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Relation between urbanization and relative toxicity of semipermeable membrane device extracts in the Lake Tahoe Basin and Truckee River watershed, Nevada and California

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ABSTRACT

Rapid growth in urban areas of the United States has caused concern about the effects on water quality of streams and aquatic ecosystems. One way to assess the effects of urbanization on stream-water quality is through deployment of passive samplers that accumulate many of the organic environmental contaminants associated with urban landscapes. Semipermeable membrane devices (SPMDs) use a lipid (triolein) to mimic contaminant accumulation in fatty tissue of aquatic organisms. These devices concentrate many organic compounds in the water column including polycyclic-aromatic hydrocarbons (PAHs), certain pesticides and urban compounds and many other hydrophobic-organic contaminants (HOCs).

Possible effects of urbanization on stream-water quality in the Truckee River and Lake Tahoe Basins of Nevada and California were examined using toxicity tests on organic compounds extracted from SPMDs deployed during the summer baseflow period August-September 2002. Sampling sites included six in the Lake Tahoe Basin, a Truckee River tributary and main-stem site in the upper reaches and two main-stem and two tributary sites in and near the Reno/Sparks urban area.

SPMD toxicity tests resulted in higher relative toxicity and higher PAH concentrations in urban areas within Reno compared to less urbanized areas in the Lake Tahoe Basin; however, low levels of 'relative toxicity' were found at all sites in the Lake Tahoe Basin. A second relative toxicity value (EC_{50}) was generally associated with more urbanized sites, but there was no statistical difference between Lake Tahoe Basin and Truckee River sites and no correlation with land use, indicating that the EC_{50} test does not discriminate well for urbanization in these watersheds. The Pyrene Index (PI) showed the best correlation between PAH concentration and urbanization, suggesting that it could be used as an indicator of urbanization in the Lake Tahoe and Truckee River watersheds.

INTRODUCTION

Water is a valuable and limited commodity in many parts of the world today, and as the population increases, the concern over water quality and availability grows (Gleick, 1999). This concern has greatly increased in arid [less than 25 centimeters (cm) of precipitation per year] areas of the world. Additional and timely information is needed to determine the extent of contamination of aquatic environments and water resources. Typical evaluation of water quality has been done through discrete water-column and bottom-sediment sampling. The problem with this approach is that discrete samples only provide “instantaneous” conditions of water quality conditions and do not represent significant changes in water quality that may occur at different times. Events such as hazardous waste spills, urban stormwater runoff, or pesticide applications can be difficult to predict and sample properly.

Rapid growth in urban areas of the United States has caused concern about the effects of this growth on the water quality of streams and aquatic ecosystems. Nevada has been among the fastest growing states for over 10 years (Nevada State Demographer’s Office, 2004) and there has been concern about degraded water quality in urban areas. Bevens and others (1998) found in 1992-96 that urban landscapes have been sources of synthetic organic compounds. Semivolatile organic-compound (SVOC) concentrations in bottom sediments downstream from Las Vegas and Reno, NV urban areas were greater than the 75th percentile, in comparison to 19 other basins sampled for the National Water Quality Assessment (NAWQA) Program. In addition, pesticides found in Las Vegas Wash in bottom sediments also were greater than the national 75th percentile.

In high enough concentrations, environmental contaminants in urban areas can result in harmful effects to aquatic biota such as anomalies in fish, chronic and acute relative toxicity and endocrine disruption (Kime, 1998; McLachlan, 2001). Fish communities in the Truckee River downstream of the Reno-Sparks urban area were more degraded than the national median (Bevens and others, 1998). In Las Vegas Bay, which receives treated sewage and urban runoff from Las Vegas, NV, fish were exposed to and accumulated more environmental contaminants than fish from a reference site in Lake Mead (Bevens and others, 1996). This increased exposure reduced and altered hormone levels and reproductive development in male fish (Bevens and others, 1996; Patino and others, 2003).

A unique approach to assess potential effects of contaminants on aquatic biota over time is deployment of integrative passive samplers, such as SPMDs. SPMDs use a lipid (triolein) to mimic contaminant exposure and accumulation in fatty tissue of aquatic organisms. These devices have been deployed for over a decade and can be used to show the presence, bioavailability, and bioconcentration potential of many organic compounds in water, sediment, and air (Huckins and others, 1990, 1993; Petty and others, 1995, 2000). Compounds accumulated by SPMDs include PAHs, certain pesticides, and many other HOCs with octanol/water partitioning coefficients ($\log K_{OW}$) greater than 3.0. SPMDs give reproducible results, are durable in severe environments, and do not metabolize the accumulated compounds like aquatic organisms.

Why use SPMDs?

The use of biological tissue as a media for chemical analysis is commonly hampered by the lack of a common aquatic species at all sampling sites and the metabolism of important chemical contaminants such as PAHs. Chemical analysis of bed sediment does not address questions related to bioavailability. SPMDs concentrate dissolved neutral hydrophobic organic molecules, the fraction that is bioavailable. During this study, SPMDs were used to concentrate contaminants from streams along an urban gradient (increased urbanization levels) as an alternative to sampling biological tissues, bed sediment and water.

SPMDs are polyethylene membrane tubes containing a purified synthetic lipid triolein similar to found in fish tissue. The permeability of the membrane is similar to fish gills in terms of selectivity. SPMDs were developed by Huckins and others (1990) as a passive in-situ sampler to concentrate organics for subsequent chemical analysis. SPMDs have successfully been used in a wide variety of environmental settings to determine environmental conditions in aquatic environments (Lebo and others 1995, Huckins and others 1996, Moring and Rose, 1997, Echols and others, 2000, Wang and others, 2001, Rantalainen and others, 2000). In Nevada, SPMDs have been used to determine the occurrence of organochlorine pesticides and SVOCs in Las Vegas Wash and Lake Mead in 1992 and 1995 (Bevans and others, 1996).

In the Lake Tahoe Basin, Lico and Pennington (1999) used SPMDs to investigate the occurrence of several types of organic compounds and found organochlorine and PAH compounds in the same six tributary stream sampling sites and SVOCs and VOCs at eight lake sampling sites. These findings helped lead to the banning of two-stroke engines in Lake Tahoe which were found to be significant sources of PAHs and benzene, toluene, ethylene, and xylene (BTEX) compounds in the lake. The current study was designed to sample the same tributary stream sampling sites examined by Lico and Pennington (1999) but differs in approach by using relative toxicity tests to assess potential contaminant effects to aquatic biota and comparing the results to the degree of urban land use in Lake Tahoe Basin and along the Truckee River. The results of relative toxicity tests from small urban drainages in the Lake Tahoe Basin are then compared to a larger Reno-Sparks urban area.

The objectives of this paper are (1) to assess the potential relative toxicity of HOCs from SPMD extracts to aquatic biota and (2) to determine the urban influence on aquatic environments in the Lake Tahoe Basin and along the Truckee River where it passes through urban areas. The results described in this paper are part of a larger study that is examining seasonal variations in the relative toxicity of organic compounds in the Lake Tahoe Basin and along the Truckee River.

STUDY AREA

The study area includes the Lake Tahoe Basin and the Truckee River watershed in Nevada and California. These two areas were chosen because both have increased urban growth and it is necessary to determine the effects of this growth on aquatic ecosystems. The Truckee River begins at Tahoe City, CA in the Sierra Nevada at a maximum altitude of 3,300 meters (m) and

extends through the Reno-Sparks urban area (1,430 m), and winds its way to terminal Pyramid Lake (1,160 m), a distance of 187 kilometers (km). Six sites were sampled in the Lake Tahoe Basin (figure 1; sites 1-6) and one site in the upper reaches of the Truckee River [Squaw Creek (site 7), an upper reach Truckee River tributary near Lake Tahoe] from August 1 to September 5, 2002. Five sites along the Truckee River were sampled from August 2 to September 6, 2002; one upper reach main-stem site [Truckee River at Farad (site 8)], two main-stem sites along the Truckee River (sites 9 & 12) and two sites tributary to the Truckee River near the Reno-Sparks urban area [Steamboat Creek and North Truckee Drain (sites 10 & 11)].

Table 1 shows the drainage area for the six Lake Tahoe Basin sites that range from 10.6 to 142 square kilometers (km^2) (table 1) (Brown and others, 1986) with an average of 43.6 km^2 . The altitudes of the Lake Tahoe sites range from 1,899 to 1,905 m (table 1), near the maximum level of the lake. The calculated zone of land use influence range from 8.87 to 20.8 km^2 with an average of 17.1 km^2 . At the Lake Tahoe sites the percent urbanization in the zone of land use influence range from 0 to 42.5 (table 1), with an average of 11.2. Squaw Creek has a drainage area of 21.3 km^2 , a site altitude of 1,853 m, a calculated zone of land use influence of 12.7 km^2 , and a percent urbanization in the zone of land use influence of 2.8. The mouth of Squaw Creek, near the sampling site, is 9.9 km below Lake Tahoe (table 1).

Drainage areas for the three main-stem Truckee River sites range from 2,410 to $4,140 \text{ km}^2$, with an average of $3,080 \text{ km}^2$. Site altitudes range from 1,571 m at Farad down to 1,289 m at Clark. Truckee River sites range from 55.3 to 125 km below Lake Tahoe. The calculated zone of land use influence for the three main-stem sites range from 12.8 to 13.6 km^2 with an average of 13.3 km^2 . At the main-stem Truckee River sites the percent urbanization in the zone of land use influence range from 4.6 to 91.3 percent, with an average of 36. Drainage areas for two Truckee River tributary sites range from 400 to 632 km^2 , with an average of 516 km^2 . Both sites altitudes were 1,334 m, as they are near the mouth of the Truckee River. The calculated zone of land use influence range from 12.9 to 20.0 km^2 with an average of 16.4 km^2 . Percent urbanization in the zone of land use influence for the tributary sites range from 37.6 at Steamboat Creek to 82.4 at North Truckee Drain, with an average of 60.

