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An Examination of gasoline pollutants from two-cycle Marine Engines within Lake Mead National Recreation Area

Brian Carter
University of Nevada Las Vegas

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Abstract

Jet skis are a very popular "toy" to have in the United States. They account for almost a third of all boat sales, and their numbers are growing rapidly. Unfortunately jet skis use two-cycle engines that pollute at unacceptable levels. Jet ski motors can emit up to 25% of its fuel right back into the water. This alarmed me and I wanted to take a deeper look into how bad jet skis pollute Las Vegas' primary water source. Lake Mead. I looked into how a two-cycle engine differs from a regular engine and I looked at the actual pollutants a two-cycle emits. After some background, I examined the water quality on Lake Mead to see if there was a contamination problem. From the data uncovered the local agencies feel there is no need for concern, and my thesis that jet skis should be banned from Lake Mead was not supported at all.

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Introduction

"Driving a jet ski for one day pollutes as much as driving an automobile does in an entire year." That statement is what first sparked this paper after hearing it on a local new report about the detrimental effects of jet skis, officially called personal watercrafts (PWCs). This seamed outrageous and hard to believe. After more research other surprising facts began to come up, "2-cycle motors spill 15 times more oil and fuel into American waterways every year then did the Exxon Valdez" (Nelson, 1994). "A recent California Air Resource Control Board analysis determined that the exhaust emissions from 2 hours of jet ski's operation equals those from driving a 1998 passenger car 13,000 miles" (Nouban, 1999). "The crude from motorboats in Lake Powell alone, amounts to a Valdez-size spill every two years" (Rauber, 1998). "PWC engines can dump six gallons of raw fuel into a reservoir in two hours..." (Bluewater, 1998). These facts were shocking, especially since over 80% of Las Vegas' drinking water originates from Lake Mead, which is a haven for boats and PWCs.

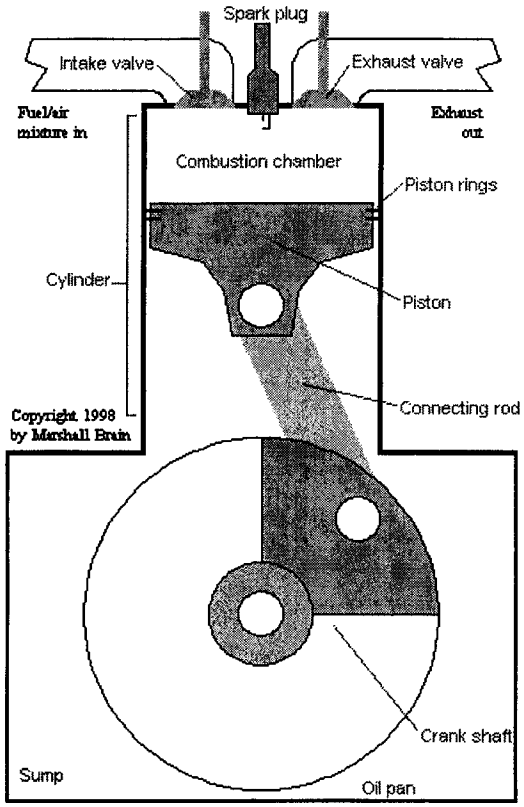
Personal watercrafts are becoming more and more popular. Developed originally by Kawasaki in the early 1980's these boats now account for over one-third of all boat sales (Bluewater, 1998). Currently there are six major manufactures of PWCs ; Sea Doo, Kawasaki, Yamaha, Polaris, Wet Jet and Tigershark that sell a wide variety of personal watercrafts in this billion dollar market. Over 34,589 boats are currently licensed here in Southern Nevada with a large number of them, 9,827 being PWCs (DOW, 2000). This does not include the hundreds of boaters that visit Lake Mead from all over the western United States. The large numbers of boats and PWCs on our drinking water source may pose a water quality problem for Las Vegas. This paper intends to look at internal

combustion engines and explain how they differ, it will also explain, in detail, the pollutants from gasoline that are the most harmful and how they may be impacting the health of over a million residents of Las Vegas.

Four-cycle engine

Most Americans have one or more cars, they get in them, turn the key on and away they go. A majority of these drivers have no clue what powers their car or know remotely how an engine works. What the modern car engine evolved from, was invented in 1867 by Nicolaus Otto (Brain, 1998). Otto designed and patented the first four-cycle internal combustion engine (ICE). The general definition of an ICE is: the combustion of fuel that takes place in a confined space producing expanding gasses that are used to provide mechanical power (Brain, 1998). The first person to combine an internal combustion engine with a automobile was Karl Benz in 1885 and in 1908 Ford developed the first affordable automobiles with the help of his new assembly line methods (Brain, 1998).

Figure 1. Cross Section of a Four Cycle Engine Combustion chamber



(Brain, 1998)

The four-cycle engine is a relatively simple process and requires few parts (Figure 1). The major parts described will be the piston, combustion chamber, spark plug, intake valve and exhaust valve. The first cycle or "stroke" of the engine requires the piston to be at the top of the combustion chamber or "cylinder". The intake valve then opens and the piston moves down drawing in a precise mixture of air and gas mixture (stroke two). The intake valve closes and the piston begins travelling back up, compressing the gas/air mixture. The spark plug fires and ignites the pressurized gas/air mixture. The explosion forces the piston back down again and chamber is now filled with the exhaust gas (stroke 3). The exhaust valve now opens and the piston moves back up the combustion chamber and forces all of the exhaust gas out of the engine (stroke 4)

and the process starts over again. A four-cycle engine has from 4 to 12 of these combustion chambers and they are each staggered one cycle to make the engine run smoothly. The exhaust gas from the engine in cars is then treated by several different emission controls that lower the amount of emissions released into the atmosphere such as mufflers and catalytic converters. Some boats have four-cycle engines, very similar to the one in your car, however they have no such emission controls and the exhaust gas is untreated.

