Water Resources Center, Desert Research Institute

Annual Technical Report

FY 2000

Introduction

None

Research Program

Basic Information

Title:	Lake Mead Indocrine Disruption in Wildlife Study
Project Number:	N-01
Start Date:	5/11/1999
End Date:	5/10/2000
Research Category:	Biological Sciences
Focus Category:	Water Quality, Toxic Substances, None
Descriptors:	Bioindicators, fisheries, impoundments, lakes, pollutants
Lead Institute:	University of Nevada, Las Vegas
Principal Investigators:	James E. Pollard

Publication

1. Pollard, James and Valerie Sheppe, 2000, Final Fish Scale Report - USGS Lake Mead Endocrine Disruption Study, Harry Reid Center for Environmental Studies, University of Nevada-Las Vegas, Report No. HRC-F-1-12-1.
2. Sheppe, Valerie and James Pollard, 2000, A Retrospective Analysis of Water Quality Studies on Lake Mead, Nevada, Harry Reid Center for Environmental Studies, University of Nevada-Las Vegas, Report No. HRC-F-1-12-2.

Problem and Research Objectives:

1. **Observation and documentation of the age classes of fish collections from two sites on Lake Mead**. In order to compare fish collections from different areas of the lake it is desirable to have comparable age and sex ratios in the collections This portion of the study was designed to define the approximate age class of all carp collected in the study from the two study sites on Lake Mead.

2. **A retrospective analysis of contaminant literature from Lake Mead and surrounding areas.** To assist the principal investigators in interpretation of results from the various endocrine disruption techniques investigated in the study, a review of pertinent literature was requested. The objective of this task was to produce an extensive annotated bibliography of fisheries literature with a focus on contaminants research. Short summaries of the more relevant literature were to be produced.

Methodologies:

1. Well documented methods of fish scale analysis were used for this task. Due to the difficulty of applying these methods to Lake Mead carp, readings were made of each fish scale by two experienced fisheries biologists. Quality assurance of the techniques were documented for the reliability of each investigator as well as third party checks of the method.

2. Library searchers and electronic data base investigations were employed to accomplish this task.

Principal Findings and Significance:

1. The collections of carp from different study areas were shown to be of comparable average age classes except during the September collection period. This result tended to validate the appropriateness of collections for analysis of endocrine disruptive effects in the subpopulations of carp collected from the lake. However, the results from September, as well as the difficulties encountered using the annular ring counting technique for aging carp from Lake Mead, rendered these conclusions tentative. Many of the annular ring patters observed on the carp scales were ambiguous and did not track well with the size of the fish as was expected. Unusual growth patterns based on year round food availability and spatially unpredictable food availability is theorized to account for these results.

2. There is a paucity of contaminant related literature for Lake Mead and surrounding areas. There is, however, a large body of water quality and fisheries related literature which is readily available to the researchers. A large annotated bibliography is provided with short summaries of selected literature.

Basic Information

Title:	A Multi-Level Approach to Modeling Ground- and Surface Water Exchange in Agriculturally-Dominated Settings
Project Number:	G-03
Start Date:	9/1/1998
End Date:	8/31/2001
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Geomorphological Processes, Groundwater
Descriptors:	surface-groundwater relationships, subsurface drainage, water quality modeling, irrigation, algae
Lead Institute:	Water Resources Center, Desert Research Institute
Principal Investigators:	Wallace Alan McKay

Publication

Statement of Problem and Research Objectives:

Flood irrigation of field crops is believed to be linked to non-point source groundwater solute returns in the lower Truckee River Basin. The objectives of the research are to characterize the source of solutes to the lower Truckee River, and determine the potential benefits in converting land and water use from agriculture to urban and municipal uses. Additional objectives include characterizing the impacts of groundwater nutrient inputs on attached benthic algal communities in the river.

Methodology:

Field studies, including drilling and coring activities, are being integrated with numerical groundwater flow and transport and surface water quality models.

