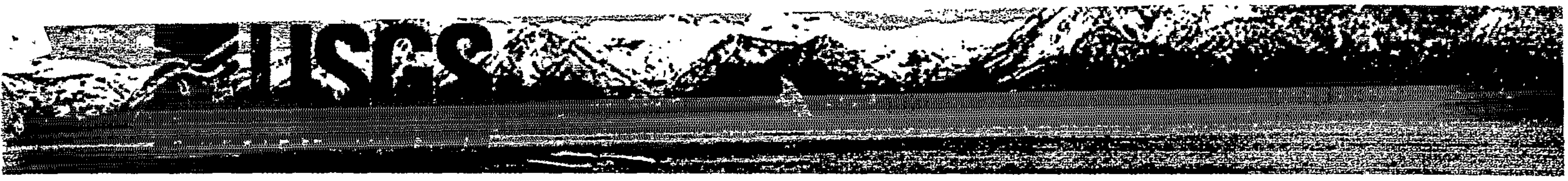

# Concentrations and Distribution of Manmade Organic Compounds in the Lake Tahoe Basin, Nevada and California, 1997-99

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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.

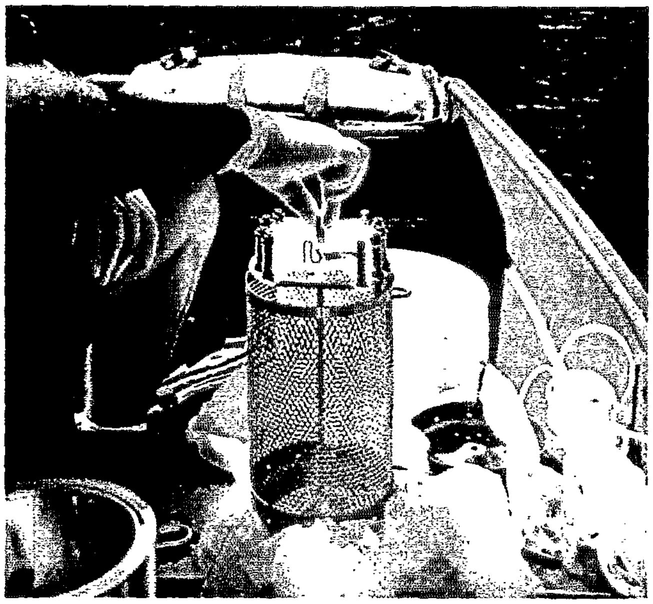
Gasoline components were found in all samples collected from Lake Tahoe during the summer boating season. Methyl *tert*-butyl ether (MTBE), benzene, toluene, ethylbenzene, and xylenes (BTEX) were the commonly detected compounds in these samples. Most samples from tributary streams and lakes with no motorized 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),