Two-cycle Engines

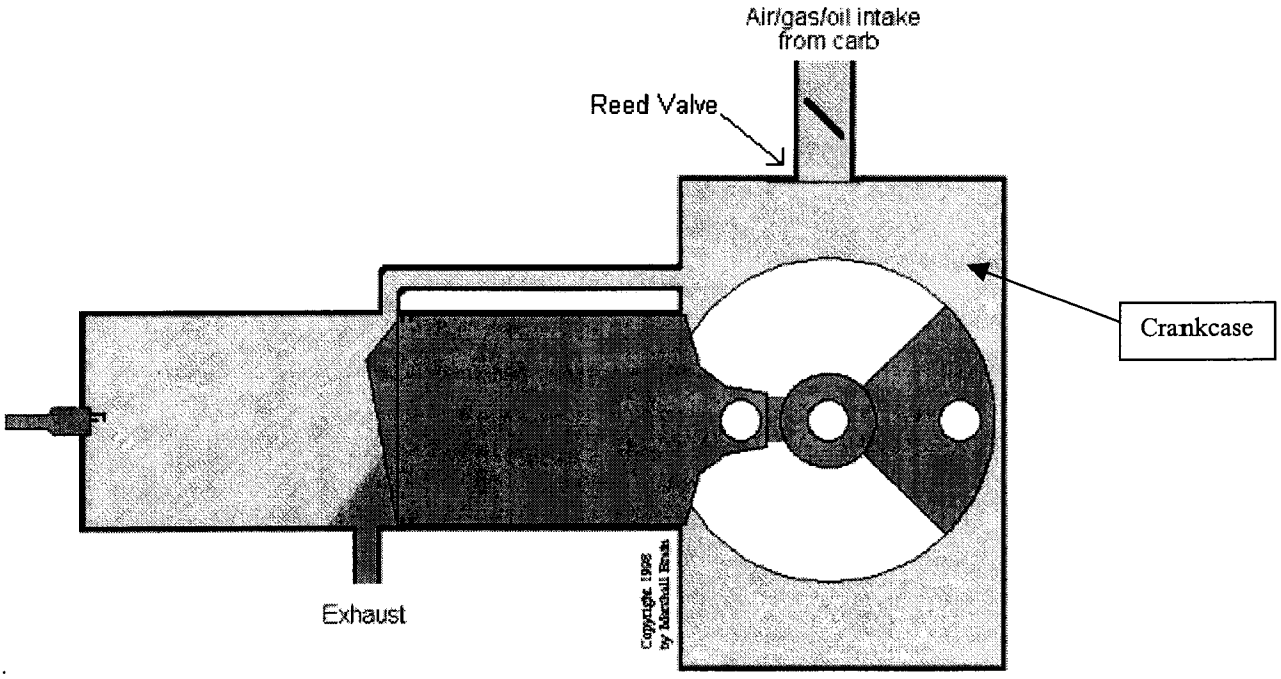
The two-cycle engine is a much simpler design, it has few moving parts and no valves. They are very easy to maintain, lightweight and relatively cheap to make compared to their four-cycle cousins. These attributes are why the two-cycle engine is used in thousands of different applications. Motorcycles, chain saws, lawnmowers, model airplanes, mopeds and jet skis all utilize the two-cycle engine as their power plants. EPA calculates that over 35 million 2-cycle motors were sold in 1995 versus 15 million automobiles (EPA (g), 1996).

An Englishman named James Clerk originally designed this engine in 1879, but they were very unreliable and rarely used commercially. The two-cycle engines were later developed by the Germans and used more widely around the start of the second World War, and in the late 50's the Japanese continued the evolution to what we know as the modern two-cycle (Brain, 1998).

The two major advantages the two-cycle has over the four are, that the two-cycle does not have valves, which simplifies their construction, and the two-cycle engine fires every revolution making it theoretically twice as powerful.

The gas/ air mixture is first drawn into the crankcase of the engine. Then as the piston returns down, the gas/air mixture is forced through a hole from the crankcase into the combustion chamber.

Figure 2. Cross Section of a Two-Cycle Engine Combustion Chamber



(Brain, 1998)

The piston moves back up, compressing the gas/air mixture and then the spark plug fires. The explosion sends the piston back down and the exhaust is sent out through a second hole. As the exhaust is leaving the exhaust hole the new, fresh gas/air mixture is flowing in right behind it, and that is where a lot of the environmental problems come in. There are no physical restrictions to keep the fresh gas/air from flowing right out of the engine and into the air. 25% of the gas used in a two-cycle engine (up to 50% if the engine is

not tuned right) will not be burned and will be released into the air or water (EPA (a), 1983). Another problem with a two-cycle engine is that the crankcase is not full of oil for lubrication like a four-cycle. The oil must be mixed in with the gasoline (four ounces of oil per gallon of gasoline) in order to keep it lubricated, but that means the oil must be burned away in the combustion cycle, leaving a cloud of blue smoke (Brain, 1998).

Fuel Injection

What doesn't leave a large cloud of smoke is the newly developed fuel injected two-cycle engines. The new technology developed by the German based, Ficht company, allows their new engines to have the power, speed and acceleration characteristics as current two-cycles, but with better fuel efficiency, low oil use, no smoke, and low emissions (Gromer, 1996). The Ficht fuel injection system sprays an ultra fine mist of highly pressurized fuel into the combustion chamber. This has two advantages over traditional carbureted systems. The fuel burns much more thoroughly when ignited by the spark plug, which improves gas mileage. Also, the fuel mist entering the chamber is timed by a small electronic control unit (ECU) computer so the exhaust port is closed when the fuel enters and almost no unburned fuel can escape (Ficht Fuel Inj. 1999). The results of the Ficht fuel injection are dramatic, tests pairing two similar two-cycle engines, one fuel injected and one carbureted showed considerable differences. The fuel injected engine reduced volatile organic chemical (VOC) emissions up to 60%, used 35% less fuel and 50% less oil (Gromer, 1996).

