Appendix C: Water Quality

I. Introduction

Waldo Lake is known for its outstanding water quality. The water has exceptional clarity and the deep blue color contributes substantially to the aesthetic appeal of the area. It is thought to be one of the most oligotrophic (nutrient poor) large lakes in the world. From the surface, it is often possible to see to depths of more than 100 feet. The high degree of clarity of Waldo Lake is due to low concentrations of organic and inorganic suspended particles and low concentration of dissolved organic substances. The water chemistry is reported to be similar to that of distilled water (Salinas 2000). The productivity of microscopic free-floating algae (phytoplankton primary production) is extremely low. Larson (2000) summarizing results of early investigations reported that Waldo Lake may be one of the least productive, freshwater, temperate lakes known.

The lake has a long water retention time estimated to be 32 years (Johnson et al. 1985). It has a maximum depth of 420 feet (128 m) and an average depth is 128 feet (39 m). There are no perennially flowing streams leading into the lake however there are numerous seasonally flowing streams generated by snowmelt runoff. The surface area of Waldo Lake is 6,298 acres (2,549 hectares) comprises approximately one-third of the entire lake basin. These factors along with the relatively stable geology and low levels of human impact are major factors contributing to low nutrient concentrations and low phytoplankton productivity in the lake.

Although the water quality of Waldo Lake remains very high, monitoring data has lead some scientists to conclude that the lake may be changing including a shift toward higher levels of biological productivity in the water column since the 1960s (Larson 2000). These potential changes are primarily based on analysis of three types of monitoring data:

- A change in the optical properties of the water resulting in reduced penetration of blue light into the deeper regions of the lake
- A 20-fold increase in the primary production of phytoplankton
- An increase in the abundance of zooplankton and a shift in the species composition

Additional data is necessary to confirm these results. The Willamette National Forest has completed a Waldo Lake Science Plan (USDA 1999) that contains a strategy for studying baseline conditions and plans for a long-term monitoring program. At the current time, portions of the Science Plan are being implemented and additional studies are anticipated.

In June of 1997, the Willamette National Forest completed a report outlining a management strategy to protect the water quality of Waldo Lake from potential adverse effects associated with recreational use of the area (USDA 1997). The Willamette National Forest has implemented facilities and management changes since 1997 to insure the long-term protection of the water quality of Waldo Lake. These actions include:

- A permanent prohibition of camping on islands

- A temporary ban on camping along a portion of the north shoreline burned in a wildfire in 1996
- Implementation of a visitor education program on low impact recreation techniques
- Decommissioning of a recreational vehicle holding-tank dump station

Projects currently underway to improve facilities in developed campgrounds include:

- Replacement of older flush toilet facilities connected to drain fields and vault toilets with new composting toilets and vault toilets
- Replacement of existing gray water sumps in North Waldo and Islet Campgrounds and installation of new gray water sumps where none previously existed in Islet Campground

The potential for recreational use of the area to have adverse effects on water quality is a concern. This appendix addresses the potential for use of motorized watercraft or shoreline dispersed recreation sites to affect the water quality of the lake.

II. Potential Impacts of Motorized Boats

Watercraft equipped with gas-powered motors release a variety of contaminants into the air and water. Pollutants are released into the water during motor operation, from spills during refueling, and by draining bilge water from boats when they are taken out of lakes at boat ramps. Boat generated turbulence can increase shoreline erosion or re-suspension of bottom sediments increasing the concentration of organic and inorganic particles and nutrients into the water column.

Generally both four-cycle and two-cycle boat motors discharge their exhaust directly into the water. Most watercraft are powered by conventional carbureted two-cycle motors, these engines are reported to expel between 25 percent to 30 percent of their fuel into the water unburned (USEPA 1996, Boughton and Lico 1998, Asplund 2000). Some pollutants evaporate rapidly or they can be mixed into the water and persist for a period of hours to several weeks. In addition some pollutants associated with internal combustion engines can be adsorbed onto particles in the water and settle to the lake bottom where they can persist in the sediments.

Factors that can affect the fuel burning efficiency of two and four-cycle motors include; engine speed, the altitude at which engines are operated and how well they are tuned. Based on the findings of several investigators, Jackivicz and Kuzminski (1973) concluded that outboard motors are less efficient at lower engine speeds. The lower air pressure at high altitudes results in less complete fuel burning, and a poorly tuned outboard engine can use approximately three times more fuel than one properly tuned (Boughton and Lico 1998). A report prepared for the Environmental Quality Commission by the Oregon Department of Environmental Quality reviewed studies assessing the effects of motorized boats on water quality in lakes (Correll 1999). The report concluded that gas-powered boat motors have some negative but as yet unquantified impact on water quality in Oregon.