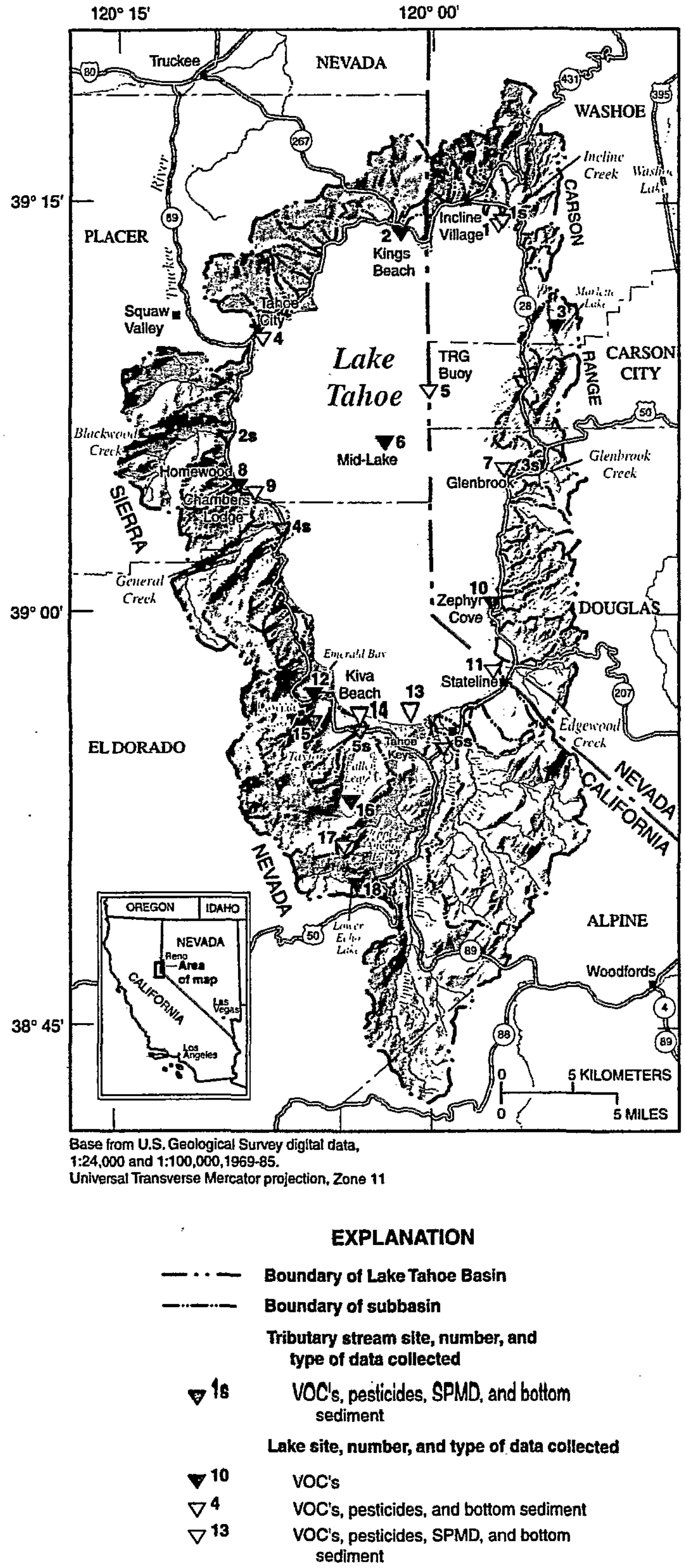


**Figure 1.** Lake and tributary stream sampling sites in Lake Tahoe Basin, Nevada and California.

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] | Ethylbenzene[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).

## Acknowledgments

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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

[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

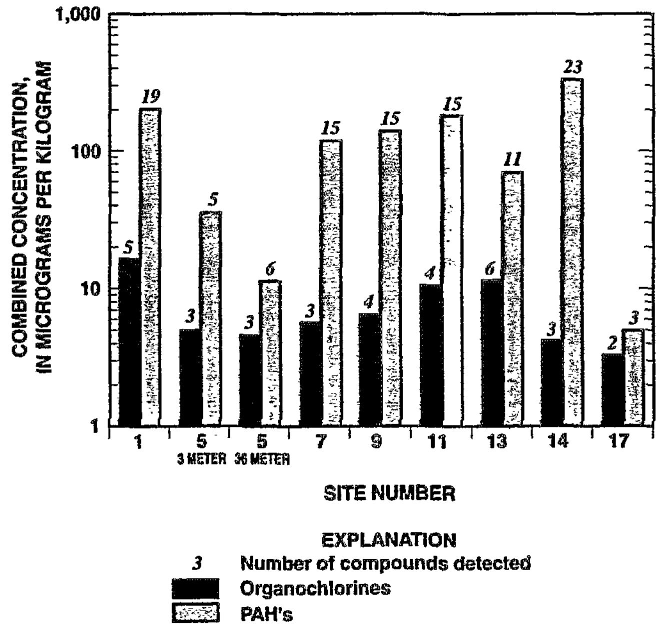

**Figure 2.** Number and combined concentration of semivolatile organic compounds (organochlorine and polycyclic aromatic hydrocarbon compounds) detected in samples from semipermeable membrane devices placed in Lake Tahoe and Upper Angora Lake, July-August 1998. Sites are shown in figure 1. Site 17 (Upper 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).

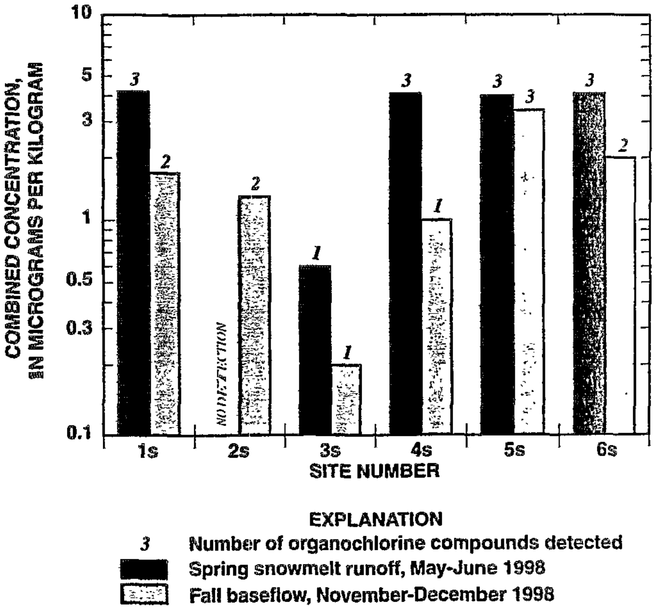

**Figure 3.** Number and combined concentration of organochlorine compounds detected in semipermeable membrane devices placed in Lake Tahoe Basin streams during spring snowmelt runoff (May-June 1998) and fall baseflow (November-December 1998) periods. Site locations are shown in figure 1.

