DRY SEASON TEMPORAL VARIABILITY OF NITROGEN, PHOSPHORUS, AND SEDIMENT IN RUNOFF FROM A RESIDENTIAL NEIGHBORHOOD IN SOUTHERN CALIFORNIA

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TABLE OF CONTENTS

ABSTRACT

In semi-arid climates, such as that of southern California, dry weather flows dominate for more than half of the year and are driven by water runoff resulting from irrigation. The objective of this study was to determine the temporal variation in nitrogen (N), phosphorus (P), and sediment concentrations and loads in dry weather from a residential neighborhood (28 ha) using intensive sampling techniques. Triple composite water samples were automatically collected at 3-hour intervals for one-week during June 2008 at the outlet pipe that drains the residential area. Flow was recorded continuously from October 2007 through September 2008. Both flow and nutrient concentrations increased and decreased in a daily cycle, with lowest values observed from 6:00 a.m. to noon and highest values between 6:00 p.m. and midnight. Mean (n = 56) concentrations of total N, total P, and total suspended solids (TSS) at the outlet pipe were 10.9, 1.3, and 52.2 mg L^{-1}, respectively. The calculated dry season (153 day) export of total N, total P, and TSS was 20.2, 2.3, and 97.1 kg ha^{-1}, respectively. The dry season loading of N and P was greater than most annual loading rates found in comparable runoff studies (TN: 5.0-23.9 kg ha^{-1} yr^{-1}, TP: 0.4-2.3 kg ha^{-1} yr^{-1}). Dry season load of TSS in this study was approximately 25% of the annual rate found in a comparable study (TSS: 387 kg ha^{-1} yr^{-1}). However mean concentration of TSS during the one-week of intensive sampling was elevated. It is likely that additional input of nutrients and sediment from the use of reclaimed water for irrigating common areas in the evening and early morning hours as well as several transient events within the watershed caused greater nutrient losses. The intensive sampling data from this semi-arid residential area suggests that watershed nutrient export rates could be underestimated if water quality monitoring assessments do not consider dry weather flows resulting from irrigation applications and the use of reclaimed water within the watershed.

1. Introduction

Surface waters increasingly receive pollutants that diminish water resources. Previous research has shown numerous negative impacts from anthropogenic activities on water quality (e.g., Conley, 2009, Diaz, 2008). The scientific community has been investigating urban stormwater runoff for the past several decades as local and state governments have been charged with protecting surface and groundwater resources and creating total maximum daily loads (TMDLs) for contaminants of concern for various water bodies. Nationwide studies have proven too broad to predict activities occurring in local watersheds, although they have brought light to the impacts of point and nonpoint source pollution on receiving waters (Rast and Lee, 1983; USEPA, 1983b) Understanding the fate and transport of pollutants from land to water can allow for the development and fine-tuning of best management practices (BMPs) to protect sensitive water bodies and aquatic ecosystems.

Urban nonpoint and point source pollution have been identified as an important cause of surface water quality degradation in the United States (Coulter, 2004; Easton, 2004; Foley, 2005; Groffman, 2004; Pratt and Chang, 2012; USEPA, 1983b). Understanding the many factors that contribute to urban surface water pollution will aid in the development of more accurate pollutant loading estimates. Water running over the land's surface carries contaminants such as nutrients, nitrogen (N) and phosphorus (P), that enter adjacent water bodies causing harm to aquatic ecosystems (Golterman, 1991; Goonetilleke, 2005; Nyenje et al., 2010; Yu et al., 2011). Although N is a limiting nutrient in marine systems and P a limiting nutrient in freshwater systems, estuarine systems can show N and P limitations at varying temporal and spatial scales (Bergström, 2010; García-Pintado et al., 2007; Gin et al., 2011). Conley (2009) suggests that a dual approach, that considers N:P ratios and seasonal shifts in limiting nutrients, when managing

N and P in surface waters may reduce water quality impacts and provide a more permanent solution to protect water resources (Conley, 2009).

In urban systems, natural hydrology is significantly altered which amplifies runoff. Urban development increases impervious (e.g. pavement and rooftops) surface area (ISA), which decreases infiltration, increases runoff, and shortens the residence time of runoff water and pollutants in the soil (Brion et al., 2011; Pfeifer and Bennett, 2011). Increasing ISA, reduces opportunities for the breakdown and retention of pollutants by soil processes resulting in increased pollutant concentrations in runoff (Brezonik and Stadelmann, 2002; Conley, 2009; Lewis and Grimm, 2007). Other factors that influence runoff volume and pollutant concentrations in the urban environment include climate and rainfall characteristics (antecedent dry days and rainfall intensity), topography and geology (soil permeability and slope), anthropogenic activities (irrigation and fertilizer application), and land classification (population density and level of disturbance) within the watershed (Caccia and Boyer, 2007; Chua et al., 2009; Line, 2002; Miguntanna et al., 2010; Roberts and Prince, 2010; Tomer, 2003). All these factors exhibit great variability in urban areas making it difficult to draw comparisons from existing studies.

To date, most water quality studies have examined runoff from broad land uses such as forest, agricultural, and urban. This approach assumes that developed or urban land use is spatially homogeneous within the watershed. A better approach would be to characterize land uses within the urban drainage network. A typical urban watershed could contain land classified as lawn, open space, parks, industrial, construction, commercial, golf courses, and high and low density residential. The few studies that differentiate between urban land uses have shown that the type of urban land affects both surface water flow and pollutant concentrations (Atasoy et al., 2006; King et al., 2007; Line, 2002). More specifically classifying urban land uses will also make it easier to predict possible pollutants and their sources.

In the urban landscape, pollutants of concern include nutrients, bacteria, industrial chemicals, heavy metals, and sediments(Brown Gaddis et al., 2007; Conley, 2000; Miguntanna et al., 2010). In a residential catchment, the main sources of these pollutants are lawn fertilizer, vehicular traffic, atmospheric deposition, organic matter (i.e. lawn clippings), detergents, recycled water used for irrigation, and pet waste (Carpenter et al., 1998; García-Pintado et al., 2007; Law et al., 2004; Steele, 2010). Anthropogenic activities in the residential setting influence not only the pollutant source, but also their possible transport to adjacent surface waters. Regional variability associated with loading factors has illustrated the need for local studies to more accurately estimate urban runoff pollution and assess the potential risk to surface waters in the drainage network.

The objective of this study was to examine temporal variation in flow, nutrients (N and P), sediment concentrations, and nutrient and sediment loads from a residential catchment using intensive sampling. Interest in N and P stems from their key role as limiting nutrients for aquatic systems (Diaz, 2008; García-Pintado et al., 2007). Suspended solids were analyzed to aid in describing fluxes in nutrients due to the relationship between TSS and the organic and inorganic forms of N and P (Bennett et al., 2001; Graves, 2004; Lado and Ben-Hur, 2009). This study is limited to the urban residential land use as urbanization has hastened the conversion of pervious rural land to impervious urban land (Foley, 2005; Vadeboncoeur et al., 2010). The hypothesis of this study was that (1) intensive sampling in the residential catchment would illustrate patterns in nutrient and sediment loads that are not detected with more conventional infrequent sampling techniques (weekly, bi-weekly, or monthly grab samples) and (2) in semi-arid environments dry weather near-continuous low flows can contribute significant amounts of nutrient and sediment loads. This data will provide a better understanding of how residential land use contributes to urban surface water pollution. If temporal cycles in residential runoff flow and nutrient concentrations are detected, better sampling methods and more representative loading estimates can be developed. This study also calculated nutrient loading during the dry season in a semi-arid environment to expand current information on surface water contamination contributed to annual nutrient export totals from non-storm events. Data from this study was compared to existing urban runoff studies, although there were no other studies available for comparison that focused specifically on residential dry weather nutrient concentrations.

2. Methods

This study analyzed data collected from a residential drainage area within a predominately urban watershed. Water quality data was extracted from a larger study conducted in Orange County, California (California, 2006). The larger study was designed to quantify levels of various pollutants in residential runoff during dry weather and early season storm events as well as evaluate BMPs to reduce pollutant loads. The complete study included four residential sites of similar size, age, income, and demographics. This study focused on the only site where intensive sampling was utilized and was limited to seasonal dry weather loading of TN, nitrate-N, TP, orthophosphate-P, and TSS. Other water quality parameter data collected were turbidity, electrical conductivity, and total organic carbon.

2.1 Site Description

This study was conducted in a coastal residential community in southern California located in Orange County, California (Figure 1). The sampling location lies within the Aliso Creek Watershed. The watershed is approximately 80 km south of Los Angeles and 105 km north of

San Diego. The main waterway within the watershed is Aliso Creek, which drains a long, narrow coastal canyon with headwaters in the Cleveland National Forest. The creek ultimately discharges into the Pacific Ocean at Aliso Beach. The watershed includes portions of the cities of Aliso Viejo, Laguna Beach, Laguna Hills, Laguna Niguel, Laguna Woods, Lake Forest, and Mission Viejo (County, 2006). The watershed covers approximately 7,844 ha with roughly 45.5% of the land (3,572 ha) classified as residential. The other major land uses are public (2,385 ha, 30.4%) and commercial (964 ha, 12.3%) (Pappas, 2009). Water sampling conducted in the watershed indicated that main contaminants of concern were bacteria, N, P, and Selenium (CDM, 2009).