Currently only Sea Doo and OMC are incorporating this new technology into some of their engines. Revisions to the Clean Air Act of 1990 state that engine

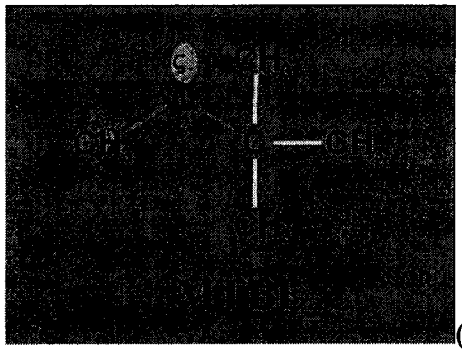
manufactures must reduce conventional two-cycle motors production by 75% by the year 2006 (EPA (g), 1996). Some companies are showing interest in developing four-cycle personal watercraft engines, but direct fuel injection looks to be more predominant in the future. You get the benefits of the power and the light weight of the two-cycle but the emissions are much less.

A majority of marine engines have "wet exhaust" meaning that the exhaust that is produced from the engine is sent out through the water. The pollutants and chemicals released from the combustion of gasoline are then directly injected into the water the boat or jet ski is traveling on (Ferren, 1980). All engines pollute to some degree, but as mentioned earlier, the two-cycle engines are a much bigger problem. 20-30% of the gasoline used in a two-cycle engine is released, unburned, into the water causing potential water quality problems (EPA (a), 1983). Many lakes and other freshwater bodies are "multi-use" facilities. They can be used for recreation such as boating, swimming, fishing and the same body of water may also be a drinking water source. The four major constituents of engine exhaust that are closely monitored in drinking water are; MTBE, benzene, toluene, ethylbenzene, and xylene (BTEX) (Miller, 1998).

MTBE

MTBE or Methyl Tertiary Butyl Ether is a fuel additive that started being added to gasoline in the late 1980's.

Figure 3. Chemical Model of Methyl Tertiary Butyl Ether (MTBE)


(Book, 1998)

Its structure $(CH_3)_3C\text{-}O\text{-}CH_3$ contains oxygen and allows the gasoline to burn more thoroughly, reducing carbon monoxide, nitrous oxide and sulfur oxide emissions. Areas that were in "non-attainment" air quality wise all across the nation were mandated to use oxygenated fuel by the Clean Air Act of 1990, and MTBE was the most common additive used by states (EPA (b), 1993). MTBE was cheap, readily available and effective, reducing carbon monoxide emissions by up to 20% (Smith, 1998). Unfortunately a few years after wide scale usage of MTBE, it began showing up in drinking water all across the nation. It made its way into the water either through leaky fuel tanks and pipelines, by spillage of gasoline on the surface, or by marine engine exhaust. In Nevada, gasoline is only about 3% MTBE but in California the MTBE makes up 10% and in the winter months up to 15% of the gasoline (Miller, 1998).

One reason that MTBE is getting so much attention, is that it can be smelled and tasted at very few parts per billion (ppb). At 10 ppb people can begin to taste "turpentine" in their water and at around 25 ppb people can detect the odor. California has set a health advisory for drinking water of 13 ppb, but the EPA's health advisory is far greater at 20-40ppb. (EPA (b), 1993).

If exposed to high acute doses of MTBE orally, symptoms include: irritation to the mucus membranes and respiratory tract, vomiting, nausea, and diarrhea. Long term chronic effects are not known. Liver and kidney damage has been shown as well as possible nervous system damage. MTBE is not listed as a carcinogen (causes cancer) but there has been a lot of evidence supporting that it is one. Long-term exposures are thought to give flu-like symptoms and are hard to pinpoint and differentiate from other viral flues (EPA (b), 1993). The effects are thought to be due to the metabolites of MTBE. Formaldehyde, TBF (tertiary butyl formate), and TBA (tertiary butyl alcohol) all have detrimental effects on the body. Formaldehyde is a probable carcinogen, TBF destroys mucus membranes in the body and TBA acts much like wood grain alcohol and causes intoxicating effects (EPA (b), 1993)

MTBE's effect on water quality has a little more impact then some of the other gasoline constituents because it is so hydrophilic, or soluble in water (5g/L for MTBE, 1.8g/L for Benzene comparatively) (DeZuane, 1997). The BTEX (benzene, toluene, ethylbenzene and xylene) gas constituents are absorbed into soil, volatilized, or biodegraded fairly quickly. MTBE is extremely mobile and can spread out over very far distances, polluting the water it comes into contact with, and does not biodegrade nearly as fast (Smith, 1998)

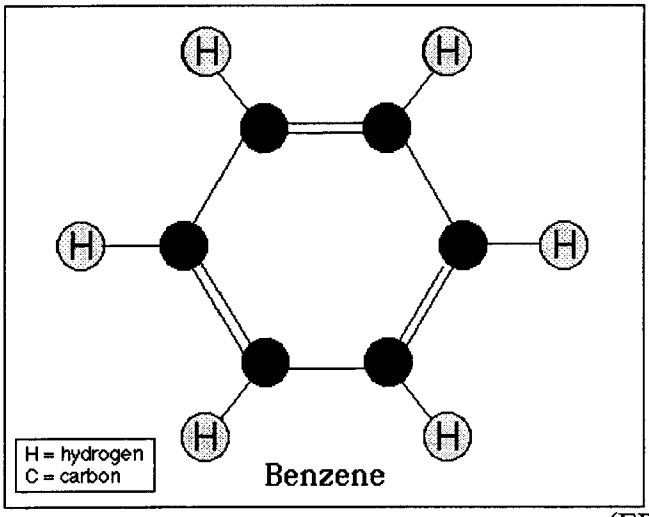
Benzene

Benzene, toluene, ethylbenzene, and xylene are all very similar compounds. They all basically have the same structure but with one only one different functional group.

The four compounds have many of the same effects on the body and are grouped together with the acronym, BTEX.

