Concentrations and Distribution of Manmade Organic Compounds in the Lake Tahoe Basin, Nevada and California, 1997-99

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Abstract

The U.S. Geological Survey, in cooperation with the Tahoe Regional Planning Agency and the Lahontan Regional Water-Quality Control Board, sampled Lake Tahoe, major tributary streams to Lake Tahoe, and several other lakes in the Lake Tahoe Basin for manmade organic compounds during 1997-99.

Gasoline components were found in all samples collected from Lake Tahoe during the summer boating season. Methyl *tert*-butyl ether (MTBE), benzene, toluene, ethylbenzene, and xylenes (BTEX) were the commonly detected compounds in these samples. Most samples from tributary streams and lakes with no motorized boating had no detectable concentrations of gasoline components. Motorized boating activity appears to be directly linked in space and time to the occurrence of these gasoline components. Other sources of gasoline components to Lake Tahoe, such as the atmosphere, surface runoff, and subsurface flow, are minor compared to the input by motorized boating. Water sampled from Lake Tahoe during mid-winter, when motorized boating activity is low, had no MTBE and only one sample had any detectable BTEX compounds.

Soluble pesticides rarely were detected in water samples from the Lake Tahoe Basin. The only detectable concentrations of these compounds were in samples from Blackwood and Taylor Creeks collected during spring runoff. Concentrations found in these samples were low, in the 1 to 4 nanograms per liter range.

Organochlorine compounds were detected in samples collected from semipermeable membrane devices (SPMD's) collected from Lake Tahoe, tributary streams, and Upper Angora Lake. In Lake Tahoe, SPMD samples collected offshore from urbanized areas contained the largest number and highest concentrations of organochlorine compounds. The most commonly detected organochlorine compounds were cis- and trans-chlordane, *p,p*'-DDE, and hexachlorobenzene. In tributary streams, SPMD samples collected during spring runoff generally had higher combined concentrations of organochlorine compounds than those collected during baseflow conditions. Upper Angora Lake had the fewest number of organochlorine compounds detected of all lake samples. Dioxins and furans were not detected in SPMD samples from two sites in Lake Tahoe or from two tributary streams.

The number of polycyclic aromatic hydrocarbon (PAH) compounds and their combined concentrations generally were higher in samples from Lake Tahoe than those from tributary streams. Areas of high-motorized boating activity at Lake Tahoe had the largest number and highest concentrations of PAH's. PAH compounds were detected in samples from SPMD's in four of six tributary streams during spring runoff, all tributary streams during baseflow conditions, and at all lake sites. The most commonly detected PAH's in tributary streams during spring runoff were phenanthrene, fluoranthene, pyrene, and chrysene, and during baseflow conditions were phenanthrene, 1-methylphenanthrene, diethylnaphthalene, and pyrene. Upper Truckee River, which has an urban area in its drainage basin, had the largest number and highest combined concentration of PAH's of all stream samples.

Diver retrieving semipermeable membrane device from Lake Tahoe, near Glenbrook, Nev. Photograph by R.J. Hoffman, U.S. Geological Survey, August 1998.

Semipermeable membrane sampling device, Upper Angora Lake, Calif., July 1998. Photograph by K.J. Hill, Tahoe Regional Planning Agency.

Bottom-sediment from Lake Tahoe had detectable concentrations of p-cresol, a phenol, in all but one sample. A sample collected near Chambers Lodge contained phenol at an estimated concentration of 4 micrograms per kilogram (µg/kg). Bottom-sediment samples from tributary streams had no detectable concentrations of organochlorine or PAH compounds. Several compounds were detected in bottom sediment from Upper Angora Lake at high concentrations. These compounds and their concentrations were *p,p*’-DDD (10 µg/kg), *p,p*’-DDE (7.4 µg/kg), 2,6-dimethylnaphthalene (estimated at 190 µg/kg), pentachlorophenol (3,000 µg/kg), and p-cresol (4,400 µg/kg).

INTRODUCTION

Lake Tahoe is a high alpine lake renowned for its clear, deep waters and has been designated an Outstanding National Resource Water. The lake is a destination for outdoor sporting enthusiasts who visit the lake throughout the year. Its proximity to the San Francisco Bay Area, about 240 kilometers (km) to the west, and setting in the Sierra Nevada make it one of the premier summer vacation spots in the country. In recent years, the clarity of Lake Tahoe has been decreasing at a rate that will make it a lake less extraordinary in appearance within the next 30 years (Goldman and others, 1998). The cause of this loss of clarity is due to increased algae populations within the lake. Scientists and regulators require more information that would allow them to make appropriate decisions on remedial actions needed to reverse this trend. All sewage effluent has been exported from the Lake Tahoe Basin since the mid-1970’s. Other more recently enacted regulations in the Tahoe Basin include prohibition of most two-stroke engines and controlling sediment, and thus nutrient, input into the lake. Increased urbanization and its associated activities may be an important contributor to the reduction of Lake Tahoe’s clarity. Pesticide and fertilizer use, leaking underground fuel storage tanks, and atmospheric deposition can all be important sources of manmade compounds that could upset the natural ecological systems within the lake.

Before 1997, little was known about the concentrations of manmade organic compounds in Lake Tahoe and its tributary streams. During 1997, the U.S. Geological Survey (USGS) in cooperation with the Tahoe Regional Planning Agency and the University of California, Davis, Tahoe Research Group (TRG) collected the first data documenting the presence of the gasoline components benzene, toluene, ethylbenzene, xylenes, methyl *tert*-butyl ether (MTBE), and *tert*-amyl methyl ether (TAME) in the lake (Boughton and Lico, 1998). Every sample taken from the lake during the summer months had detectable concentrations of MTBE. The findings of this study (Boughton and Lico, 1998) prompted a more detailed investigation, the results of which are reported herein.