The watershed sampling location is set in the San Joaquin Hills, in the coastal northwestern portion of California's Peninsular Ranges geomorphic province. The San Joaquin Hills consist primarily of Miocene and Pliocene age marine sedimentary rocks that have been uplifted, faulted, and dissected by stream erosion (Consulting, 2007). The site itself is located on steep and rocky terrain with slopes ranging from 15 to 75%. Major soils within the area are typically clayey and have slow infiltration rates, which correlates to high runoff potential when wet. The Bosanko-Balcom Complex with 15 to 30% slopes comprises 31.5% of the study area followed by Soper-Rock Complex with 30 to 75% slopes (16.7% of area), and Balcom Clay with 15 to 30% slopes (11.8% of area) (NRCS, 2011).

The study area has a semi-arid climate with warm dry summers and cool wet winters. Historic 40-year rainfall data from a local gauging station shows annual average precipitation of approximately 38 cm. During the wet season, October to April, an average of 36 cm (95% of annual precipitation) of rainfall occurs. The dry season occurs from May to September, and average rainfall during this time is 2 cm (5% annual precipitation) (Crompton, 2006). Mean annual air temperature during the dry season is 20° C and wet season mean temperature is 15° C.

The study site was a residential homeowners association (HOA) community consisting of 307 single-family homes constructed in the mid to late 1990's (Haver, 2011). According the U.S. Census Bureau, median household income in the study area was $95,498 during the time of the study (Bureau, 2012). The parcels within the study were largely owner occupied and had similar, mature, well-maintained yards. The selected site covered 28.13 ha of land. Commercial multispectral aerial imagery from QuickBird (QB) and geographic information system (GIS) raster analysis was used to classify land uses within the study site. It was determined that single-family home sites occupied 53% (this includes homes, private yards, and driveways), streets occupied 22%, and the remaining 25% was classified as other. Land classified as "other" consisted mainly of common lawn and common green space. Impervious surface area for the entire site included rooftops, driveways, and streets, and was estimated at 56% of total land area.

Residents of the single-family homes used potable water for landscape irrigation, while common areas were managed by a property management company, hired by the HOA, and irrigated with reclaimed water. According to data provided by the local water district, average monthly potable household water use at the time of the study (summer, May to September 2008) was 56,070 L. Monthly household average water use ranged from 48,100 L to 66,800 L with the month of August having the highest household potable water use (District, 2011). Access to reclaimed water use data during the time of the study was not obtained. To reduce the occurrence of human contact with possible contaminants present in water the Southern Orange County Water Authority (SOCWA) prohibited the use of reclaimed water for lawn irrigation between the hours of 9:00 a.m. and 6:00 p.m. There were no restrictions on the use of reclaimed water to irrigate sloped, non-turf landscapes in the study area. Although exact irrigation schedules could not be determined for the site, it was noted that irrigation of common areas, with reclaimed water occurred from 10:00 p.m. to 5:00 a.m. Most of the residential irrigation with potable water occurred from 5:00 a.m. to 9:00 a.m. Runoff from the residential landscape collected in a gutter system that was outfitted with a 107-cm storm outflow pipe that discharged water into the drainage network of Aliso Creek Watershed. Flow was measured and water samples were collected at the outlet of the outflow pipe prior to the water entering any tributary.

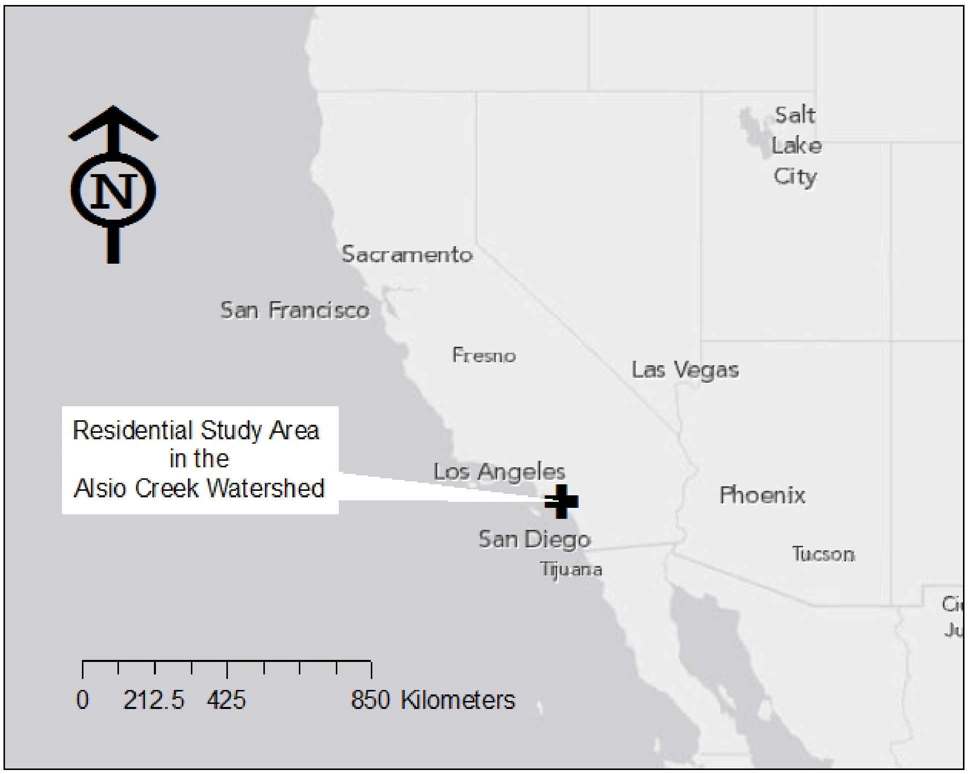

Figure 1. The residential study area within the Aliso Creek Watershed in southern California where one-week of intensive water quality sampling was conducted from June 16 to 23, 2008.

2.2 Flow Measurement

The outflow pipe in the study area had continuous flow, which was mainly attributed to lawn irrigation during the dry season. Flow was measured at the 107-cm outflow pipe with an automated in-situ flow meter (Hach Sigma 950Flowmeter, Hach Company, Loveland, Colorado). The flow meter measured flow continuously at 2-min intervals from October 2007 through

September 2008. The flow meter collected data utilizing an area velocity sensor placed in the bottom of the pipe. This method measures the mean velocity (*V*) of the water, as well as the depth (using a bubbler), and determines flow (*Q*) based on the dimensions (*A*) of the outfall pipe (Q= A × V) (Grant, 1997). No rainfall events occurred during the intensive sampling period of one week (June 16 to 23, 2008). The flow meter was checked at weekly intervals and data were downloaded. Due to the large volume of flow data collected, 2-min flow data were averaged into hourly flows for the entire flow record. Recorded negative flows were considered erroneous and omitted. Using the depth of flow and the size, shape, slope, and roughness of the channel, the Manning formula is frequently used as a substitute or means of confirming unreliable field flow data (Grant, 1997). It was determined that positive measured flows at the outflow pipe were usable when compared to calculated flows using the following Manning formula:

$$Q = \frac{KAR^{2/3}S^{1/2}}{n}$$

where Q is the flow rate (L s^{-1}), K is constant dependent on units, A is the cross sectional area of the pipe (m^2), R is the hydraulic radius (m)(an expression of A p^{-1}, or cross sectional area of water, A, divided by the wetted perimeter, *p*), S is pipe slope (m m^{-1}), and *n* is a roughness coefficient corresponding to the texture of the pipe (Manning, 1891). Constant low flows were observed at the outflow pipe during the intensive sampling. Onsite observations using a float indicated that runoff water from one irrigation event could reach the outflow pipe in less than 30 minutes.

2.3 Sample Collection and Processing

One-week of intensive water sampling was conducted at 3 h intervals starting at 9:00 a.m. on June 16, 2008 and ending at 9:00 a.m. on June 23, 2008. The auto sampler (Hach Sigma

900Max Sampler, Hach Company, Loveland, Colorado) was calibrated to take a 300 mL sample every hour and then create a triple composite sample of 900 mL every three hours. Water samples were continuously collected at 3-hour intervals (8 samples per day) for 7 d, resulting in 56 samples for the whole week. Samples were removed from the auto sampler every 24 h. The core of the sampling machine was iced and new ice was added every 24 h to maintain the integrity of the samples.

After collection, samples were transferred on ice to the laboratory where Environmental Protection Agency (EPA) standard analyses protocols were used to analyze total N (40 CFR 141), nitrate-N (EPA 350.1), total P (EPA 365.1), orthophosphate (EPA 365.3), total suspended solids (TSS) (EPA 160.2) turbidity (EPA 180.1), electrical conductivity (EC), and total organic carbon (TOC)(EPA 9060A)(USEPA, 1983a). Other-N (organic and ammonium) was calculated as difference between TN and nitrate-N. Other-P (particulate and organic) was calculated as difference between TP and orthophosphate. Nutrients (N and P) are pollutants of concern as the watershed is listed in the EPA's 303(d) list of the Clean Water Act. It is common for water quality samples and flow data to be taken infrequently (monthly or less) throughout the year. In this study, one-week of intensive sampling was conducted to determine if this method gives a comparable picture of nutrient transport and loading to surface waters or if there is additional information that can be gained by increasing the frequency of sampling.