A. Hydrocarbons and Other Pollutants

Exhaust from conventional outboard motors contains a variety of pollutants. The most commonly studied are several volatile organic compounds (VOCs) including the hydrocarbons; benzene, toluene, ethlybenzene, xylene (BTEX). It is also possible that the fuel and exhaust may contain Methyl *tert*-butyl ether (MTBE). In addition, exhaust emissions contain polycyclic aromatic hydrocarbons (PAHs), and nitrous oxides (Boughton and Lico 1998). The EPA has estimated that a typical new outboard motor can emit as many VOCs in one hour as the typical passenger car traveling 800 miles (USEPA 1991). Motor boat use has also been associated with the potential for discharge of sewage and wastes into lakes. Little is known about the effects of chronic exposure to low concentrations of many motorized boat emissions. Several factors can influence the susceptibility of aquatic organisms to adverse effects of pollution including species specific sensitivity and the life stage of the organism (Bouchard 2000-01).

Volatile Organic Compounds

Although the concentration of BTEX can be exceptionally high immediately after the passage of a motorized boat, the concentration of these compounds in the water declines rapidly as a large portion is volatilized into the air (Correll 1999, Bouchard 2000-01). The rate of evaporation will depend to some extent on the air and water temperature and the degree of mixing with deeper water. If BTEX compounds are mixed below 3.3 feet, the rate of evaporation slows and is a function of the rate of mixing in the water column (Correll 1999).

The BTEX compounds can cause short and long-term adverse health effects. Oregon Administrative Rules for drinking water include maximum contaminant levels[1] (MCL) for VOCs including the BTEX compounds[2]. Oregon Administrative Rules for water quality list benzene, toluene, and ethylbenzene as priority water pollutants[3] (see Table 1).

MTBE is added as a fuel oxygenator for more complete combustion of fuel and has been found in lakes with motorized boating activity. MTBE is highly soluble in water and is resistant to biodegradation (Sakata 2000-2001). The presence of MTBE in lake water has been found to follow the general pattern of recreational use by motorized watercraft with internal combustion engines. The highest concentrations of MTBE are found around marinas or other areas of heavy motorized use (Lico 2004). Studies have measured the highest concentrations during the peak of the boating season and suggest that there is little inter-annual persistence (Reuter et al. 1998). Volatilization is a major mechanism resulting in the loss of MTBE from lake water with wind speed being a primary factor affecting the transfer rate of MTBE from the water to the air (Reuter et al. 1998).

In Oregon, ethanol rather than MTBE is generally used as an oxygenator in motor fuel. Ethanol biodegrades more quickly than MTBE and is expected to have a lower level of risk for drinking water. Although the Oregon Department of Environmental Quality

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[1] Maximum contaminant level (MCL) – the highest level of a contaminant that is allowed in drinking water. MCLs are enforceable standards.
[2] OAR 333-061-0030, Table 4
[3] OAR 340-41, Table 20: Water Quality Criteria Summary

(DEQ) does not require MTBE to be added to gasoline in Oregon, it has been detected in small amounts in the state's gasoline supply. Surveys conducted by DEQ found up to 2 percent MTBE in the gasoline supply. It is thought that it may be entering the state's gasoline supply as a residual component of gasoline from neighboring states such as California that use MTBE extensively. Small amounts of MTBE may also be added to gasoline sold in Oregon to increase octane levels (ODEQ, MTBE Fact Sheet).

Table C-1:. Maximum Contaminant Levels (MCL) and Concentrations for Protection of Aquatic Life as Specified in Oregon Administrative Rules

Contaminant	**MCL (mg/L)**	**Concentration for Protection of Aquatic Life (mg/L)** Fresh Water Acute Criteria
Benzene	0.005	5.300
Toluene	1.	17.500
Ethylbenzene	0.7	32.000
Xylenes (total)	10	-

Small concentrations of MTBE can cause drinking water to be non-potable due to offensive taste and odor. At higher levels it may pose a risk to human health. In December of 1997 the EPA released a non-regulatory advisory for MTBE in concentrations of 20 to 40 parts per billion to avoid unpleasant taste and order effects. The EPA believes MTBE in gasoline poses an unreasonable risk to the environment and has proposed rules to reduce or eliminate its use as a gasoline additive (USEPA, Federal Register, March 24, 2000, Volume 65, no. 58, Proposed Rules, p. 16094-16109).

During the summer of 1997, the U.S. Geological Survey, in cooperation with the Tahoe Regional Planning Agency and the Tahoe Research Group, sampled lakes in the Tahoe Basin for VOCs to determine the presence of gasoline products from watercraft or other sources (Boughton and Lico 1998). Sample sites included areas of boating activity on Lake Tahoe, as well as other lakes with limited or no motorized boating activity as background reference sites.

Results from the USGS study showed detectable levels of MTBE in all Lake Tahoe samples. Concentrations of MTBE were highest in areas with substantial motorized boat activity. In addition, some of the Lake Tahoe samples contained BTEX compounds. In lakes with no motorized boating or where use was limited to a few boats with small two-cycle engines, no MTBE, benzene, or ethylbenzene was detected. Small concentrations of toluene and xylene were detected in some samples from lakes with little or no motorized activity, as well as some quality control samples. Unintentional sample contamination was suspected in those samples from lakes with little or no motorized boating activity. Pollutants from boat motors varied spatially and temporally during the sample period, however, no violations of drinking water standards or health advisories were detected.