Table 1. Information for sampling sites.[Abbreviations: no., number; m, meters; km, kilometers; km² square kilometers, USGS, U.S. Geological Survey]

Site no.	USGS station name (short name underlined)	USGS site identification	Altitude (m) above sea-level	Drainage area (km ²)	Distance below Lake Tahoe (km)	Calculated zone of land use influence (km ²)	Percent urban land use (in zone of land use influence)
1	<u>Upper Truckee River</u> at South Lake Tahoe, CA	10336610	1,899	142		10.6	42.5
2	<u>Taylor Creek</u> near Camp Richardson, CA	10336628	1,905	43.2		20.3	<1
3	<u>General Creek</u> near Meeks Bay, CA	10336645	1,905	19.3		8.87	0
4	<u>Blackwood Creek</u> near Tahoe City, CA	10336660	1,900	29.0		20.8	0
5	<u>Incline Creek</u> near Crystal Bay, NV	10336700	1,904	17.3		15.9	20.7
6	<u>Glenbrook Creek</u> at Glenbrook, NV	10336730	1,902	10.6		9.33	3.1
7	<u>Squaw Creek</u> near Squaw Valley, CA	10337855	1,853	21.3	9.9	12.7	2.8
8	<u>Truckee River</u> at Farad, CA	10346000	1,571	2,410	55.3	12.8	4.6
9	<u>Truckee River</u> at Sparks, NV	10348200	1,430	2,680	96.7	13.5	91.3
10	<u>North Truckee Drain</u> at Kleppe Lane near Sparks, NV	10348300	1,334	400	101	20.0	82.4
11	<u>Steamboat Creek</u> at Cleanwater Way near Reno, NV	10349980	1,334	632	101	12.9	37.6
12	<u>Truckee River</u> at Clark, NV	10350500	1,289	4,140	125	13.6	12.4

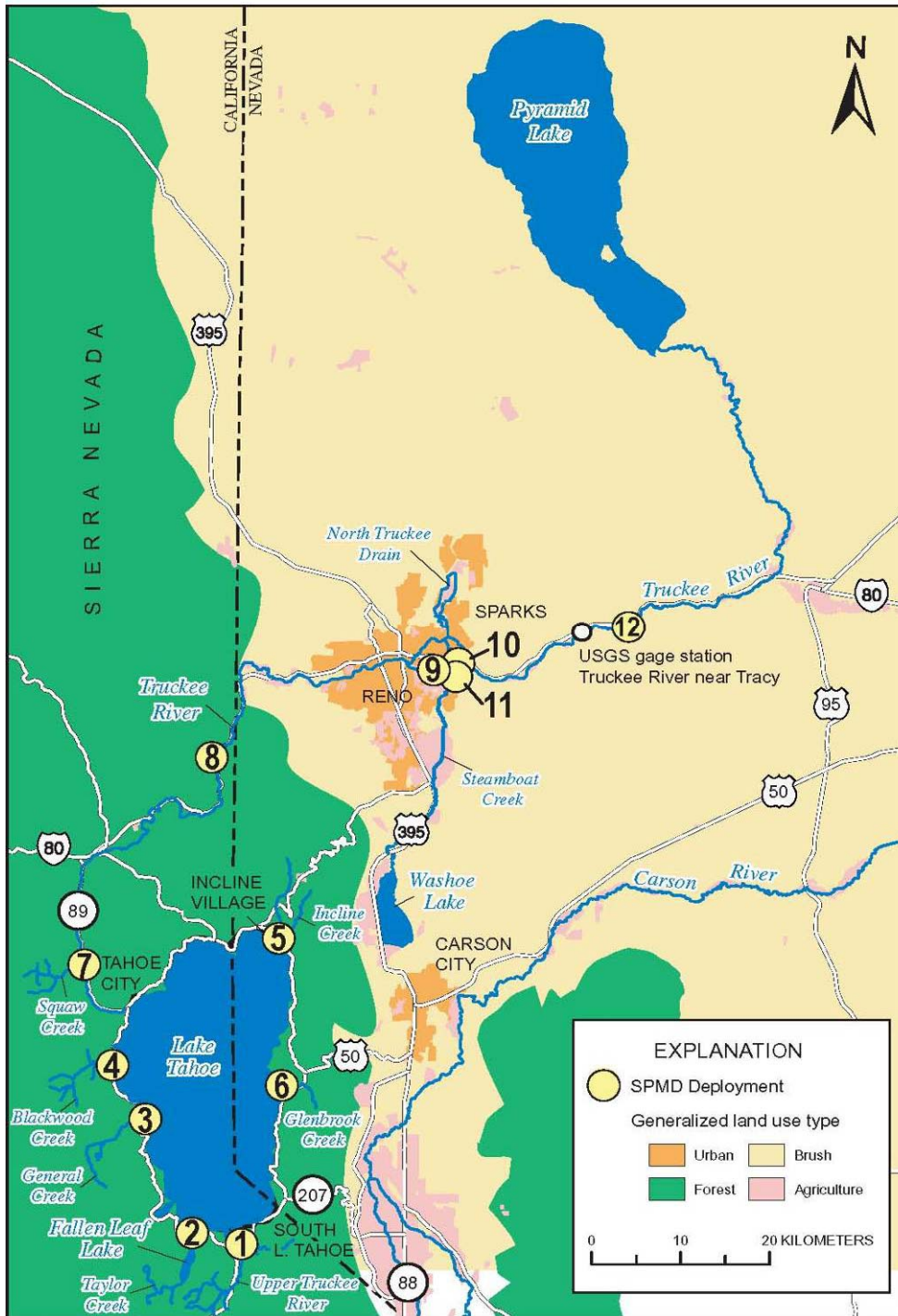


Figure 1. SPMD deployment sites in the Lake Tahoe Basin and along the Truckee River near the Reno-Sparks, Nevada urban area, August through September 2002. See table 1 for location information.

METHODOLOGY

Land Use Characterization

This study utilized a Geographic Information System (GIS) to classify land use within a zone upstream of the sampling sites that could possibly contribute environmental contaminants. The extent of these zones of land use influence were mapped using a process of stream zoning at each of the 12 sampling sites. Base-map data for the Truckee River, Steamboat Creek, and North Truckee Drain as well as contributing drainage basins were derived from the U. S. Geological Survey (USGS) National Water Information System (NWIS). Contributing areas for each sampling site were defined as the stream segment 6 km upstream of the sampling site and a 1 km wide area zone on each side of each channel of the stream, to the extent of the contributing drainage area (figure 2A). Recent work by King and others (2005) found stream ecosystems to be more sensitive to increases in developed land if development was located closer (<1 km) to the sampling station. They studied Contributing areas around Lake Tahoe were defined in the same way, except that in the Lake Tahoe Basin, the drainage areas were smaller, so that if the drainage-basin boundary was less than 1 km from each channel of the stream, the boundary stopped at the drainage area boundary. The calculated zone of land use influence could vary above the expected area (6 x 2 km) 12 km², due to channel curvature, more than one channel and/or the presence of a lake.

The zone of influence area of 1 km buffer was chosen because it was thought to have the most direct influence on the stream or river. It is possible that other sources of contaminants exist outside the calculated area of influence. Most likely the important influences are in relatively close proximity to the streams because organic contaminants degrade over time and distance, thereby possibly reducing contributions farther away. Further study is currently being done to verify that the contribution zone used in this study best define these zones at each sampling site.

In order to identify land uses within these areas of influence, a combination of Washoe County parcel data and aerial imagery were added to the GIS. Digital Ortho Quarter Quadrangle (DOQQ) data from the 1990's formed the foundation for classifying land uses into nine categories: agricultural, barren, floodplain, forest, impermeable, urban, residential-septic, residential-sewer, and open water. For this study, six categories were used; urban areas were defined as a combination of impermeable (road), urban and residential (both septic and sewer) areas. Additionally, brush and barren land covers were defined as brush. ArcGIS 8.3 (Environmental Systems Research Institute[®]) enabled on-screen digitizing of land use based on the DOQQs, which was guided by parcel data from Washoe County (figures 2A and B). Land that had been developed since the aerial images were captured was identified in the parcel map, providing a source for identifying recent changes in land use. Once mapping land use for each contribution zone was completed, data were exported to GIS for analysis.

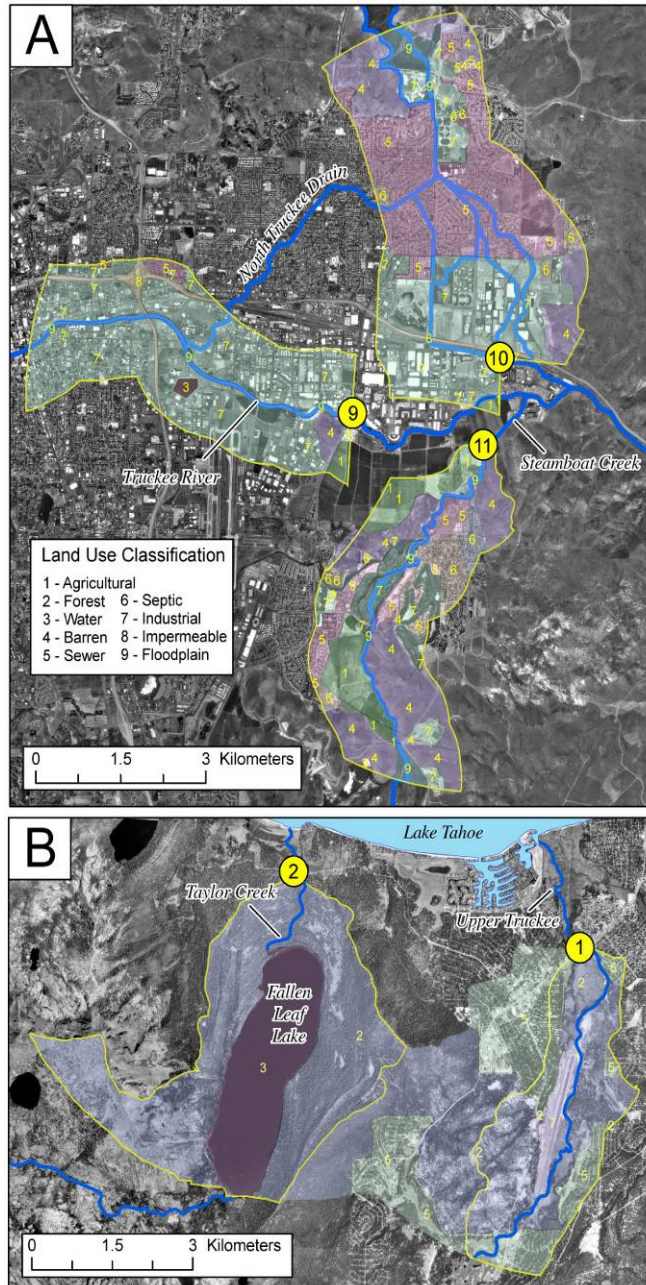


Figure 2. Examples of the zones of influence used to define urbanization within a river/stream segment in: **A)** Truckee River and **B)** Lake Tahoe Basin. Numbered yellow dots are SPMD deployment sites (see table 1).