2.4 Calculating Nutrient Loads

Dry season nutrient export rates and loading estimates were calculated for TN, TP, and TSS. Dry season export rates were calculated on a per hectare basis for the study site. Loading estimates assumed a dry season of 153 days (May to September). Export rates were calculated by multiplying mean nutrient concentrations by the mean flow recorded during the intensive sampling period. This averaging method is called the “simple method” for estimating nutrient loading and is widely used in water quality monitoring studies. The “simple method” is well suited for short-term studies and has proven to be a robust method for baseflow estimates (Endreny et al., 2005; Johnson et al., 1998; Li et al., 2003). The equation used is as follows:

$$L_{k,i}^{e} = \frac{Q_{k}^{e} C_{k,i}^{e}}{A^{e}}$$

where $L_{k,i}^{e}$ is the dry season (153 d) loading rate for site k, for constituent i, in kilograms per hectare (kg ha^{-1}). Q_{k}^{e} is the averaged sampled dry weather flow from site, k, in liters per second (L s^{-1}), $C_{k,i}^{e}$ is the average measured concentration of constituent, i, from site, k, in milligrams per liter (mg L^{-1}), and L^{e} is the total area of the site in hectares (ha). Temporal variation in nutrient loading for each constituent was calculated by multiplying the 3-h composite constituent concentration with the averaged 3-h flow.

3. Results & Discussion

3.1 Flow Dynamics

Averaged flow during the entire 2008 dry season (May to September) ranged from 0 to nearly 30 L s^{-1}, with a mean value of 3.10 L s^{-1}. The mean flow for the intensive sampling period of one-week (June 16 to 23, 2008) was slightly higher (3.96 L s^{-1}) than the mean dry season and mean flows recorded for the individual months (Table 1). It is likely that the difference between mean flow for the intensive sampling period and mean flows for the individual months was caused by an increase in irrigation and handwatering prompted by extreme heat during the week of intensive sampling. During the intensive sampling period, minimum and maximum flow was 1.55 L s^{-1} and 7.23 L s^{-1}, respectively. The intensive sampling showed that flow rates increased and decreased diurnally, with the lowest flow measured each day just before noon. After 12:00 p.m. flow at the outflow pipe continued to increase and the maximum flow rate occurred each morning near 6:00 a.m. (Figure 2). This cycle was consistent throughout the one-week intensive sampling period (Figure 2) as well as for the month of June (Figure 3). This variation in daily flow is not uncommon. An urban runoff loading study conducted in Los Angeles, California showed that dry weather flows in arid urban watersheds can exhibit predictable daily variation with flows changing by 40% during the course of a single day (Stein and Ackerman, 2007).

Flow data collected from this southern California site, during May through September 2008, showed that irrigation schedules dictated daily flow patterns in this semi-arid residential drainage basin during the dry season. Variations in flow would be missed if the flow were not measured with in-situ, time or flow sensitive, methods. Similar flow values and daily variability in flow during one-week of intensive sampling and for the entire dry season flow (Figure 3) indicated a representative snapshot of flow patterns for this residential drainage network was captured with intensive sampling. Previous studies have shown that dry weather flows, or baseflows, can be significant contributors to annual flows, especially in semi-arid climates. For example, a study in Los Angeles estimated that dry weather flows contributed 10 to 50% of annual flow, with greater contributions from dry weather flow occurring in years of little precipitation (McPherson et al., 2005). Using the monthly mean flows measured in this residential catchment from October 1, 2007 through September 30, 2008, it was estimated that dry season flows (May to September) from this catchment contributed 37% of annual discharge, while the wet season (October-April) contributed 63% (Table 1). Understanding the flow patterns specific to the drainage network are essential in creating sampling protocols to capture variability in pollutant transport.

Table 1. Mean recorded flow at the outflow pipe draining a southern California residential watershed during 2007-2008 wet and dry seasons.

Season	Month	Flow ($L\ s^{-1}$) Mean	Range	Total Flow (L)
Wet	October 2007	1.93	0.02-49.45	516,131.20
	November 2007	3.27	0.19-151.24	847,558.42
	December 2007	2.65	0.01-99.97	710,055.36
	January 2008	8.18	0.01-364.57	2,189,688.62
	February 2008	4.15	0.01-168.39	1,003,051.30
	March 2008	3.09	0.28-15.84	826,480.81
	April 2008	3.64	0.38-12.60	942,319.14
	Wet season	3.84	0.01-364-57	7,035,284.86 (63% of total)
Dry	May 2008	3.53	0.08-29.80	945,297.56
	June 2008	3.30	0.08-9.07	856,231.07
	July 2008	3.75	0.15-17.46	100,4177.65
	August 2008	2.92	0.14-8.61	781,871.26
	September 2008	1.99	0.0-12.20	515,319.36
	Dry season	3.10	0.0-29.80	4,102,896.90 (37% of total)
	Week of intensive sampling	3.96	1.55-7.23	-

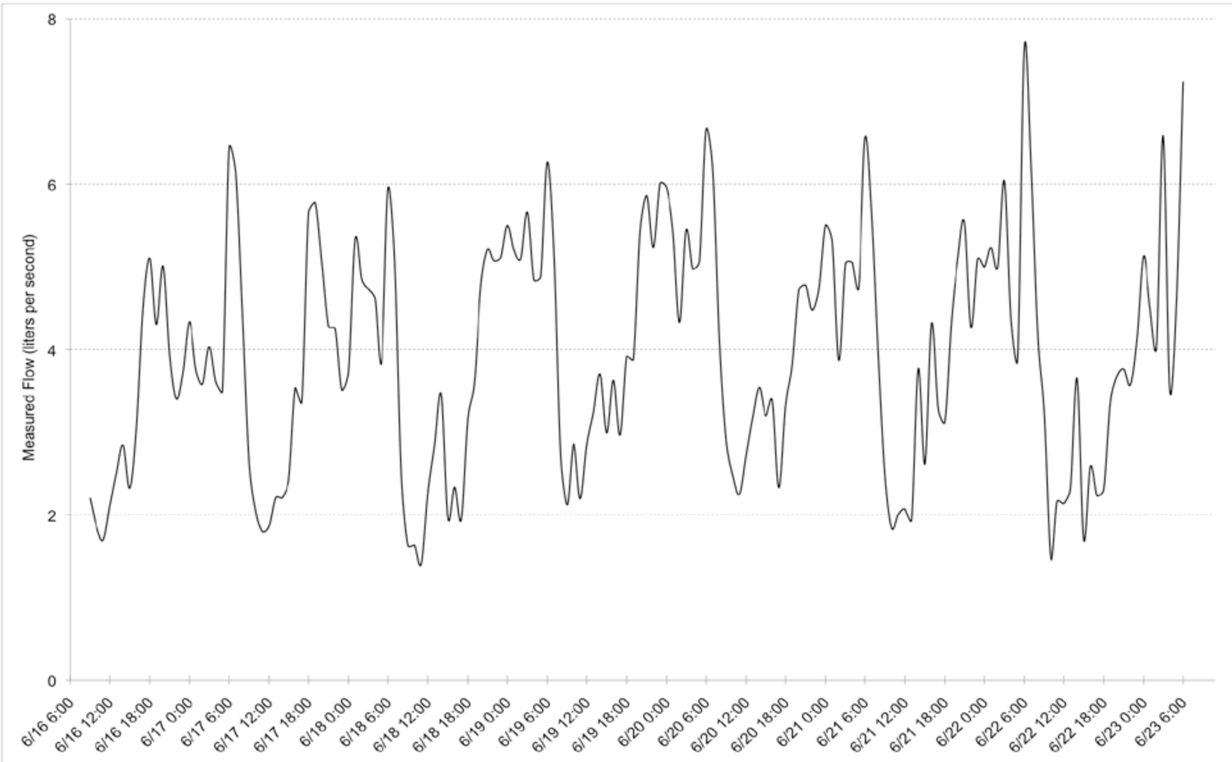

Figure 2. Measured flow at the outflow pipe draining a southern California residential watershed during an intensive sampling period of one-week from June 16 to 23, 2008.

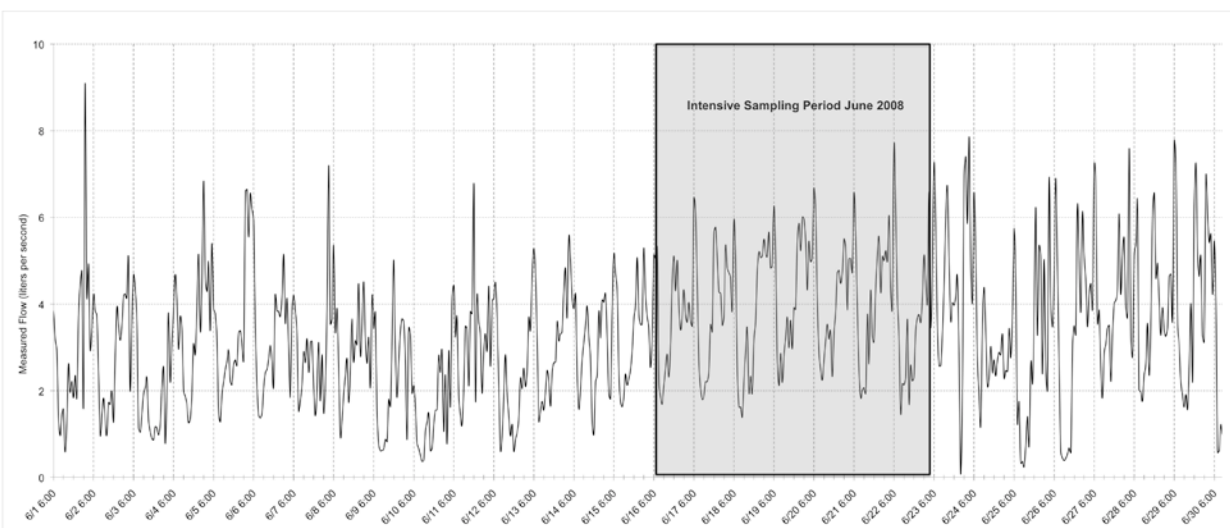

Figure 3. Measured flow at the outflow pipe draining a southern California residential watershed for June 2008, with highlighted intensive sampling period of one-week, from June 16 to 23, 2008.