Purpose and Scope

This report documents the occurrence and distribution of selected manmade organic compounds in water and bottom sediment from Lake Tahoe, its major tributaries, and other Lake Tahoe Basin lakes. Organic compounds investigated during this study include gasoline components (VOC’s), soluble pesticides, and semivolatile compounds (including organochlorine compounds, PAH’s, dioxins, and furans). Locations of sampling sites are shown in figure 1. Ancillary data collected as part of this study can be found in a report by Preissler and others (1999, p. 508-520). The results of this study are documented to provide a useful benchmark from which future comparisons can be made.

Lake Tahoe was sampled at 10 locations during August 1998 for VOC’s and soluble pesticides. Samples for VOC’s were taken from Lake Tahoe at five sites during January 1999. Semipermeable membrane sampling devices (SPMD’s) were deployed to sample hydrophobic organic compounds at eight locations at Lake Tahoe (July-August 1998). Water samples were obtained from six tributary streams during spring runoff (May 1998) and during baseflow (October 1998) conditions. SPMD’s were deployed in the tributary streams for two periods of approximately 8 weeks each (May-June 1998 and November-December 1998) to sample the hydrophobic organic compounds. Lists of analytes for the several classes of compounds can be found in tables 1-4 and in the following reports—Connor and others (1998), Foreman and others (1995), Furlong and others (1996),

Base from U.S. Geological Survey digital data,
1:24,000 and 1:100,000,1969-85.
Universal Transverse Mercator projection, Zone 11

EXPLANATION

— · · — Boundary of Lake Tahoe Basin

—··—··— Boundary of subbasin

Tributary stream site, number, and type of data collected

▼ 1s VOC's, pesticides, SPMD, and bottom sediment

Lake site, number, and type of data collected

▼ 10 VOC's

▼ 4 VOC's, pesticides, and bottom sediment

▽ 13 VOC's, pesticides, SPMD, and bottom sediment

Figure 1. Lake and tributary stream sampling sites in Lake Tahoe Basin, Nevada and California.

and Zaugg and others (1995). In Upper Angora Lake, about 8 km southwest of Lake Tahoe, water samples were taken for VOC's and soluble pesticides during August 1998, and hydrophobic organic compounds (using SPMD's) during July-August 1998. Bottom sediment was collected for analysis of hydrophobic organic compounds at seven sites from Lake Tahoe, six tributary streams, and Upper Angora Lake during August 1998. Two other lakes, Fallen Leaf Lake and Lower Echo Lake, were sampled for VOC's during August 1998. Upper Angora Lake has no motorized boats and nearby automobile traffic is minor. Fallen Leaf and Lower Echo Lakes have substantial boating traffic during the summer months. Analytical results of water samples collected during 1997 and reported by Boughton and Lico (1998) are included in the discussion section of this report.

Sample Collection and Analysis

Water samples for VOC's were collected using methods described by Shelton (1997). A stainless-steel sampler, described by Shelton (1997), was lowered to the desired depth on a stainless-steel cable connected to a calibrated reel. The sampler contained four 40-milliliter (mL) vials. Each vial was flushed with seven volumes of sample and the final 40 mL remained in the vial. Although this sampler was designed for suburban streams, its ability to allow sample vials to be purged ensures the water sample in the vials is representative. Approximate flushing volumes at 3- and 30-meter (m) depths are 260 and 230 mL, respectively (R.J. Hoffman, U.S. Geological Survey, written commun., 1999). Immediately upon retrieval and before opening, the sampler was placed in a preservation chamber (Shelton, 1994) to minimize contamination of the samples by atmospheric sources. Samples were removed from the sampler, preserved with 1:1 hydrochloric acid, capped, placed on ice, and sent overnight to the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo. VOC's were analyzed using gas chromatography-mass spectrometry as described by Connor and others (1998). Sampler performance was documented by Halde and others (1999). Quality-assurance samples for VOC's included sampler blanks (a measure of potential contamination by the sampler) and ambient blanks (a measure of potential contamination from the atmosphere).

Water samples for soluble pesticides were collected using the same stainless-steel sampler used for VOC's with the exception that no vials were in the sampler. Water from the sampler was collected and composited in a 3-liter teflon bottle. The water sample was filtered through a glass fiber filter, placed on ice, and sent overnight to the NWQL. Soluble pesticides (86 compounds) were extracted from water samples using solid-phase extraction procedures outlined by Sandstrom and others

Table 1. Volatile organic compounds in water samples collected at Lake Tahoe, other nearby alpine lakes, and tributary streams, July 1997-January 1999

[Concentrations in micrograms per liter; <, less than; --, not determined]