Principal findings and significance (progress report):

To-date, approximately 40 shallow and deep wells have been installed in the study area. These wells are providing valuable information on the nature and distribution of subsurface salts and nutrients in the study area. Additionally, the wells are serving as monitoring wells for hydrologic and geochemical data collection. A computer geologic model of the study area has been completed. The numerical groundwater flow model has been developed; to-date, flow model boundaries and hydraulic parameters have been assigned. The model has been calibrated to transient conditions. Both the transport and mixing cell models are complete as well, and we are currently comparing results through multiple model runs.

Bench-scale experiments addressing periphyton growth under varying groundwater fluxes are complete. The metabolism chambers appear to be working well, have been installed in the field, and experiments are underway. Biomass monitoring has been ongoing for the past year, and results suggest subsurface nutrient inputs at several reaches throughout the lower river basin; i.e., we are seeing biomass increases in areas of no apparent surface nutrient inputs.

Basic Information

Title:	Development of a Prototype System Dynamics Based Decision Support System to Aid in Integrated Watershed Planning for the Lake Tahoe Watershed
Project Number:	B-03
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Management and Planning, None, None
Descriptors:	Decision models, Planning, Systems Engineering, Model Studies, Ecosystems
Lead Institute:	Water Resources Center, Desert Research Institute
Principal Investigators:	John C. Tracy

Publication

1. Tracy, J. C., Bernknopf, R.A., Forney, W. and Hill, K., 2000, "A Prototype for Understanding the Efffects of TMDL standards; Tying Property Values to Sediment Loads in the Lake Tahoe Basin," to be published in the Proceedings of the Conference on Watershed Management and Operations Management 2000, June 21-24, 2000, Ft. Collins, CO.

Problem and Research Objectives:

During the last half of the twentieth century the management of the United State's western watersheds has become an increasingly complex task. Initially, the development and operation of the watersheds were dictated by each basin's hydrologic characteristics and the economic benefits produced through hydropower generation, enhanced water availability and flood protection. Thus, the primary method of managing western watersheds was through the development of operating criteria that were based on maximizing the short term economic benefits of water operations within the basin. However, in more recent times, the long term economic and environmental consequences of operating watersheds in this fashion have come to light. Altered stream flows have had significant impacts on the morphology of stream beds, resulting in alterations in channel shapes and the sediment loads entering lakes and reservoirs. These changes have lead to modifications in the ecology of many western watersheds. This in turn has resulted in intangible economic losses, such as endangering the sustainability of some plant and animal species; to more tangible economic losses, such as the degradation of lake clarity or increase in fire risk within the Lake Tahoe Watershed. These effects have demonstrated that the operation of controlled watersheds is an extremely complex issue, and that more advanced modeling and analysis tools are required by personnel charged with the planning and management of water resources within these watersheds.

It is the purpose of this project to aid in the development of a land use Decision Support System for the Tahoe Regional Planning Agency in conjunction with Dr. R. Bernknopf of the USGS Mapping Division in Menlo Park, CA. Dr. Bernknopf has previously developed an economic decision making model for aiding in land development planning in the Upper Truckee watershed in the Lake Tahoe basin. This model links the environmental attributes of the watershed to individual parcel property values. The objective the model is to maximize the property values of parcels within the watershed subject to meeting water quality standards associated with the designated beneficial uses of water bodies within the watershed. Since this project proposes to develop a prototype decision support system, only the total suspended sediment water quality standard was chosen for use as a constraint in the land use decision making model. Total suspended sediment is a good indicator of the condition of many of the other water quality parameters in the Upper Truckee River, and a relatively good record of total suspended sediment data exists near the outlet of the Upper Truckee River. Thus, the objective of this project is develop a model that describes the effect that land use changes have on total suspended sediment loads within the Upper Truckee River. The model formulation must be able to be linked to attributes of individual parcels within the watershed that relate to the parcel's valuation. In this fashion, an explicit link between the value of a parcel (either developed or preserved) and the environmental consequences of developing that parcel is created. This in turn allows for watershed scale land planning decisions that can be made with an understanding of the tradeoffs that exist between environmental and economic concerns.