3.2 Variation in Nutrient Concentrations

The mean (n = 56) concentration of TN was 10.9 mg L^{-1}, nitrate-N was 5.42 mg L^{-1}, and other-N (organic and ammonium) was 5.43 mg L^{-1}. During the intensive sampling period average composition of TN was 58% nitrate-N and 42% other-N (Table 2). During the sampling period, the lowest concentrations of TN, nitrate-N, and other-N were 4.27, 2.42, and 0.09 mg L^{-1}, respectively. Nitrogen concentrations exhibited a diurnal pattern with highest concentrations during each 24-hour period occurring between 8:00 p.m. and midnight, while lowest concentrations occurred between 6:00 a.m. and noon each day (Figure 4). Nitrogen concentrations in the beginning of the sampling period (June 16, 2008) were higher than those sampled near the end of the sampling period (June 23, 2008).

Table 2. Concentrations of nitrogen, phosphorus, and total suspended solids at the outflow pipe draining a southern California residential watershed during one-week of intensive sampling in June 2008.

Nutrient Concentration	Total N	Nitrate-N	Other-N	Total P	Orthophosphate	Other-P	TSS
				mg L^{-1}			
Mean	10.85	5.42 (58%)[a]	5.43 (42%)[a]	1.27	0.82 (75%)[a]	0.45 (25%)[a]	52.18
Minimum	4.27	2.42	0.09	0.51	0.41	0.02	3.44
Maximum	29.80	9.50	21.82	7.47	1.79	7.06	274.36
Standard Deviation	6.34	1.72	5.24	1.03	0.36	1.00	59.11

[a]data in parentheses are average percent of total N or of total P during the intensive sampling.

Nearly 80% of samples collected contained 50% or more nitrate-N. Of 56 sampling events, runoff from 18 sampling events recorded other-N (organic and ammonium-N) as the dominant N form. Twelve of these samples coincided with the higher concentrations of TN that occurred in the first two days (June 16 to June 18, 2008) of the sampling period. The high concentration of other-N during the beginning of the sampling period coincides with weekend gardening activities and the washdown of hardscapes by homeowners. Plant debris (organic-N) being flushed into the drainage network, as well as the application of ammonium fertilizer and compost, is a common contributor of nitrogen to urban runoff (Andrews, 1998; Groffman, 2004; Vadeboncoeur et al., 2010). For the remainder of the intensive sampling period (June 19 to June 23, 2008), nitrate-N varied between 45% and 100% of TN, with the highest percentages of nitrate-N occurring each day at around noon. Subsequently, other-N remained less than 60% of TN with the highest contributions of other-N to TN occurring near midnight each 24-hour period. Other water quality studies in urban areas showed variation in predominant N forms that are dependent on N sources within the watershed (Caccia and Boyer, 2007; Yu et al., 2011). One explanation of this diurnal switching of N forms could be the use of reclaimed water (treated wastewater) on common areas in the residential community during nighttime hours. Reclaimed water usually contains higher concentrations of ammonia than potable water (Asano, 1987; Metcalf et al., 2007). Constituent concentrations of reclaimed water vary by source and treatment (secondary, tertiary, or advanced wastewater treatment) and ammonia-N has been shown to be the predominant form of N in some reclaimed water (Asano, 1987; Evanylo, 2010; Metcalf et al., 2007; Taebi and Droste, 2004). Finally, it has been shown that diurnal variation in nutrients can be controlled by biogeochemical processes, photosynthesis, and respiration in river ecosystems (Iwanyshyn et al., 2008). More studies focused on characterizing chemical and physical transformations of pollutants in urban drainage networks would aid in developing appropriate BMPs to control nutrient losses (Barber et al., 2005).

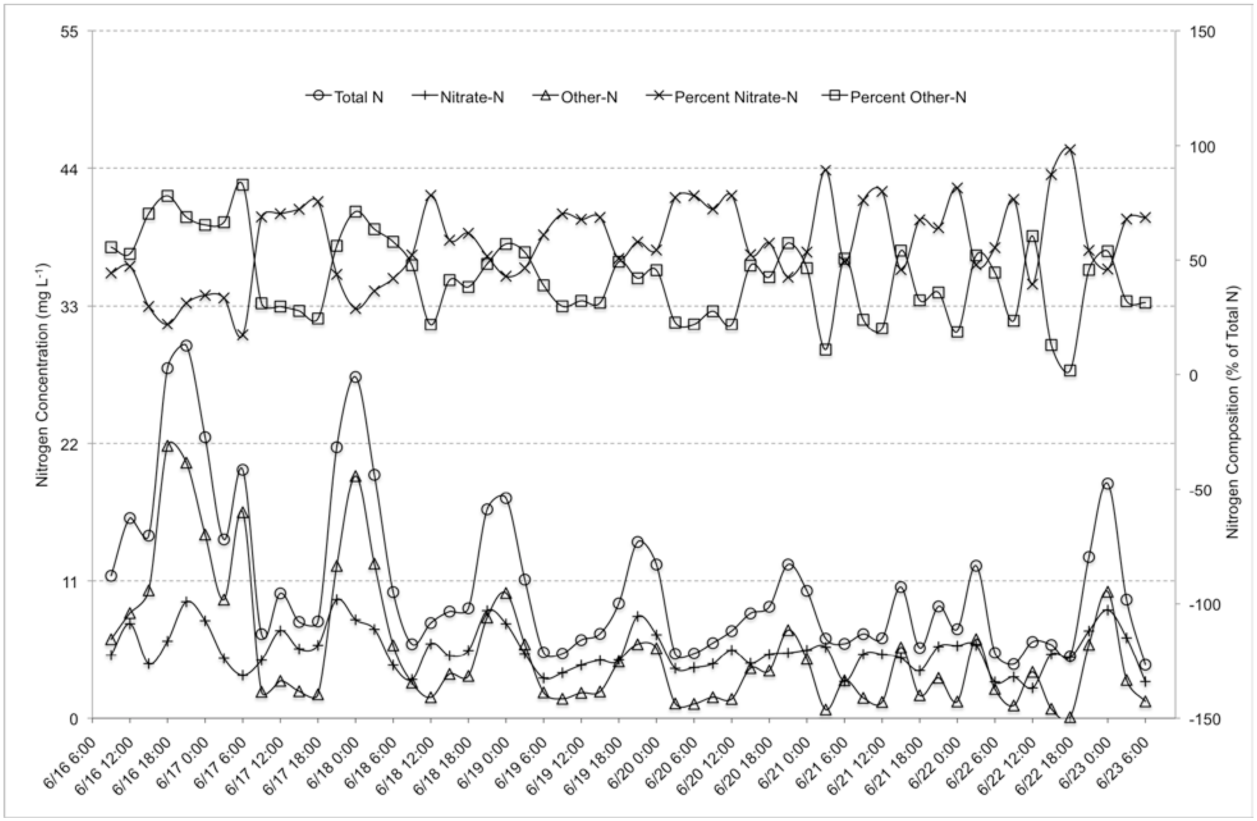

Figure 4. Nitrogen concentrations in runoff collected from the outflow pipe draining a southern California residential watershed during an intensive sampling period of one-week from June 16 to 23, 2008.

The mean concentration of TN (10.9 mg L^{-1}) found in this study was 40 to 200% higher than residential runoff sampled during other water quality studies conducted throughout the United States (Table 3). One study in North Carolina, measured water quality parameters from a small residential catchment (2.54 ha) using 69 storm events over the period of 2.3 years, they found an event mean concentration (EMC) for TN of 6.71 mg L^{-1} (Line, 2002). Although reclaimed water is likely affecting TN concentration in the southern California residential watershed, TN values from the two studies were comparable. One explanation for the closeness of TN values in the North Carolina and southern California runoff studies could be attributed to similarities in land classification and drainage network (gutter system), the relatively large quantity of samples taken, and the small size of the watersheds. Studies that showed much lower

N concentrations were conducted with fewer samples, in areas with mixed land uses, and in much larger watersheds (CDM, 2009; McPherson et al., 2005). Water quality studies have shown that the size of the watershed can yield varying results for nutrient losses and that a large watershed may provide more biogeochemical opportunities to capture and retain N, keeping it from leaving the study area (Chua et al., 2009; Lewis and Grimm, 2007). There are several other factors that may be influencing the elevated levels of N seen in this southern California residential study, like seasonality in nutrient concentrations and the absence of storm events.