**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 milligrams 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 |

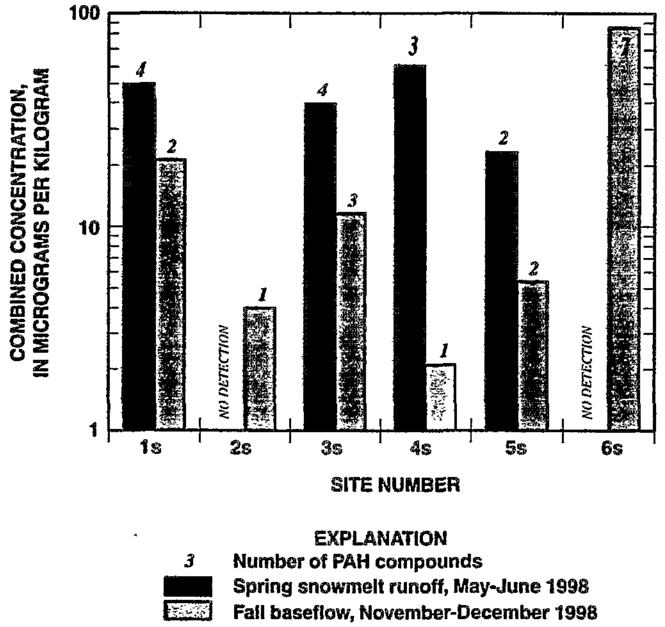

**Figure 4.** Number and combined concentration of polycyclic aromatic hydrocarbon (PAH) compounds detected in the semipermeable membrane devices placed in Lake Tahoe Basin streams during spring snowmelt runoff (May-June 1998) and fall baseflow (November-December 1998) periods. Site locations are shown 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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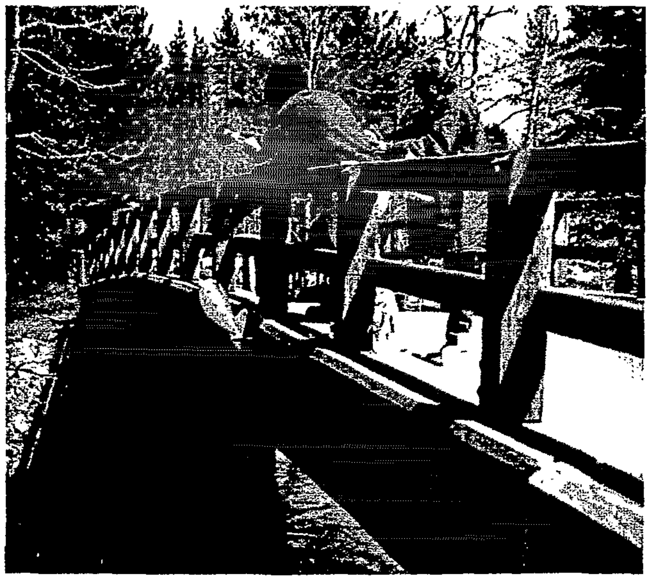
[1] ng/kg is an abbreviation for nanograms per kilogram (equivalent to parts per trillion) and is equal to 0.001 µg/kg.

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

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# LAKE TAHOE NUTRIENT AND SEDIMENT TOTAL MAXIMUM DAILY LOAD

## WINTER 2003-04 NEWSLETTER

Nevada Division of Environmental Protection Lahontan Regional Water Quality Control Board

6-14

This edition highlights two additional research projects contributing to development of the Lake Tahoe Total Maximum Daily Load (TMDL) for sediment and nutrients, which has the objective of restoring the lake's clarity to its exceptional historic levels. The first article below describes a project that is characterizing the impacts of air pollution on lake clarity, the sources of atmospheric pollutants, and whether they originate within or outside the Lake Tahoe Basin. Study coordinators and researchers are introduced briefly in a separate piece following the project description. The second research effort described is called the Near Shore Clarity study. This project examines in detail the clarity of waters along the shoreline of Lake Tahoe and which pollutants are affecting clarity. Both these projects will provide information key to development and implementation of the TMDL.

## LAKE TAHOE ATMOSPHERIC DEPOSITION STUDY

The numerous parties collaborating on the development of the Lake Tahoe TMDL require, to the extent possible, a comprehensive and accurate account of the most significant and controllable sources of pollution that impact lake clarity. Therefore, the researchers must consider a source not normally associated with water quality assessments: direct deposition of pollutants from the air to the lake surface. It has been demonstrated, based on a 20-year period of monitoring in a single watershed within Lake Tahoe Basin, that air deposition could be a major contributor of both fine sediment (or dust) and nutrients (phosphorus and nitrogen) directly to the lake. Air deposition appears to be a major pollutant source because the lake itself occupies such a large surface area (500 km$^2$) relative to its drainage basin (800 km$^2$).