Site number (fig. 1)	Depth (meters below land surface)	Date	Benzene [1]	Toluene[1]	Ethyl-benzene[1]	Ortho-xylene[1]	Meta- and para-xylene[1]	Methyl *tert*-butyl ether[1] (MTBE)	*Tert*-amyl methyl ether[1] (TAME)
Lake Tahoe Samples									
1	3	09/03/1997	E0.5	0.13	E0.02	E0.03	E0.09	0.45	E0.05
1	3	08/11/1998	.17	1.0	.24	.42	1.0	.84	.10
1	3	01/13/1999	<.10	<.05	<.03	<.064	<.064	<.17	<.11
2	3	09/03/1997	.13	.68	.12	.20	.52	1.7	.14
4	3	07/29/1997	.15	.58	E.09	.16	.42	1.5	E.09
4	3	08/02/1997	.33	1.9	.39	.60	1.6	4.2	.20
4	3	08/12/1998	.11	.56	.097	.17	.44	1.3	.15
5	30	07/29/1997	<.032	<.04	<.03	<.064	<.064	.19	E.02
5	3	08/02/1997	<.06	E.04	<.03	<.064	E.03	.59	E.04
5	10	08/02/1997	<.06	<.07	<.03	<.064	E.04	.61	<.11
5	30	08/02/1997	<.032	<.04	<.03	<.064	<.064	.26	<.11
5	3	08/11/1998	<.10	E.08	<.03	<.064	<.064	.45	<.11
5	30	08/11/1998	<.10	<.05	<.03	<.064	<.064	.22	<.11
5	3	01/13/1999	<.10	<.05	<.03	<.064	<.064	<.17	<.11
5	30	01/13/1999	<.10	<.05	<.03	<.064	<.064	<.17	<.11
6	3	09/03/1997	E.04	E.09	<.03	<.064	E.05	.42	E.05
6	30	09/03/1997	E.02	E.04	<.03	<.064	<.064	.18	<.11
7	3	09/02/1997	E.04	E.1	E.01	<.064	E.06	.30	E.04
7	3	08/11/1998	<.10	.27	E.06	.099	.26	.47	<.11
7	3	01/13/1999	<.10	<.05	<.03	<.064	<.064	<.17	<.11
8	3	09/02/1997	E.05	.15	E.02	E.04	E.1	.45	E.05
9	3	08/12/1998	<.10	.27	E.04	E.07	.19	.78	.13
10	3	09/02/1997	.15	.70	.12	.23	.52	1.0	.14
10	3	08/11/1998	.61	4.4	1.1	2.0	4.7	1.3	.17
10	3	01/13/1999	<.10	E.02	<.03	<.064	E.02	<.17	<.11
11	3	08/12/1998	.21	1.0	.18	.36	.94	2.4	.45
12	3	08/12/1998	.44	1.5	.20	.59	1.5	4.0	.85
13	3	09/02/1997	E.07	.26	E.04	E.06	E.2	.68	E.07
13	3	08/12/1998	.18	.91	.17	.28	.72	2.0	.34
13	3	01/13/1999	<.10	<.05	<.03	<.064	<.064	<.17	<.11
14	3	08/12/1998	.17	.78	.12	.23	.58	1.8	.34
Tributary Stream Samples									
1s	--	05/13/1998	E.004	<.038	<.03	<.064	<.064	<.11	<.11
1s	--	10/27/1998	<.10	E.02	<.03	<.064	<.064	E.06	<.11
2s	--	05/121998	<.032	<.038	<.03	<.064	<.064	<.11	<.11
2s	--	10/27/1998	<.10	<.05	<.03	<.064	<.064	<.17	<.11
3s	--	05/13/1998	<.032	<.038	<.03	<.064	<.064	<.11	<.11
3s	--	10/28/1998	<.10	<.05	<.03	<.064	<.064	<.17	<.11
4s	--	05/12/1998	<.032	<.038	<.03	<.064	<.064	<.11	<.11
4s	--	10/27/1998	<.10	E.04	<.03	<.064	<.064	<.17	<.11
5s	--	05/13/1998	<.032	<.038	<.03	<.064	<.064	<.11	<.11
5s	--	10/28/1998	<.10	<.05	<.03	<.064	<.064	<.17	<.11

Table 1. Volatile organic compounds in water samples collected at Lake Tahoe, other nearby alpine lakes, and tributary streams, July 1997-January 1999—Continued

Site number (fig. 1)	Depth (meters below land surface)	Date	Benzene [1]	Toluene[1]	Ethyl-benzene[1]	Ortho-xylene[1]	Meta- and para-xylene[1]	Methyl *tert*-butyl ether[1] (MTBE)	*Tert*-amyl methyl ether[1] (TAME)
6s	--	05/13/1998	<0.032	<0.038	<0.03	<0.064	<0.064	<0.11	<0.11
6s	--	10/28/1998	<.10	E.01	<.03	<.064	<.064	<.17	<.11
Other Nearby Lake Samples [2]									
3	3	09/05/1997	<.032	<.04	<.03	<.064	<.064	<.11	<.11
3	9.1	09/05/1997	<.032	E.01	<.03	<.064	<.064	<.11	<.11
15	3	09/04/1997	<.032	E.04	<.03	<.064	E.02	<.11	<.11
15	15	09/04/1997	<.032	E.02	<.03	<.064	<.064	<.11	<.11
16	3	08/10/1998	<.10	.11	<.03	<.064	E.08	.78	.14
17	3	09/04/1997	<.032	E.02	<.03	<.064	<.064	<.11	<.11
17	10	09/04/1997	<.032	<.04	<.03	<.064	<.064	<.11	<.11
17	3	08/13/1998	<.10	<.054	<.03	<.064	<.064	<.17	<.11
17	6	08/13/1998	<.10	<.054	<.03	<.064	<.064	<.17	<.11
18	3	08/10/1998	.40	3.5	.71	1.1	1.5	7.7	2.2

[1] When an "E" is reported, the compound has passed all criteria used to identify its presence, and only the concentration is estimated (Connor and others, 1998).

[2] Lake sites 3 and 17 have no motorized boating activity.

(1992) and Zaugg and others (1995) and then analyzed by gas or high-performance liquid chromatography. Sampler blanks were collected for quality-assurance purposes.

Bottom-sediment samples were collected and processed using protocols developed for the National Water-Quality Assessment Program (Shelton and Capel, 1994). Sediment samples were sent overnight to the NWQL. The sediment samples were extracted and analyzed for organochlorine compounds (28 compounds), PAH's (79 compounds), and PCB's (total) by gas chromatography (Foreman and others, 1995; Furlong and others, 1996). Sediment samples from two tributary streams and two sites at Lake Tahoe were sent to a contract laboratory for determination of dioxins and furans (25 compounds) using methods described by U.S. Environmental Protection Agency (1986).