SPMD Deployment

The SPMDs were installed onto metal holders and shipped overnight from Environmental Sampling Technologies (EST) Laboratories in St. Joseph, MO, sealed in unused, clean metal

paint cans. The cans were kept in a freezer until deployment. The cans were brought to the deployment sites in coolers with sealed ice containers. During deployment the metal holders containing the SPMDs were placed in metal deployment devices and then placed in the water as quickly as possible, within a couple of minutes.

SPMDs were deployed at 12 sites for 34 days during August-September of 2002, the summer low-flow (baseflow) period in (figure 1, table 1). Sites were chosen for their varying levels of urban development, low at the reference site at General Creek (site 3) to high at the urban site at North Truckee Drain (site 10). All sites were located near existing USGS streamflow gaging stations except for Squaw Creek, Taylor Creek and Truckee River at Clark.

The SPMDs were installed in the water column in an area with at least 0.03 meters per second (m/s) velocity and 0.1 m in depth. The metal deployment devices were attached by cleaned nylon ties to cleaned steel rebar, pounded into the bottom substrate (figure 3). Ties and rebar were soaked in soapy water for a few hours and then scrubbed with a plastic brush and rinsed with water. The devices were mounted at a minimum of 0.06 m above the stream bottom but low enough to stay at least 0.05 m below the water surface. It is assumed that all the SPMDs remained within the water column during deployment.

A trip blank, an SPMD filament in a can, was opened at each site while the field-deployed SPMD was in the air next to the stream. When the SPMDs were retrieved, the process was reversed. Latex gloves were worn at all times by all handlers during deployment and retrieval. The retrieved SPMD filaments then were placed in a cooler with ice and brought back to the office where they were stored in the freezer until shipment. The frozen cans were shipped to EST overnight in coolers with sealed ice containers where they were extracted by dialysis.

The trip blank was tested for relative toxicity to determine if there was any contamination coming from the air collectively when the SPMDs were deployed. A small amount of contamination was found in the trip blank. The amount of contamination was not subtracted from the results because the contamination is a cumulative result of opening the same trip blank at different sites and it would not represent the amount of contamination at any particular site. The results for the trip blank were limited as only one blank was used for all 12 sites during both deployment and retrieval. An improved design would have had one trip blank per site.

Field measurements

Velocity measurements were made at each SPMD location using a pygmy meter on a wading rod. Total depth and depth of the SPMD were measured and recorded. Discharges for the period were obtained from existing USGS streamflow gaging stations where available. Nine of the sites had operating gaging stations and mean daily discharges were used. Although the Truckee River at Clark site did not have a gage, there was a USGS gaging station, Truckee River near Tracy (station number 10350340); located about 5.5 km upstream with no significant diversions or returns, therefore mean daily discharges from this station were used. Note the difference in drainage area between these two stations was less than 51.8 km². Gaging station discharge values were obtained from the USGS Automatic Data Analysis and Processing System (ADAPS) and NWIS web for Nevada (<http://waterdata.usgs.gov/nv/nwis/nwis>) databases. Taylor

Creek and Squaw Creek did not have gages, therefore instantaneous discharge measurements were made at deployment and retrievals and average values used respectively.

Measurements of dissolved oxygen, pH, specific conductance, and water temperature were made on-site using hand-held and calibrated meters according to USGS National Field Manual field measurement protocols (U.S. Geological Survey, various dates). These measurements, along with velocity and depth, were made at deployment and again 34 days later when the SPMDs were retrieved.

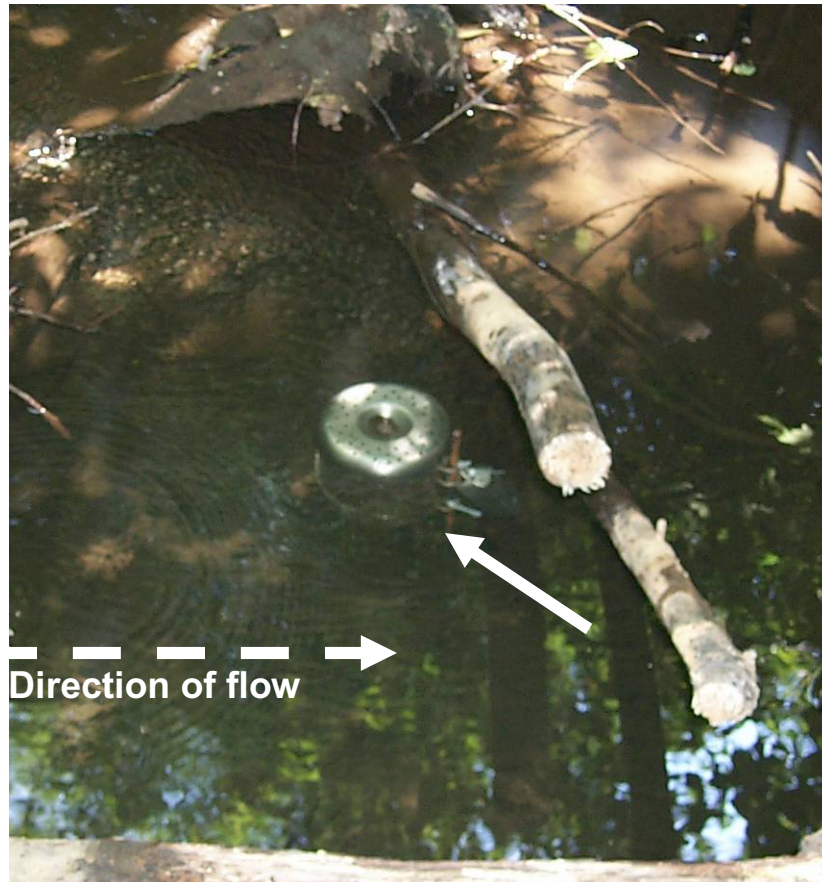


Figure 3. Photograph of an SPMD (solid arrow) deployed in Glenbrook Creek. The SPMD is underwater. The rebar (right above the arrow) is holding the deployment device near the stream bottom. Dashed arrow shows direction of flow.

Lab analysis

Extraction and dialysis of SPMDs

SPMDs were removed from the carrier, washed with tap water, brushed and cleaned with water, and then rinsed in a beaker containing hexane and rinsed with 1 N HCl for 30 seconds. They were then rinsed with tap water, followed by acetone, and allowed to air dry. SPMDs were then put in clean jars with at least 180 mL of hexane in an incubator at 18°C for 24 hrs. The hexane was then decanted into another jar and the first jar was filled again with hexane and both

were further incubated for 8 hrs after which the contents were combined into a dialysate jar. The combined sample was then concentrated in a Kuderna-Danish flask and further concentrated with N₂ to approximately 1 mL and put into amber ampules.

The SPMD extracts were split in two and put into separate ampules, one contained isoctane and the other dimethyl sulfoxide (DMSO). The isoctane portion was sent to Dr. V. McFarland at the U.S. Army Corps of Engineers Research and Development Center in Vicksburg, MS, for testing for the presence and relative amount of compounds that bind to the aryl hydrocarbon receptor (AhR) using the P450RGS dioxin screening assay (Ang and others, 2000). The DMSO portion was sent to Dr. B.T. Johnson of the USGS Columbia Environmental Research Center in Columbia, MO, for relative toxicity testing with a bioluminescent bacteria using Microtox (Johnson and others, 2000) and semi-quantification of PAH concentration by UV-fluorescence scan (Fluoroscan)(Johnson and others, 2004).

Micro-scale relative toxicity testing

Many relative toxicity tests have been developed and validated, but micro-scale testing using bacterial and cellular in-vitro assays has emerged as important ecotoxicological screening tools (Burton, 1991). Three micro-scale assays were used: the P450RGS assay, the Fluoroscan test (reported as a Pyrene Index), and the Microtox EC₅₀ test. These tests offer a simple cost effective and sensitive alternative to traditional and costly whole animal tests with fish and invertebrates (Johnson, 1997; Ang and others, 2000). The protocols are simple, well defined, and have been used successfully in many environmental studies (Bulich, 1979, Johnson, 1992; McConkey and others, 1997; McFarland and others; 2002, Johnson, and others, 2004). The P450RGS assay responds mostly to PAHs and certain organochlorine pesticides. The Pyrene Index (PI) responds mostly to PAH compounds, therefore the P450RGS assay and Pyrene Index may yield similar comparisons. The EC₅₀ test responds to a much broader range of organic compounds and may not respond in the same way as the other two tests.

Toxic Equivalents (TEQ) - P450RGS Assay

The use of bioassays based on the increased content and activity of mixed function oxygenase (MFO) induces response to certain classes of compounds is well documented in the literature (Payne and others, 1987; Safe, 1990). These assays have been applied to a variety of media including: whole sediment, whole water, extracts of water, sediment and biological tissues. The utility of SPMD extracts to concentrate MFO inducers has also been documented (Huckins and others, 1996; Parrott and Tillitt, 1997; Petty and others, 2000).

Bioassays based on the MFO cytochrome P450IA1 family of enzymes have been used as biomarkers of exposure to PAHs, planar PCBs, chlorinated dibenzo-p-dioxins, chlorinated dibenzofurans, chlorodiphenylethers, chlorinated naphthalenes and plant flavones (Safe, 1990). Many of these compounds are highly toxic. Increases in MFOs have been associated with changes in reproduction, growth, pathology, and physiology of fish (Spies, and others, 1996; Parrott and Tillitt, 1997).

The specific CYP1A test used, P450RGS, employs human hepatoma HepG2 cells that are transfected with a plasmid containing the human CYP1A promoter sequence fused to the firefly luciferase (luc) gene as a reporter. The induction of the CYP1A gene results in the production of

luciferase and the light produced responds to the presence of chemicals that bind to the aryl hydrocarbon receptor (AhR) quantitatively. Results are reported in TEQ, which is the amount [in picograms (pg)] of the dioxin, 2, 3, 7, 8-Tetrachlorodibenso-p-dioxin (TCDD) in 1 mL of SPMD extract that would cause the same response as the sample. Details of the protocols can be found in Ang and others (2000) and at <http://el.erd.c.usace.army.mil/elpubs/pdf/doerc10.pdf>. The assay conforms to APHA Standard Method 8070, ASTM Standard E-1853, and EPA Method 4425.