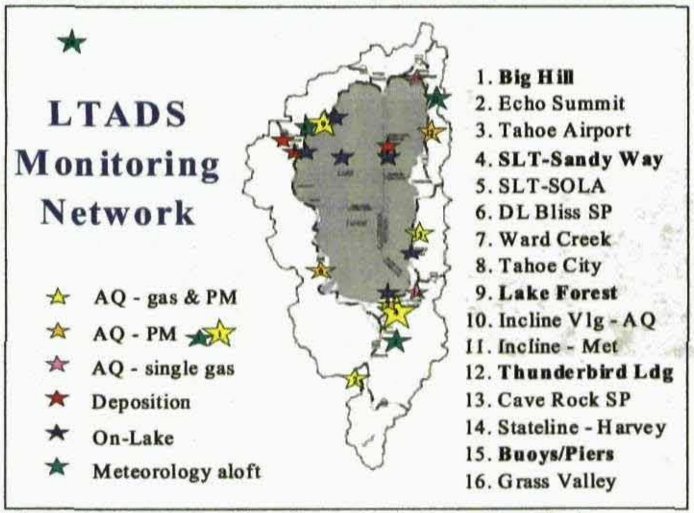

**Figure 1.** The Lake Tahoe Atmospheric Deposition Study monitoring network. Sites in bold have Two-Week Samplers (see Figure 3) or Mini-Volume Samplers that provide critical data for the atmospheric deposition analyses. AQ =Air Quality monitoring station, where gas and/or particulate matter (PM) samples are taken.

To quantify atmospheric loading to the lake, the Lahontan Regional Water Quality Control Board (RWQCB) and the Nevada Division of Environmental Protection (NDEP) are fortunate to benefit from the expertise and resources of the California Air Resources Board (CARB), a highly regarded scientific and regulatory authority with extensive expertise in characterizing and controlling air pollution. CARB is currently completing over a year of intensive monitoring of air pollution and meteorology in and near the Lake Tahoe Basin to provide refined estimates of the inputs of various pollutants that can impact water clarity. During the coming year, CARB staff will continue to validate and analyze the data being collected to provide the most up-to-date assessment of the magnitude and origins of atmospheric deposition to the lake. This information, in combination with our assessment of pollutant loading from the watershed, will be a key input to the Lake Clarity Model (see Spring 2003 edition), which will determine the mix of phosphorus, nitrogen and fine sediment load reductions necessary to achieve the desired lake clarity.

## Prior Research

Based upon air deposition sampling prior to the current monitoring program, air pollutants reaching Lake Tahoe have been estimated to represent nearly one quarter of the Lake's total phosphorus inputs, and over one half its nitrogen load. Monitoring of nutrient deposition on the watershed and the lake by the UC Davis-Tahoe Research Group first identified atmospheric deposition as a potentially major source for both phosphorus and nitrogen (Jassby et al., 1994). Recent work at the Desert Research Institute has further characterized nitrogen deposition (Tarnay et al., 2001). While acknowledging the limited amount of field data, the Lake Tahoe Watershed Assessment (Reuter and Miller, 2000) hypothesized that atmospheric nitrogen is largely associated with automobiles while phosphorus is most likely associated with wood smoke from various sources and with road dust.

## New Research

Thus, air pollution may be considered among the most critical, if also challenging, pollutant sources to characterize and to control. The potential importance of air deposition prompted CARB to design a ~$2 million study of air quality and deposition in the Lake Tahoe Basin, entitled "Lake Tahoe Atmospheric Deposition Study," or LTADS, to contribute to the TMDL research program. This study has the objectives of better characterizing atmospheric deposition of nitrogen, phosphorus, and particulate matter (see Figures 1 & 2), emission sources in the Tahoe Basin, and transport of pollutants from outside the Tahoe Basin.

**Figure 2.** Measurements of particulate matter and meteorology on piers is important for refining deposition estimates to Lake Tahoe. Note the inversion layer in the distance. The complex meteorology of the Tahoe Basin often traps smoke and other pollution in layers above the Lake.

**Figure 3.** The Two Week Sampler (TWS) is the cornerstone of the LTADS monitoring program for nitrogen and phosphorus compounds that deposit to the Lake and contribute to algal growth. TWS measurements represent ambient conditions during every minute of the more than 1-year field study portion of LTADS.

