Comparison of the pollutant loads in dry and wet weather runoff in a southern California urban watershed

T.N. McPherson*, S.J. Burian, H.J. Turin***, M.K. Stenstrom**** and I.H. Suffet*******

* MS-F604, TSA-4, Los Alamos National Laboratory, Los Alamos, New Mexico, 87545 and Environmental Science and Engineering Program, University of California Los Angeles, Los Angeles, California, 90095, USA

** Assistant Professor, Department of Civil Engineering, 4190 Bell Engineering Center, University of Arkansas, Fayetteville, Arkansas 72701, USA

*** MS-J534, E-ET, Environmental Technology, Los Alamos National Laboratory, Los Alamos, New Mexico, 87545, USA

**** Professor, Department of Civil Engineering, University of California Los Angeles, Los Angeles, California, 90095, USA

***** Professor, Environmental Science and Engineering Program, University of California Los Angeles, Los Angeles, California, 90095, USA

Abstract This research compares the relative contributions of potential contaminants discharged in dry weather flow (DWF) and wet weather flow (WWF) from the highly urbanized Ballona Creek watershed (BCW) in southern California using empirical and deterministic models. These models were used to compare the loading of the following pollutants: total suspended solids, biochemical oxygen demand, total nitrogen, total inorganic nitrogen, total Kjeldahl nitrogen, total phosphorus, copper, lead, arsenic, nickel, cadmium, and chromium. The results indicate DWF contributes approximately 10–30% of the total annual flow discharged from Ballona Creek. The annual DWF volume was fairly consistent; the variation in DWF percentage contribution was dependent on the highly variable volume of WWF. The relative contribution to the annual pollutant load varied considerably between each pollutant. In general, the DWF load was found to be significant, especially in years with lower precipitation totals. The results from this investigation have identified the relative relationship between DWF and WWF loads in the BCW and will aid in the decision-making process during the development of an integrated DWF-WWF management plan and allocation of water pollution control funds between DWF and WWF management.

Keywords Dry weather flow; heavy metals; non-point sources; nutrients; watershed management; wet weather flow

Introduction

Urban wet-weather flow (WWF) discharges to receiving waters have long been recognized as significant sources of pollutants and causes of water-quality degradation. (APWA, 1969; Field and Turkeltaub, 1981; Heaney and Huber, 1984). However, in the southwestern U.S., with a Mediterranean climate, the rainy season occurs only between November and April, and storm drains may also convey a significant quantity of pollutants during dry weather conditions. Dry weather flow includes allowable NPDES permitted discharges, incidental nuisance flows or inappropriate discharges. In Los Angeles, for example, dry weather flow (DWF) from storm drains is comprised mostly of nuisance flows and NPDES permitted discharges having high concentrations of potential pollutants (Lau and Stenstrom, 1993). The concern for controlling WWF in recent years has reduced the attention given to DWF discharging from storm drains into receiving waters, but DWF conditions are predominant throughout the year in Southern California and especially during critical life stages of many organisms. Effective watershed management requires the assessment of each pollutant source. Dry and wet weather runoff from urban areas (i.e., streets, parking lots, and yards)

Water Science and Technology **Vol 45 No 9 pp 255–261**

can contain pesticides, persistent organic pollutants, heavy metals, nutrients, bacteria and sediments. In order to mitigate adverse impacts from urban watersheds, an understanding of the pollutant contributions from urban DWF and WWF is necessary. This study evaluates the contribution of DWF contaminant loads to degraded receiving water quality and whether it should be included in watershed management plans.

This study uses historical data, field sampling protocols, and modeling results to characterize long-term DWF and WWF discharges from the Ballona Creek watershed (BCW), a coastal watershed in Los Angeles, California (Figure 1). The BCW is an extremely urbanized watershed draining approximately 330 km^2 (127 mi^2) of Los Angeles County, California. The land use is 61% residential, 17% commercial, 15% parks or open space, and 7% industrial. Ballona Creek has been highly modified to promote effective stormwater drainage and has consistently failed to maintain its beneficial uses due to poor water quality. This watershed also has been determined to be a major source of contaminants to Santa Monica Bay, a National Estuary Program estuary. This study analyzed total suspended solids (TSS), total nitrogen (TN), total inorganic nitrogen (TIN), total phosphorus (TP), total Kjeldahl nitrogen (TKN), copper (Cu), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb) pollutant loading from the BCW.