Scientists studying Lake Tahoe concluded that 2-cycle motors used in personnel watercraft and other outboard motors accounted for more than 90 percent of the MTBE, 70 percent of the benzene, and 80 percent of the toluene into the lake. By contrast, four-cycle, inboard, fuel injected motors emitted 8 percent of the MTBE, 28 percent of the benzene, and 17 percent of the toluene. There was no evidence of deposition or accumulations of MTBE or BTEX to the bottom of the lake (USDA 2000a).

In another study on Lake Tahoe, researchers found in open waters with motorized boat use, concentrations of MTBE and BTEX were at or below detectable limits. At sites with concentrated use by 50 to 100 watercraft motors, samples contained MTBE and benzene concentrations that exceeded drinking water standards, however, concentrations did not approach the criteria for protection of aquatic life (USDA 2000a).

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds that include several petroleum products and their derivatives. PAHs make up approximately 30 percent of the compounds found in gasoline. The PAHs in gasoline have primarily two or three benzene rings[4] and during the combustion process, heavier four or five ring compounds can be formed. In general, PAHs with more than three rings have poor biodegradability and can bioaccumulate (TRPA 1999).

The presence of PAHs in aquatic environments has been documented in many locations around the world (Wakeham et al. 1980, Helfrich and Armstrong 1986, Mastran et al. 1994, Vilanova et al. 2001). PAHs in the environment originate from many sources including; natural petrogenic (petroleum-generating) processes (Mastran et al. 1994), combustion processes including forest and prairie fires, decaying organic matter (Wakham et al. 1980), and volcanic eruptions (Ogunfowokan et al. 2003). The combustion of gasoline and diesel fuels, coal and wood are most likely the greatest sources of anthropogenic PAHs (Helfrich and Armstrong 1986). Inputs of anthropogenic PAHs into aquatic environments can come from atmospheric deposition (Heit and Klusek 1984, Vilanova et al. 2001), urban storm water runoff, municipal or industrial effluents (Helfrich and Armstrong 1986), or from motorized boat emissions (Mastran et al. 1994, Mosisch and Arthington 2001). PAHs have been detected even in remote mountain lakes with little human disturbance in their basins indicating atmospheric deposition as the primary pathway in these locations (Vilanova 2001, Heit and Klusek 1984). The concentration of PAHs found in remote aquatic environments is much lower than levels found in polluted aquatic systems associated with higher levels of human use (Heit and Klusek 1984).

Although some PAHs in lakes can originate from atmospheric deposition or are carried to the lake in surface water runoff, internal combustion engines associated with boating activity are thought to be the significant source of PAHs in lakes with this activity

[4] A single benzene ring is composed of 6 carbon atoms and 6 hydrogen atoms

(Mastran et al. 1994, Mosisch and Arthington 2001). Mastran et al. (1994) found detectable levels of PAHs in the water column of a reservoir used as a source of drinking water and for boating with engines size limited to a maximum of 10 horsepower during peak boating periods. In that study no PAHs were detected in the water column during periods of low boating activity. Concentrations of PAHs tend to be highest in the vicinity of marinas or other area of heavy boating activity (Mastran et al. 1994, Asplund 2000, Lico 2004).

PAHs are not as soluble as some other pollutants (Mastran et al 1994) and tend to evaporate at a lower rate than BTEX compounds (TRPA 1999, Bouchard 2000-2001). The PAHs benzo(a)pyrene, chrysene, fluoranthene, phenanthrene and pyrene are known to be associated with the combustion of fossil fuels (Mosich and Arthington 2001). Mastran et al. (1994) reported that fluoranthene, phenanthrene, and pyrene were common in the sediments of a reservoir with motorized boating activity. Mosisch and Arthington (2001) reporting on PAH residues from motor boats in the sediments of a lake found benzo(a)pyrene, fluoranthene, and pyrene at all sample locations. PAHs derived from combustion sources tend to have more of the higher molecular weight compounds including phenanthrene, fluoranthene, pyrene, and benzo(a)pyrene (Helifrich and Armstrong 1986, Mastran et al. 1994). The lower molecular weight PAHs (acenaphthene, naphthalene, and fluorene) are generally rapidly removed from the water column through volatilization and microbial degradation. The higher molecular weight PAHs are more susceptible to losses due to photo-oxidation and may be deposited in the sediments (Mastran et al. 1994). As a result, PAHs found in the water column do not persist one season to the next (Bouchard 2000-01) and are generally associated with recent or chronic pollution (Mastran et al. 1994). It has been estimated that up to 50 percent of the higher molecular weight PAHs entering the water can be deposited into bottom sediments where they are resistant to degradation and can persist for long periods of time (Mosisch and Arthington 2001).

In a study at Lake Tahoe before and after a ban on two-stroke motors, Lico (2004) reported that PAH concentrations and distributions were similar before and after the ban. Lico (2004) noted that the newer type of direct-injected two-stroke motors have been reported to emit similar amounts of PAHs when compared to those released by older carbureted two-stroke motors.