Water quality studies have found that many constituents show seasonal shifts as nutrient sources change and biogeochemical processes in the watershed change (Beckert et al., 2011; García-Pintado et al., 2007; Lewis and Grimm, 2007). Studies also show that N concentrations in dry weather baseflows tend to be higher because storm flows can dilute N concentrations, especially nitrate-N (Brion et al., 2011; Fan et al., 2012; Tsegaye et al., 2006). Samples from this study were collected from baseflows during the summer, in a small watershed, conditions which are conducive to increased concentrations of TN. Reclaimed water use within the study site, an estimated impervious surface area of 56%, the sloped topography of the site, as well as the clayey nature of the soil, likely contributed to the high mean TN concentration measured in this catchment. It is important to note that even the minimum N concentration recorded during one-week of intensive sampling was more than double the proposed nitrogen TMDL for the Aliso Creek mainstem (1.0 mg L^{-1}) (Watersheds, 2012). This information is important for water quality managers trying to identify N pollution sources within the Aliso Creek Watershed. When TN concentration from this study (10.9 mg L^{-1}) was compared to dry weather TN concentration (1.36 mg L^{-1}) at the outlet of the Aliso Creek Watershed (Table 3) it was apparent that this residential neighborhood is most likely a significant a contributor of TN within the watershed.

Table 3. Comparison of nitrogen, phosphorus, and total suspended solids concentrations in runoff collected from the outflow pipe draining a southern California residential watershed with runoff from data from previous studies.

Land Use	TN (mg L^{-1})	TP (mg L^{-1})	TSS (mg L^{-1})	Sampling	Location	Study Area	Reference
Single Family Residential	6.71 [a] Mean EMC[c]	0.59 Mean EMC[c]	73 Mean EMC[c]	Automated flow-weighted storm runoff for 69 events	Nuese River Basin, NC	2.54 ha 25% ISA[b] 2-10% slopes sandy loam 2.3 year	(Line, 2002)
Mixed Residential	2.14[a]-2.46[a] Median EMC[c]	0.14-0.32 Median EMC[c]	24-61 Median EMC[c]	Periodic storm sampling	Ballona Creek Watershed, CA	30,180 ha 3 sites channelized semi-arid 4 years	(McPherson et al., 2005)
Mixed Residential	5.16[a] Mean	0.63 Mean	19.5 Mean	18 dry weather grab samples	Ballona Creek Watershed, CA	30,180 ha 3 sites combined channelized semi-arid 4 years	
Downstream (3km) from the study site	1.36[a] Mean	0.39 Mean	225 Mean	4 wet weather grab samples	Outflow Aliso Creek Watershed, CA	7,844 ha 45.5% Residential downstream 2002-2005	(CDM, 2009)
Downstream (3km) from the study site	1.25 [a] Mean	0.17 Mean	7.6 Mean	9 dry weather grab samples	Outflow Aliso Creek Watershed, CA	7,844 ha 45.5% Residential downstream 2002-2005	
Single Family Residential	10.85 Mean	1.27 Mean	52.18 Mean	Automated dry weather intensive sampling	Aliso Creek Watershed, CA	28.13 ha 15-30% slopes 56% ISA[b] clayey semi-arid 1 Week	This Study

[a]TN is the sum of Nitrate-N and TKN
[b]ISA denotes Impervious Surface Area
[c]EMC is mean concentration for flow weighted storm flows

Mean (n = 55) concentrations of TP, orthophosphate, and other-P (particulate-P, which included organic and recalcitrant inorganic forms) were 1.27, 0.82, and 0.45 mg L^{-1}, respectively (Table 2). During the intensive sampling period the average composition of TP was 75% orthophosphate-P and 25% other-P. All forms of P reached daily maximum concentrations between 6:00 p.m. to midnight with the exception of one event where TP sampled was nearly 6-times the recorded mean. This increase in TP occurred at noon on June 19, 2008 and was comprised of almost entirely other-P (95%) (Figure 5). This event had little effect on orthophosphate and indicated that other-P (particulate-P) was washed (flushed) into the drainage network by anthropogenic activities, mimicking the "first flush" phenomena.

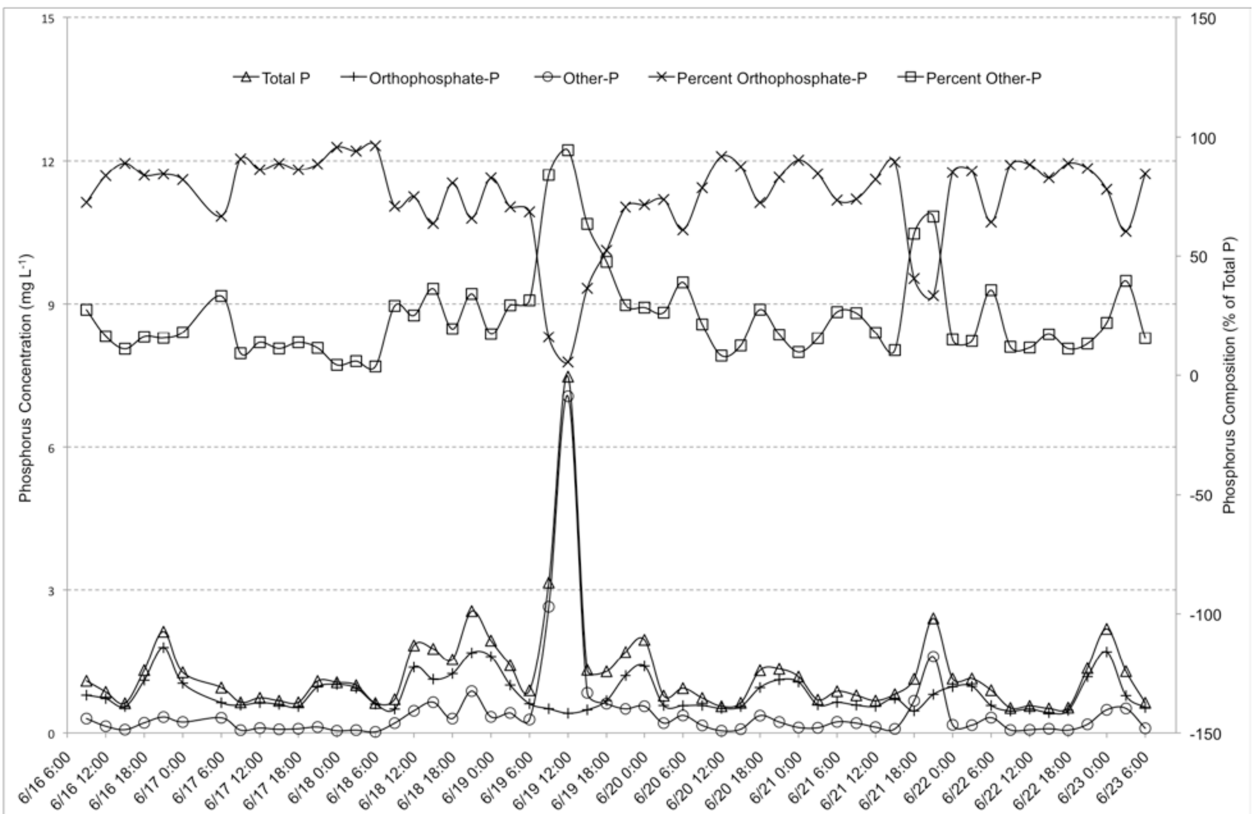

Figure 5. Phosphorus concentrations in runoff collected from the outflow pipe draining a southern California residential watershed during an intensive sampling period of one-week from June 16 to23 2008.

Studies have shown that between rain (or irrigation) events, solids accumulate on the surface of the drainage network. When substantial wetting occurs (e.g. storm or hosing off of driveway) there is a marked increase of certain constituent concentrations as these solids are flushed off of the urban surface and into drainage system. Studies show that response to "first flush" is greatest for TSS>TP>TN, with particulate and organic forms of P and N being more mobile during this time than their dissolved inorganic counterparts (Beckert et al., 2011; Gray, 2004; Kim et al., 2007; Obermann et al., 2007). Although it is not possible to say for certain whether the two events are related, there was also a spike (5 times the mean concentration) in TSS 12-h prior to the noted increase in TP; there was no response in TN during this time. It is possible that sediment and organic material (TSS) transported during the runoff event also transported particulate-P but at a varied time scale influenced by change in flow intensity, suspended particle size, and the speciation of P (Daroub, 2002; Uusitalo et al., 2000). Studies show that particulate-P is the dominant form in urban runoff and that accumulation of P in urban regions is mainly a surface problem, whereby particulate-P, associated with the finer fraction (1-25 microns) of sediment, accumulates on impervious surfaces and is then transported into surface waters by rain or irrigation events (Bennett et al., 2001; Forsberg, 1995; Johannesson et al., 2011; Vaze and Chiew, 2002). For example, in this southern California residential watershed, particulate-P and other solids accumulate on driveways and sidewalks. During the dry season, transport occurs when this build-up is washed into the drainage network by human activities or irrigation. This type of unpredictable anthropogenic activity is sometimes referred to as a transient event. Transient events are significant contributors to nutrient loss form urban environments and can drive up mean constituent values (Lee et al., 2009; Lim, 2003).