Methodology:

In the first phase of this project, completed last year, the modeling approach that was used to develop a model that simulates the yearly sediment load in the Upper Truckee River related the runoff and sediment yield from each parcel in the watershed to the natural and land development

characteristics of the parcel. In this fashion, the land development system that is in place within the Lake Tahoe basin, referred to as the IPES program, can be directly related to one of the environmental characteristics used to assess the health of the basin, this being the yearly sediment load to Lake Tahoe from the Upper Truckee Watershed. Following this approach, the spatial distribution of sediment yield for each water year was computed on a parcel-by-parcel basis.

For decision making purposes, a more useful description of the erosion within the watershed and the resulting yearly sediment loads entering Lake Tahoe would be as a stochastic process, instead of the deterministic process that was previously developed. To achieve this goal, the previously developed model will be run using Monte-Carlo simulations in which the yearly precipitation and land form characteristics of the parcels are considered stochastic model parameters. The existing yearly precipitation totals at the reference SNOTEL Gage (Heavenly Valley Gage) and the land form parameters will be analyzed using parametric and non-parametric procedures to estimate their respective statistical distributions and parconsidered stochastic model parameters. The existing yearly precipitation totals at the reference SNOTEL Gage (Heavenly Valley Gage) and the landform parameters will be analyzed using parametric and non-parametric procedures to estimate their respective statistical distributions and parconsidered stochastic model parameters. The existing yearly precipitation totals at the reference SNOTEL Gage (Heavenly Valley Gage) and the landform parameters will be analyzed using parametric and non-parametric procedures to estimate their respective statistical distributions and parameters. The resulting stochastic description of these model parameters will then be used in the previously developed yearly sediment load model. For each model simulation a random realization of the yearly precipitation and each set of landform parameters will be produced using a random number generator. Approximately 10,000 simulations will be performed using independently generated sets of parameter realizations. The resulting yearly sediment loads will then be used to determine to estimate the first two moments that describe the statistical distribution of the predicted sediment load for the Upper Truckee River. In addition to the Monte-Carlo simulations, First Order Second Moment (FOSM) simulations will also be employed to predict the first and second moments of the statistical distribution describing the sediment load. This FOSM approximation will then be compared to the Monte-Carlo simulations to determine if this highly efficient computational procedure can provide adequate descriptions of the sediment load's statistical distribution.

The resulting model description will thus be presented as a probability of exceeded a predefined sediment load in the stream. This in turn will allow planners to view the risk posed to the environment by various development strategies within the watershed to Lake Tahoe's ecosystem through increased sediment loads.

Principal Findings and Significance:

The statistical distribution of the total yearly precipitation recorded at the Heavenly SNOTEL Gage (reference gage) was analyzed for the available 18 years of record. Although this is a relatively limited data set for analysis, the yearly precipitation totals appear to follow a log-normal type distribution. Thus, the yearly precipitation totals were described using estimates of the first two moments of the natural log of the total yearly precipitation. There were found to be two significant landform parameters that had a relatively high degree of variability, these being the erodability factor

and the curve number parameters. Both parameters are significantly correlated with the soil type and vegetative cover at the parcel scale. However, field data collected at over 1,000 parcels within the Upper Truckee Watershed demonstrated that these parameters were not perfectly correlated with soil type and cover. There were approximately 50 different soil classifications and three states of vegetative cover noted in the study area. It was determined that the variability of the landform parameters could be best described using non-parametric statistical methods. Each of the landform parameters were divided into bins of equal size, and the probability of the erodability factor or curve number falling in a given bin for a specified soil type and vegetative cover condition was calculated using the available field data.

Subsequent simulations using Monte-Carlo and First Order Second Moment (FOSM) procedures demonstrated that for this analysis the FOSM procedure proved to provide similar results to the Monte-Carlo method and can be used describe the uncertainty of predictions in the sediment loads in the Upper Truckee watershed.