Detection of semivolatile compounds in water is problematic because of their low concentrations and transient nature. Semipermeable membrane devices (SPMD's) were used to sample for these compounds in the water column. SPMD's are devices that contain triolein in a low-density polyethylene tube (Huckins and others, 1990). These devices are effective in sequestering dissolved organic compounds from water and are useful in assessing their potential bioavailability (Bevans and others, 1996). For quality-assurance purposes, a blank (SPMD's transported to the sampling sites and opened to the atmosphere at the sites) was collected during each round of SPMD deployment. Compounds are recovered from the SPMD's by dialysis and gel-permeation chromatography and analyzed by gas chromatography-mass spectrometry. Models exist to estimate water concentrations of organic compounds from SPMD concentrations (Huckins and others, 1993; Ellis and others, 1995).

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OCCURRENCE OF MANMADE ORGANIC COMPOUNDS

Water

During the summers of 1997 and 1998, water samples from 13 sites in Lake Tahoe were collected and analyzed for gasoline components (table 1). All summer samples from Lake Tahoe had detectable concentrations of the oxygenate MTBE and most samples had measurable concentrations of BTEX (benzene, toluene, ethylbenzene, and xylene) compounds (table 2). MTBE concentrations ranged from 0.18 to 4.2 micrograms per liter (µg/L), with the highest concentrations found in samples from near Tahoe City (site 4) and in Emerald Bay (site 12). Another gasoline oxygenate, TAME, was found in 19 of 25 samples at concentrations as great as 0.85 µg/L (in Emerald Bay). One other gasoline oxygenate, ethyl *tert*-butyl ether (ETBE), was not detected in any sample at a reporting level of 0.11 µg/L. BTEX compounds were detected in 88 percent of the samples collected from Lake Tahoe. The highest concentrations of BTEX compounds were measured in samples collected from Zephyr Cove (site 10), Emerald Bay (site 12), and near Tahoe City (site 4). The most commonly detected BTEX compound was toluene (found in 84 percent of the samples) with a maximum concentration of 4.4 µg/L found in a sample from Zephyr Cove. Benzene was detected in 68 percent of the samples collected and the maximum concentration (0.61 µg/L) was in a sample from Zephyr Cove. Ethylbenzene was detected in 68 percent of the samples and had a maximum concentration of 1.1 µg/L in a sample from Zephyr Cove. Xylenes were detected in 64 percent (ortho isomer) and 80 percent (meta and para isomers) of the samples collected. The maximum concentration for total xylene was 6.7 µg/L in a sample from Zephyr Cove.

During January 1999, samples were collected from five locations (sites 1, 5, 7, 10, and 13) in Lake Tahoe and analyzed for the same gasoline components discussed above. MTBE, TAME, and most BTEX compounds were not detected in these samples. Toluene and meta-and para-xylene were detected in a sample from Zephyr Cove (site 10) at estimated concentrations of 0.02 and 0.02 µg/L, respectively.

Water samples collected from six tributaries to Lake Tahoe had only a few detections of manmade organic compounds (tables 1 and 3). During spring runoff, benzene was detected in a sample from Incline Creek (site 1s) at an estimated concentration of 0.004 µg/L. Two pesticides were detected in a sample from Blackwood Creek (site 2s)—simazine estimated at 0.0038 µg/L and atrazine estimated at 0.0031 µg/L. One pesticide was detected in a sample from Taylor Creek (site 5s)—DCPA estimated at 0.0012 µg/L. During the fall baseflow period, VOC's were detected at low concentrations in three samples. Toluene was detected at estimated concentrations of 0.01, 0.02, and 0.04 µg/L in the Upper Truckee River (site 6s), Incline Creek (site 1s), and General Creek (site 4s), respectively. MTBE was detected in a sample from Incline Creek at an estimated concentration of 0.06 µg/L. No pesticides were detected in water samples collected from tributary streams during baseflow conditions.

Other Tahoe Basin lakes sampled for gasoline components during this study were Lower Echo (site 18), Fallen Leaf (site 16), Cascade (site 15), Marlette (site 3), and Upper Angora (site 17) Lakes. Of these lakes, Upper Angora and Marlette Lakes have no motorized boating activity, Cascade Lake has limited motorized boating activity, and Lower Echo and Fallen Leaf Lakes have considerable motorized boating activity. Samples from Upper Angora and Marlette Lakes had no detectable concentrations of MTBE, ETBE, TAME, and BTEX compounds,

Table 2. Percent detection and concentration ranges of gasoline components in water samples from Lake Tahoe and other nearby lakes

[Concentrations in micrograms per liter. Abbreviations: E, estimated concentration [1]; MTBE, methyl *tert*-butyl ether; TAME, *tert*-amyl methyl ether]

Compound	Lake Tahoe				Other nearby lakes [2]			
	Percent detection		Concentration range of detection		Percent detection		Concentration range of detection	
	Summer	Winter	Summer	Winter	Motorized boats	No motorized boats	Motorized boats	No motorized boats
Benzene	68	0	E0.02-0.61	--	25	0	0.40	--
Toluene	84	17	E0.02-4.4	E0.02	100	33	E0.02-3.5	E0.01-E0.02
Ethylbenzene	68	0	E0.01-1.1	--	25	0	0.71	--
Ortho-xylene	64	0	E0.03-2.0	--	25	0	1.1	--
Meta- and para-xylenes	80	17	E0.03-4.7	E0.02	75	0	E0.02-1.5	--
MTBE	100	0	0.18-4.2	--	50	0	0.78-7.7	--
TAME	76	0	E0.02-0.85	--	50	0	0.14-2.2	--

[1] When an “E” is reported, the compound has passed all criteria used to identify its presence, and only the concentration is estimated (Connor and others, 1998).

[2] Categories represent motorized boats, all types of motorized boats are allowed on the lakes; and no motorized boats, no motorized boats are allowed on the lakes.