Methods

This study consisted of two separate phases. Phase 1 was a modeling study comparing the annual pollutant loads from WWF and DWF. Phase 2 was an analysis of the partitioning of trace metals in DWF and WWF between dissolved and suspended solids phases. WWF loads were estimated using ArcView GIS and the U.S. EPA Storm Water Management Model (SWMM). SWMM input parameters were developed from land use information from the Southern California Association of Governments (SCAG), storm drainage system information from the Los Angeles County Department of Public Works (LACDPW), digital elevation models (DEMs) from the USGS, and roadway locations from the U.S. Census Tiger Data. Separate stormwater models were developed for the Ballona, Sepulveda, and Centinela Catchments (Burian *et al.*, 2000). WWF pollutant loads were estimated using the event mean concentration procedure. The EMC procedure was used because the goal of this research is a long term evaluation of stormwater impacts not an intrastorm evaluation. Use of EMCs is appropriate for most long-term studies of storm-

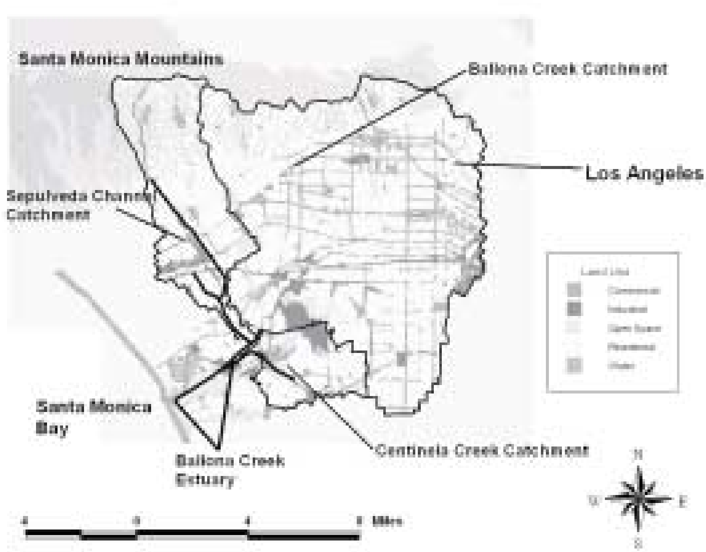

Figure 1 The Ballona Creek Watershed

water impacts on receiving waters because most larger receiving water bodies respond slowly to storm inflows compared to the rate of change of contaminant concentrations during a storm event (Charbeneau and Barrett, 1998). DWF loads were estimated using an empirical model based on flow data collected by the Los Angeles County Department of Public Works (LADPW) coupled with water quality data drawn from the Santa Monica Bay Urban Runoff Database (SMBURD) and a summer 1999 water quality monitoring program. Samples were collected at locations in Ballona Creek, Sepulveda Channel, and Centinela Creek. At each site, DWF samples were collected three times per day for six days during June–August 1999. Samples were analyzed for TSS, Total Inorganic Nitrogen (TIN), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), BOD, and dissolved and suspended solids forms of As, Cd, Cr, Ni, Pb, and Cu. The analytical methods used were similar to those used in a sampling study of WWF (Suffet *et al.*, 1999) to facilitate comparison of partitioning between DWF and WWF. SMBURD was queried for the constituents of interest and the retrieved data were defined as wet-weather or dry-weather using the available rainfall record. The dry-weather data were then combined with the summer 1999 monitoring data to calculate the median concentration of each contaminant. The DWF load from each catchment was calculated according to:

$$W = n \times \sum_{j=1}^{n} C_m \times Q_j \qquad (1)$$

where W is the load over a prescribed period, n, C_m (µg/L) is the median concentration at the site of interest, and Q_j (m^3/s) is the DWF on day j. This approach is similar to the sample mean approach listed in Mukhopadhyay and Smith (2000) in which the mean concentration and the average flow on each given day are multiplied and then summed over the period of interest. Because of the unavailability of concentration data for the period of our simulation, the entire water quality dataset was used to calculate one concentration for each parameter at each site.