The stochastic suspended sediment loading model is currently being integrated with the property value models in the land use decision model developed by Dr. R. Bernknopf at the USGS in Menlo Park. A prototype of the stochastic land use decision model is nearly complete and will be presented to the Tahoe Regional Planning Agency in the near future. The significance of this prototype is that it will allow for an explicit evaluation of the tradeoffs that exist between increased environmental standards and the impacts these new standards will have on economic conditions within the watershed. Once this prototype has been fully developed it is anticipated that additional economic and environmental parameters will be included in the land use decision model to provide a more comprehensive assessment of the impacts of land use plans within a watershed.

References

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Tracy, J. C. 2000. A Statistical Evaluation of the Effectiveness of the IPES Program in Relation to Suspended Sediment Loads in Lake Tahoe's Tributaries, Draft Report submitted to TRPA, 31 pps., in review.

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Basic Information

Title:	Estimation of Groundwater Recharge Using Environmental Tracers and Comparison of Results to Other Estimation Methodologies
Project Number:	B-01
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Water Quantity, None
Descriptors:	Groundwater Recharge, Arid Climates, Springs
Lead Institute:	Water Resources Center, Desert Research Institute
Principal Investigators:	Steve A Mizell, Chuck E. Russell

Publication

Problem and Research Objectives:

Nevada and other areas of the desert southwest United States rely heavily on groundwater resources for municipal, domestic, and industrial needs. An accurate estimate of the available resource is essential to planning community growth and development. In Nevada, a state-wide reconnaissance assessment of water resources was undertaken during the 1960's and early 1970's (Shamberger, 1962 and 1991). Results continue to provide the basic information for planning and development decisions faced by resource managers. New assessment tools have often indicated that significantly more water is available in central Nevada (Nichols, 1994) and in southern Nevada (Russell and Minor, 1998) than previously believed. It is essential to develop more accurate estimates of groundwater recharge in order to make appropriate planning and development decisions.

Specific objectives of this research include:

1. Estimation of groundwater recharge in Steptoe Valley, eastern Nevada, using environmental tracer enrichment methodologies.

2. Comparison of reconnaissance level estimates of recharge completed in 1967 (Eakin and others, 1967), discharge-based estimates recently prepared by the USGS (D. Maurer, personal communication, 1998), and estimates made using environmental tracer enrichment methodologies.

3. Validation of the environmental tracer enrichment methodology in additional areas of Nevada.

Methodology:

The concentration of chloride in spring discharge is used as an environmental tracer to estimate groundwater recharge in Steptoe Valley, eastern Nevada. Steptoe Valley is chosen for the study because: 1) there appears to be little underflow entering or leaving the valley; 2) a large number of springs, exhibiting a wide range of elevation, location and catchment size, are available for sampling; 3) the USGS has recently used the discharge-based method to estimated recharge in the valley.

The vertical and horizontal distribution of chloride in soil in arid and semi-arid areas has been shown to be related to the amount of local precipitation and recharge (Eriksson, 1969; Fouty, 1989; Lyles and Tyler, in preparation). In addition, Claassen and others (1986) have quantified recharge by comparison of the relative mass of chloride in spring water and precipitation. Recently, the chloride tracer method for estimating groundwater recharge has been applied at the Nevada Test Site in southern Nevada. In this application, an elevation-dependent mass balance analysis based on spring data was utilized to estimate recharge (Russell and Minor, 1998).

This investigation employs an aquifer-response method for estimating groundwater recharge in which the chloride concentration in the groundwater is compared to chloride inputs in the recharge area to develop a chloride-enrichment factor. The chloride-enrichment factor indicates the relative portion of precipitation which eventually becomes groundwater recharge. Recharge to a groundwater basin is determined by sub-dividing the recharge area into elevation zones for which the precipitation and chloride-enrichment factor are determined. Multiplying these two parameters and the elevation zone area, then summing over the elevation zones, provides an estimate of recharge to the groundwater basin.

Chloride enrichment is a function of the evapotranspiration processes operating in the recharge area of the groundwater basin. Springs offer opportunity to access the groundwater basin and evaluate the enrichment factor at various elevations. Evaluation of numerous springs, representing a variety of catchment area elevations, determines the elevation dependent chloride-enrichment factor.