Benzene, C_6H_6, is a natural occurring substance produced by volcanoes, forest fires and is present in many plants and animals.

Figure 4. Chemical Model of a Benzene Ring



(EPA (h), 1999)

Benzene is also a major industrial chemical made from coal and oil, it is used to make plastics, detergents, pesticides, dyes, rubber, and many other synthetic materials. It is also a component of gasoline, about 1-2% by volume (EPA (d), 1999).

Acute exposure to benzene may cause drowsiness, dizziness, headaches, and unconsciousness in humans. Large doses of benzene orally, may result in vomiting, convulsions and death. Long term, chronic exposures to benzene have a harmful effect on the tissues that form blood cells. The U.S. Department of Health has overwhelming evidence that benzene is a carcinogenic and people that have been exposed to benzene long term have a much higher rate of anemia and leukemia (cancer of the bone marrow tissues that form blood cells). (EPA (h), 1999) Menstrual disorders, genetic disorders

and adverse effects on the fetus have also been displayed on animals exposed to high levels of benzene. EPA has set the drinking water standard to 5 ppb (parts per billion) or 5 ug/L, to reduce risk of cancer or other health effects (DeZuane, 1997)

Toluene

Toluene is also an "aromatic ring" like benzene, except one of the hydrogen atoms is replaced by an ethyl group ($-CH_3$). (see Figure 4) Toluene $C_6H_5CH_3$ is also in gasoline (almost 8-12%) and has a somewhat different effect on humans who drink it. The central nervous system (CNS) is the primary target organ for toluene, in both acute and chronic exposures. CNS dysfunction and narcosis are frequently found with people exposed with low to moderate levels of toluene by inhalation. Symptoms include fatigue, sleepiness, headaches and nausea. Liver and kidney damage is also common in animals exposed long term but toluene is not thought to be a carcinogen. (EPA (e), 1999) In drinking water, toluene is thought to be not as toxic and amounts under 2 mg/L are acceptable (DeZuane, 1997)

Ethylbenzene

Ethylbenzene is a benzene ring with one of the hydrogen atoms replaced with a ethyl group ($-CH_2CH_3$). Ethylbenzene, also found in gasoline, is an industrial solvent used to make paints, glues, asphalt, pesticides and many other products. Acute exposures can result in respiratory effects such as throat irritation, chest constriction, dizziness, and irritation of the eyes. Chronic exposures damage the liver and kidneys, and also in not

considered a carcinogen (EPA (c), 1999). The EPA's water quality standards for ethylbenzene are .7 mg/L (DeZuane, 1997).

Xylene

Xylenes are another major component of gasoline production , making up to 15% of gasoline. Xylene C_8H_{10} is a benzene ring with two of the six hydrogen atoms substituted by a methyl group ($-CH_3$). The positioning of the methyl groups is important but the toxic effect of the different xylenes are similar and have been lumped together for simplicity. Xylene's acute effects are nausea, vomiting, and neurological effects. Chronic exposures primarily result in central nervous system effects, such as headaches, dizziness, fatigue, tremors and incoordination. Xylene is not considered a carcinogen and recent studies show that chronic exposure to mothers may result in skeletal deformities in fetuses (EPA (f), 1999). .44 mg/L is the maximum amount of total xylenes allowed in drinking water (DeZuane, 1997).

The Las Vegas Valley Water District is in charge of monitoring these and other pollutants. Currently they feel that the levels of the above mentioned pollutants are small enough, not to be concerned with them, but this paper will take an independent look at water quality levels in Lake Mead. There is a large amount of boat and PWC traffic on Lake Mead any many people depend on its water for survival. Our only resource of water cannot be contaminated, and we should follow in the same footsteps as other areas of the U.S. that have limited PVC use on drinking water reservoirs. Carbureted two-cycle marine engines should be banned from Lake Mead.

Materials and Methods

The research done on two-cycle engines, gasoline constituents and water quality levels were all found in the library and/or the Internet. To determine if an actual problem exists in Lake Mead, the problem needed to be broken down into smaller parts to get a better general understanding as well as focus on any specific problems.

The first area that needed to be researched was the way an actual internal combustion engine works. Also very important to understand are the differences between a two-cycle and a four-cycle engines. Only after you know how a two-cycle engine works you begin to see how it poses a pollution problem both to the air and water.

The pollution itself was the next thing that needed to be examined. The main constituents of gas that are harmful to humans and ecosystems are BTEX (benzene, toluene, ethyl benzene and xylene) and MTBE. (methyl tert butyl ether). The effects of these chemicals were all researched and the acceptable quantities in the drinking water were also listed.

The last area that needed researched was any similar problems that have been encountered in other areas of the United States. Drinking water contamination from BTEX and MTBE is beginning to be a common occurrence across the nation, unfortunately, most are contaminated by leaking underground storage tanks. Lake Tahoe in northern Nevada/California does have a similar problem as Lake Mead may have. There has been extensive research done to specifically determine if two-cycle marine engine have negatively effected the water quality of Lake Tahoe. It was determined that two-cycle engines were damaging to the lake and non fuel-injected two cycles have since been banned. Although Lake Mead and Lake Tahoe are in extremely different

ecosystems, some of the criteria determining if two-cycle engines are polluting our drinking water will be similar.

The little hard data that is used in this paper was courtesy of the USGS. Ken Covay of USGS water resource division of southern Nevada. The USGS did a preliminary study on Lake Mead and Lake Mohave, to determine if there was reason to do a large scale study. The study is unpublished data, and as of now it is limbo. The USGS has no plans on doing further research on BTEX or MTBE in Lake Mead.