Specifically the study approach includes:

- Enhancing the ambient monitoring network (air quality and meteorology) to better characterize the spatial variations in conditions (see Figure 1 for map of monitoring network);
- Conducting a year-long enhanced monitoring program to capture temporal variations in deposition and to quantify total annual air pollutant loadings to the Lake (see Figure 3);
- Conducting special short-term field experiments to better characterize atmospheric processes such as transport of pollutants from the shoreline to mid-lake locations;
- Characterizing pollutant emission sources (e.g., analyzing their chemical composition and the extent and nature of the activities that produce them) in order to determine the relative contributions from various potential stationary and mobile sources such as wood burning, vehicle exhaust, and road dust; and
- Analyzing the data obtained during the field study to estimate ranges of atmospheric deposition and the associated uncertainties.

**Figure 4.** Data from six monitoring sites in the Sierra Nevada and southern Cascade mountain chain are being used to evaluate the relative importance of particulate air pollution transport into Lake Tahoe Basin versus what is locally-generated. (CRLA: Crater Lake; LAVO: Lassen Volcanic National Park; BLIS: D. L. Bliss State Park; SOLA: South Lake Tahoe; YOSE: Yosemite National Park; SEQU: Sequoia National Park.)

Using inferential models adapted to extrapolate measurements into basin-wide deposition calculations, short-term (daily, weekly, seasonal) LTADS observations will be used in concert with other existing information to refine historical estimates of atmospheric deposition to the lake. Together with existing data and published reports, this study will also include an evaluation of the impacts of in-basin versus out-of-basin emission sources.

CARB is finalizing an Interim Report, which will be viewable by clicking on the Lake Tahoe link at http://www.arb.ca.gov/research/ecosys/ecosys.htm (currently, the website contains slides summarizing the report and monitoring results to date). The report describes the field research program currently underway and analysis of existing data, both from within Lake Tahoe Basin and from a series of comparable monitoring stations located throughout the

Sierra Nevada and southern Cascade mountain ranges (see Figure 4). CARB will use data from these stations to estimate the role of long range transport of aerosols (or air-borne particles) on particulate matter concentrations. Lastly, the report explains how the deposition of nitrogen, phosphorus and particulate matter on the lake will be estimated, taking into account spatial and temporal dynamics of pollutant transport to and within the basin. For additional information, please contact Leon Dolislager of CARB at ldolisla@arb.ca.gov.

## AIR DEPOSITION RESEARCH TEAM

The Lake Tahoe Atmospheric Deposition Study is spearheaded by the Atmospheric Processes Research Section of the California Air Resources Board (see Figure 5 below) and includes a supporting cast of over 50 employees, collaborators, and contractors, providing thousands of hours of dedicated efforts and hundreds of thousands of dollars in funding. Besides CARB, funding sources include the U.S. Environmental Protection Agency, the Tahoe Regional Planning Agency (TRPA), NDEP, and Lahontan RWQCB. Peer review of the LTADS workplan, reports, and other work products are provided by the University of California. LTADS contractors and associates making field measurements include CARB's Monitoring & Laboratory Division, UC Berkeley, UC Davis, UC Riverside, Desert Research Institute, Tahoe Research Group, TRPA, Lahontan RWQCB, and the National Oceanic and Atmospheric Administration.

**Figure 5.** LTADS staff from CARB's Atmospheric Processes Research Section include, from left to right: Dongmin Luo, Leon Dolislager, Ash Lashgari, Eileen McCauley, Tony VanCuren, William Vance, and Jim Pedersen.

The Atmospheric Processes Research Section, headed by Eileen McCauley, includes Tony VanCuren, William Vance, Jim Pederson, Dongmin Luo, Ash Lashgari, and Leon Dolislager. All members of the section have doctoral degrees except Mr. Pederson and Mr. Dolislager, who have master's degrees. McCauley, Luo, and Vance have chemistry degrees; Pederson, and Dolislager have meteorology degrees; VanCuren has geography degrees, and Lashgari has engineering and environmental degrees. In addition, Dr. Lashgari recently earned his law degree. The section has been greatly aided by the office and field assistance of students Sarah Connelly and Charles Cozad.

# WATER QUALITY NEAR THE SHORE OF LAKE TAHOE

Lake Tahoe may be considered to consist of two regions, the deep middle portion of the lake and the shallow areas near the shore. The near shore zones of Lake Tahoe are the areas less than 30 meters deep or within 100 meters of shore, whichever extends further from shore. Although most of our current research and modeling are focused on the mid-lake region, the Lake Tahoe TMDL will address all areas of the lake, including the near-shore areas most visible to residents and visitors. Consequently, Lahontan RWQCB, NDEP, and the Tahoe Regional Planning Agency (TRPA) funded a TMDL research project by the Desert Research Institute (DRI) to assess variations in near-shore clarity and to determine the constituents that reduce clarity.

**Fig. 6** The Desert Research Institute used a boat to measure the water quality near the shore of Lake Tahoe. The boat and water quality instruments inside can operate in poor and cold weather. The boat can also operate in very shallow water because it is equipped with a jet drive instead of a propeller. A probe on the bow was used to collect water samples while the boat was moving.