Table 3. Soluble pesticides in water samples and semivolatile organic compounds in semipermeable membrane sampling devices detected in tributaries to Lake Tahoe, Nevada and California

Site (fig. 1)	Compounds detected	
	Soluble pesticides (concentrations in micrograms per liter)	Semivolatile compounds
1s Incline Creek		
Spring Runoff	none detected	cis-and trans-chlordane, chrysene, fluoranthene, hexachlorobenzene, pentachloroanisole, phenanthrene, pyrene
Baseflow	none detected	trans-chlordane, *p,p'*-DDE
2s Blackwood Creek		
Spring runoff	simazine (E0.0038 [1]), atrazine (E0.0031)	none detected
Baseflow	none detected	trans-chlordane, *p,p'*-DDE
3s Glenbrook Creek		
Spring Runoff	none detected	cis- and trans-chlordane, chrysene, fluoranthene, 1-methylpyrene, pyrene
Baseflow	none detected	trans-chlordane
4s General Creek		
Spring runoff	none detected	cis-and trans-chlordane, fluoranthene, 4,5-methylpyrene, pentachoroanisole, phenanthrene
Baseflow	none detected	trans-chlordane
5s Taylor Creek		
Spring Runoff	DCPA (E0.0012)	cis- and trans-chlordane, *p,p'*-DDE, fluoranthene, benzo (g,h,i) perylene
Baseflow	none detected	trans-chlordane, *p,p'*-DDE, pentachloroanisole
6s Upper Truckee River		
Spring runoff	none detected	cis- and trans-chlordane, pentachoroanisole
Baseflow	none detected	cis- and trans-chlordane, *p,p'*-DDE, 1,6-dimethylnaphthalene, naphthalene

[1] When an "E" is reported, the compound has passed all criteria used to identify its presence, and only the concentration is estimated (Connor and others, 1998).

with the exception of an estimated toluene concentration of 0.01 µg/L in a sample from Marlette Lake and an estimated concentration of 0.02 µg/L in a sample from Upper Angora Lake (table 1). An equipment blank from this sample period also contained toluene at an estimated concentration of 0.04 µg/L; thus, these values may be from contamination of the sampler. Lower Echo Lake had the highest measured MTBE and TAME concentrations found during this study. MTBE concentration was 7.7 µg/L and TAME concentration was 2.2 µg/L. BTEX compounds were found at the following concentrations in Lower Echo Lake: benzene, 0.40 µg/L; toluene, 3.5 µg/L; ethylbenzene, 0.71 µg/L; ortho-xylene, 1.1 µg/L; and meta- and para-xylenes, 1.5 µg/L. Fallen Leaf Lake had detectable concentrations of MTBE (0.78 µg/L), TAME (0.14 µg/L), toluene (0.11 µg/L), and meta- and para-xylene (estimated 0.08 µg/L).

Water samples were collected from eight sites in Lake Tahoe and two depths from Upper Angora Lake for soluble pesticide analysis. Soluble pesticides were not detected in any sample from Lake Tahoe or Upper Angora Lake.

Among the most commonly detected classes of semivolatile organic compounds were organochlorines, polycyclic aromatic hydrocarbons (PAH's), and phthalates. Organochlorine compounds were detected in samples from all sites in Lake Tahoe and Upper Angora Lake (table 4). Samples from near Incline Beach (site 1), Chambers Lodge (site 9), near Edgewood Creek (site 11), and Tahoe Keys (site 13) had the greatest number of compounds and the highest combined concentration of organochlorine compounds (fig. 2). Upper Angora Lake (site 17) had the fewest number of organochlorine compounds and was among the lowest combined concentration, as were samples from the TRG buoy (site 5), near Glenbrook (site 7), near Chambers Lodge (site 9), and near Kiva Beach (site 14). Trans- and cis-chlordane and *p,p'*-DDE were detected in all samples from Lake Tahoe. Hexachlorobenzene was detected at four Lake Tahoe sites and had the highest concentration in samples from near Incline Beach and near Edgewood Creek.

PAH's were detected in samples from all locations sampled at Lake Tahoe and Upper Angora Lake (site 17). The number of compounds detected ranged from a low value of 3 (Upper Angora Lake) to an upper value of 23 (near Kiva Beach, site 14). Samples taken near Incline

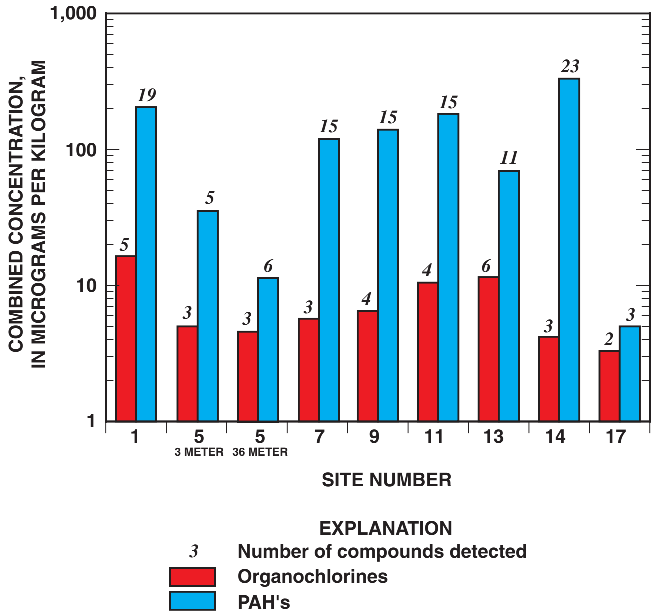

Figure 2. Number and combined concentration of semivolatile organic compounds (organochlorine and polycyclic aromatic hydrocarbon compounds) detected in samples from semipermeable membrane devices placed in Lake Tahoe and Upper Angora Lake, July-August 1998. Sites are shown in figure 1. Site 17 (Upper Angora Lake) is the only lake sampled for semivolatile organic compounds that has no motorized boating activity.