Results

As of 1999 there were 34,589 registered watercraft in Clark County. That includes all types of motorized boats and, 9,827 of those boats were personal watercrafts (PWCs) (NV. Dept. of Wildlife, 2000) Two-cycle jet skis make up almost a third of all boats that are in the valley. If we assume that the average jet ski owner, uses his boat once a month during the summer (3 times total). Assuming also that the average personal watercraft has a ten gallon fuel cell, and during a trip to the lake that fuel cell will be refueled once (20 gallons total). Finally, it was noted before that PWC engines can emit around 25% of its fuel back out into the water. Using some extremely rough calculations; 9,827 personal watercrafts, times 3 "uses" per year, times 20 (gallons used/uses) times 25% (gallons emitted/gallons used). A ballpark amount of gasoline released by PWCs in Lake Mead yearly is 147,405 gallons. If the MTBE content of gasoline is approximately 3%, as it is here in Nevada, then around 4,400 gallons of MTBE is potentially dumped into Southern Nevada's drinking water source. Granted, some of the number are fuzzy and may not accurately portray the exact amounts of

contaminants, what it does show, is the general trend of large amounts of petroleum by-products being released into Lake Mead. Also not taken into account are the large number of boaters that come to Lake Mead from California and Arizona. The boats and personal watercraft, especially those from California amplify the problem already being created by local boaters.

If there are 28,587,000 acre-feet of water in Lake Mead (NV Dept. of Wildlife, 2000) and 4,400 gallons of MTBE being released into the water that is almost 1.7 Liters of MTBE for every 3,526,175,000 Liters of water. It doesn't sound like a large amount of MTBE, but remember the drinking water standards are 12 parts per billion, meaning that out of a billion molecules of water, no more than 12 molecules can be MTBE.

Not many studies have actually been done on Lake Mead regarding BTEX and MTBE and there seems to be little concern that either of the pollutants are a problem from both the Las Vegas Valley Water District,(LVVWD) who supplies the valley with our fresh water, or the United States Geological Survey (USGS). In Lake Tahoe many studies have been done recording the amounts of MTBE and BTEX in the water after holiday weekends or after large amounts of boat and PWC traffic. Unfortunately, only one small study has been done on Lake Mead recently. The USGS, headed by Ken Covay, did a preliminary study after Memorial Day weekend in 1999. Seven shallow water samples were taken from various areas of Lake Mead and four shallow water samples taken from Lake Mohave. (Lake Mohave is located down the river from Lake Mead, and it is a much smaller water body). Below are tables that show some of the preliminary, unpublished data that was recorded by the USGS.

Figure 5 Map of Lake Mead

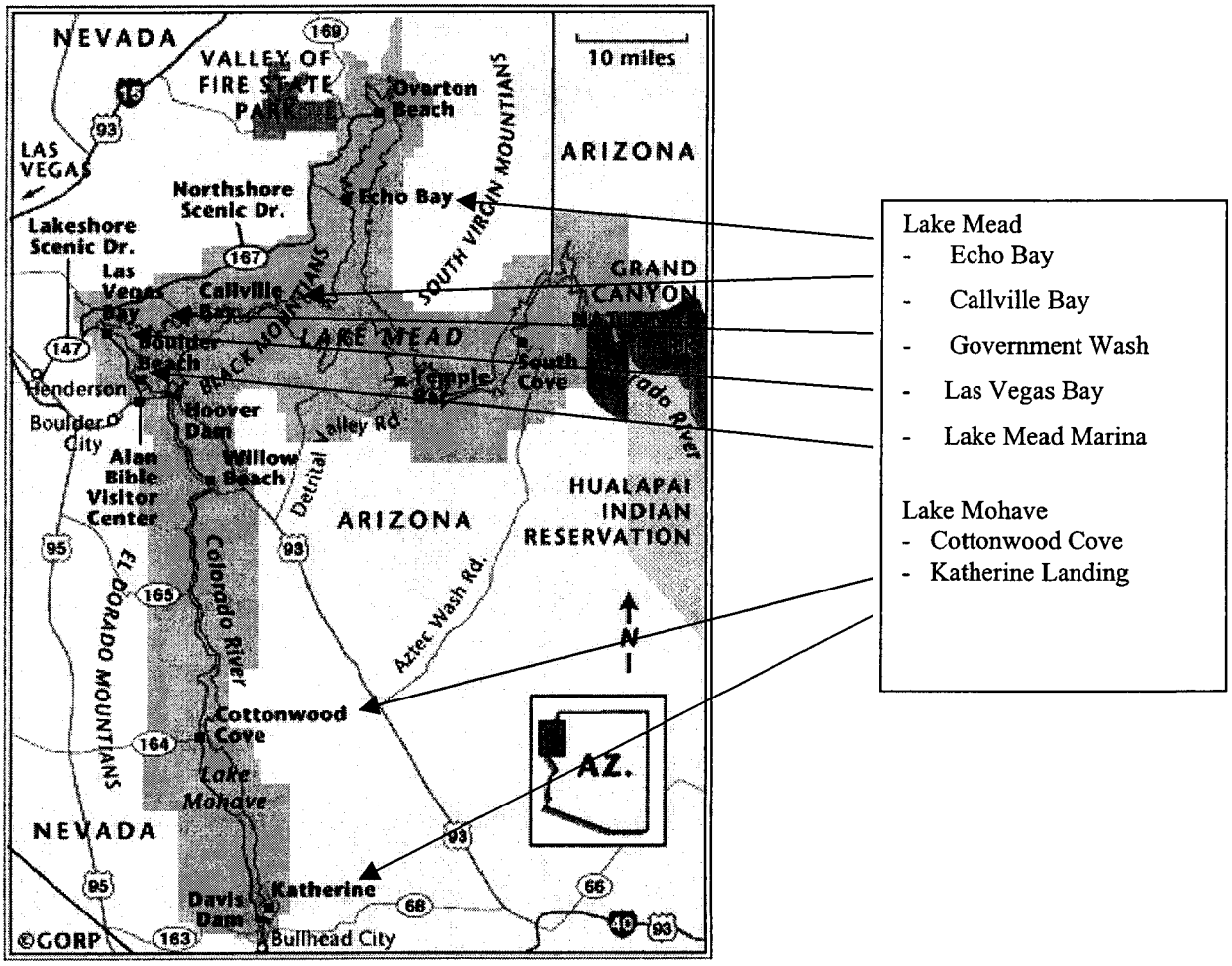


Table 1 Amounts of MTBE/BTEX Sampled in Echo Bay, by the USGS, May 1999

MTBE	.5816 ppb
Benzene	.7096 ppb
Toluene	3.688 ppb
Ethylbenzene	.597 ppb
Xylenes (Total)	1.007 ppb