PAHs are known carcinogens and mutagens, and are toxic to aquatic organisms. Oris et al. (1998) conducted a series of experiments at Lake Tahoe to assess the potential toxic effects of ambient levels of motorized watercraft emissions on zooplankton and fish larvae. These investigators found sufficient concentrations of PAHs present to cause measurable adverse impacts on fish larvae growth and zooplankton survival and reproduction; and that the PAH concentration was related to the level of motorized watercraft activity. In a study of the effects of outboard motor emissions on fish, Koehler and Hardy (1999) concluded that moderate use of two-cycle outboard motors on large lakes resulted in little to no adverse effects on water quality. However, these investigators found that heavy use of two-cycle motors on small lakes with limited dilution capacity could result in PAH concentrations large enough to inhibit early life stage development of some fish. Table 2 contains threshold effect and probable effect concentration values for PAHs for the protection of aquatic life in sediments as stated in guidelines proposed by the US Environmental Protection Agency (USEPA 2002).

Nitrogen Oxides

Nitrogen oxide compounds are released into the water from outboard motors and can potentially be converted to nitrates. Nitrogen oxide compounds discharged into the air from boat motors can also be transformed into nitrates by atmospheric processes and potentially be deposited into the lake (TRPA 1997). Nitrates are essential nutrients for aquatic plants and algae and their availability often limits plant growth in aquatic environments.

Table C-2: Consensus-based Threshold Effect Concentrations[5] (TEC) and Probable Effect Concentrations[6] (PEC) for PAHs in Sediment in µg/kg dry weight (USEPA 2002).

PAH compound	Consensus-Based TEC	Consensus-Based PEC
Naphthalene	176	561
Acenaphthylene	NG	NG
Acenaphthene	NG	NG
Fluorene	77.4	536
Phenanthrene*	41.9	1170
Anthracene	57.2	845
Fluoranthene*	111	536
Pyrene*	53	1520
Benzo(a)anthracene	31.7	1050
Chrysene*	57.1	1290
Benzo(b)fluoranthene	NG	NG
Benzo(k)fluoranthene	NG	NG
Benzo(a)pyrene*	31.9	1450

***** PAHs known to be associated with the combustion of fossil fuels. NG – No Guidance

[5] Threshold Effect Concentration below which harmful effects are unlikely to be observed (USEPA 2002)
[6] Probable Effect Concentration above which harmful effects are likely to be observed (USEPA 2002)

Sewage and other wastes

Discharge of sewage and other wastes from boats has the potential to degrade water quality particularly where motorized boat use is concentrated. Large boats can discharge black wastes[7] or gray water[8] from facilities on board or human wastes can be tossed over the side of boats. Liddlf and Scorgie (1980) noted that the degree sewage from boats has potential to impact the nutrient status of a water body depends to some extent on the "natural" nutrient status of the water body and the quantity and composition of the effluent. In oligotrophic lakes, even a small increase in nutrient availability can promote the growth of algae.

B. Sediment and Physical Disturbance from Motorized Boats

Physical effects of motorized boat operation can include the cutting effects of propeller action on aquatic vegetation, and direct contact of the boat or motor with benthic organisms (Liddlf and Scorgie 1980, Mosisch and Arthington 1998). In addition, studies have shown motorized boats can generate suspended sediment due to shoreline erosion from boat wakes, or in shallow areas, by the turbulence created near the sediment water interface (Asplund 2000). The re-suspension of bottom sediments can also incorporate nutrients that promote the growth of phytoplankton into the water column. Yousef et al. (1980) concluded that suspension of bottom sediments by motorboats can increase turbidity and concentrations of orthophosphate and total phosphorus in the water column potentially increasing lake productivity. However, Yousef et al. (1980) found that in a deep lake with a sandy bottom the potential to effect turbidity or nutrients was significantly reduced.

An additional factor that can reduce the potential for phosphorus mixed into the water column by boat turbulence to contribute to lake productivity is how well the nutrient phosphorus is strongly adsorbed onto sediment particles under oxygenated conditions (Wetzel 2001). Increases in suspended particulate matter, either organic or inorganic, has the potential to reduce water clarity. In addition, particles suspended in the water can reduce light penetration potentially reducing the productivity of a lake (Kirk 1985).

C. Revised EPA Standard for Boat Motors

The EPA established a new standard for watercraft motors that went into effect December 3, 1996 (USEPA, Federal Register, October 4, 1996, Volume 61, No. 194, Rules and Regulations, pp. 52087-52169). These regulations apply only to new outboards and new personal watercraft motors.

