements were included in this program to provide a more sensitive measure of sediment quality. Previous studies have detected interstitial water toxicity in Southern California sediments that did not affect amphipod survival (SCCWRP 1995b and 1996). The sea urchin fertilization test of interstitial water did detect toxicity in one sample at the northern end of the Ballona Creek study area. Sediment chemistry results indicate that this station is outside the area most influenced by the Creek (Figure 4). As interstitial water toxicity did not correspond to variations in sediment contamination, it is unlikely that the toxicity was related to Ballona Creek stormwater. A cause for the interstitial water toxicity cannot yet be identified. This toxicity may indicate the presence of unidentified contaminants from an unknown source, or it may reflect temporary variations in sediment quality caused by natural factors or sediment storage. Additional research is needed to clarify the significance of the results. Additional toxicity tests of sediments from the Ballona Creek study area are in progress to assess the sublethal effects and bioavailability of the sediment-associated contaminants.

- **Are infaunal communities impaired?**

No dramatic biological effects in the benthic community structure were evident from the first wet season of sampling. There were no indications of a strongly degraded environment. Differences in community composition between sites offshore of the two creeks were most likely a result of variations in sediment characteristics (e.g., grain size) rather than differences in sediment-associated contaminants.

Due to relatively small sample sizes ($n \leq 4$), it is premature to reach conclusions regarding community disturbance at this time. However, these preliminary results are similar to previous surveys of reference areas which have reported 273-358 individuals and 78-91 species per grab at depths of 30 m during the summer months (Thompson *et al.* 1987, 1993). Completion of the second year of infaunal analysis will provide a greater ability to detect subtle differences in communities across gradients of stormwater influence and determine whether the results are consistent over time.

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