Table 2 Amounts of MTBE/BTEX Sampled in Callville Bay, by the USGS, May 1999

MTBE	.7684 ppb
Benzene	.6866 ppb
Toluene	2.99 ppb
Ethylbenzene	.4661 ppb
Xylenes (Total)	.7605 ppb

Table 3 Amounts of MTBE/BTEX Sampled in Wash, by the USGS, May 1999

MTBE	1.74 ppb
Benzene	1.06 ppb
Toluene	5.013 ppb
Ethylbenzene	.7027 ppb
Xylenes (Total)	1.546 ppb

Table 4 Amounts of MTBE/BTEX Sampled in Las Vegas Bay Inlet, by the USGS, May 1999

MTBE	.8219 ppb
Benzene	.05318 ppb
Toluene	.1182 ppb
Ethylbenzene	.0102 ppb
Xylenes (Total)	.02711 ppb

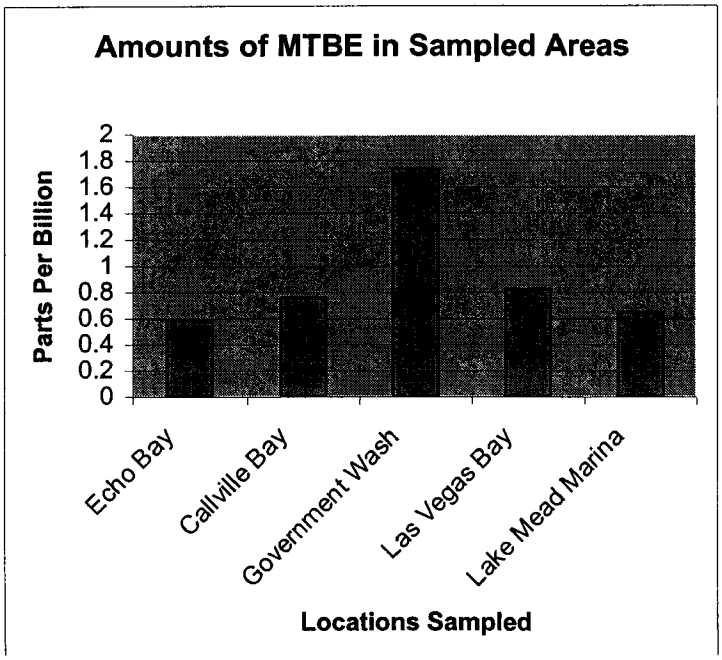
Table 5 Amounts of MTBE/BTEX Sampled in Lake Mead Marina, by the USGS, May 1999

MTBE	.6473 ppb
Benzene	.6042 ppb
Toluene	2.935 ppb
Ethylbenzene	.4265 ppb
Xylenes (Total)	.7399 ppb

Table 6 EPA Drinking Water Standards for Appropriate Pollutants

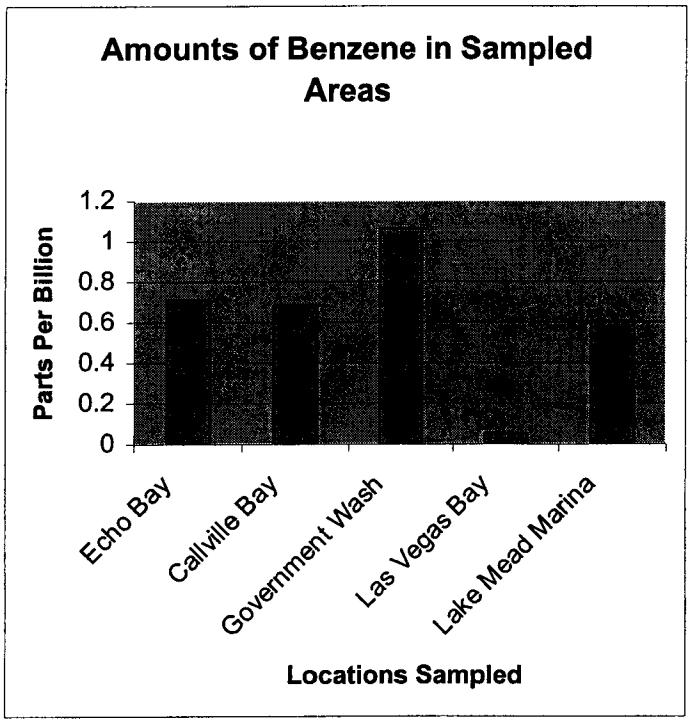
MTBE	5 (ppb) (taste)(California) 13 (ppb) (health-based)(California) 20-40 (ppb) (EPA)
Benzene	.005 (milligram/Liter)= (ppm) 5 (microgram/Liter) =(ppb)
Toluene	2 (ppm) 2000 (ppb)
Ethylbenzene	.7 (ppm) 700 (ppb)
Xylenes (Total)	.44 (ppm) 440 (ppb)