The new standard requires a 75 percent reduction in hydrocarbon emissions, from 1996 levels by the year 2006. The new standard is being applied on a corporate average basis requiring that the average emissions of engines for a manufacturer must comply over its

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[7] "Black waste" means human body wastes including feces, urine, or other extraneous substances of body origin and toilet paper. OAR 340-071-0100(16)

[8] "Gray water" means sewage such as bath water and kitchen waste water that does not contain human body wastes including feces, urine, other extraneous substances of body origin and toilet paper. OAR 340-071-0100(68)

entire product line. Some new engines could still use conventional technology after the year 2006 as long as emission reductions are achieved when averaged over the entire range of products. The emission controls for these new engines have an increasingly stringent phase-in period that began in 1998. One benefit the EPA anticipates from the new emission standards is an increase in fuel economy. The EPA estimates changing outboard engines from conventional two-cycle to four-cycle technology will result in decreased fuel consumption by approximately 31.5 percent (USEPA 1996b)

The new EPA emission standards are expected to increase the amount of nitrogen oxide emissions from outboard and personal watercraft motors by a relatively small amount. Nitrogen oxide emissions from these engines are expected to increase from a range of 0.5 g/kw/hr up to 4.0 g/kw/hr to a maximum rate of 6.0 g/kw/hr over the phase-in period (USEPA 1996b). Depending on the amount of nitrate and nitrite which is converted from nitrogen oxide emissions, this change in engine technology has potential to increase nitrogen loading to the lakes to some extent.

There are a number of existing motor technologies that currently meet the new EPA standard for reduced hydrocarbon emissions. These available options include two-cycle direct fuel injection engines, four-cycle engines, and electric motors.

III. Dispersed Recreation Sites

Studies attempting to link the intensity of dispersed recreation on water quality have produced a variety of conflicting results ranging from a positive correlation to none (USDA 2000a). Nevertheless, dispersed recreation sites have the potential to be source areas for sediment or other contaminants introduced by visitors.

A. Sediment and Dispersed Recreation

Heavily impacted dispersed recreation sites located on or near the shoreline of lakes can be source areas of sediment. Although the impacts of dispersed recreation on sediment delivery have not been systematically quantified (USDA 2000a), the trampling of vegetation in heavily used sites results in core areas of bare soil and user defined trails that lack soil-stabilizing vegetation. Lifflf and Scorgie (1980) noted that along shorelines some people will deliberately clear marginal vegetation to gain easier access to the water and vegetation may also be damaged by people walking parallel to the water’s edge. Surface runoff from heavily impacted sites has the potential to contribute sediment to adjacent water bodies. As the frequency of dispersed site use or the number of dispersed sites increases around a water body, there is the potential for adverse water quality effects by sediment transport from these dispersed recreation sites.

B. Microorganisms and Pollutants

Improper use of soaps and detergents by people using dispersed recreation sites can also be a source of pollution for lakes. Introduced soaps and detergents, particularly those with high phosphorus content, have the potential to increase the availability of nutrients for algae or aquatic plants growing in the lake. Increased growth of phytoplankton in lakes has the potential to decrease water clarity and penetration of light to deepwater areas.

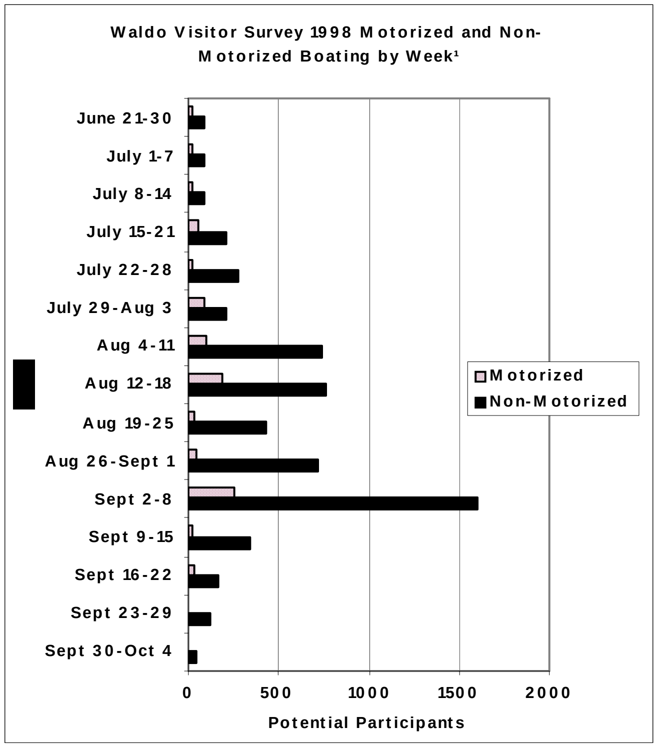
Improper disposal of wastes from humans or their animals has the potential to introduce pathogenic microorganisms (i.e. *Cryptosporidium* spp. and *Giardia* spp.) into adjacent water bodies. However, pathogenic microorganisms have been found in water in watersheds where recreation is prohibited (USDA 2000a). Human or animal waste in lake water can also be a source of nutrients (particularly nitrogen and phosphorus) that can increase productivity in the lake.

IV. Potential Impacts to Waldo Lake

A. Motorized Boats

The number of motorized boats currently using Waldo Lake during the summer boating season is low. The peak recreation season is short, generally from mid-June through the first week of September with the most of the use occurring on weekends. The majority of current boating use on Waldo Lake is non-motorized (boats propelled by paddle or sail). Figure 1 displays a summary of data collected during the 1998 summer season comparing the numbers of people using motorized verses non-motorized boats.
The State of Oregon has placed a speed restriction for motorized boats over the entire surface of Waldo Lake (OAR 830.185/250-020-0221). A 10 mph speed limit applies to the majority of the lake, however within 300 feet of a boat ramp or moorage, a slow no wake, 5 mph maximum is in effect. These speed restrictions have essentially eliminated water skiing and use by personal watercraft (e.g. brand name Jetskis or similar watercraft) is very rare.