Pyrene Index

SPMD extracts in DMSO were exposed to ultraviolet light at 280 nanometers (nm) to determine presence of PAH compounds using the Fluoroscan methods developed by Johnson and others (2004). Semi quantitative estimates also were made using a fluorometer to measure the fluorescence of the extract from each site, which were compared to a standard curve using pyrene as the index PAH compound. The estimated PAH concentration for each site is reported as the equivalent number of micrograms (μg) of pyrene in 1 mL of SPMD extract that would produce the same fluorescence and is called the PI.

Acute toxicity assessment - EC₅₀

Microtox bioassays were conducted according to the standard protocol for the basic test described in the Microtox Manual, Volume III. Suspensions of a selected strain of glowing luminescent bacteria (*Vibrio fischeri*, Azur Environmental, Inc., Carlsbad, CA) were exposed to each SPMD extract in a standard four-tube plus controls 1:2 dilution series. Samples were incubated at 17°C in a temperature controlled incubator and light emissions were measured after 5 minutes with a luminometer (Azur Analyzer 500). Phenol and DMSO were the assay's standard positive and negative controls, respectively, and the carrier solvent did not exceed 5 percent of the sample volume. The standard dose response curve method was used to determine the concentration that caused a 50 percent loss of light production in the bacteria. A standard log-linear model was used to calculate the EC₅₀ values of the test samples. The EC₅₀ values of SPMD samples were expressed as the mean value of three replicates with confidence intervals (milligrams of SPMD extract per milliliter carrier solvent). Microtox results are reported as the effective concentration in milligram/milliliter of SPMD extract that reduces light output by 50 percent, EC₅₀, meaning the lower the number, the more toxic the extract. Samples were designated "relatively toxic" when their EC₅₀ values were significantly less than the EC₅₀ value of the DMSO control.

RESULTS

Land Use

The calculated zone of influence for Lake Tahoe sampling sites range in size from about 9.3 to 20.8 km² (table 1), with an average of 14.3 km². Squaw Creek (site 7) had a zone of 12.7 km². The three main-stem Truckee River sites (8, 9, and 12) range from 12.8 to 13.6 km² with an average of 13.3 km². The two Truckee River tributary sites (10, 11) range from 12.9 to 20.0 km² with an average of 16.4 km².

Agricultural land use was found in 25 percent (3 of 12) of the sampling site influence zones and range in area from 0.4 to 18.9 percent (figure 4). The highest percentage of agriculture was found in the Steamboat Creek zone of influence. Agriculture was only present in the zones in and

below Reno-Sparks (sites 9, 10, and 11) and not present above Reno-Sparks and in the Lake Tahoe Basin. Brush land uses occurred in half of the zones and ranged in area from 1.6 to 85.6 percent; with the highest percentage found at Truckee River at Farad zone (site 8). Brush land use generally was present in contribution zones in the vicinity of Reno-Sparks but not in those within the Lake Tahoe Basin. Open water bodies (i.e. lakes/ponds) occurred in zones of influence for only 3 zones and ranged from 0.3 to 27.7 percent; the highest percentage associated with Taylor Creek (site 2) in the Lake Tahoe Basin, due to the presence of Fallen Leaf Lake (figure 2). Floodplains were noticeably present within contribution zones at 5 sites and ranged from 1.0 to 10.8 percent; the highest percentage associated with the Truckee River at Clark site (site 12). Forested areas were found in 7 zones, ranging from 57.5 to 100 percent; the highest associated with General and Blackwood Creeks (sites 3 and 4). Forested areas existed in all contribution zones within the Lake Tahoe Basin (sites 1-6) and Squaw Creek (site 7). Sites near or downstream of the Reno-Sparks urban area were not considered influenced by a forested landscape. Urban areas occurred around 75 percent of the zones and ranged from 3.1 to 91.3 percent; the highest associated with Truckee River at Sparks. Urban areas occurred in the vicinity of Reno-Sparks and around sites 1, 5 and 6 in the Lake Tahoe Basin. Truckee River at Sparks (site 9) and Steamboat Creek (site 11) had the most diverse land-use classifications, with five different types of land use each. In general, land use changes through the study area from predominately forested lands with light urban (residential and urban) in the Lake Tahoe Basin to brush-barren land above Reno to urban (urban/residential) in Reno to barren-shrub, agriculture, and floodplain below Reno to Pyramid Lake.

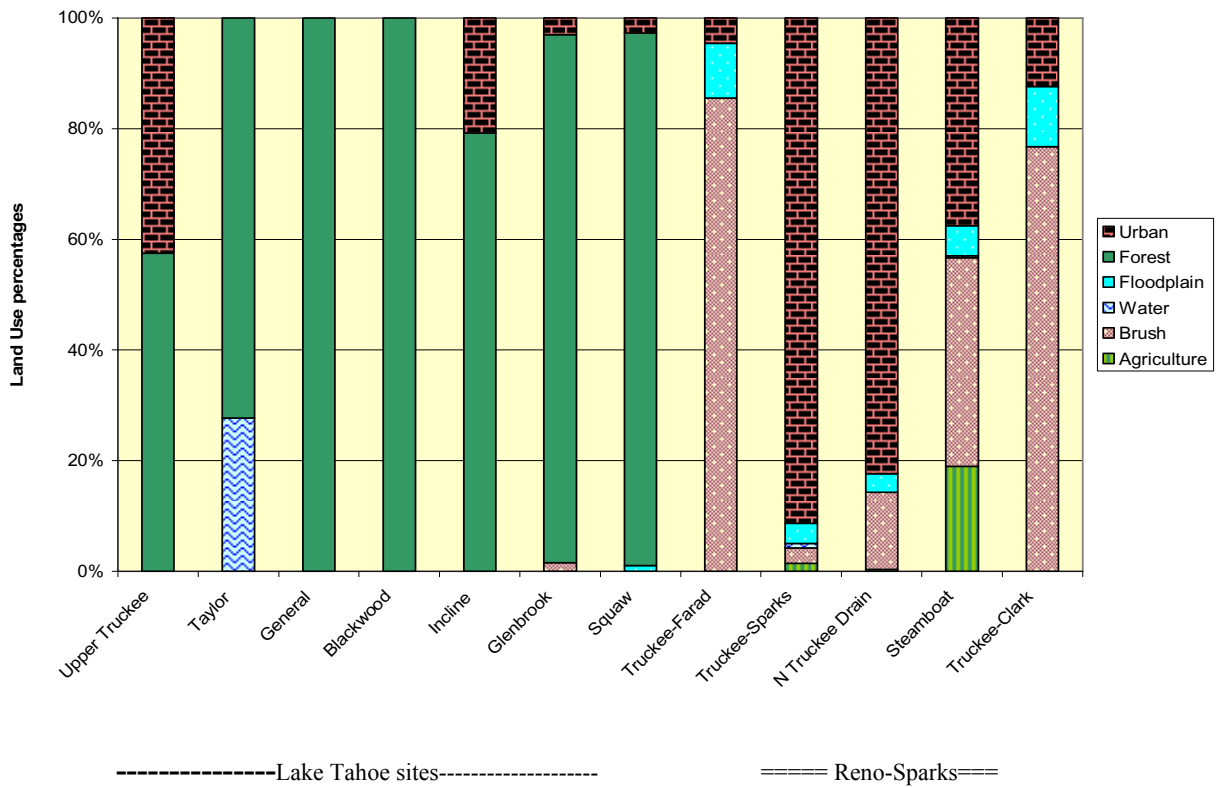


Figure 4. Land use classification percentages at SPMD deployment sites within the Lake Tahoe Basin and along the Truckee River, including Reno-Sparks, Nevada urban area.

Hydrology

Surface Water

On the basis of stream characteristics within the study area, streams can be placed into three groups, Lake Tahoe, Truckee River, and tributaries to the Truckee River. A typical Lake Tahoe Basin annual daily mean discharge hydrograph (figure 5) is shown for Incline Creek near Crystal Bay USGS gaging station (station number 10336700, site 5, figure 1). Annual daily discharge for 2002 water year ranged over an order of magnitude from 0.048 to 0.453 cubic meters per second (m^3/s) with a mean of 0.133 m^3/s (table 2). The peak discharge and most of the annual discharge occurred during spring snowmelt runoff. Other peaks included autumn rain events and early spring rain-on-snow events. The hydrograph for the SPMD deployment for Incline Creek (figure 5) is included in the annual hydrograph and shows a general decline for the 34-day deployment period. The mean daily discharges during the deployment period ranged from 0.054 to 0.068 m^3/s (table 2) with a median of 0.059 m^3/s . Discharge frequencies for the other Lake Tahoe Basin gaging stations were similar to Incline Creek and discharges had all decreased by the end of the deployment period. Median discharges for the six Lake Tahoe Basin sites averaged 0.050 m^3/s . Only Taylor Creek had some regulation, at the outlet of Fallen Leaf Lake.

Discharges for the Truckee River are represented by Truckee River near Tracy (white dot about 5.5 km above site 12, figure 1). Annual daily discharges ranged from 5.07 to 47.9 m^3/s , with an annual mean of 14.8 m^3/s . The peak discharge and most of the discharge also occurred during spring snowmelt runoff. The hydrograph for the SPMD deployment period for Truckee River near Tracy was included in the annual hydrograph and was similar to the other Truckee River gaging stations, with a decline following a peak and then a general rise with a couple of small rises from summer thunderstorms. Discharges along the main-stem Truckee River decrease going downstream from Truckee River at Farad (mean of 11.3 m^3/s) until Truckee River at Sparks (mean of 4.02 m^3/s), mainly due to diversions. Flows are then up slightly at Truckee River near Tracy (mean of 7.05 m^3/s) with inputs from treated sewage to Steamboat Creek with flows into the Truckee River just below Sparks. The discharges for the main-stem Truckee River sites ranged from 5.07 to 10.8 m^3/s (table 2) with a median of 7.05 m^3/s during the deployment period. It should be noted that during this summer low-flow period a large portion (about 40 percent) of the discharge in the lower Truckee River comes from the treated sewage return flows, which are discharged into Steamboat Creek just above the mouth to the Truckee River. Discharges were slightly higher at the end of deployment for the main Truckee River sites (sites 8, 9, and 12). Median mean daily discharges for the three Truckee River sites for the deployment period averaged 7.46 m^3/s . All three Truckee River sites are affected by regulation upstream.