Management actions will influence the near-shore zone years before their effect may be detected in the middle of the lake because water quality near the shore responds faster to on-shore activities and to land use changes than does the middle of the lake. Furthermore, near-shore water quality along any particular section of the lakeshore is most significantly influenced activities in close proximity to the affected area of the lake. By mapping the water quality near the shore it is possible to identify neighborhood sized areas that are contributing undesirable material to the lake. Near-shore water quality may therefore be considered a short-term, immediate indicator of both the effectiveness of on-shore pollution control activities and expected future deep lake quality. This characteristic could be used to track our progress toward restoring clarity during TMDL implementation.

Mid-lake clarity is measured with a Secchi disk, but this method cannot be used close to shore because the water is usually not deep enough for the disk to fade from view before it rests on the bottom. Instead, the clarity of the near-shore zone is commonly described in terms of the turbidity of the water, which is a measure of how the water scatters light. High turbidity water is murky and scatters light more than low turbidity water, which is clear.

To study the near shore zone the DRI outfitted a boat for year round research (see Figures 6 and 7). A water-sampling probe was mounted on the bow to collect water from a foot below the surface. The water was pumped through instruments on the boat that measured the concentration of turbidity and chlorophyll (which indicates the presence of organic matter such as algae) and the temperature of the water. Measurements were

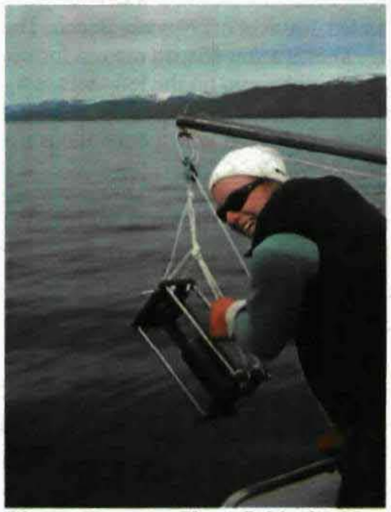

**Fig. 7** Margaret Shanafield of DRI prepares an instrument used to measure how the turbidity of the water changes with depth.

made every 20 feet while the boat was moving at speeds of up to 15 miles an hour. The boat operators were guided by a computer display that showed the measurement results and location of the boat. This made it possible to quickly measure near shore turbidity. Between July 2002 and July 2003 turbidity and chlorophyll surveys were conducted every few weeks along the south shore of the lake. Water samples were also collected to determine if the particles in the water were minerals or organic material (i.e. fine sediments or algae, see Figure 8). These surveys showed which near shore areas had the greatest turbidity and if the elevated turbidity was caused by mineral or organic material. High levels of organic material are likely caused by excessive nutrient inputs to that part of the lake.

Several surveys were done around the entire perimeter of the lake to identify sections of the shore that persistently have high turbidity. The south shore has the highest turbidity water. To a much lesser extent, there is occasionally elevated turbidity in waters near Lake Forest, Kings Beach, and Tahoe Vista. The waters near the shore of Bliss State Park and the undeveloped portions the east shore have turbidity as low as the middle of the lake.

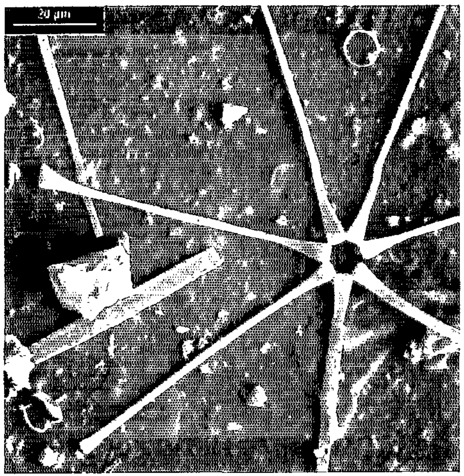

**Fig. 8** A scanning electron microscope image of the particles in a water sample collected 100 feet off Nevada Beach. The image shows a star shaped diatom formed by a type of algae, and on the left there is a block like mineral grain. The background of the filter is covered with a continuous mat of algae.

The near shore surveys showed (see Figure 9) that the Upper Truckee River, which enters the lake at its southernmost point, is the largest cause of increased turbidity in the near shore zone. Nearby Bijou Creek was also a major problem area. Smaller but still significant problem areas were the Ski Run Marina and Al Tahoe areas. This increased turbidity was always caused by mineral particles. It is tempting to attribute the high turbidity water quality to the shallow water in these areas. Close examination of the water depth and results of the water quality surveys showed other shallow areas did not have high turbidity, so the near shore turbidity in these areas was not a natural occurrence.