Figure C-1: Boating Use by Week



[1] Data includes only surveyed visitors, not total boating use, as a representative sample.

Hydrocarbons and Other Pollutants

Since the majority of motorized boat use on Waldo Lake occurs in late summer when air and surface water temperatures are relatively high, volatilization rates of unburned hydrocarbons, including BTEX compounds and lower molecular weight PAHs, will be high. In addition, the water of Waldo Lake generally contains few suspended particles that would potentially act adsorption sites for higher molecular weight PAHs.

Waldo Lake becomes thermally stratified during the summer boating season causing warmer surface waters to be highly resistant to mixing with deeper, colder water. Since the average depth of Waldo Lake is 128 feet (39 m) and the thermocline is generally at a depth between approximately 33 feet (10 m) and 66 feet (20 m) (Salinas 2000), a large portion of the bottom area of the lake is isolated from surface waters during the summer boating season. This stratification minimizes the potential for direct impacts of boat motor emissions to the biota of these deeper areas.

The risk of contamination by detectable levels of MTBE in Waldo Lake is low due to the small percentage of the state's gasoline supply containing MTBE, low motorized use levels on Waldo Lake, volatilization rates of MTBE, and short season of use. In addition, it is likely the use of MTBE as a gasoline additive will be greatly reduced or eliminated in the future.

Areas near boat ramps and docks are more susceptible to impacts from motorized boats than open water areas. Waters around the North Waldo and Shadow Bay boat ramps, and to a lower degree at the Islet boat ramp, experience more concentrated motor boat use and related vehicle traffic. These waters are also shallow and partially confined by islands or peninsulas which limit the degree they mix with water from the large, open portions of the lake. These factors result in a decreased dilution potential near these boat ramps.

In addition to more concentrated boat traffic, boats frequently refuel at these sites, bilge water is drained from boats when removed from the lake on ramps, operators frequently warm-up the boat engines by idling them in one location for period of time, and gas and oil residues from tow vehicles can wash into the water. In the vicinity of boat ramps and docks, PAHs or BTEX compounds may be detectable in the water column during peak boating periods primarily from August 1 through the Labor Day weekend. These pollutants would not be expected to persist in the water column from one season to the next. Due to the potential for PAHs to be adsorbed onto sediment particles and the slower rate of biodegradation of these compounds, there is a potential for accumulations of PAHs in sediments adjacent to boat ramps where they could potentially be damaging to benthic organisms.

Limited monitoring data is available to determine the current level of hydrocarbon or other potential pollutants from boat motors in Waldo Lake. To determine if motorized boat emissions have resulted in significant build-up of PAHs in the sediments of Waldo Lake, sediment samples were collected in November 2003 at eight sites in Waldo Lake and analyzed for PAHs. Two samples were taken near each of the three boat ramps and two additional samples were taken at more remote sites in the southern portion of the lake. CH2M Hill Applied Science Laboratory located in Corvallis, Oregon performed the PAH analysis on these samples. These samples were analyzed for PAHs known to persist in lake sediments and include those PAHs associated with the burning of fossil fuels and motorized boat use. None of the samples analyzed contained concentrations of PAHs above detectable levels at the specified reporting limits as displayed in Table 3. All of the reporting limit values from Waldo Lake sediment samples (Table 3) were lower than the Threshold Effect Concentrations (Table 2) below which harmful effects are unlikely to be observed (USEPA 2002).

As newer reduced-emission engines become more common in the future, the potential for watercraft engines to adversely affect water quality will decrease. It likely will be several years, however, before significant reductions in emissions can be achieved through new emission standards as the replacement of older engines with new technology has been moderately slow.

Table C-3: Lowest Detectable Reporting Limit for PAHs in Waldo Lake Sediment Samples (µg/kg dry weight)

	Sample Location and Site Number							
Analyte (PAH)	**North Waldo 1**	**North Waldo 2**	**Islet 1**	**Islet 2**	**Shadow Bay 1**	**Shadow Bay 2**	**South Waldo[1] 1**	**South Waldo[1] 2**
Naphthalene	16	19	10	15	13	13	14	14
Acenaphthylene	16	19	10	15	13	13	14	14
Acenaphthene	16	19	10	15	13	13	14	14
Fluorene	16	19	10	15	13	13	14	14
Phenanthrene[2]	16	19	10	15	13	13	14	14
Anthracene	16	19	10	15	13	13	14	14
Fluoranthene[2]	16	19	10	15	13	13	14	14
Pyrene[2]	16	19	10	15	13	13	14	14
Benzo(a)anthracene	16	19	10	15	13	13	14	14
Chrysene[2]	16	19	10	15	13	13	14	14
Benzo(b)fluoranthene	16	19	10	15	13	13	14	14
Benzo(k)fluoranthene	16	19	10	15	13	13	14	14
Benzo(a)pyrene[2]	16	19	10	15	13	13	14	14