North Truckee Drain (site 10) annual mean daily discharge hydrograph (figure 7) is typical for the two Truckee River tributary gaging stations. Annual mean daily discharges ranged from 0.085 to 1.90 m^3/s and an annual mean of 0.449 m^3/s . The urban area hydrographs showed higher discharges during the summer irrigation season and lower discharges during the non-irrigation periods of the fall and winter. Note that the peak discharges for this urban site were attributed to a rain event in December, which was outside of the study period. The hydrograph for the SPMD deployment period is included in the annual hydrograph for North Truckee Drain gaging station. There had been a thunderstorm induced peak just prior to SPMD deployment and then a sharp decline followed by a general rise during the deployment period (figure 7). Daily discharges for

the deployment period ranged from 0.566 to 1.05 m³/s (table 2) with a median of 0.708 m³/s. The deployment period occurred during summer irrigation season influenced by urban runoff and irrigation from lawns. Discharges had slightly increased at the end of deployment for North Truckee Drain (site 10) but had decreased for Steamboat Creek (site 11). Discharges in Steamboat Creek can be affected by diversions. Median mean daily discharges for the two Truckee River tributary sites for the deployment period averaged 0.659 m³/s

Discharges during the SPMD deployment period were higher for the three main Truckee River sites and lower for urban tributary sites and also the Lake Tahoe Basin sites. Discharges did not dramatically change for all sites during the SPMD deployment period. Only the tributary sites were affected by initial higher discharges from a prior summer thunderstorm event.

Table 2. Median, maximum and minimum daily discharges for SPMD deployment periods, August-September 2002, and annual daily mean, maximum, minimum discharge for 2002 water year. [Abbreviations: m³/s, cubic meters per second; SPMD, semipermeable membrane device]

Site no.	USGS Station short name	Daily Median, SPMD period (m ³ /s)	Daily Maximum, SPMD period (m ³ /s)	Daily Minimum, SPMD period (m ³ /s)	2002 annual Daily Mean (m ³ /s)	2002 annual Daily Maximum (m ³ /s)	2002 annual Daily Minimum (m ³ /s)
1	Upper Truckee River	0.092	0.229	0.054	1.93	10.0	0.037
2	Taylor Creek	.06*					
3	General Creek	.024	.031	.023	0.351	2.69	.020
4	Blackwood Creek	.062	.108	.051	.780	4.87	.028
5	Incline Creek	.059	.068	.054	.133	0.453	.048
6	Glenbrook Creek	.002	.004	.001	.031	.150	.001
7	Squaw Creek	.01*					
8	Truckee River at Farad	11.3	14.0	11.0	15.4	46.4	6.40
9	Truckee River at Sparks	4.02	6.82	3.71	11.6	43.9	3.62
10	North Truckee Drain	.708	1.05	.566	.449	1.90	.085
11	Steamboat Creek	.609	2.29	.425	.881	5.98	.312
12	Truckee River nr Tracy	7.05	10.8	5.07	14.8	47.9	5.07

*estimated, gage not present

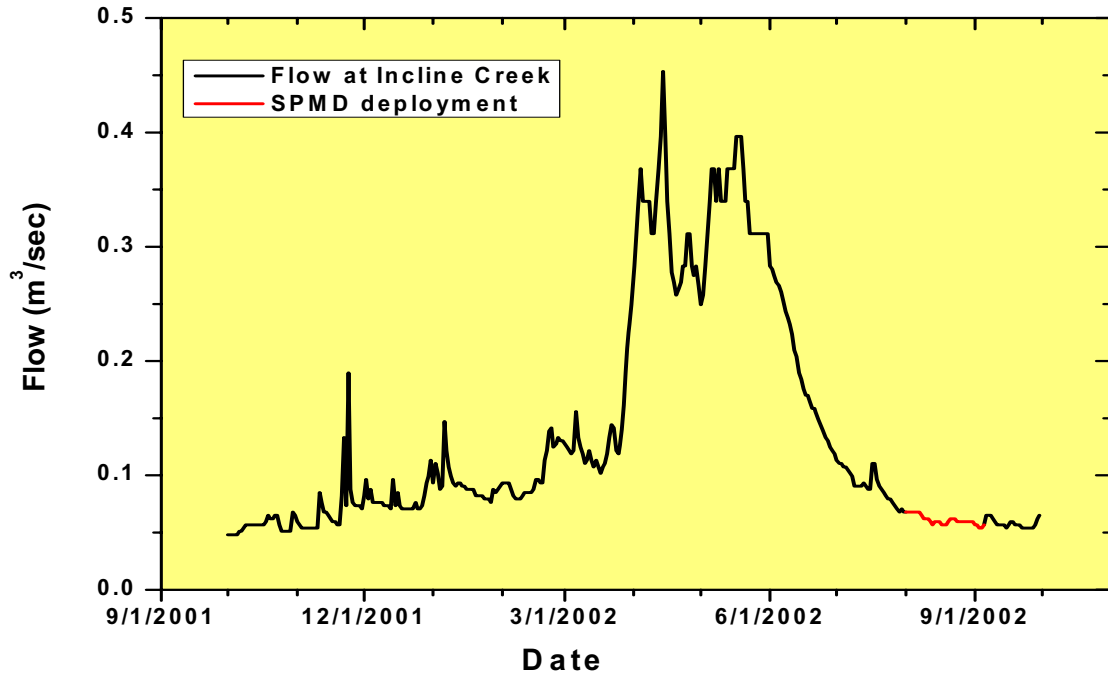


Figure 5. Annual daily mean discharge hydrograph for water year 2002 at Incline Creek near Crystal Bay (USGS station number 1033670, site 5), a Lake Tahoe site. SPMD deployment period is in red.

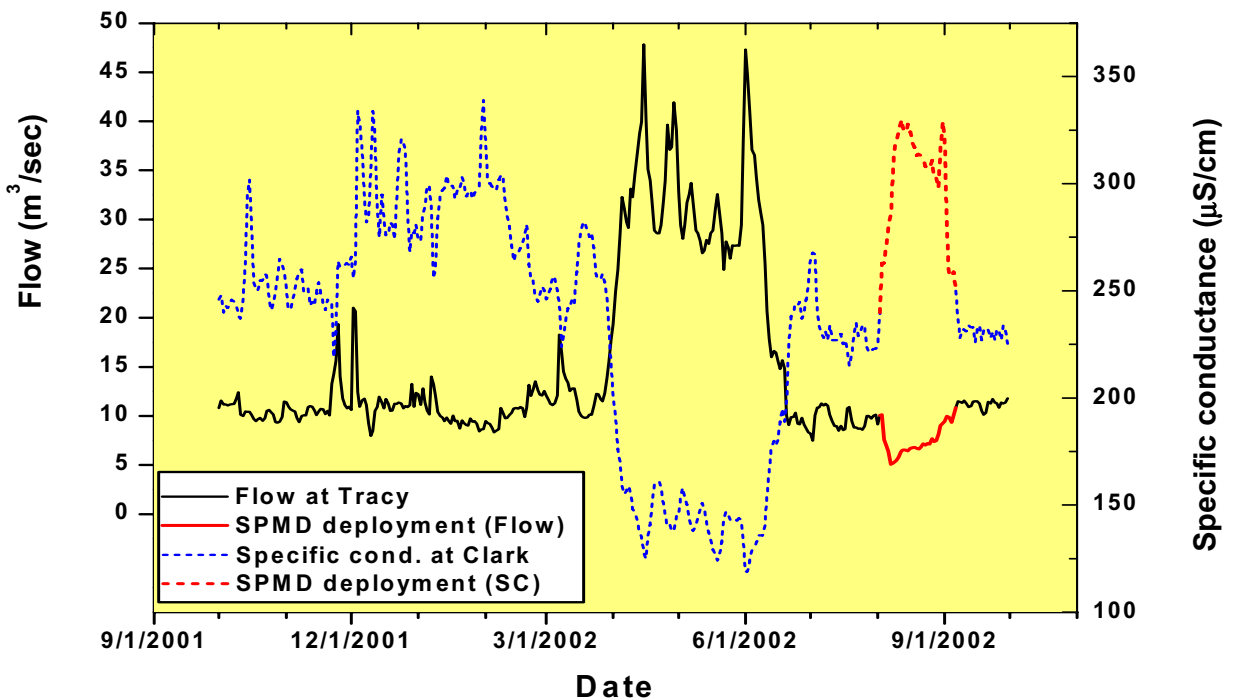


Figure 6. Annual daily mean discharge hydrograph (black and red solid lines) for Truckee River near Tracy (USGS station 10350340) and specific conductance graph (blue and red dashed lines) at Truckee River at Clark (USGS station 10350500, site 12). SPMD deployment period is marked in red. Note the antithetic relation between discharge and specific conductance.

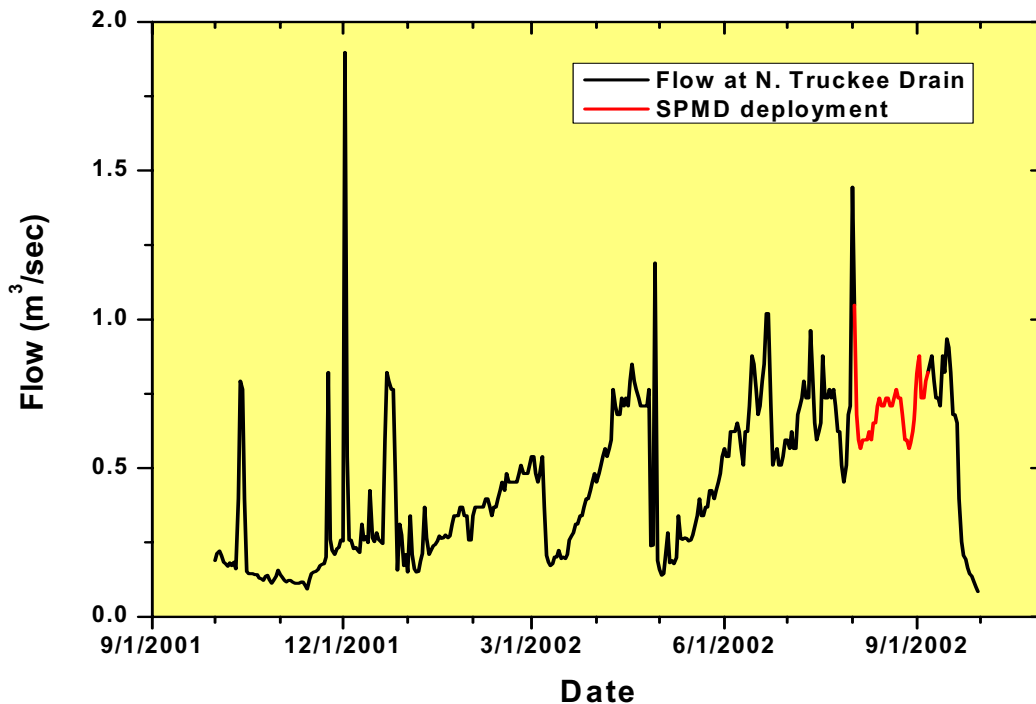


Figure 7. Annual daily mean discharge hydrograph for water year 2002 at North Truckee Drain near Kleppe Lane (USGS station number 10348300, site10), a Truckee River tributary. SPMD deployment period is in red.