Results

The goal of this study was to evaluate the relative importance of the conventional and trace metal pollutant loads in DWF and WWF in terms of the magnitude of the total load. A second goal was to evaluate the distribution of the trace metal loads between suspended solids and dissolved concentrations. Figure 2 shows the annual volume of flow in DWF and WWF

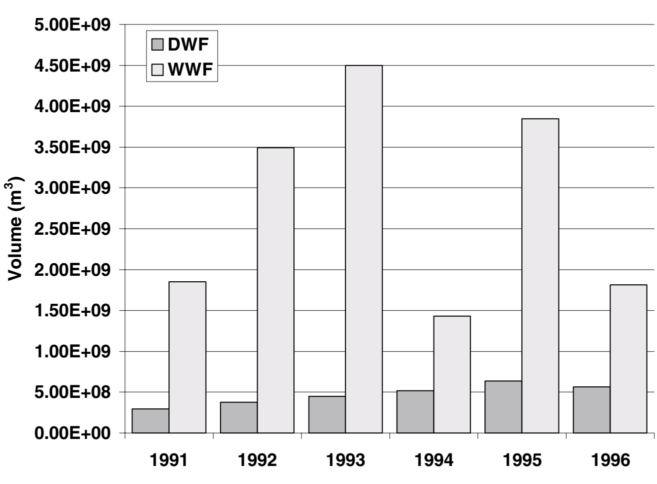

Figure 2 Annual volume of DWF and WWF in Ballona Creek Watershed

for the 1991 to 1996 water years. DWF accounts for 10–30% of the annual volume of water discharged from this watershed. The DWF contribution to the annual pollutant load varies widely across the constituents evaluated. Figure 3 shows the annual average load of nutrient and oxygen demanding pollutants. WWF is the predominant source of all conventional contaminants producing approximately 99%, 96%, 77%, 76%, 80%, and 95% of the average annual TSS, BOD, TIN, TN, TKN, and TP loads, respectively. This suggests WWF contributes more to coastal nutrient problems, such as shifts in population dynamics and reduced light penetration, than DWF. DWF nutrient and oxygen demanding constituents loads may be adversely affecting nearshore coastal ecosystems, such as wetlands, tidal rivers, and small estuaries. Field data indicates rapid shifts in chlorophyll-a concentrations in the Ballona Creek Estuary (BCE), the receiving water that first receives discharges from the watershed. Dissolved oxygen (DO) dynamics in that receiving water also appear to follow a cycle of supersaturation during the day followed by DO drops late at night (McPherson, unpublished data 1999).

WWF was also the primary source of toxic contaminants evaluated. Figure 4 shows the average annual loads of total trace metals from DWF and WWF. WWF is the major source