[1] Remote sites distant from areas of concentrated use near boat ramps
[2] PAHs known to be associated with the combustion of fossil fuels

The EPA expects that emissions of hydrocarbons from boat motors will be reduced by 50 percent by the year 2020, and by 75 percent by the year 2025 (USEPA 1996a). It should be recognized however that a 75 percent reduction in hydrocarbons is measured as a corporate average, and it is possible that the cumulative emissions of motorized boats used on Waldo Lake may not actually achieve this level of reduction. In addition, hydrocarbon emissions from motors operated at Waldo Lake could be greater due to the lake's altitude. Engines properly tune for lower elevations would likely burn fuel less efficiently at the elevation of Waldo Lake (5,414 feet), and potentially increase emissions during operation.

Nutrient loading from motorboats has the potential to increase in the future depending on the amount of nitrogen oxide emissions converted to nitrate. The extent that nitrogen compounds from boat motor emissions would add to the nutrient loading of the lake cannot be reliably estimated. Algal bioassays conducted on water from Waldo Lake by Miller et al. (1974) indicated that the addition of nitrogen alone did not increase algal growth, so some other nutrients (other than nitrogen or phosphorus) could be limiting algal growth in Waldo Lake. In addition, several species of cyanobacteria capable of fixing nitrogen are known to cover a large portion of benthic surfaces in Waldo Lake (Johnson and Castenholz 2000). These benthic cyanobacteria can provide a nitrogen source in a form that plants can utilize for growth when nitrogen becomes limiting. Because nitrogen has not been found to limit algal growth in Waldo Lake, it is not likely that increased nitrogen loading from motor boat use in Waldo Lake would have a significant effect on the water quality or lake biota.

The 10 mile-per-hour speed limit on Waldo Lake when combined with new engine technology would likely reduce the potential for contaminants from outboard motors. Four-cycle outboard motors operating at the low to mid-range of their capability are very fuel-efficient and generally would achieve the maximum speed allowed within this range of operation. At full throttle, however, both four and two-cycle of engine tend to use more fuel and are similar in efficiency (Fleming 2000).

Some outboard motors on Waldo Lake are used primarily for auxiliary power. Large sailboats often use outboard motors only while maneuvering near boat ramps and bays, or when wind conditions are not favorable for sailing under wind power alone.

Contamination during refueling is likely to be a small source of pollutants due to the relative low numbers of motorized boats and a lack of refueling facilities within the basin. Releases that do occur during refueling are the result of individual operator error, but should be infrequent.

As use of gasoline-powered boat motors, including older two-cycle motors, continues on Waldo Lake into the future and use levels increase in parallel with projected population increases in Oregon, contaminate levels in Waldo Lake from boat motor use will likely increase for at least several years. The new EPA emission standard will likely decrease the potential for pollution from boat motor hydrocarbons over time. Detectable impacts to water quality could occur in the future, however, if there is a substantial increase in the number of gasoline-powered motorboats. Due to unknown factors related to the future rate of emissions and variables affecting the persistence of pollutants in the environment, a threshold for acceptable gasoline-powered boat motor use to avoid adverse environmental effects cannot be reliably quantified.

Sewage

Since the majority of boat use is non-motorized and large boats comprise a small component of the recreation use, the current discharge of sewage into Waldo Lake from motorized boats is not likely to be a notable problem. This finding is consistent with observations by Forest Service personnel who have noted few problems associated with the discharge of sewage from boats. In addition, the Forest Service has received few complaints from lake visitors related to the discharge of sewage from boats. Improperly treated human waste from dispersed recreation areas along the shoreline of the lake could represent a higher risk of water pollution than waste discharge from boats.

Sediment and Physical Disturbance from Motorized Boating

Nearly all of the shoreline of Waldo Lake is composed of rocky substrate of various sizes highly resistant to the erosive effects of waves. In addition, the State of Oregon has placed a 10 mph speed limit for motorboats and a slow no-wake maximum 5 mph speed restriction within 300 feet of boat ramps. These speed limits further reduce the potential for significant shoreline erosion from boat wakes (ORS/OAR 830.185/250-020-0221).

Because the majority of Waldo lake is relatively deep (average depth 128 feet), only a small portion of the lake bottom is susceptible to suspension of sediments from boat motor-generated turbulence. Due to the small area affected, re-suspension of bottom sediments and associated nutrients (primarily nitrogen and phosphorus) are not likely to have a significant effect on water quality. Algal bioassays conducted on water from Waldo Lake by Miller et al. (1974) indicated that some other nutrients besides nitrogen or phosphorus could limit algal growth in the Waldo Lake.

Adverse effects to submerged aquatic plants from motorized boating in Waldo Lake is likely to be minor because of average water depths and the generally rocky substrate near shore does not support an extensive macrophyte population in this shallow water zone. Although boating use does result in disturbance to emergent vegetation along the shoreline in popular areas where people pull their boats up onto the shore, overall the number of dispersed sites impacted by this activity is higher from non-motorized boat use.