Water Quality

Water quality results generally were similar at the beginning and end of deployment period for all sites (table 3). Field water temperature at different sites ranged from 11.0 to 23.5 °C during the summer low-flow period. Generally, water temperatures were cooler at the Lake Tahoe Basin and upper reaches of the Truckee River, increasing gradually with distance downstream along the Truckee River (table 3). Three SPMD sites had continuous water temperature monitors; Upper Truckee River, Truckee River at Sparks and Truckee River at Clark. The Upper Truckee temperature monitor was not in operation during the SPMD deployment period. Truckee River at Sparks and Truckee River at Clark (figure 8) annual graphs were similar. Higher temperatures occurred during the summer low-flow periods and the maximum temperatures (25.5 and 26.0 °C for Sparks and Clark respectively) during the SPMD deployment period. Colder temperatures, down to near freezing, occurred during the winter months. Water temperature during the SPMD deployment generally did increase downstream with the main-stem Truckee River sites.

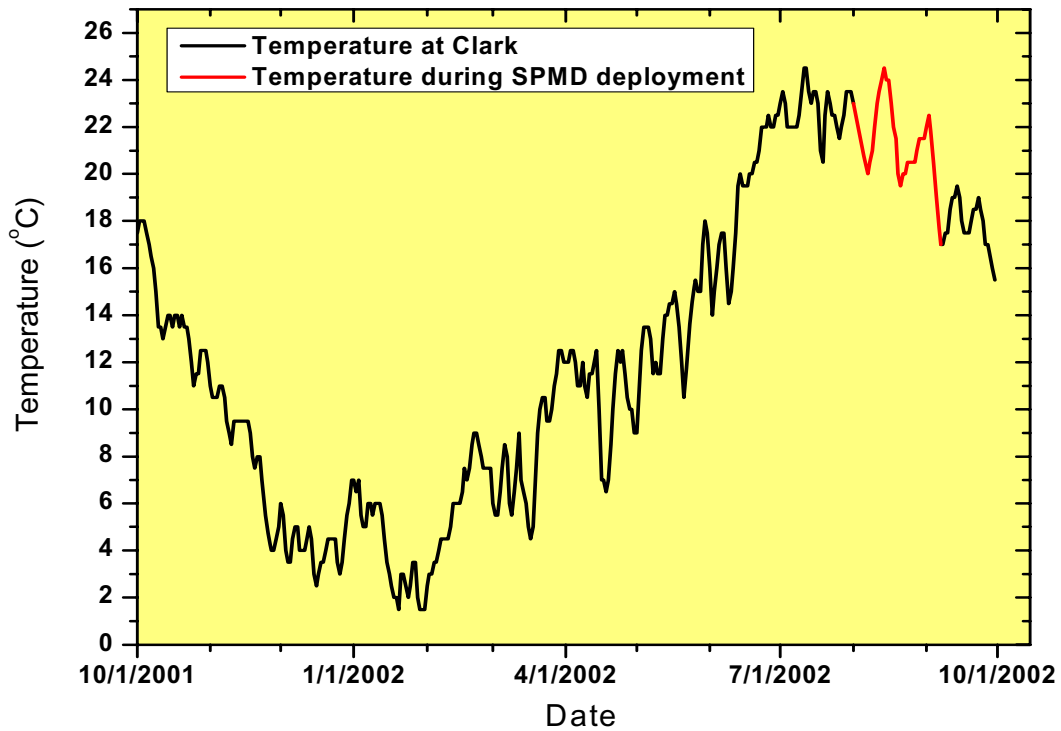


Figure 8. Annual daily mean water temperature graph for water year 2002 at Truckee River at Clark (USGS station 10350500, site12). SPMD deployment period is in red.

Table 3. Water quality data for SPMD deployment sites, August-September 2002 [abbreviations: °C, degrees Celsius; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25°C; mg/L, milligram per liter; begin, date of SPMD deployment; end, date of SPMD removal, max, maximum, min, minimum]

Site no.	USGS Station short name	Water Temperature (°C)		Specific Conductance ($\mu\text{S}/\text{cm}$)		pH (standard units)		Dissolved Oxygen (mg/L)	
		begin	end	begin	end	begin	end	begin	end
1	Upper Truckee River	14.0	15.8	88	105	7.6	7.3	8.2	8.3
2	Taylor Creek	23.0	17.4	22	22	7.0	7.1	6.5	7.7
3	General Creek	19.5	14.6	53	59	7.1	7.2	6.8	7.6
4	Blackwood Creek	21.9	17.0	61	73	7.6	7.6	6.1	7.4
5	Incline Creek	11.5	12.7	76	77	7.3	7.4	8.5	8.2
6	Glenbrook Creek	13.0	11.0	466	500	7.2	7.5	7.2	7.4
7	Squaw Creek	21.9	18.9	145	263	7.3	7.3	6.6	8.1
8	Truckee River at Farad	16.5	13.5	105	118	7.6	7.0	8.4	8.1
9	Truckee River at Sparks: a) field measurement	19.9	15.2	129	119	7.8	7.2	8.6	8.7
	b) continuous monitor, during SPMD deployment	<i>median=19.2</i> <i>max = 25.5</i> <i>min = 16.5</i>							
10	North Truckee Drain	21.5	16.6	443	369	7.6	7.4	7.1	8
11	Steamboat Creek	23.5	17.0	327	613	7.2	7.9	3.1	7.2
12	Truckee River at Clark: a) field measurement	23.4	18.1	236	257	8.3	7.7	9.1	7.7
	b) continuous monitor, during SPMD deployment	<i>median=21.5</i> <i>max = 26.0</i> <i>min = 18</i>		<i>median=310</i> <i>max = 364</i> <i>min = 227</i>					

Specific conductance generally was the same at the beginning and end of the deployment period for most sites. North Truckee Drain showed a drop from 443 to 369 microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$) and Steamboat Creek an increase from 327 to 613 $\mu\text{S}/\text{cm}$ and Squaw Creek increased from 145 to 263 $\mu\text{S}/\text{cm}$. Specific conductance generally increases from the Lake Tahoe Basin sites downstream along the Truckee River (table 3). The highest specific conductance values were from the Truckee River urban tributaries and one Lake Tahoe Basin site, Glenbrook Creek.

Specific conductance was monitored continuously at the Truckee River at Clark (figure 6) and Truckee River at Sparks sites for the 2002 water year. The lowest values during the year were during spring snowmelt runoff period (April-June). Higher specific conductance values were in the winter (December-February) and late summer (August-September), which was during the SPMD deployment. The cause of this high conductance peak during later summer

likely is related to the lowest discharges and higher temperatures of the year (figure 6). An antithetic relation between discharge and specific conductance exists most of the time at this site.

Field pH values were fairly similar at all sites from neutral to slightly basic (table 3). Dissolved oxygen (DO) concentrations showed little difference among sites (table 3), except for one reading at Steamboat Creek, which may have been affected by the probe being in contact with the bottom sediment.

SPMDs

The TEQ ranged from low values of 52 picograms per milliliter (pg/mL) at Squaw Creek and 74 pg/mL at the General Creek reference site to 1,730 and 1,870 pg/mL at North Truckee Drain and Steamboat Creek urban tributary sites, respectively (table 4). Lake Tahoe Basin sites averaged 414 pg/mL, Incline Creek was the highest at 817 pg/mL. Squaw Creek had a low TEQ of 52 pg/mL. TEQ on the main-stem Truckee River sites averaged 768 pg/mL and generally increased with distance downstream ranging from 495 pg/mL at Truckee River at Farad to 901 and 908 pg/mL at Truckee River at Sparks and Truckee River at Clark, respectively. Truckee River tributary sites in the Reno-Sparks urban area average 1,800 pg/mL and ranged from 1,730 pg/mL at North Truckee Drain to 1,870 pg/mL at Steamboat Creek. The trip blank combined for all sites was less than 50 pg/mL.

EC₅₀ results ranged from 2.70 milligram per milliliter (mg/mL) (least toxic) at Glenbrook Creek to 0.13 mg/mL (most toxic) at Steamboat Creek (table 4). General Creek (the reference site), and another Lake Tahoe Basin site, Taylor Creek, and Squaw Creek all showed unexpected higher EC₅₀ readings (0.62, 0.91, and 0.65 mg/mL respectively), possibly due to the location of all three deployment sites to near-by Highway 89. Another source of contamination to Taylor Creek could be from Fallen Leaf Lake. Fallen Leaf Lake is used for motorized water-craft recreation and is surrounded by residential development. The Lake Tahoe Basin sites had an average EC₅₀ of 1.46 mg/mL and ranged from 2.70 to 0.62 mg/mL. EC₅₀ along the three main-stem Truckee River sites averaged 1.42 mg/mL with a range of 2.07 at Sparks to 0.19 mg/mL at Clark. Truckee River tributary sites averaged 0.73 mg/mL and ranges from 1.33 to 0.13 mg/L at North Truckee Drain and Steamboat Creek respectively. The Lake Tahoe Basin sites appeared to be less toxic, followed by the Reno/Truckee River sites, which averaged 1.14 mg/mL, but this difference is not statistically significant. The Truckee River generally increased in relative toxicity with distance downstream ranging from about 2.00 mg/mL at Farad and Sparks to 0.19 mg/mL at Clark. The trip blank combined for all sites was found to be greater than 10 mg/mL.

The PI ranged from 470 µg/mL at Squaw Creek to 9,990 µg/mL at North Truckee Drain site (table 4). The Lake Tahoe Basin sites averaged 1,420 µg/mL for PI, and ranged from 1,050 to 2,475 µg/mL at Blackwood and Glenbrook Creeks to Incline Creek. Main-stem Truckee River sites were averaged 3,100 µg/mL with a range from 2,380 µg/mL at Truckee River at Farad to 4,180 µg/mL at Sparks. Truckee River urban tributaries were the highest, ranging from 6,790 µg/mL at Steamboat Creek to 9,990 µg/mL at North Truckee Drain, with an average of 8,390 µg/mL. The trip blank combined for all sites was only 35 µg/mL.