Table 7 MTBE Levels in Lake Mead, from USGS study



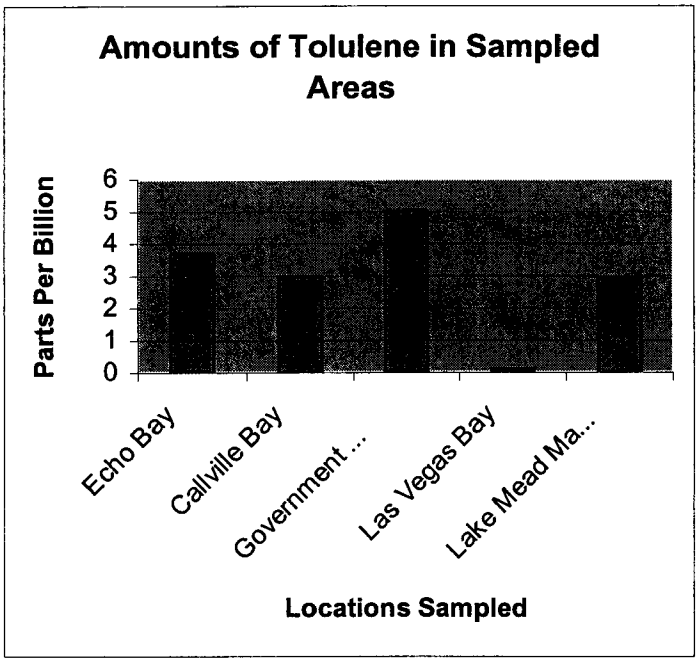
Water Quality Standards
5 ppb (Taste)
13 ppb (health-based)

Table 8 Benzene Levels in Lake Mead, from USGS study



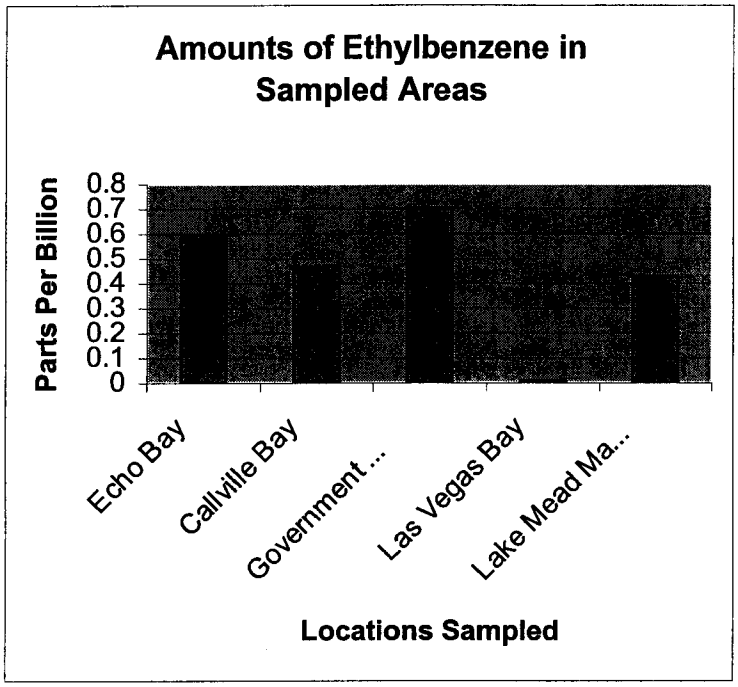
Water Quality Standards
5 ppb

Table 9 Toluene Amounts in Lake Mead, from USGS study



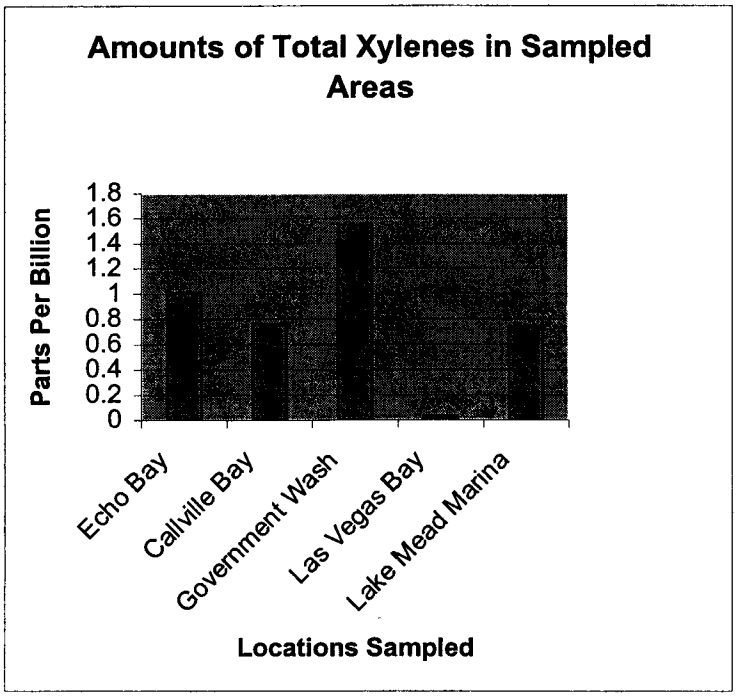
Water Quality Standards
2000 ppb

Table 10 Ethylbenzene Amounts in Lake Mead, from USGS study



Water Quality Standards
700 ppb

Table 11 Total Xylene Amounts in Lake Mead, from USGS study



Water Quality Standards
440 ppb

From the results shown above, none of the pollutants examined exceeded water quality standards. They do not even approach the levels that the EPA has set to ensure human health. From these results it appears that the pollutants released from personal watercrafts and boats do not threaten the Las Vegas valley's drinking water. The USGS took several more water samples the following day of summer 1999. These samples were taken from Lake Mohave, which is several miles downstream from Lake Mead. Lake Mohave is a smaller lake with considerable less boat traffic. The results were surprising, the amounts of MTBE and BTEX were relatively high.

Table 12 Amounts of MTBE/BTEX Sampled in Cottonwood Cove, Lake Mohave, from USGS study, May 1999

MTBE	.7674 ppb
Benzene	.2423 ppb
Toluene	1.217 ppb
Ethylbenzene	.1871 ppb
Xylenes (Total)	.3983 ppb

Table 13 Amounts of MTBE/BTEX Sampled in Katerine Landing, Lake Mohave, from USGS study, May 1999

MTBE	4.162 ppb
Benzene	1.252 ppb
Toluene	6.184 ppb
Ethylbenzene	1.009 ppb
Xylenes (Total)	1.828 ppb

The Las Vegas Valley Water District which is directly in charge of monitoring the drinking water that is being pumped into the valley, claims they have been randomly

testing for BTEX for almost 10 years now and have never had an exceedence of EPA's drinking water standards. MTBE levels in the intake water have been monitored for the past four years and they have only been detected at very small levels, >1 ppb (Zikmund, 2000).