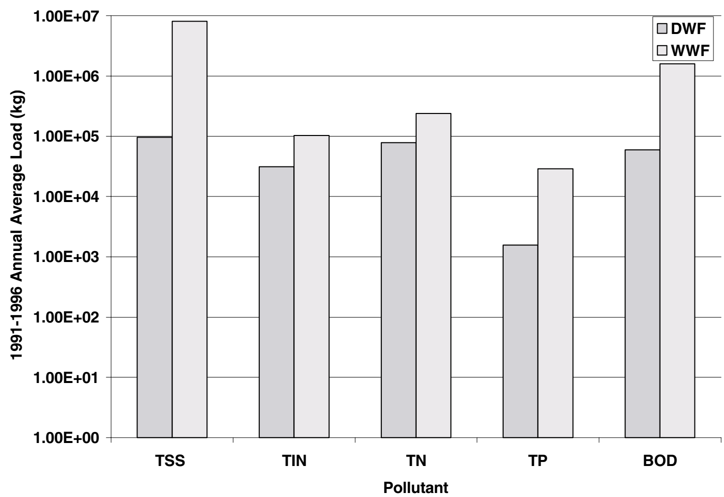

Figure 3 Conventional pollutant loads in Ballona Creek Watershed urban runoff

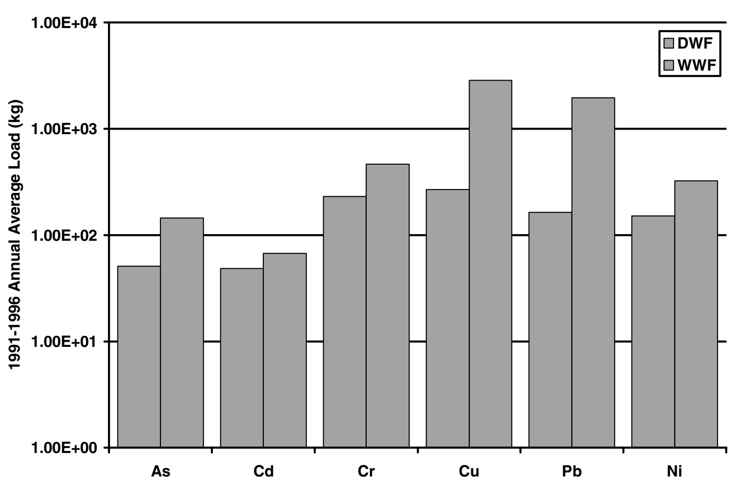

Figure 4 Trace metal pollutant loads in Ballona Creek Watershed urban runoff

of the listed trace metals producing 75%, 58%, 67%, 91%, 92%, and 68% of the total As, Cd, Cr, Cu, Pb, and Ni, respectively. DWF was also an important source, contributing 8–42% of the annual total trace metal pollutant load. Although WWF is the major source of most trace metals especially Cu and Pb, DWF conditions in the watershed still produce exceedances of water quality criteria in near shore water bodies. Figure 5 shows the average dissolved Cu concentrations in the BCE. Ambient dissolved Cu concentrations at five locations in the BCE exceed the 3.1 μg/L Cu water quality criteria listed in the California Toxics Rule in 100% of the samples collected during DWF conditions.

A second concern with DWF versus WWF loads is the form of the toxics load. WWF pollutant loads are consistently in the suspended solids phase (Sansalone and Buchberger, 1997). Differences between the fraction of DWF and WWF in the dissolved phase could affect the selection of treatment technologies for each flow type. Table 1 shows the average dissolved fraction of each metal analyzed in each sample. Except for arsenic, trace metals in WWF are predominantly associated with the suspended solids phase while DWF metal loads are mostly in the dissolved phase. This result is not indicative of any inherent differences in the partitioning of metals in the two flow types, but more likely a result of the low TSS concentrations in DWF.

Discussion

This research indicates WWF is the major non-point source of pollutants in this watershed. Eighty to ninety six percent of the nutrient and oxygen depleting pollutants are discharged in WWF. WWF is also the major non-point source of trace metals, generating 67–92% of the average annual load. While the DWF contribution to the annual load is low, DWF loads

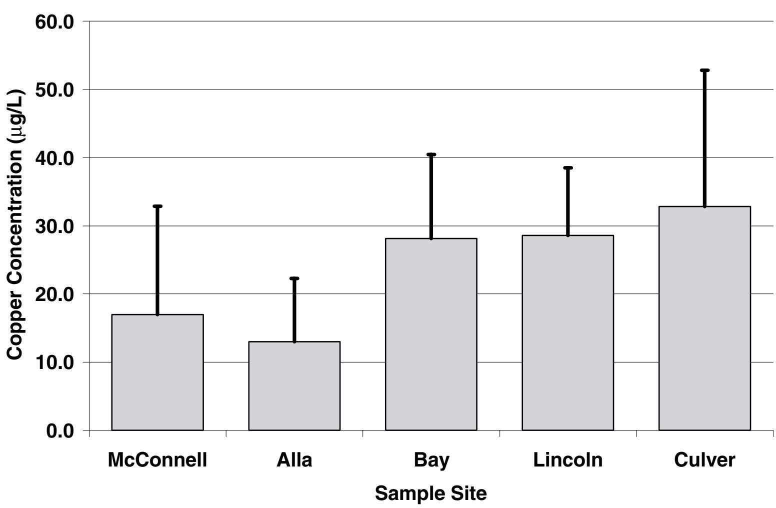

Figure 5 Ambient copper concentrations in the BCE during the 1999 dry season

Table 1 Average dissolved fractions of trace metals in DWF and WWF. Calculated as the average of the ratio of soluble concentration to total concentration in each water sample collected

Metal	DWF	WWF
Arsenic	62	85
Cadmium	69	27
Chromium	58	37
Copper	77	37
Lead	49	14
Nickel	78	20

may still be adversely affecting near coast ecosystems such as wetlands and small estuaries. The near coast waterbodies in this watershed are listed on the California 303d list for TMDL development. DWF loads of toxics are also in a more bioavailable form suggesting DWF may be adversely impacting organisms in the near shore systems following discharge and dispersion. WWF loads are predominantly in the suspended solids phase and most of its contaminant load is not available to organisms in near coast systems directly following the storm. LADPW (2000) have determined that a large proportion of the WWF load is discharged to Santa Monica Bay where it settles to local sediments. WWF may be affecting nearshore ecosystems in dry weather conditions due to the chronic release of metals from contaminated sediments that originated in WWF.