A strong correlation ($R^2 = 0.84$, $P < 0.001$) exists between the results of the TEQ and PI (figure 9). This indicates that PAHs are mostly responsible for the values observed because both tests respond to PAHs; however, the TEQ test also responds to other organic contaminants such

as organochlorine compounds. If other substances were inducing the CYP1A gene, in addition to the PAH compounds, a poorer correlation would be observed.

Table 4. SPMD Toxic Equivalent, Micro-tox and Pyrene Index results during deployment period, August-September 2002. [Abbreviations: TEQ, toxic equivalent; EC₅₀, micro-tox; pg/mL, picograms per milliliter; mg/mL, milligram per milliliter; µg/mL, microgram per milliliter]

Site number	USGS Station short name	TEQ (pg/mL)	EC ₅₀ (mg/ml)	Pyrene Index (µg/mL)
1	Upper Truckee River	415	1.67	1,420
2	Taylor Creek	440	0.62	1,400
3	General Creek	74	0.91	1,10
4	Blackwood Creek	111	1.23	1,040
5	Incline Creek	817	1.63	2,480
6	Glenbrook Creek	627	2.70	1,040
7	Squaw Creek	52	0.65	470
8	Truckee River at Farad	495	2.00	2,380
9	Truckee River nr Sparks	901	2.07	4,180
10	North Truckee Drain	1,730	1.33	9,990
11	Steamboat Creek	1,870	0.13	6,790
12	Truckee River at Clark	908	0.19	2,770
1-12	Trip Blank (combined)	<50	>10	35
1-6	Lake Tahoe Basin mean	414	1.46	1,420
8,9, & 12	Truckee River mean	768	1.42	3,100
10 & 11	Truckee R. Tributary mean	1,800	0.73	8,390

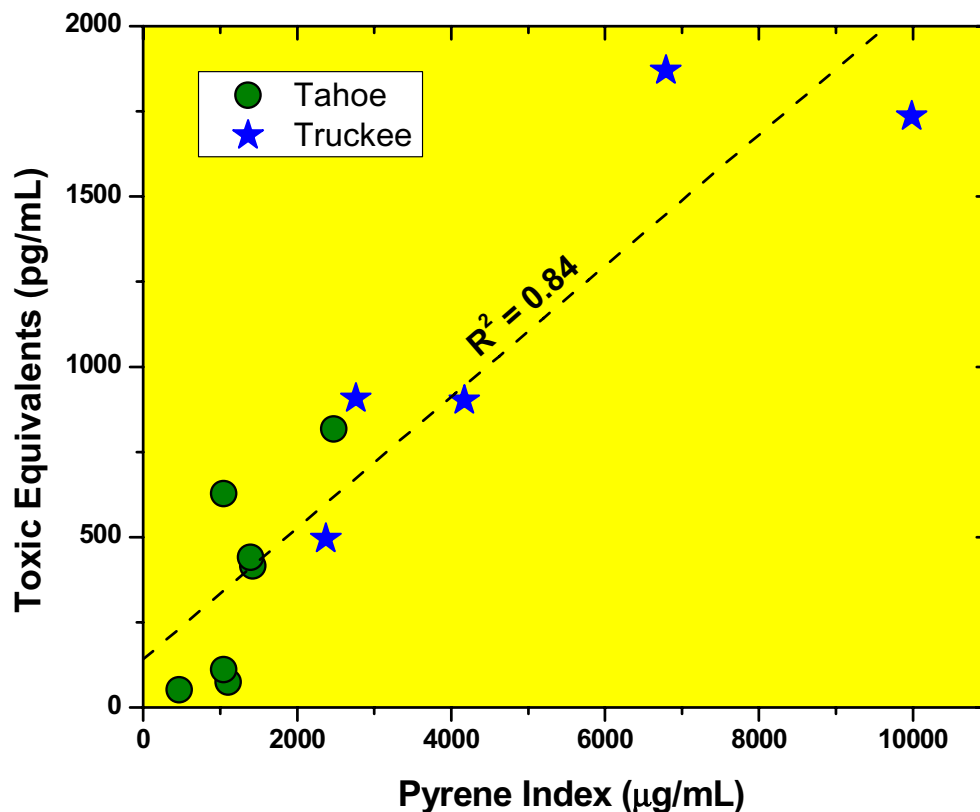


Figure 9. Relation between Toxic Equivalents (TEQ) and Pyrene Index (PI) results plot. The correlation indicates that PAHs are the main organic compounds to which both tests are responding.

Testing of the SPMD extracts showed higher TEQ and PI from urban areas within Reno-Sparks. North Truckee Drain showed the highest PI and Steamboat Creek with the highest TEQ (table 4). With the exception of Incline and Glenbrook Creeks, TEQ and PI for sampling sites within the Lake Tahoe Basin were relatively low compared to sites along the Truckee River. Squaw Creek results were both low. All sites included in this study had EC_{50} values that were considerably lower than the negative control used during the EC_{50} Microtox bioassay. Environmental EC_{50} values were more variable and were found not to correlate well to land use in this study. EC_{50} values from all sites indicated relative toxicity values (less than 3) were present.

Accumulation of compounds by the SPMDs is related to molecular size and the compounds octanol-water partition coefficient ($\log K_{OW}$). Initially it was thought that the rate-limiting step for uptake of compounds was diffusion across the membrane (Huckins and others 1996); however, further research has shown that water velocity passing the membrane will influence the uptake of contaminants by the SPMDs (Huckins and others, 2002). Higher velocities will allow more water volume and possible organic compounds past the membrane over time, providing higher uptake of organic compounds than at lower velocities and lower volumes. Instantaneous velocities measured at the sampling sites in this study do not correlate with SPMD results,

indicating that water velocity does not directly influence the results in this study. The influence of temperature on contaminant uptake is important over relatively small temperature ranges. The maximum increase in PAH accumulation was greater than two fold over a 16°C temperature rise, but for organochlorine pesticides uptake increased almost four times over the same temperature range (Huckins and others, 2002). For this study, the difference in temperature among the sampling sites was potentially enough to influence organic-compound uptake. However, plots of temperature versus PI results showed no significant correlation, indicating that temperature alone could not be responsible for the variations. In streams with thick deposits of fine sediments, bioturbation may also enhance uptake of organic compounds by the SPMDs because many organic contaminants are bound to the fine sediments, and organisms that burrow through the fine sediments pass the contaminated material back up to the surface where it can be dissolved back into the water column (Thibodeaux and Bierman, 2003). However, only two sites in this study, Steamboat Creek and North Truckee Drain, had thick deposits of fine sediments. Bioturbation may possibly influence the results at these two sites, but the organic compounds still must have been present in the water column for there to be a relative toxicity.

DISCUSSION

Relation between urbanization and relative toxicity

The correlation between the percent urbanization (table 1) and SPMD results (table 4) are presented for TEQ (figure 10A), Microtox EC₅₀ (figure 10B), and PI (figure 10C). TEQ shows a slight positive correlation with percent urbanization ($R^2 = 0.41$, $P = 0.02$). Three of the four highest TEQs are found at sites with the urbanization above 30 percent. Microtox EC₅₀ results had no correlation with urbanization ($R^2=0.04$, $P=0.5$). PI results showed only a slight positive correlation with urbanization ($R^2=0.55$, $P=0.005$), providing the best relation of the three SPMD tests used here. It also appears that most of the higher TEQ and PI occur above 30 percent urbanization.

The results from this study indicate that SPMDs can be used to assess potential organic compounds in streams in the Lake Tahoe Basin and along the Truckee River, but are not sensitive to predicting relative toxicity based on percent urbanization. Because the PI correlated well with percent urbanization, indicating PAHs that are common in urban runoff, the PI may be the more suitable test for assessing the influence of urbanization on organic contaminant concentrations in aquatic systems. The TEQ test is largely indicative of PAH relative toxicity, and therefore also shows fairly good correlation with urbanization. The more general EC₅₀ test may not be sensitive enough to show the effects of urbanization on stream water quality within the Lake Tahoe Basin or along the Truckee River, because the compounds may be derived from non-urban sources.

TEQ and EC₅₀ relative toxicity tests and PI results generally showed higher results within urban areas in the Reno-Sparks area. Truckee River tributaries, North Truckee Drain (site 10) and Steamboat Creek (site 11), with the high urbanization percentages, had the highest results. Relative toxicity results for TEQ and EC₅₀ along the main-stem Truckee River tend to increase with distance downstream. PI results increased from Truckee River at Farad to Sparks, but declined again at Clark.

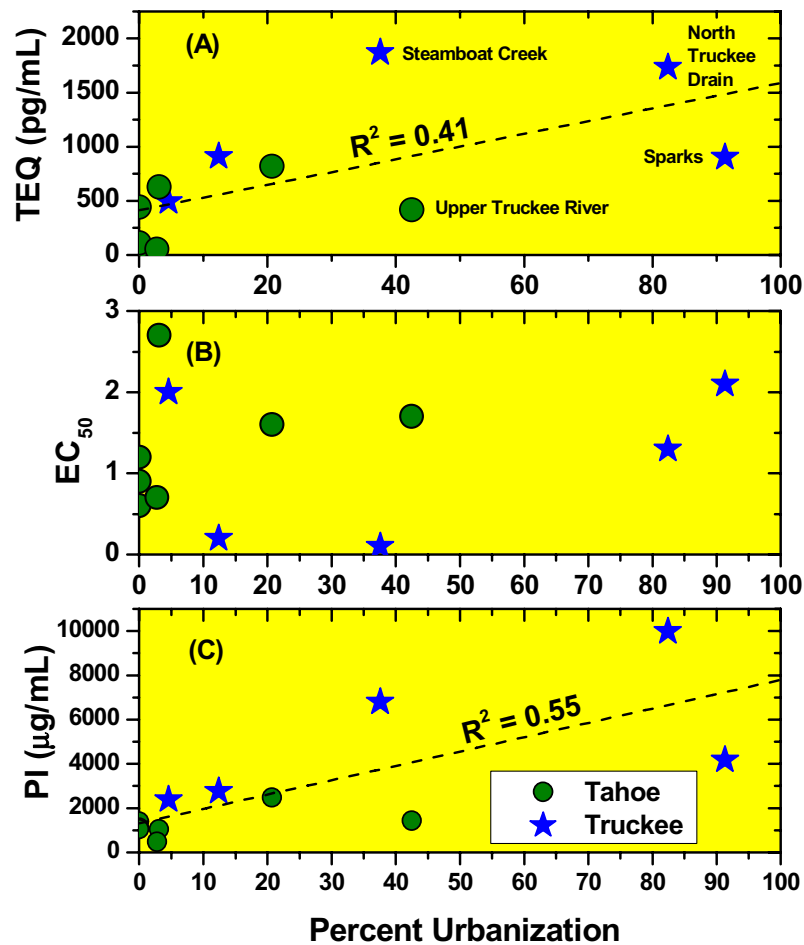


Figure 10. Correlation plot results between **A)** Toxic Equivalents (TEQ); **B)** micro-tox (EC₅₀); and **C)** Pyrene Index (PI) and percent urbanization at each SPMD deployment site.