Chloride is conservative when dissolved in water. It does not enter into either oxidation or reduction reactions, form important solute complexes with other ions unless the chloride concentration is extremely high, form slats of low solubility, sorb on mineral surfaces in significant quantities, or play a vital role in biogeochemical interactions.

Sources of chloride in the subsurface are generally restricted to evaporites, incompletely leached marine sediments, or porous rocks that have been in contact with the ocean. In areas where these conditions are absent, atmospheric sources are significant. Chloride is present in rain and snow owing primarily to physical processes, that entrain

marine solutes in air at the surface of the ocean (Hem, 1985). Once entrained, the chloride is transported in the atmosphere and reaches the land surface via precipitation (wet fall) or as an aerosol (dry fall).

The chloride-enrichment factor is defined as the chloride concentration in spring discharge divided by the effective chloride concentration in precipitation. Effective chloride concentration in precipitation incorporates the contribution of both wet fall and dry fall. Groundwater recharge to a spring catchment basin is determined as the mean annual precipitation divided by the chloride enrichment factor.

The local hydrographic basin is used as the initial surrogate for the actual recharge basin contributing to a spring. The hydrographic basin is refined by identification of impermeable geologic formations, determination of formations whose orientation would tend to direct recharge water away from the spring, and recognition of mapped faults, whose orientation might contribute to spring discharge. This effort to define the catchment basin is accomplished using a digital-elevation model in conjunction with a geographic information system data base. Regression analysis was used to determine the relationship between the chloride-enrichment factor and catchment basin elevation.

Precipitation data is developed using the PRISM model developed at the Oregon Climate Center (Daly, 1994). This model uses point data and a digital elevation model to generate estimates of monthly and annual precipitation data on a grid pattern of 4 km spacing.

To estimate recharge to a hydrographic basin, the recharge area is first delineated. This area is overlain by a 2-km grid. The mean elevation for each grid cell is determined from a digital elevation map and used to evaluate the chloride-enrichment factor based on the elevation dependent regression equation. Annual precipitation for the 2-km grid cell is evaluated using the PRISM model. The recharge is calculated by multiplying the precipitation value, chloride-enrichment factor, and area of the grid cell. Summation of all cells in the recharge area of the hydrographic basin generates the total annual recharge estimated for the basin.

Principal Findings and Significance: (progress report)

Twenty-five springs in Steptoe Valley were selected for sampling (Table 1). Criteria used in the spring selection included: elevation, aspect, and geology. Elevation and surficial geologic environment were generally determined at the spring orifice. In instances were the orifice occurred at a geologic contact the geology of the presumed catchment area was determined. Aspect was characterized as the principal compass direction toward which the spring catchment area faced. Each characteristic was determined from 1:100,000 scale topographic maps.
The lowest point in Steptoe Valley, approximately 1780 m, is centrally located near the north end of valley. The highest points are North Schell Peak, at 3622 m, in the Schell Creek Range on the east side of the valley and Ward Mountain, at 3293 m, in the Eagan Range on the west side of the valley. Elevation of selected springs ranges from 2025 to 2850 m.

Steptoe Valley is orientated north-south. Thus, drainage basins emanating from the mountains have predominately east-west orientations. Spring catchment exposures reflect this general pattern. Thirteen spring catchments exhibit a westerly exposure; 10 springs exhibited an easterly exposure. Northerly or southerly orientations were each exhibited at one spring.

Surficial geology of Steptoe Valley is dominated by four major rock types. The valley floor consists of alluvial sediments. Paleozoic carbonate rocks predominate in the southern half of the Schell Creek Range on the east side of the valley and throughout the Egan Range on the west side of the valley. The northern half of the Schell Creek Range and the Antelope Range at the north end of the valley expose Tertiary/Mesozoic volcanic rocks. These and Tertiary/Cretaceous volcanics also occur in smaller outcrops in the Egan Range and the southern half of the Schell Creek Range. Finally, there are a small number of exposures of Cambrian/Precambrian clastic rocks on both sides of the valley in the central portions of the Egan and Schell Creek Ranges. Orifices and/or catchment areas for 15 of the sampled springs occur in Paleozoic carbonate rocks. Seven sampled springs occur in Tertiary volcanic rocks. Three sampled springs occur in Cambrian/Precambrian clastic rocks. Although there are numerous occurrences, no springs located in alluvial material were selected for sampling.