Discussion

The USGS and the Water District feel that MTBE and BTEX levels in Lake Mead are low enough that there is no need for alarm. From the data received from the USGS and talking with the Water District both seem to not support my thesis that 2 cycle motors need to be banned from Lake Mead. The evidence is just not there to rationalize banning over 10,000 boats from one of the largest recreational areas in the southwestern US. More research definitely needs to be done, it was difficult to base and entire thesis on one unpublished sample from the USGS, but unfortunately, that was all that was there to work with. More data needs to be collected, to better understand the dynamics of Lake Mead and how boat traffic may or may not affect the quality of Las Vegas' drinking water.

To fully understand if a water quality problem exists due to boat traffic, a more extensive, seasonal study needs to be done. To explain the problem of Lake Mead's water pollution, a large study beyond the scope of this paper would be needed. A study that sampled the major marinas, the freshwater intake to Las Vegas, and several random areas in the lake for background. The same areas should be sampled at several different times throughout the year. This could show if there was an obvious relationship between the number boats that use the lake and the levels of MTBE and BTEX during that same

period. Similar studies have been done in Lake Tahoe and Lake Donner, Nevada, and those studies showed much different results than the one, unpublished study preformed by the USGS. In the Lake Tahoe and Donner studies, they detected an extremely large amount of MTBE and BTEX after a holiday weekend with a large amount of boat traffic (Miller, 1998)

The next aspect that needs to be explored is the cumulative effects of boat exhaust pollution. The Lake Mohave levels of BTEX and MTBE were high compared to the amount of boat traffic and size of the lake. One explanation may be that the MTBE/BTEX levels recorded in Lake Mojave were actually pollutants that washed downstream from Lake Mead and Lake Powell. The second reason that the pollutant levels were relatively high in Lake Mohave is that, boaters from California frequent Lake Mohave more. California's gasoline has a larger amount of MTBE in it than the gasoline in Nevada and Arizona.

The water from the Colorado River flows on from Lake Mohave to Lake Havasu, the water then is fed into canals that supply water to both southern Arizona and southern California. (Lake Havasu, is also the arena for many of the jet ski competitions in the world. Hundreds of PWCs visit that lake every year for races and competitions, adding to the pollution problem.). If pollution from boat exhaust is cumulative by the time the water reaches its final destination downstream, it may have extremely high levels of MTBE and BTEX in it.

Only after one or both of those aspects are looked into more closely, will administrators be able to decide if personal watercraft should be banned from Lake Mead.

One way to detour having to ban all personal watercraft is to use the existing technology to reduce the amount of gasoline the two-cycle emits. The technology is available to make the PWC motors run cleaner. The fuel injected two-cycle engines need to be more available to the public, either through incentives from the government or mandates such as the one in Lake Tahoe. That satisfies both the jet ski enthusiasts, as well as protects the public who drinks the water from the lake. New four-cycle jet skis are also being developed and they would be another cleaner alternative to using traditional jet skis.

The main area of concern with the amount of raw gasoline a two cycle marine engine releases into the freshwater reservoirs, is the amount of benzene, toluene, ethylbenzene and xylenes, and MTBE being released. Benzene and the rest of the BTEX compounds, have been studied extensively, MTBE on the other hand hasn't been explored as much. The EPA doesn't quite know the properties of this gasoline additive, and it is listed as a "probable" carcinogen (EPA (b), 1993). The effects on aquatic plants and animals are largely unknown and EPA's safe drinking water standard is a huge window of 20-40 parts per billion (ppb). California has set a drinking water standard for MTBE at 5 ppb for the taste threshold and 13 ppb for health based reasons. Nevada's drinking water limits are 20 ppb for now (NDEP, 2000). The individual states are waiting for EPA's recommendation concerning safe MTBE levels in drinking water, which will not be officially released until August 2001.

As seen in the previous results section, MTBE and BTEX levels are not even close to exceeding any of the water quality limits. Only in one area, Government Wash, did the MTBE levels even reach halfway to the minimum acceptable levels. Again, this

was only one sample, but it was recorded after a fairly high traffic boat day. The samples would still be more relevant if they were recorded at the end of the boating season versus in June, when Lake Mead is just starting to receive most of its boat traffic. But, from the small data set it appears that neither MTBE nor the BTEX compounds pose a threat to Las Vegas' drinking water.

Discussing whether or not MTBE from two-cycle engines is a problem may almost be a mute point in the near future. On March 25, 1999 Governer Davis ordered a phase out of MTBE in all of California's gasoline by December 31, 2002 (Tiemann, 1999). The two and a half year window is for refineries and scientists to develop an alternative to MTBE. This may cause problems with some petroleum companies, on account of MTBE being the second most produced chemical in the United States, 8,000 million kilograms. Although ethanol can be substituted for MTBE, it isn't as effective as MTBE and it is much more expensive. Recently there also has been a strong push in the federal government to relax the Clean Air Act nationwide until a gas-oxygenate substitute can be found. The Clinton administration wants to also phase out MTBE nationwide, but feels that it will realistically take almost ten years to do so.

Overall my findings did not support my thesis. My initial statement that two-cycle marine motors pollute excessively and should be banned from Lake Mead came up empty-handed. No evidence was found to backup my claim. The drinking water that Las Vegas receives from Lake Mead appears, for the most part, to be free of MTBE and the BTEX compounds. Both the Water district and USGS, recognize the problems that two-cycle engines pose, but nothing has been proposed to limit or restrict them. From all the feedback I received from most southern Nevada agencies, Lake Mead is thought of as

recreational area first, and then Las Vegas' drinking water source second, and few measures have been taken to protect the water quality.

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