The near shore water quality was good during very cold or dry periods when there was only a small amount of water flowing in the streams and storm drains. The near shore waters became more turbid when storms or spring runoff filled the streams and storm drains with moving water. With the exception of the west side of Al Tahoe neighborhood, all the near shore areas with high turbidity had an obvious cause such as a stream or storm drain. The higher turbidity area off western Al Tahoe may have been caused by outflow from the Upper Truckee River that moved along the shore in water that was too shallow to survey.

A report on this project will be available on line at http://tahoenearshore.dri.edu in March 2004. The project is led by Ken Taylor, with Rick Susfalk and Margaret Shanafield (all with DRI) assisting with data collection and analysis. Geoff Schladow with the University of California at Davis also provided analytical support. Funding for this project comes from the Lahontan RWQCB, the Nevada Department of State Lands (using funds from the sale of vehicle license plates with a Lake Tahoe motif), TRPA, and DRI. Tahoe Keys Marina and Sand Harbor State Park provided logistical support.

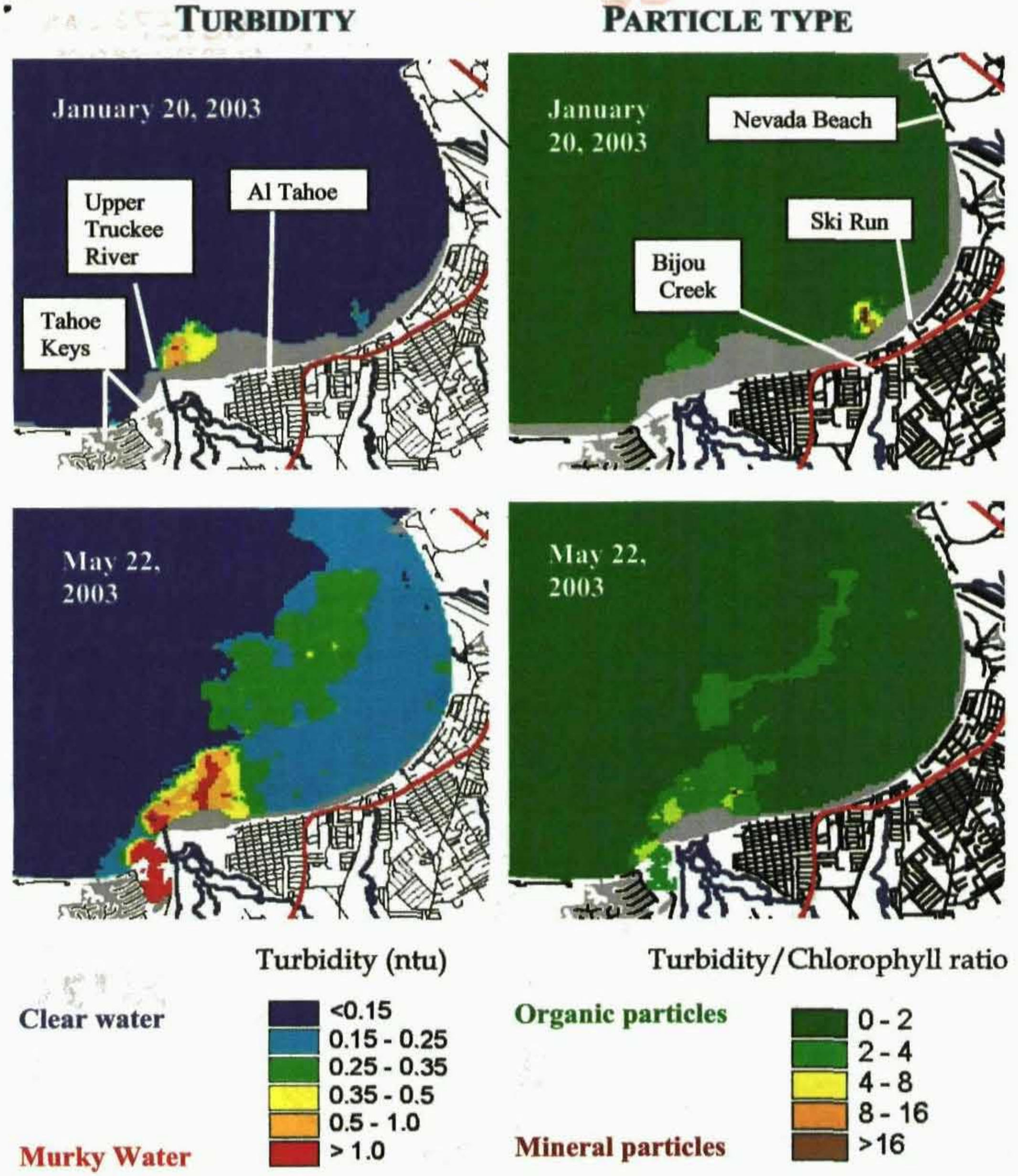

**Fig. 9** The examples above show survey results from January 20, 2003 (top) and May 22, 2003 (bottom). Overall, 23 surveys of the south shore were done between July 2002 and August 2003. The colors in the left figures show the turbidity of the water. Red areas were murky and had high turbidity, blue areas were clear and had low turbidity. Areas with other colors had intermediate values. The colors in the right figures show what type of particles were in the water. Brown, orange and yellow areas had mostly mineral particles, green areas had mostly organic particles. The particle type was determined by using a scanning electron microscope and measurements of chlorophyll and turbidity. In January the near shore zone had mostly clear water except at the outlet of the Upper Truckee River and Bijou Creek. In May during the spring run off murky water from the Upper Truckee was spread by currents along the whole southeast shore.

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Recycle

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**Lahontan RWQCB Website**
www.swrcb.ca.gov/rwqcb6/

**Nevada Division of Environmental Protection Website**
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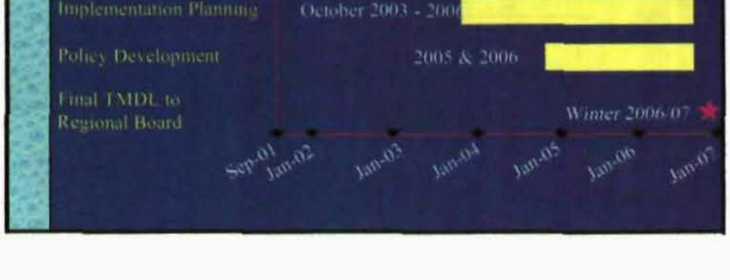
Lake Tahoe TMDL Timeline

6-13

**Judith Unsicker**
**<JUnsicker@rb6s.swrcb.ca.gov>**
02/09/2004 03:00 PM

To: RobertK Hall/R9/USEPA/US@EPA
cc:
Subject: Fwd: Re: USEPA Visit to Collect Information/Data for 2004 Section 303(d) List Update

Attached is a message that I received Friday from the head of our Truckee River Watershed Unit indicating that the TTSA discharger monitoring data are available electronically.