Four of the 25 springs were inaccessible or had inadequate discharge and were not sampled. The remaining springs were sampled twice. Determination of chloride, bromide, oxygen-18, and deuterium were made on samples collected in October and November 1999. A full suite of major ion constituents, including chloride, were determined on samples collected in September and October 2000. The chloride enrichment factor was determined using the assumed regional value of 0.3 mg/L for the combined wet fall / dry fall chloride input.

Preliminary assessment of the elevation dependence of Cl-enrichment using spring orifice elevation is given by

$$\text{Cl-enrichment} = 1.0 + 11204.3 \times \text{Exp}(-0.00284 \times \text{elevation})$$

As discussed previously, the mean elevation of the catchment basin contributing to a spring is a better indicator of the precipitation and evapotranspiration processes affecting chloride concentration in spring discharge. Analysis of the DEM was used to make an initial delineation of the catchment basin. This did not provide a reasonable estimate of the catchment basins. Spring discharge could provide a further constraint on the catchment basin delineation. However, discharge data is not currently available for the sampled springs.

Table 1. Steptoe Valley Springs Selected for Sampling

Name	Location[1]	Elevation	Aspect	Geology[2]
Rosebud	13N 65E 10ba	2300	NW	Pzc
South Taylor	14N 65E 15ba	2450	SW	Pzc
Summit	15N 65E 22cb	2600	SW	Pzc
North	15N 65E 12bc	2700	W	Pzc
Sage Hen	16N 64E 12ab	2650	NE	Pzc
Steptoe	16N 64E 3cd	2450	W	Pzc
North Fork Berry Creek	17N 65E 12cd	2850	W	Pzc
Camp	24N 65E 11ab	2750	NE	Pzc
Moonshine	28N 63E 34db	2150	E	Pzc
Cheat Grass	26N 63E 3cb	2150	E	Pzc
Pipe 21N 62E 11bd	2650	E	Pzc	
Meadow	21N 62E 14ca	2550	W	Pzc
Riepe	16N 62E 36dc	2350	NE	Pzc
Log Cabin	25N 63E 32bd	2400	SE	Pzc
Indian Creek	21N 65E 32aa	2650	W	Pzc
Timber Creek	18N 65E 25ab	2850	W	CpCc
Axehandle	17N 64E 11bd	2375	E	CpCc
Kid	18N 63E 14cb	2150	E	CpCc
Goat 18N 63E 34cd	2025	SE	TKi	
North Creek	20N 65E 27cc	2675	S	TMv
Queen	22N 65E 18da	2250	W	TMv
Upper Schellbourne Pass	22N 65E 7aa	2175	W	TMv
Long Gulch	23N 64E 13aa	2225	W	TMv
Cherry	23N 65E 6dd	2250	N	TMv
Lookout	26N 67E 30da	2037	NW	TMv

[1] from USGS 1:100,000 topographic maps - metric: Currie (1987), Kern Mountains (1988), and Ely (1987).
[2] CpCc = Cambrian / Precambrian clastic rocks; Pzc = Paleozoic carbonate rocks; TKi = Tertiary / Cretaceous volcanic rocks; TMV = Tertiary / Mesozoic volcanic rocks; based on Eakin, Hughes, and Moore (1967).