An exception to the deep water condition is the area near the boat ramp in Shadow Bay. Due to the shallow water in this area, particularly during the late summer and fall seasons, turbulence from motorized boats can disturb fine bottom sediments. Surface observations have shown that the visible effects of this sediment disturbance are short in duration. In addition, under oxygenated conditions, the phosphorus potentially released from the sediments by motor turbulence in this area is strongly adsorbed back onto particles in the water and the majority of phosphorous returns to the lake bottom with sediment particles. Due to the small area affected, a short boating season, and lower use levels than the North Waldo boat ramp, disturbance of lake sediments by boat motors is not likely to have significant adverse effect on water quality in the lake.

B. Dispersed Recreation Sites

Visitor surveys from the Waldo Lake area indicate the majority of overnight visitors stay in developed campgrounds where facilities help to reduce the potential impact of concentrated use. Use of dispersed sites is less regulated and has the potential to produce adverse impacts.

One important factor for reducing water quality impacts from dispersed recreation activities is visitor education that emphasizes proper waste disposal and appropriate camping behaviors. The Willamette National Forest has an ongoing visitor education program at Waldo Lake during the summer season. Goals of this program include educating visitors about low impact techniques to help protect the water quality of Waldo Lake, and the unique qualities of the Waldo Lake ecosystem.

Sediment and Dispersed Recreation

Currently fifty-one (51) inventoried dispersed recreation sites are located along the lakeshore outside of developed campgrounds. The principal use of these sites is for overnight camping. These sites typically have barren core areas of compacted soil and trails which lack soil stabilizing vegetation or a buffering duff/litter layer. Currently the combined barren core area of all 51 dispersed recreation sites totals less than two acres.

Without mitigating management actions, an increase in the use of dispersed recreation sites in the future would likely lead to expansion of the barren core areas of at least the most popular sites. In addition, as the number of visitors exceeds the capacity of the existing number of sites, additional new sites will likely be established in the future to meet demand.

Although it is unlikely that dispersed recreation sites are creating measurable adverse impacts to water quality at the current time, a substantial increase in the number or size of barren core areas and user trails in the future cumulatively could have the potential to produce adverse effects.

Microorganisms and Pollutants

Since pathogenic microorganisms have been found in water even where human recreational use is prohibited, the presence of these organisms in Waldo Lake is possible under any dispersed site use level. Increasing human use in the future could increase the risk of introduced contaminants from human wastes or products such as soaps or detergents affecting the water quality of Waldo Lake. A short season of high recreational use, the fact that most overnight visitors stay in developed campgrounds where wastes can be more effectively managed, and the dilution capacity of the lake all contribute to lowering the potential for adverse water quality effects from human contaminants. This potential is not likely to change much in the future, at the projected rate of growth in recreation use at Waldo Lake.

Algal bioassays have shown that increases in nitrogen alone to Waldo Lake water did not stimulate algal growth (Miller et al. 1974). In addition, several species of cyanobacteria are known to cover a large portion of benthic surfaces within Waldo Lake (Johnson and Castenholz 2000). Some of these species of cyanobacteria are known to have the ability to fix nitrogen and have the potential to be a significant source of this nutrient under conditions when nitrogen limits productivity. As a result, an increase in the availability of combined nitrogen in Waldo Lake from human waste as a result of dispersed recreation use is not likely to significantly increase productivity in Waldo Lake.

The addition of the phosphorus to Waldo Lake from improperly disposed human waste at dispersed recreation sites, however, does have the potential to increase nutrient availability to a limited degree. Such increases are not likely to significantly increase the productivity of the lake due to factors such as a short season of use and the concentration of overnight use in the campgrounds where human wastes can be effectively managed. Current management direction prohibiting camping on islands also ensures that human wastes are not deposited near the shoreline of the lake. Finally, the environmental education program at Waldo Lake helps mitigate phosphorous sources by providing visitors with information on how to properly dispose of human waste and kitchen water.

Additional management regulations that limit use or restrict certain types of visitor behavior would reduce the potential for adverse affects to water quality in the future. Requiring potentially high impact activities to occur further from the edge of the lake (e.g. designating the location of overnight dispersed sites) would reduce the risk of adverse effects to water quality from human use.

V. Conclusions

No evidence currently exists that conclusively links recreation activities on or in the vicinity of Waldo Lake to a decline in the water quality of the lake. If water quality has indeed changed over the last 30 years, increasing recreational use (including motorized boating or dispersed camping) has potential to contribute to changes in water quality. Further studies will be necessary to understand how these recreational uses may be impacting the ecology of the lake.

At current use levels, however, it is unlikely that motor boats or dispersed site use is having significant adverse effects on the water quality or biota of the lake. In the future, as population growth continues in the state's urban areas, recreational use of Waldo Lake is likely to grow in all seasons but particularly during the mid-summer to fall seasons. Increasing recreational use is likely to place more stress on the relatively fragile environment surrounding the lake, which may require additional measures to protect these unique qualities of Waldo Lake.

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