Judith Unsicker
Staff Environmental Scientist
Lahontan RWQCB
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South Lake Tahoe CA 96150
Phone: (530) 542-5462
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Email: JUnsicker@rbs.swrcb.ca.gov

----- Message from "Scott Ferguson" <SFerguson@rb6s.swrcb.ca.gov> on Fri, 06 Feb 2004 08:45:20 -0800 -----

**To:** "Judith Unsicker" <JUnsicker@rb6s.swrcb.ca.gov>
**Subject:** Re: USEPA Visit to Collect Information/Data for 2004 Section 303(d) List Update

Judith,

Sorry for the late response, but your contact should contact TTSA for an electronic copy of its monthly and sometimes twice per month monitoring of the Truckee River and Martis Creek that has been occurring since approximatley 1980. TTSA samples the Truckee River in 3 locations and Martis Creek in 2 locations below Martis Creek Reservoir.

Scott C. Ferguson, Chief
Truckee River Watershed Unit
Lahontan Regional Water Quality Control Board
530-542-5432
Sferguson@rb6s.swrcb.ca.gov

>>> Judith Unsicker 01/30/04 09:22AM >>>
There will be a 2004 list update, although the State Board has not yet set a definite schedule, and it's not clear what assessment criteria will be used. EPA Region IX has committed staff and consultant (TetraTech) time to collect data from the Regional Boards and create an electronic database for use in the update.

Bob Hall of EPA will be visiting our SLT offices on the afternoon of Wednesday Feb. 4 (and possibly on Feb. 5) to copy relevant data and information (e.g., discharger monitoring data) from our files. He is also interested in other recent reports and datasets that may not be in the files or library, including electronic datasets. Chuck Curtis and I talked with him in December and gave him a list of datasets that might be "out there," and provided him with copies of several technical reports related to TMDLs. Later, I emailed Mr. Hall a number of links to sources of online data. I also gave him phone numbers for Dale Payne, Bruce Warden, Dave Roberts, Jill Wilson, and Martin Goldberg as people who might have, or be knowledgeable about additional datasets or reports. Bob Hall may want to talk to some of you if you're in one of the SLT offices when he comes next week, or he may call you later if you're not available then. (Mr. Hall is not currently planning to visit the

Victorville office, but Chuck gave him Cindi Mitton's name/phone number as a South Lahontan contact person.)

If anyone on SLT tech staff is aware of datasets or technical reports with data on Lahontan Region surface waters that should be considered as part of the 2004 list update, please let me know by Wednesday morning, February 4. To ease the burden on our copiers on February 4-5, I would welcome paper or electronic copies provided in advance.

Thanks! Please contact me if you have any questions.