References:

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Basic Information

Title:	Determination and Source Apportionment of Polycyclic Aromatic Hydrocarbons (PAHs) from Watercraft in Recreational Lakes in Northern Nevada and Eastern California
Project Number:	B-04
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Water Quality
Focus Category:	Water Quality, Toxic Substances, Surface Water
Descriptors:	water chemistry, mountain lakes/streams, pollutants, recreation, boating, zooplankton, polycyclic aromatic hydrocarbons
Lead Institute:	Water Resources Center, Desert Research Institute
Principal Investigators:	Glenn C. Miller, Mary Miller

Publication

Statement of results or benefits:

The focus of the this investigation was to establish PAH emissions profiles for some common recreational watercraft engines and to establish a relationship between watercraft use and the presence of PAH compounds in Lake Tahoe. The analytical method (EPA Method 550.5) was modified to increase the sensitivity and give detection limits of several of the PAH compounds at 4 ng/L. Several samples were collected and analyzed during the summer of 2000 at Lake Tahoe. PAH was not detected at sites near the center of the Lake Tahoe, but several samples at near shore areas showed low PAH concentrations.

Emissions profile experiments were conducted in a controlled environment at the California Air Resources Research Facility in El Monte, Ca. during July of 1999 and again during winter of early 2001. Three different outboard engines; a 90 hp four stroke, a 90 hp direct fuel injected (Ficht technology), and a 90 hp carbureted engine were investigated. Data collected (Table 1) were analyzed to determine whether the newer and reportedly "cleaner" engines were capable of contributing significant levels of potentially toxic PAH compounds to recreational water bodies. Simultaneous sampling for the volatile fraction indicated that the newer direct fuel injected engine indeed showed 60-80% reduction in release of MTBE, benzene, toluene, xylene and ethyl benzene. However, these results also demonstrated that greater amounts of PAHs were exhausted and found in the water from the direct fuel injection (Ficht technology) compared to the carbureted 2-cycle engine (Table 1). This suggests that, while the newer technology can be expected to contribute less volatiles (gasoline) into water, the biological impact of using these newer engines may be significant, particularly when extensive use of these newer engines occurs in recreational lakes. The lubrication technology of both types of engines is similar, and the PAH appear to be derived from the oil. The PAH concentrations (as well as the volatile gasoline fraction) emitted from the four stroke engines were substantially lower than from the other two engine types and the component profiles were distinctly different.

Table 1. PAH compounds determined in water samples subjected to various marine engines (Data from 1999 sampling date)

	90 HP Direct Injection 30 minute run	90 HP Carbureted 30 minute run	90 HP 4-Stroke 30 minute run
Acenaphthylene	18000 ng/L	54000 ng/L	Not determined
Acenaphthene		41000	Not determined
Fluorene	18000	1400	450
Phenathrene	13000	2000	76
Fluoranthene	9700		200
Chrysene	3600		
Benzo(b)fluoranthene	2800		8

In addition to the emissions profile study, samples were collected on two separate occasions from Lake Tahoe during the summer of 2000, during mid-August and immediately following the Labor Day holiday weekend, both traditionally high use period and during November. Phototoxic PAH compounds were found in samples

collected in high use areas during August and the Labor Day holiday weekend but were not detected from mid-lake low use sites. During the high use times, the PAH component found in greatest concentration was fluoranthene, a compound considered to be the single most important phototoxic PAH. This compound was found during the August 14, 2000 sampling in the Tahoe Keys Home Owners Lagoon (5.3 ng/L), the Tahoe Keys Fuel Dock (12.2 ng/L), and the Tahoe Keys East Channel (10. 7 ng/L), and Camp Richardson (5.3 ng/L). The only other PAH's found above the quantitation limit during the August 18 sampling was chrysene (8.4 ng/L) and benz(a)anthracene (4.5 ng/L), both at Camp Richardson. Samples at the Mid-Lake Buoy, Rubicon, Ski Run Marina and Homewood did not reveal any PAH compounds at concentrations above 4 ng/L. During the September 4, 2000 sampling, the sites at the Mid-Lake Buoy, Tahoe City, Camp Richardson, Homewood, Emerald Bay, Ski Run and Sunnyside did not reveal any PAH above quantitation limits. Fluranthene was again detected at Tahoe Keys Beach (3.8 ng/L), Tahoe Keys East Channel (4.6 ng/L), Tahoe Keys Home Owners Lagoon (4.6 ng/L).