In this residential watershed, daily P loss was predominately orthophosphate-P. For 91% of the one-week sampling period, orthophosphate-P comprised 50% or more of TP. Orthophosphate-P is probably associated with reclaimed water used within the residential watershed, as treated wastewater is known to have higher levels of orthophosphate compared to natural or potable water (Asano, 1987; Endreny et al., 2005; Metcalf et al., 2007; Metcalf, 1916). There were two separate occasions (June 19 and June 21, 2008) where other-P was the predominant form of P in this study. During these two events, P associated with organic matter and the fine fraction of soil sediment was transported with the residential runoff. Although only five runoff samples showed TP to be primarily composed of other-P, this increase in particulate-P was responsible for driving up mean TP concentrations and more than quadrupling P loss during the event. Reclaimed water is contributing to P loss from our catchment as highest TP concentrations in this residential watershed corresponded to the recommended hours of reclaimed water use (6:00 p.m. to 9:00 a.m.). However, during the sampling period of one-week, the transient event (increase in other-P and TP concentration) captured with intensive sampling was exerting a greater influence on mean TP concentration than reclaimed water usage.

Mean TP concentration from the site was high when compared to other residential water quality studies (Table 3). For comparison, one study estimated a mean TP concentration of 0.63 mg L^{-1}, which is 50% the concentration (1.27 mg L^{-1}) found in the southern California residential watershed study. The previous study was conducted in a mixed residential area, the Ballona Creek Watershed in Los Angeles, California. In this large watershed (30,180 ha) mean TP concentration was calculated using 18 dry weather samples (collected during 1 summer) and existing flow data (4 years) (McPherson et al., 2005). Fewer samples collected and the large size of the watershed help to explain why the mean TP concentration from the Ballona Creek

Watershed was lower than the value found in the southern California residential watershed. The mean concentration of TP found in this residential study was 13-times greater than the proposed TMDL of 0.1 mg L^{-1} that applies to the Aliso Creek mainstem and several tributaries (Watersheds, 2012), including the tributary adjacent to the residential outflow pipe. Total P concentration at the outflow pipe was 7-times greater than the dry weather concentration of TP (0.17 mg L^{-1}) found downstream (3 km) from the residential site, proving again that this community is a source of nutrient enrichment to the Aliso Creek Watershed (CDM, 2009).

Mean (n = 56) TSS for the one-week sampling period was 52.2 mg L^{-1}. There was a noted increase in TSS midway through (June 18, 2008) the intensive sampling when TSS reached close to 300 mg L^{-1} (Figure 6). This event could be linked to the increase in TP and other-P, concentrations because particulate P has been shown to positively correlate with turbidity and TSS (Chua et al., 2009; Daroub, 2002; Graves, 2004; Uusitalo et al., 2000). For the rest of the sampling period, TSS concentrations were below 100 mg L^{-1} (Figure 6). Highest concentrations of TSS often occurred between 8:00 p.m. and 6:00 a.m., which corresponds to the recommended irrigation times for reclaimed water.

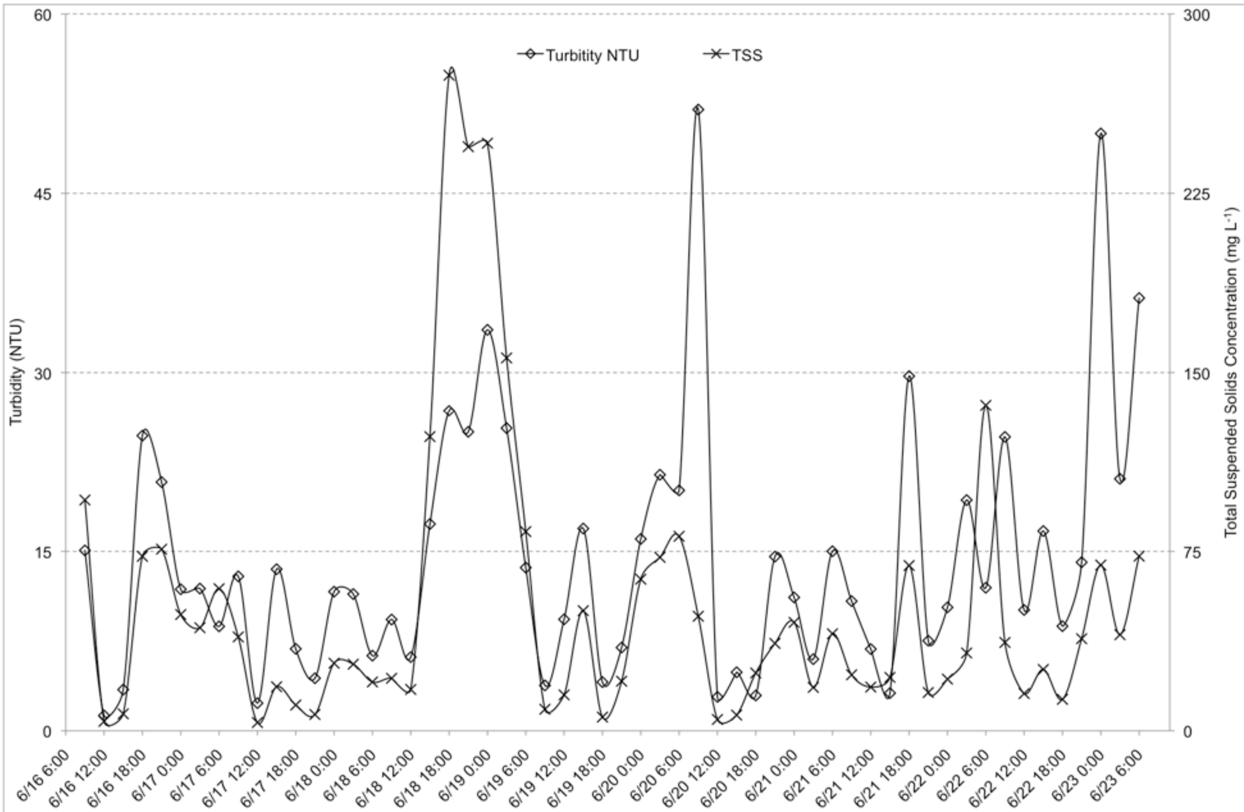

Figure 6. Total suspended solids concentrations and turbidity in runoff collected at the outflow pipe draining a southern California residential watershed during an intensive sampling period of one-week from June 16-23 2008.

Reclaimed water used in southern California has been shown to contain increased levels of TSS (Asano, 1987). Lowest concentrations for TSS mirrored reduced flows in the catchment with lowest values occurring at noon each day. Irrigation runoff and transient anthropogenic events (e.g. car washing, erosion from slopes, construction, and washing of impervious surfaces) are the primary mechanism for TSS transport in this residential study area. Sediment loss is a function of soil properties, land management, and water characteristics. The steep and sustained slopes in this residential watershed are conducive to erosion if not properly managed. Because TSS transport is related to the intensity and duration of runoff events, a decrease in TSS concentration (<20 mg L^{-1}) occurred when irrigation ceased each day (near noon) and flow dropped to less than 2.0 L s^{-1}. Comparison of mean TSS from this study with other residential runoff studies found that dry weather concentration from the southern California residential site was more similar to concentrations found in studies that conducted wet weather or storm sampling (Table 3). Similar results were found from the small (2.54 ha) residential catchment in North Carolina where 69 storm events were sampled to calculate an EMC of 73 mg $L^{-1}$for TSS. The dry weather mean TSS concentration from this study was comparable to storm TSS concentrations, suggesting that the "first flush" phenomena can be caused by irrigation and anthropogenic activities at the catchment scale, especially in watersheds with sloped topography that contain soils of low infiltrability.

3.3 Reclaimed Water Use in the Watershed

Reclaimed water has become increasingly important in the water scarce southwest. In an effort to conserve high quality potable water, the use of reclaimed water as an alternative source for landscape and agricultural irrigation has become vital to states like California and Florida. Proper management of reclaimed water for irrigation is crucial as reclaimed water is inherently higher in nutrients, suspended solids, dissolved organic matter, and soluble salts (Lado and Ben-Hur, 2009; Metcalf et al., 2007). These additional inputs in the urban landscape can hinder plant growth, alter the soil structure, and lead to increased nutrient losses as this study illustrates. Because reclaimed water quality parameters vary by treatment type as well as effluent source, a range of constituent concentrations found in select treatment facilities in California (Asano, 1987) is presented along with potable water quality parameters (Table 4). Potable water data was compiled from the most recent District Water Quality Report (District, 2012) and from a study conducted where potable and reclaimed water was used to irrigate turfgrass plots (Evanylo, 2010). Information from the turfgrass study was necessary for comparison, as data related to potable (tap) water nutrient concentrations is very limited.

Table 4. Comparison of water quality parameters among residential runoff from this study, treated wastewater (reclaimed water), and potable water from various sources.