Beach (site 1), near Edgewood Creek (site 11), Glenbrook (site 7), and Chambers Lodge (site 9) had high numbers and large combined concentration of PAH’s (fig. 2). Sample sites with low combined concentrations of PAH’s were Upper Angora Lake and both depths at the TRG buoy (site 5). The most commonly detected compounds were 9H-fluorene, fluoranthene, 1-methylphenanthrene, acridine, and 1-methyl-9H-fluorene.

The number and combined concentration of organochlorine compounds in the tributaries were greatest in Incline Creek (site 1s), General Creek (site 4s), Taylor Creek (site 5s), and Upper Truckee River (site 6s) during spring runoff (fig. 3). The most commonly detected organochlorine compounds were cis- and trans-chlordane, pentachloroanisole, and hexachlorobenzene (table 4). During baseflow conditions, Taylor Creek, Upper Truckee River, and Incline Creek had the greatest number and combined concentration of organochlorine compounds. Trans-chlordane and *p,p*’-DDE were the most commonly detected compounds during baseflow conditions. Concentrations were generally higher during the spring runoff than the baseflow-sampling period (fig. 4). During spring runoff, PAH’s were detected in four of the six tributary streams. Concentrations of PAH’s from Blackwood Creek (site 2s) and Upper Truckee River (site 6s) were below detectable levels. Incline (site 1s) and Glenbrook (site 3s) Creeks had the greatest number and combined concentration of PAH’s during this period (fig. 4). General Creek (site 4s) had the highest combined concentration of PAH’s during the spring runoff period. The most commonly detected PAH’s were phenanthrene, fluoranthene, pyrene, and chrysene. During baseflow conditions, PAH’s were detected in samples from all six tributary streams. The greatest number of compounds and highest combined concentration were found in samples from Upper Truckee River. Taylor, Blackwood, and General Creeks had the lowest number of compounds and combined concentration. Phenanthrene was detected in samples from all tributary streams. Other commonly detected PAH’s were 1-methylphenanthrene, diethylnaphthalene, and pyrene.

Dioxins and furans were analyzed in samples collected from Upper Truckee River (site 6s) and Incline Creek (site 1s) and in Lake Tahoe near Edgewood Creek (site 11) and near Incline Beach (site 1). No dioxins or furans were detected in any of these samples.

Bottom Sediment

Bottom sediment was collected from seven sites at Lake Tahoe, six tributary streams, and one site at Upper Angora Lake during the summer of 1998 (fig. 1). These sediment samples were analyzed for semivolatile compounds (organochlorines, PAH’s, PCBs, and phenol), and for two samples, dioxins and furans. Bottom-sediment samples from Lake Tahoe had few detectable manmade organic compounds. One compound, p-cresol, was found in all Lake Tahoe bottom-sediment samples except from near Incline Beach (site 1). Concentrations of p-cresol ranged from an estimated value of 17 µg/kg near Tahoe City (site 4) to 140 µg/kg near Glenbrook (site 7).

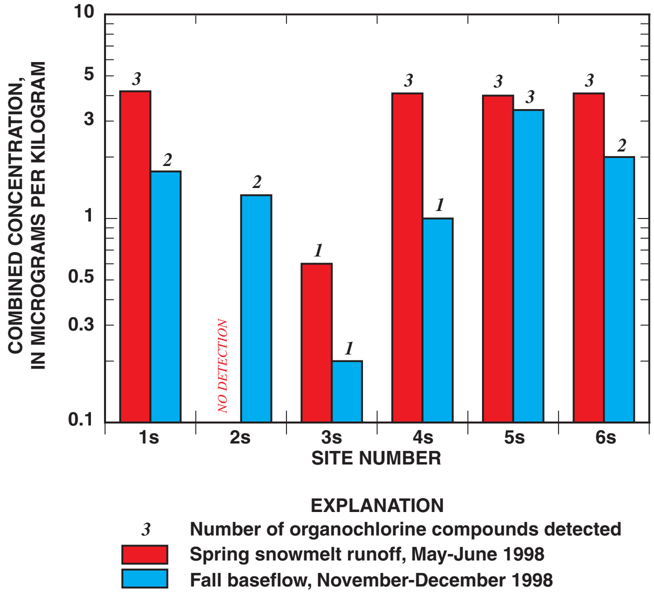

Figure 3. Number and combined concentration of organochlorine compounds detected in semipermeable membrane devices placed in Lake Tahoe Basin streams during spring snowmelt runoff (May-June 1998) and fall baseflow (November-December 1998) periods. Site locations are shown in figure 1.

Table 4. Concentrations of semivolatile organic compounds in Lake Tahoe and Upper Angora Lake. Concentrations were determined on extracts from semipermeable membrane sampling devices. Site numbers correspond to those in figure 1.

[Concentrations in micrograms per kilogram of lipid; all concentrations are estimated. Abbreviations: m, meter; <, less than]