Based on research of Oris and others (1998), toxicity impacts become apparent at concentrations as low as 10 ng/L of fluoranthene. The concentrations detected in these samples only rarely exceeded this concentration. However, other PAH compounds observed below quantitation limits, when summed together still may contribute to a phototoxic level of total PAH. Whether these summed concentrations pose a significant ecological threat remains unclear, although it is likely that only the most sensitive species would probably be affected. The evidence to support marine engines as a primary source of PAH is strong, although not conclusive. PAH was found primarily in areas that receive extensive watercraft usage, and was not found in areas that received low use by watercraft. During the late fall, when watercraft usage was very low, no PAH has been identified in any of the samples taken at Lake Tahoe.

Nature, scope, and objectives of the research:

Emissions from marine engines represent a serious concern for aquatic life at Lake Tahoe and other recreational lakes that receive intensive use by watercraft. Although current management measures in place at Lake Tahoe have been effective in reducing the release of raw gasoline, there is limited information on their effectiveness in controlling the most toxic component of marine engine exhaust known as polycyclic aromatic hydrocarbons (PAHs). This class of compounds is inherently toxic to aquatic organisms under any conditions, but is highly toxic to organisms in mountain lakes due to low water solubility and ultra-violet (UV) light conditions (Ireland, et al., 1996; Pelletier, 1997). Preliminary assessments have indicated that the new direct fuel injected two-stroke engines, while reducing releases of raw gasoline, do not show significant reductions in PAH emissions and in fact may have higher PAH emissions as compared to the older carburetor engines. Although all internal combustion engines form these compounds, two-cycle engines are a particularly large source of these compounds. The impacts of these marine engine emissions are potentially problematic in clear waters of high elevation lakes.

One of the studies that raised additional concerns about the toxicity of marine engine emissions was a project directed by Dr. James Oris of Miami University of Ohio, working with the Tahoe Research Group (Oris, et al., 1998). Dr. Oris and his cooperators found that Lake Tahoe water, which received significant watercraft activity was toxic to fathead minnows (Pimephales promelas) and a zooplankton (Ceriodaphnia dubia). The results suggested that emissions from watercraft were responsible, particularly the polycyclic aromatic hydrocarbons (PAH) resulting from incomplete combustion. These compounds are known to be toxic and carcinogenic. They also possess the characteristic of "photo-enhanced toxicity." Because of their very low solubility in water, these compounds tend to partition into biological material, and when exposed to ultraviolet light, result in reactions which increase the toxicity of the compounds dramatically. From studies such as these, the No-observed effect-concentrations (NOEC) may be as low as 0.01 µg/L (parts per billion) in Lake Tahoe (Oris, et al., 1998).

The goals of this study were to (1) compare PAH emissions from a variety of two and four-stroke engine technologies, and, (2) assess the concentration of PAH at a variety of sites of varying watercraft use in both Lake Tahoe at varying times throughout the year. This research will continue with additional sampling at Lake Tahoe and analysis of the samples collected during the 2001 trip to the California Air Resources Laboratory.

Related research:

Ireland, D. S., G. A. Burton, and G. G. Hess. 1996. In situ toxicity evaluations of turbidity and photoinduction of polycyclic aromatic hydrocarbons. Environmental Toxicology and Chemistry. 15:574-581.

Oris, J. T., et al 1998. Toxicity of ambient levels of motorized watercraft emissions to fish and zooplankton in Lake Tahoe, California-Nevada, USA.

Pelletier, M. C., R. M. Burgess, K. T. Ho, A. Kuhn, R. A. McKinney and S. A. Ryba. 1997. Phototoxicity of individual polycyclic aromatic hydrocarbons and petroleum to marine invertebrate larve and juveniles. Environmental Toxicology and Chemistry. 16:2190-2199.

Information Transfer Program

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3		0	0	3
Masters	3	2	1	0	6
Ph.D.	0	1	0	0	1
Post-Doc.	0	1	0	0	1
Total	0	0	0	0	0

Notable Awards and Achievements

None

Publications from Prior Projects

1. Hannam, K. and L. Oring, 2000, "Salinization of Inland Waters Threatens Shorebird Reproductive Success" submitted to Condor: An International Journal of Avian Biology.