Water Quality Constituent	Residential Runoff	Reclaimed water (secondary and tertiary treatment)	Potable water
pH	8.15	6.8-7.6	7.0-8.6[a]
EC (dS m^{-1})	2.11	1.02-1.44	0.27[b]
Total nitrogen (mg L^{-1})	10.85	17.2-24.9	1.4[b]
NH_4-N (mg L^{-1})	-[a]	1.4-25	-
NO_3-N (mg L^{-1})	5.66	0.7-21.3	0-0.4[a]
Organic-N (mg L^{-1})	-[a]	0.2-2.6	-
Total phosphorus (mg L^{-1})	1.26	12.5	.25[b]
Orthophosphate-P (mg L^{-1})	0.83	3.4-30.8	-
Total dissolved Solids (mg L^{-1})	1350	476-940	440-490[a]
Total Suspended Solids (mg L^{-1})	52.18	1-26	1.0[b]
Reference	Mean runoff concentrations from this study	Mean concentration ranges from select treatment facilities in California (Asano, 1987)	a=Moulton Niguel Water Quality Data (District, 2012) b= water used to irrigate turfgrass plots in Virginia (Evanylo, 2010)

[a]Mean values of NH_4-N plus Organic-N were 5.2.

The mean concentrations of nutrients found in this study for were elevated as a result of reclaimed water use within the residential watershed as well as unpredictable human activities. The mean TSS concentration found in runoff from this residential study was high compared to concentrations typically found in reclaimed water. Although reclaimed water may be a source of TSS in this watershed, transport caused by anthropogenic activities within the catchment played a bigger role in TSS losses. The mean TN and nitrate-N concentrations from this study are comparable to the concentrations exhibited by reclaimed water. During the one-week of intensive sampling it would appear that reclaimed water use had the greatest effect on TN losses from this catchment. The mean concentrations of TP and orthophosphate from this study were lower than usually found in reclaimed water. No information on particulate P (the primary source during transient events) in reclaimed water could be found for comparison. TP loss from this study was heavily influenced by transient events (possible construction or landscaping activities) captured with intensive sampling as well as by reclaimed water use. Another indicator that reclaimed water was influencing nutrient losses from this community was the extreme salinity (soluble salts) and elevated total organic carbon (TOC) concentrations found during hours of reclaimed water use. Electrical conductivity (EC) measured at the outflow pipe ranged from 1.43 to 3.64 dS m^{-1}, which is equivalent to about 915-2330 mg L^{-1} of total dissolved solids (TDS). Mean concentration of TOC was 13.1 mg L^{-1} which is typical for wastewater that has received secondary treatment (Metcalf et al., 2007). Frequently, lowest EC and TOC values occurred at 6:00 a.m., which corresponds to the daily increase in potable water irrigation (Figure 8). Prolonged reclaimed water use in this residential catchment could lead to salt accumulation at the soil surface. Adverse effects associated with soil salinity include lowered plant productivity, decreased water infiltration by clogged soil pores and clay dispersion, and increased runoff. Soil salinization commonly occurs in arid climates when adequate water is not available to flush the salts deeper into the soil profile and is more prevalent in soils with high clay content (Lado and Ben-Hur, 2009; Martinez, 2009; Metcalf et al., 2007).

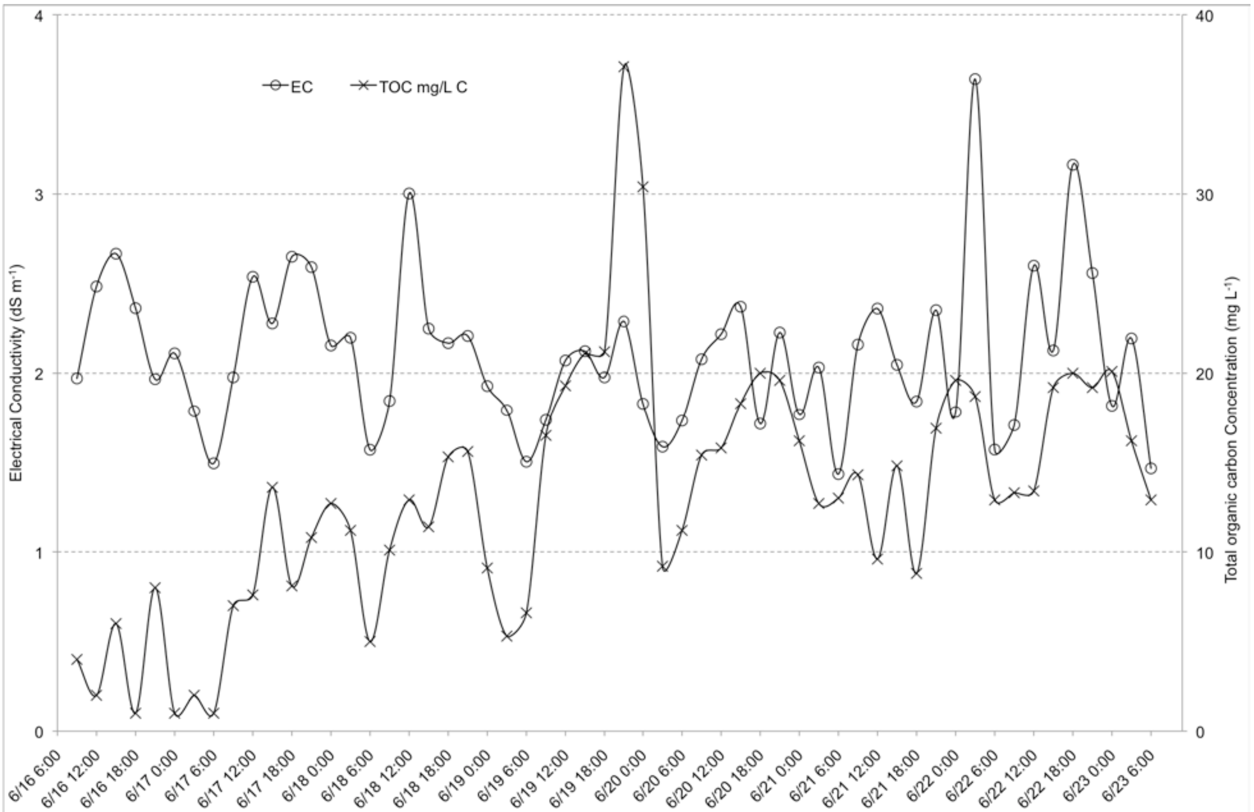

Figure 8. Electrical conductivity and total organic carbon concentrations in runoff collected at the outflow pipe draining a southern California residential watershed during an intensive sampling period of one-week from June 16 to 23 2008.

3.4 Variation in Nutrient Loading Rates

Nutrient loading exhibited daily variations that were similar to flow and nutrient concentrations. The mean loading rate for TN was 3.84 kg day^{-1} (Table 5). Lowest TN load occurred from 6:00 a.m. to noon and highest loads frequently occurred from 6:00 p.m. to midnight each day (Figure 7). The mean TP load was 0.44 kg day^{-1}. Total P load was also lowest from 6:00 a.m. to noon each day. Total P loads were elevated close to midnight with the exception of one event where TP load was greatest at noon during the middle (June 19, 2008) of the intensive sampling period. The mean loading rate for TSS was 19.7 kg day^{-1}. Total suspended solids load exhibited lowest values near noon each day and highest loads at various times within recommended reclaimed water irrigation hours (6:00 p.m. and 9:00 a.m.). Like TP, a significant increase in TSS load (nearly 6-times the mean rate) occurred in the middle (June 18, 2008) of the sampling period (Figure 7). As mentioned previously, unexplained transient events created a flushing effect that is likely responsible for the increase in TSS and TP loads that occurred during June 18 to June 19, 2008. Total suspended solids are closely related to turbidity and this change in water quality during the middle of the intensive sampling period was confirmed by turbidity (NTU) measurements (Figure 6). Total N loads increased in response to an unknown event on June18 to June 20, 2008. Nutrient and sediment loading in this catchment were related to anthropogenic activities and reclaimed water use within the site. With a few exceptions, all constituents showed greatest losses during the recommended irrigation hours for reclaimed water.

Table 5. Loads of nitrogen, phosphorus and total suspended solids in runoff collected at the outflow pipe draining a southern California residential watershed during one-week of intensive sampling in June 2008.

Loading Rates	Total N	Nitrate-N	Other-N	Total P	Orthophosphate	Other-P	TSS
				kg day^{-1}			
Mean	3.84	1.95 (51%)[a]	1.89 (49%)[a]	0.44	0.29 (66%)[a]	0.15 (34%)[a]	19.71
Minimum	0.80	0.44	0.02	0.09	0.07	0.01	0.62
Maximum	11.63	4.20	8.94	2.10	0.75	1.99	11.89
Standard Deviation	2.70	0.91	2.08	0.34	0.17	0.28	25.26
Simple Method[b]	3.72	1.94	1.78	0.43	0.28	0.15	17.85

[a]data in parenthesis are percent of total N or total P load.
[b]Simple method was calculated by multiplying the mean constituent concentration (mg L^{-1}) by the mean flow (ls^{-1}) for the one-week sampling period (Endreny et al., 2005; Johnson et al., 1998; Li et al., 2003).