Compound	Site 1 (3 m)	Site 5 (3 m)	Site 5 (36 m)	Site 7 (3 m)	Site 9 (3 m)	Site 11 (3 m)	Site 13 (3 m)	Site 14 (3 m)	Site 17 (3 m)	Blank
Acenaphthalene	6	<100	<100	5	5	<100	5	6	<100	<100
Acenapthene	<100	<100	<100	<100	<100	<100	<100	18	<100	12
Acridine	29	24	<100	24	26	32	24	25	<100	<100
Anthracene	<100	<100	<100	<100	<100	<100	<100	18	<100	<100
Benz(a)anthracene	<100	<100	<100	<100	<100	<100	<100	11	<100	<100
Benzo(b)fluoranthene	28	<100	<100	<100	23	25	<100	24	<100	<100
Benzo(k)fluoranthene	2	<100	<100	<100	<100	.7	<100	2	<100	<100
Benzo(g,h,i)perylene	10	<100	<100	<100	<100	<100	<100	8	<100	<100
9H-Carbazole	<100	<100	<100	<100	16	<100	<100	<100	<100	<100
Chrysene	<100	<100	<100	<100	<100	<100	<100	4	<100	<100
Fluoranthene	41	24	26	27	35	47	24	94	24	23
9H-Fluorene	4	1	1	2	2	3	2	11	1	<100
1-methyl-9H-Fluorene	11	8	<100	8	9	11	9	11	<100	<100
Indeno(1,2,3-cd)pyrene	20	<100	<100	17	17	18	<100	16	<100	<100
Naphthalene	11	4	6	6	6	6	6	11	4	7
1,2-dimethylnaphthalene	5	<100	<100	3	<100	<100	<100	4	<100	<100
1,6-dimethylnaphthalene	14	<100	<100	10	<100	11	10	12	<100	<100
2,6-dimethylnaphthalene	8	<100	<100	6	6	6	5	6	<100	<100
2-ethylnaphthalene	15	<100	<100	12	12	12	11	13	<100	<100
2,3,6-trimethylnaphthalene	4	<100	<100	.2	.8	7	.09	2	<100	<100
Phenanthrene	28	19	27	22	24	20	18	59	21	22
1-methylphenanthrene	27	24	24	24	25	26	24	29	26	23
4,5-methylenephenanthrene	9	<100	<100	2	4	7	3	14	<100	<100
Phenanthridine	<100	<100	<100	22	<100	23	<100	<100	<100	<100
Phenol	13	13	13	14	13	12	13	15	13	13
Pyrene	30	23	24	23	24	24	22	44	23	23
Bis(2-ethylhexyl)phthalate	42	60	51	48	48	43	37	36	48	41
Diethylphthalate	20	22	29	32	33	14	20	23	24	30
Dimethylphthalate	8	<100	<100	<100	<100	<100	<100	<100	<100	7
Di-n-butylphthalate	24	28	29	27	27	25	24	24	24	25
Di-n-octylphthalate	23	24	<100	23	24	23	23	22	24	<100
Hexachlorobenzene	9.5	<5.0	<5.0	<5.0	1	5	1	<5.0	<5.0	<5.0
Cis-chlordane	2	2	1	3	2	2	4	2	2	<5.0
Trans-chlordane	2	2	2	2	2	2	3	2	2	<5.0
p,p'-DDE	1	.9	1	.9	1	.9	1	.8	<5.0	<5.0
Dieldrin	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	1	<5.0	<5.0	<5.0
trans-Nonachlor	1	<5.0	<5.0	<5.0	<5.0	<5.0	1	<5.0	<5.0	<5.0

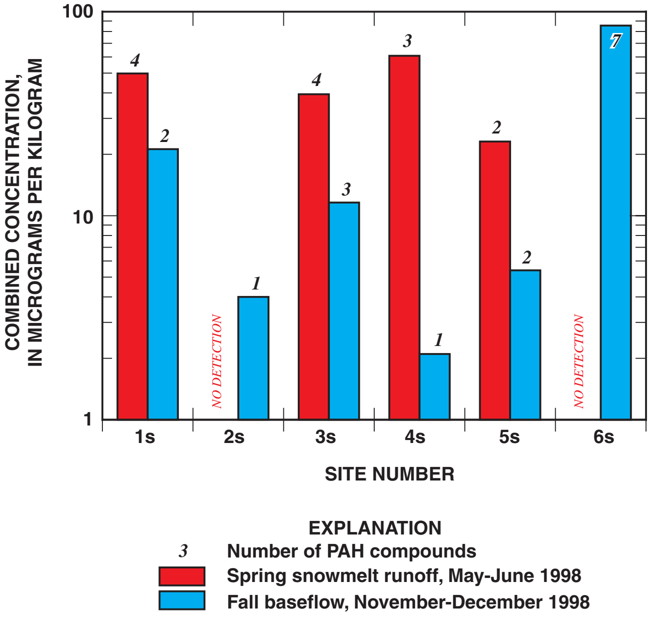

Figure 4. Number and combined concentration of polycyclic aromatic hydrocarbon (PAH) compounds detected in the semipermeable membrane devices placed in Lake Tahoe Basin streams during spring snowmelt runoff (May-June 1998) and fall baseflow (November-December 1998) periods. Site locations are shown in figure 1.

Kiva Beach (site 14) had a concentration of p-cresol (110 µg/kg). Several phthalate esters were detected in these samples and may be the result of contamination during laboratory processing of the samples. Phenol was detected in a sample from near Chambers Lodge (site 9) at an estimated concentration of 4 µg/kg.

A phenol, p-cresol, was detected in bottom sediment from Taylor Creek (site 5s) at an estimated concentration of 22 µg/kg. Several phthalate esters were detected in all samples including the blanks and may be the result of contamination during laboratory preparation of the samples. Three dioxins were detected in a sample from Upper Truckee River (site 6s) at low concentrations. The dioxins found were total heptachlorodibenzo-*p*-dioxin (5.8 ng/kg[1]), 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin (2.5 ng/kg), and octochlorodibenzo-*p*-dioxin (22 ng/kg). A sample from Incline Creek (site 1s) had octochlorodibenzo-*p*-dioxin present at 5.2 ng/kg.

Several compounds were detected in bottom sediment from Upper Angora Lake (site 17) at rather high concentrations. These compounds and their concentrations were *p,p*'-DDD (10 µg/kg), *p,p*'-DDE (7.4 µg/kg), 2,6-dimethylnaphthalene (estimated at 190 µg/kg), pentachlorophenol (3,000 µg/kg), and p-cresol (4,400 µg/kg).

Discussion of Results

Organic compounds detected in water- and bottom-sediment samples collected from Lake Tahoe Basin indicate human activities have introduced potentially harmful compounds into the Basin. Even though the concentrations of these compounds are low, their presence suggests a need to monitor waters within the Lake Tahoe Basin for manmade organic compounds to ensure no further degradation of its waters.