In order to manage the non-point pollutant effects from this highly urbanized watershed, an integrated WWF-DWF management plan is required. This plan should be based on the existing geospatial limitations in the watershed, its water quality priorities, and the nature of the pollutant loads. WWF from this watershed contains the majority of the annual pollutant load of each contaminant studied. Precipitation occurs on average only 37 days per year in this area. Therefore, the majority of the annual pollutant load is being discharged from Ballona Creek during relatively short time periods during the wet season. The toxics load within WWF is primarily affiliated with suspended solids. BMPs implemented for WWF should therefore focus on high intensity stormwater flows and sediment removal. DWF loads on the other hand are consistently in the dissolved phase indicating the need for BMPs that emphasize low flows with conditions conducive to bio-uptake of contaminants and metal complexation, aggregation, and settling.

Structural treatment options are limited in this watershed by the extent of urban development. Nutrient or metal removal (especially when the metals are associated with suspended solids) is best accomplished with constructed wetlands or wet detention basins, but those BMPs require a significant amount of preexisting open space to be developed cost effectively. Only 15% of the watershed is open space and that area resides in the upstream regions of the Ballona and Sepulveda catchments. The lack of open space downstream of many developed catchments in the watershed makes the application of bioretention structures, wet detention basins, vegetated swales, or constructed wetlands unlikely. Other potential BMPs such as infiltration trenches, sand filters, water quality inlets, and hydrodynamic separators are typically ineffective at treating metals and dissolved nutrients and would therefore not be appropriate in this watershed. Retrofitting the existing storm drainage system with any of these options would be costly. An alternative option is greater emphasis on source controls. Metals discharges most likely are from metal plating facilities and vehicular traffic. Nitrogen and phosphorus are from atmospheric deposition, leaf litter decay, and residential fertilizer use. Future efforts in the watershed should emphasize public outreach with increased promotion of effective land stewardship, reliance on vegetation with low nutrient and water requirements for residential landscaping, reduced external water usage such as in car washing, and reduced vehicle miles traveled in the watershed.

Conclusions

This research indicates DWF loads from the Ballona Creek watershed are consistent throughout the year. DWF is an important pollutant load of toxics and some nutrients. DWF contaminants are in the dissolved phase and therefore may be increasing aquatic morbidity and mortality following mixing and dispersion in coastal waters. WWF is the predominant non-point pollutant source. WWF pollutant loads are large acute loads that may be impacting both pelagic species during the storm event and benthic species in the area receiving the contaminated suspended sediment load.

References

APWA (1969). Water pollution aspects of urban runoff. Report No. 11030DNS01/69, NTIS No. PB 215532, American Public Works Association, Chicago, IL.

Culliton, T.J., Warren, M.A., Goodspeed, T.R., Remer, D.G., Blackwell, C.M. and McDonough, J.J., III. (1990). "50 years of population change along the Nation's coasts, 1960–2010." U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Field, R. and Turkeltaub, R. (1981). "Urban runoff receiving water impacts: program overview." *ASCE Journal of the Environmental Engineering Division*, **107**(1), 83–100.

Lau, S.-L., Stenstrom, M.K. and Bay, S. (1994). Assessment of storm drain sources of contaminants to Santa Monica Bay. Volume V, Toxicity of Dry Weather Urban Runoff. Prepared for Santa Monica Bay Restoration Project, Monterey Park, CA. 129 p.

Los Angeles County Department of Public Works (2000). Integrated receiving water impacts report. Report submitted to the Los Angeles Regional Water Quality Control Board by the County of Los Angeles, Department of Public Works, Alhambra, CA.

Mukhopadhyay, B. and Smith, E.H. (2000). Comparison of Statistical Methods for Estimation of nutrient Load to Surface Reservoirs for Sparse Data Set: Application with a Modified Model for Phosphorous Availability. *Water Research*, **34**(12), 3258–3268.

Sansalone and Buchberger (1997). Characterization of solid and metal element distributions in urban highway stormwater. *Water Science and Technology*, **36**(8–9), 155–160.

Suffet, I.H. and Stenstrom, M.K. (1999). A study of pollutants from the Ballona Creek watershed during wet-weather flow. Final Report to US Army Corps of Engineers, UCLA, Los Angeles, California.