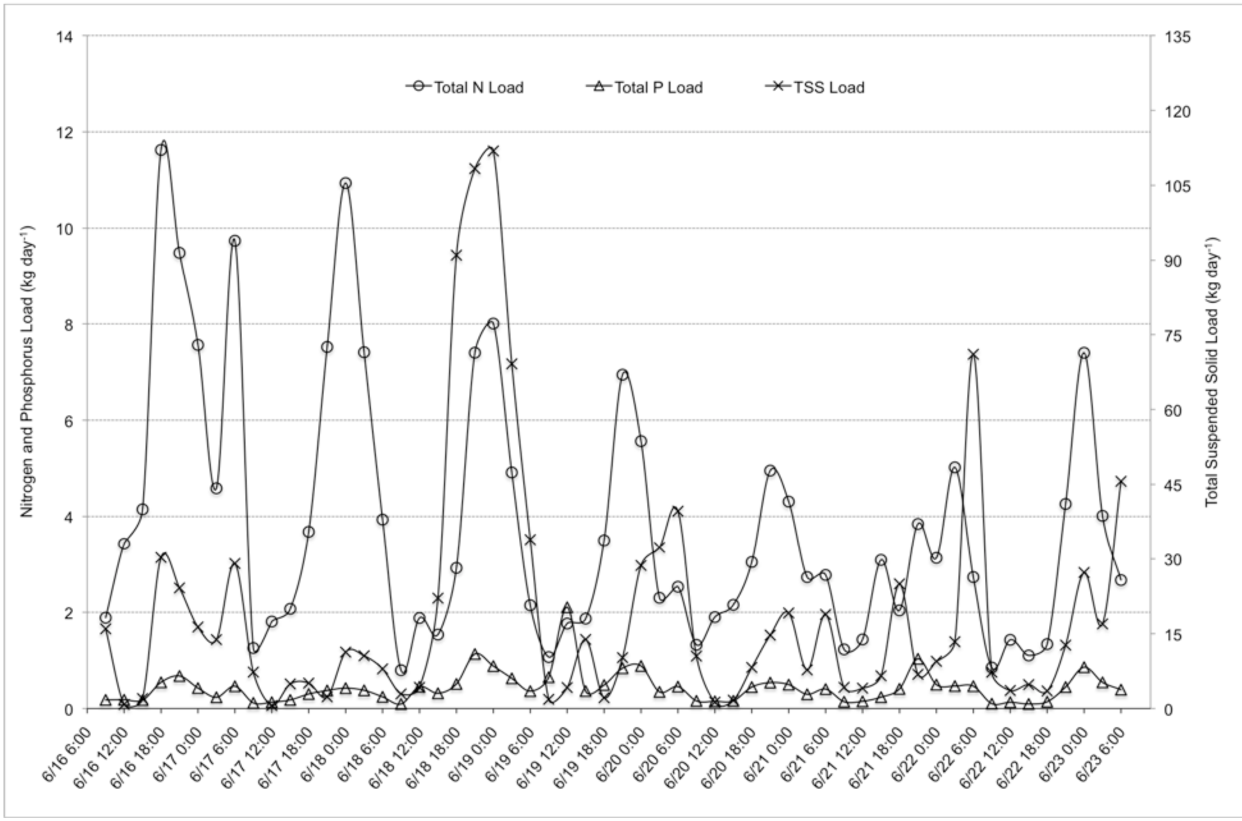

Figure 7. Total nitrogen, phosphorus, and suspended solids loads in runoff collected at the outflow pipe draining a southern California residential watershed during an intensive sampling period of one-week from June 16-23 2008.

The dry season (153 d) nutrient export rates found were 20.2 kg N ha^{-1}, 2.34 kg P ha^{-1}, and 97.1 kg TSS ha^{-1} (Table 6). Even though export rates from this southern California residential watershed only account for 42% of the year, dry season nutrient export rates calculated for TN and TP were higher than most annual nutrient export rates found in comparable urban runoff studies (Table 6). Seasonal TN loading from the southern California study was more than double any annual rate found by a literature review focused on developed lands (Dodd, 1992). Total P export from the southern California residential watershed was 1.5-times greater than any annual loading rate found by the same review. One study that had comparable export rates was conducted in a small residential watershed (2.54 ha) in North Carolina. Using the sum of all storm loads (69 events) divided by the duration of the sampling period (2.3 years) and size of the watershed (2.54 ha), the North Carolina study found annual export rates of 23.9, 2.3, and 387 kg ha^{-1} yr^{-1} for TN, TP, and TSS respectively (Line, 2002). Conservatively, if one assumes that wet weather flows from the southern California residential watershed contribute as much nutrients and sediment as dry weather flows, TN and TP export from the site would still be double the rates found in North Carolina; TSS export would be about half of the export rates found in the previous study. Result from the southern California residential watershed show, that in a semi-arid climate, dry weather flows can make large contributions to annual TN and TP loads. While the dry season load of TSS is less substantial, TSS export from this residential catchment will still impact downstream waters.

This study, in a residential community in southern California, showed that significant nutrients loss could occur in an urban area with non-storm surface flows in a semi-arid region. The previously mentioned urban runoff study, in the Ballona Creek Watershed, showed that dry weather flows could contribute up to 32% of annual TN loads and 6% of annual TP loads. Total suspended solids contributions during dry weather were shown to be 2% of annual contributions (McPherson et al., 2005). Recent studies confirm that loading estimate uncertainty can be reduced by compiling data representing numerous observations over time and that increased sampling frequency is especially important in small watersheds (Kirchner et al., 2004; Stein and Ackerman, 2007). Using intensive sampling techniques, high daily variability in nutrient export rates was seen in this study; illustrating elevated dry season nutrient concentrations caused by reclaimed water use and transient events.

Table 6. Comparisons of estimated nutrient and sediment export rates from this study and other residential runoff studies.

Land Use	TN (kg $ha^{-1}yr^{-1}$)	TP (kg $ha^{-1}yr^{-1}$)	TSS (kg $ha^{-1}yr^{-1}$)	Sampling	Location	Study Area	Reference
Residential	23.9	2.3	387	Automated flow-weighted storm runoff for 69 events	Nuese River Basin, NC	2.54 ha 25% ISA[b] 2-10% slopes sandy loam humid subtropical	(Line, 2002)
Residential	6.0	0.4	-	Storm sampling	Charlotte and Mecklenburg County, NC	humid subtropical	(Bales et al., 1999)
Residential	6.7	0.96	-	Automated storm sampling of 43 events	Chesapeake Bay	62.11 ha (2 sites) 18% ISA humid subtropical	(Hartigan et al., 1983)
Residential	8.4	1.3	-	Storm Sampling	Nationwide	81 sites in 22 cities	(U.S.EPA , 1983)
Developed	5.0-9.72	0.45-1.5	-	Literature Review	-	78 individual studies	(Dodd, 1992)
Single Family Residential	20.20[a]	2.34[a]	97.13[a]	Automated time sensitive intensive sampling for 1 week during dry weather	Aliso Creek Watershed, CA	28.13 ha 15-30% slopes 56% ISA[b] clayey semi-arid	This study

[a]Export rates are in (kg $ha^{-1}ds^{-1}$) (ds= dry season of 153 days)
[b]ISA denotes Impervious Surface Area

4. Conclusion

Several important ideas are brought to light by the results of this study. First, intensive sampling can capture temporal changes that are important in correctly describing residential runoff. Next, increasing specificity when describing urban land uses will make it easier to draw comparisons and predict nutrient losses as anthropogenic activities vary between these land uses. Lastly, dry season or baseflow contributions should be evaluated, especially in the arid southwest if water resources are to be managed effectively.

This study illustrates the variability in nutrient concentrations on a temporal scale. The intensive sampling method utilized discovered fluxes in nutrient concentrations, while highlighting the impact of transient anthropogenic activities on a catchment scale. Through intensive sampling it was discovered that the use of reclaimed water during the hours of 10:00 p.m. and 5:00 a.m. was contributing to nutrient losses within the catchment. Unexplained events within the residential catchment resulted in higher N levels at the beginning of the intensive sampling period, caused a sudden increase in TSS and TP during the middle of the intensive sampling period, and resulted in elevated nutrient concentrations. According to the results of this study, if samples were instead collected using grab samples during normal work hours (8:00 a.m. to 4:00 p.m.), mean nutrient export would most likely be underestimated as sampling would take place during times of lowest nutrient concentrations and lowest flow. Intensive sampling and diurnal patterns in nutrient loading from this site illustrate the weaknesses of standard methods of gathering water quality data.

This data shows that urban residential land use can have a negative impact on water quality and that variability in data requires the use of small-scale water quality assessments that more specifically categorize and describe land use. When compared to other urban runoff studies, data from this study showed high mean dry weather nutrient concentrations as well as seasonal export rates that exceeded most annual loading rates. The results illustrate the need to conduct nutrient loading studies at a local catchment scale to create a more comprehensive picture of nutrient loading that considers climate, geography, management, impervious surface area, and human activity. Simply classifying land as urban/developed does not provide enough useful information about the land use to accurately predict potential water quality problems.

Finally, this study demonstrates that human activities, irrigation schedules, and source of irrigation water, are the most important factors affecting nutrient loading in this semi-arid residential catchment during the dry season. Seasonality in water quality constituents and nutrient export has been observed in other studies and is extremely important in the arid southwest. Much of the previous work done to quantify nutrient exports has focused on storm loads as the “first flush” phenomenon has been deemed the primary mechanism of nutrient losses. This may be less true for regions where 80% of flows occur under dry conditions. Differentiation between dry and wet season nutrient export can provide valuable insight for environmental planning and watershed management.

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