Several lines of evidence suggest that most VOC's detected in water samples from lakes in the Tahoe Basin are the result of motorized watercraft use in the lakes.

- VOC's were found in all water samples collected from lakes where motorized boating occurred (table 2).
- Areas of high boating activity (Emerald Bay, Tahoe City, and Zephyr Cove in Lake Tahoe and Lower Echo Lake) had the highest concentrations of MTBE and BTEX compounds.
- Samples collected during periods of high boating activity (weekends during the summer), as reported by Boughton and Lico (1998), had some of the highest concentrations found in this study.
- Water samples collected at open-water sites, where boating activity is light, had some of the lowest concentrations of MTBE and BTEX found at Lake Tahoe during the boating season.
- Water samples collected during the winter months, when boating activity is low, had no detectable MTBE and minimal BTEX compounds (table 2).
- No MTBE and minimal BTEX compounds were found in lakes (Upper Angora and Marlette Lakes) where motorized watercrafts are prohibited.

The atmosphere, surface drainage of lands, and subsurface drainage within the Lake Tahoe Basin are not the primary source of the high concentrations of VOC's observed in Lake Tahoe during the summer months. Upper Angora and Marlette Lakes did not have any VOC's present at concentrations greater than 0.02 µg/L. This indicates that an atmospheric source for VOC's in the Tahoe Basin is minor, if present at all. Tributary streams sampled during spring runoff and baseflow conditions only had a few detectable concentrations of VOC's, all less than 0.06 µg/L. This indicates that tributary runoff within the basin is not a major source of VOC's. Finally, input of VOC's to Lake Tahoe by subsurface sources appears to be minor, at least in the areas investigated during this study. If a source such as this were present, VOC concentrations would be higher during the winter because the source would not be seasonally dependent.

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[1] ng/kg is an abbreviation for nanograms per kilogram (equivalent to parts per trillion) and is equal to 0.001 µg/kg.

Soluble pesticides were not commonly detected during this study, although, low concentrations were found in two water samples collected from tributary streams during spring runoff (table 3). No lake sample had a detectable concentration of any pesticide.

Organochlorine compounds are synthetic compounds mostly used as insecticides, fungicides, and wood preservatives. Organochlorine compounds were found in all SPMD and most bottom-sediment samples collected during this study. Although present, the concentration of these compounds in the water column is less than one part per trillion (as calculated using the model developed by Huckins and others, 1990). Chlordane (cis- and trans-isomers) and *p,p'*–DDE were found in all SPMD samples collected from Lake Tahoe. Chlordane and *p,p'*-DDT (which degrades into *p,p'*-DDE) were commonly used insecticides prior to the 1960's and 1970's. The use of these specific compounds was discontinued by the mid-1970's due to their effect on the environment, but, due to their persistence, they are still present. In Lake Tahoe, SPMD samples near urbanized parts of the Lake (sites 1, 11, and 13) had the highest concentration and number of organochlorine compounds suggesting their source may be urban areas. Hexachlorobenzene also was detected in four samples with the highest concentrations being in samples offshore from Incline Beach and Edgewood Creek (sites 1 and 11), both offshore from relatively dense urban development. SPMD samples from the open-water site (site 5) and Upper Angora Lake (site 17) had the lowest concentrations of all lake samples. Bottom-sediment samples from Lake Tahoe had few detectable organochlorine compounds with the exception of p-cresol, which was detected at every site, except site 1. A common ingredient in wood-preservative formulations, p-cresol probably is present in many of the treated piers and pilings in Lake Tahoe. Concentrations of organochlorine compounds in SPMD samples from tributary streams were similar to that from the open-water site in Lake Tahoe. Bottom-sediment samples collected from tributary streams had few detectable concentrations of organochlorine compounds indicating they are not a current source for most of the compounds found in Lake Tahoe.

PAH compounds are produced by high-temperature pyrolytic reactions such as in internal combustion engines, forest fires, and municipal incineration. Their occurrence in aquatic systems is reportedly due to anthropogenic sources (Smith and others, 1988). PAH's were detected in all SPMD samples from Lake Tahoe. Concentrations generally were higher in samples from Lake Tahoe than those from tributary streams. Nearshore samples had the largest number of compounds and highest combined concentrations of PAH's. PAH's are most abundant in areas where the amount of motorized boating activity is high (sites 1 and 14). Offshore from Kiva Beach (site 14), a popular water skiing location, the highest combined concentration of PAH's and the most number of compounds were found. Using the model of Huckins and others (1990), the concentration for fluoranthene is approximately 0.3 ng/kg. Samples from open water on Lake Tahoe (site 5), where motorized boating activity is low, had a low number of compounds and combined concentrations of PAH's. At this site (site 5), a sample from a depth of 36 m had lower combined concentration of PAH's than a sample from a depth of 3 m. Temporal variation in PAH concentrations within Lake Tahoe are not presently known. PAH's were not detected in bottom-sediment samples from Lake Tahoe, indicating little to no accumulation of these compounds on the sediment. PAH's were present in most SPMD samples from tributary streams in the Lake Tahoe Basin. Most of the samples had between two and four compounds, two samples had no compounds, and the sample from Upper Truckee River (site 6s) had seven compounds (fig. 4). Most streams, except Upper Truckee River, had higher combined concentrations and number of compounds during the spring runoff period than during the baseflow period. Actual concentrations of PAH's in the water column generally are less than 1 ng/kg (as calculated using the model developed by Huckins and others, 1990). Upper Angora Lake, where no motorized boating occurs, had the fewest number of compounds and lowest combined concentration of PAH's, indicating atmospheric sources are not the major input into Lake Tahoe Basin lakes (fig. 2). Controlled burning of vegetation within the Lake Tahoe Basin may be a potential source of PAH's but appears to be a minor contribution.

Sampling Taylor Creek, Nev., May 1998. Photograph by M.S. Lico, U.S. Geological Survey.

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