Relation between discharge and relative toxicity

Median daily stream discharge did show a possible negative relation ($R^2 = 0.82$) with TEQ (figure 11) for the main-stem and tributary Truckee River sites, but no relation for the Lake Tahoe Basin sites. A slight ($R^2 = 0.61$, $P=0.12$) relation was found between Microtox EC₅₀ values and discharge for all sites. A negative relation ($R^2 = 0.75$, $P=0.05$) with PI exists for the main-stem and tributary Truckee River sites, but again not for the Lake Tahoe Basin sites. However, there are not enough data to allow the strong statistical correlation observed between TEQ and discharge (Figure 11) to be used as a predictor. The downward trend in TEQ values with increasing discharge in the main-stem Truckee River sites might possibly be due to dilution from ground water inputs in the Vista area just below Sparks.

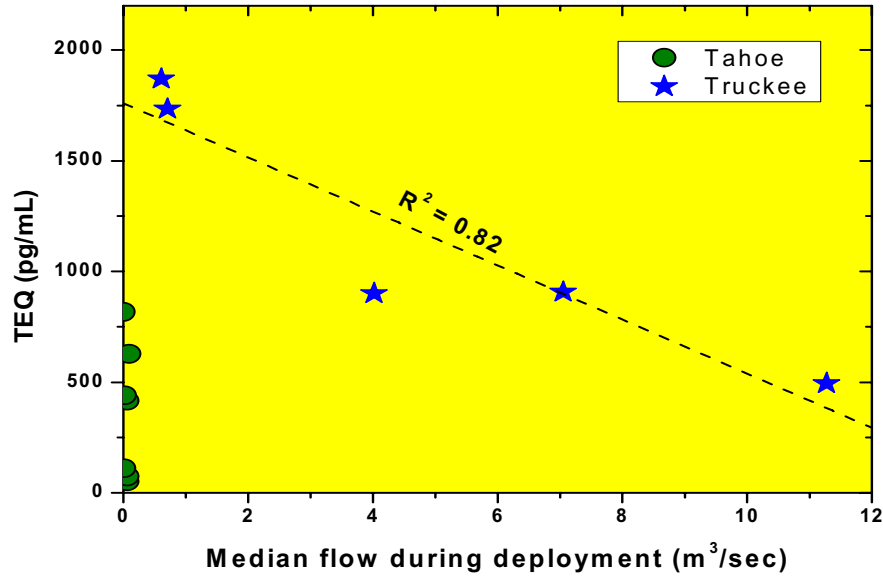


Figure 11. TEQ plotted against median discharge during the SPMD deployment period. There appears to be a correlation between discharge and Truckee River main-stem and tributary sites, but not for the Lake Tahoe Basin sites.

Relation between Specific Conductance and relative toxicity

TEQ and PI results for all sites were plotted against the average specific conductance values (table 3) during the deployment period (figure 12). The TEQ and PI results ($R^2=0.47$, $P=0.01$, $R^2=0.31$, $P=0.05$, respectively) both showed a weak positive relation (figure 12). There was no correlation between EC_{50} results (not plotted) and specific conductance.

In general, deployment sites that are located in areas with minimal urban development have low specific conductance values relative to sites within urbanized areas. Additionally, specific conductance typically increases with distance downstream. Glenbrook Creek was atypical, as there was a relatively high specific conductance but generally low urbanization. The high specific conductance in this creek probably is due to the geology of the catchment, which includes volcanic, metamorphic and sedimentary rocks (Grose, 1985) and possibly from the use of road salts during winter months on the highway in the basin upstream of the deployment site. It is expected that specific conductance values near urban areas would be higher than in non-urban areas, therefore it is not surprising that there is at least some correlation between specific conductance and organic contaminants. The utility of correlating specific conductance with relative toxicity is marginal because there are many other factors, such as geology and inorganic substances that contribute to specific conductance values.

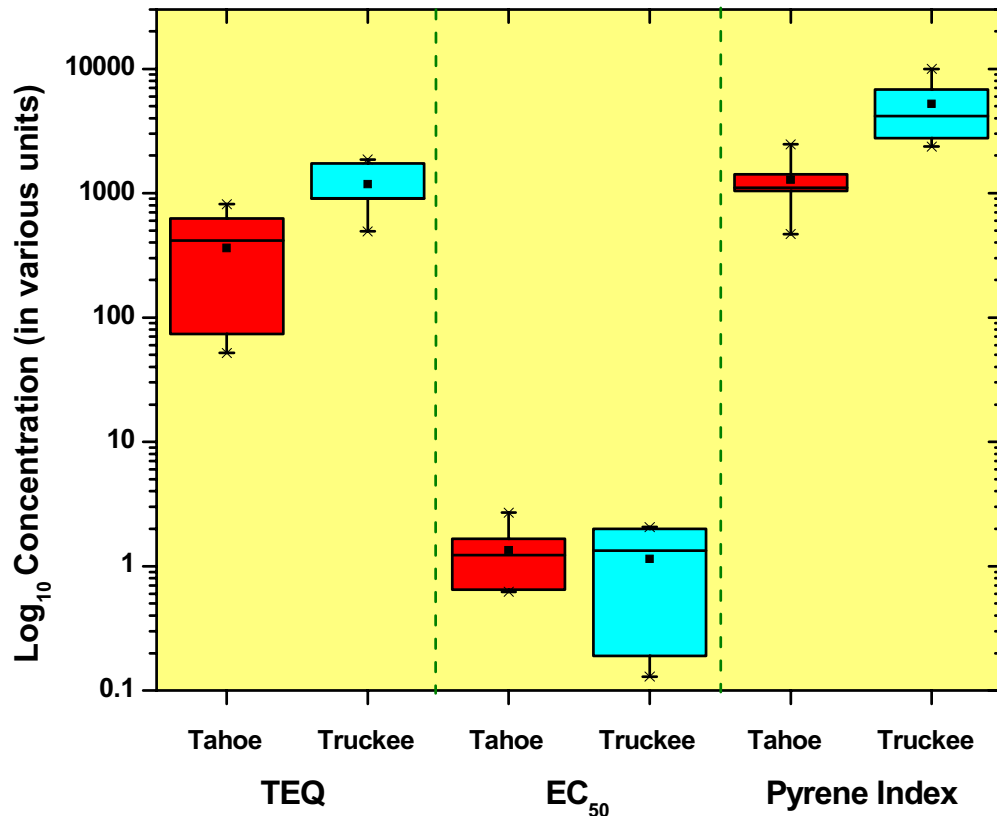


Figure 13. TEQ, EC₅₀, and PI test box plots comparing the Lake Tahoe Basin to the main-stem and tributary Truckee River watershed. The TEQ (pg/mL) and PI (ug/mL) show statistically different means for the two data sets (P<0.001), but the EC₅₀ (mg/ml) means are not statistically different between the watersheds. The black square represents the mean, and the black horizontal line is the median. Whiskers represent the 10 and 90 percentiles of the data.

Comparison with previous Lake Tahoe Basin SPMD results

In 1998 SPMDs were deployed in the same six Lake Tahoe Basin stream sites that were used in a study by Lico and Pennington (1999). They measured organic compounds in water samples and used SPMDs during spring snowmelt runoff and fall baseflow periods quantitatively, but did not employ the relative toxicity tests that were used in this study. The fall deployment was a month later than for this study. The previous study did find higher organochlorine and PAH compound results during the spring (May) snowmelt runoff period compared to the fall (October) period, except for the Upper Truckee River site. The Upper Truckee deployment site had no detections of PAH compounds in the spring, but was the highest in both the number of compounds and the combined concentration in the fall. Results from 1998 showed the PAH compounds present at all six sites in the fall, with Upper Truckee River site the highest followed in order by Incline, Glenbrook, Taylor and Blackwood Creeks down to the lowest at General Creek. The 1998 organochlorine results had detections at all six sites in the fall, with the Taylor Creek deployment site as the highest followed closely by Upper Truckee

River and in order Incline, Blackwood, and General Creeks sites down to Glenbrook Creek the lowest.

The PI results from this study during the 2002 low-flow summer months showed Incline Creek as the highest followed by Upper Truckee River and closely Taylor Creek and then General, Blackwood and Glenbrook Creeks closely behind at the low end.

The utility of this comparison is that it demonstrates that the amount of organic contamination into the stream in the Lake Tahoe Basin does occur over time and is generally persistent in the Lake Tahoe Basin. Taylor Creek appears in both studies to be one of the sites with high organic contamination, even though little urbanization (less than one percent) is occurring in the watershed. Taylor Creek shows that percent of urbanization would not always be the best predictor of possible organic contamination.

CONCLUSIONS

This study has shown that extracts from SPMDs deployed at stream sites in the Lake Tahoe and Truckee River watersheds possibly can be a useful indicator for the degree which urbanization is influencing water quality near a sampling site. Further work is being undertaken to better define the zone of influence that may affect each SPMD. The results presented here indicate that urbanization that is relatively close to the SPMD site can contribute to the relative toxicity value recorded at each site. In general, the PI test had the strongest correlation with urbanization, followed by the TEQ Assay. The EC₅₀ values did not correlate with the percent urbanization, but some of the values indicated greater relative toxicity at disturbed sites. The PI appears to be the best indicator of urbanization out of the three tests used because it specifically tests for PAH compounds that are dominant in urban runoff and probably dominant in the SPMDs in an urban setting. The EC₅₀ test samples organic compounds that are too general to be useful for this purpose. A comparison of results from this study at the same six stream sites around Lake Tahoe that were studied by Lico and Pennington (1999) indicates that the organic contamination generally is still pervasive in the basin.

Although deployment sites in the Lake Tahoe Basin generally had lower relative toxicity than main-stem Truckee River and Truckee River tributary deployment sites in the Reno-Sparks urban area, low levels of contamination were present at all sites in the Lake Tahoe Basin and some sites had relative toxicity levels that were comparable to the Truckee River sites.

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