Big Lake Water Quality Monitoring: 2013

Prepared for: Alaska Department of Environmental Conservation

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Definitions and Acronyms

µg/L	Micrograms per liter, parts per billion
mg	Milligram
m	Meter
km	Kilometer
mm	Millimeter
mi	Mile
BTEX	Constituents of gasoline (Benzene, Toluene, Ethyl Benzene, and Xylene) used to calculate TAH
C	Temperature in centigrade or Celsius units
DEC	Alaska Department of Environmental Conservation
EPA	U.S. Environmental Protection Agency
gal	U.S. Gallons
hp	Horse power, rating of motor size
mg/L	Milligrams per liter, parts per million
TAH	Total aromatic hydrocarbons; sum of benzene, toluene, ethyl benzene, and xylene
WQC	Water quality criterion (parameter specific criteria contained within the WQS)
WQS	Alaska Water Quality Standards 18 AAC 70

1.0 Summary

The Department of Environmental Conservation (DEC) conducted water quality monitoring on Big Lake in the summer of 2013 to determine whether the lake was meeting the Water Quality Criterion for Total Aromatic Hydrocarbons (TAH), which are constituents in gasoline. Previous sampling on Big Lake (2004, 2005 and 2009) found that water quality did not meet the State of Alaska criterion. DEC has been working with the community to educate boaters on ways to reduce petroleum hydrocarbons entering the lake. Water quality sampling was also conducted to examine whether improvements in water quality could be measured since implementing the “Keep Big Lake Clean” campaign.

Sampling was conducted on 9 days at 11 sampling locations. Samples were collected June 7-10, June 29 and July 4-7, 2013. Sampling was conducted over 96 hours because the chronic TAH criterion is based on 4 days of exposure. Sampling locations were in the East Basin and mirrored previous studies. The number of watercraft operating during sampling were also determined.

The project report is currently in draft format. The results of sampling found the following:

- Average 4-day TAH concentrations exceeded the Water Quality Standards criterion values of 10 µg/L at three sites during the June 7 – 10 sampling event, but not during the July 4 – 7 sampling event.
- TAH concentrations were highest at sites close to boat launches and marinas which is consistent with previous studies.
- Cumulative TAH concentrations over the 4-day sampling events were strongly correlated with cumulative watercraft hours and this relationship provides a metric to evaluate changes in water quality over time.
- Personal watercraft accounted for approximately 25% of all watercraft and known 2-cycle motors approximately 13% of all watercraft.
- Mixing depth, in addition to boat motor size and motor type, must be considered when evaluating the effects of TAH discharge from watercraft on Big Lake TAH concentrations.
- Average discharge was 0.33 gallons per boat hour. If watercraft are burning 4 gallons per hour, this represents an inefficiency of 8.2%for all boats/motor types.
- During these two sampling events, ~34 to ~200 gallons of gasoline per day were discharged into Big Lake.

TAH concentrations did not show a statistically significant increase or decrease from prior sampling events.

2.0 Introduction

2.1 Background

Portions of Big Lake have been identified as not meeting the state water quality criterion for petroleum hydrocarbons. A Total Maximum Daily Load (TMDL) plan is currently being implemented. Big Lake water quality monitoring is being conducted to determine the effectiveness of implemented control measures at reducing hydrocarbon concentrations and the temporal duration of exceedances.

The Department of Environmental Conservation (DEC) performed water quality monitoring in Big Lake in the summer months of 2004 and 2005, and the data showed that the shallow waters (less than 5 meters) of Big Lake had elevated levels of petroleum hydrocarbons. Specifically, total aromatic hydrocarbons (TAH) persistently exceeded the water quality criterion of 10 µg/L during the summer months. Based on these data, the Department added Big Lake to the Section 303(d) list of impaired waters in 2006. The 303(d) list represents those waters in the state that do not meet applicable water quality standards. Additional water quality monitoring in 2009 verified the 303(d) listing and the elevated TAH concentrations.

In 2012 the Environmental Protection Agency approved the Total Maximum Daily Load (TMDL) for Big Lake to address the impairment by petroleum products. The TMDL is expressed as a concentration, equivalent to Alaska's numeric water quality criterion for TAH of 10 µg/L. The primary source of petroleum hydrocarbons in Big Lake is motorized watercraft. Results from monitoring conducted in 2004, 2005 and 2009 show that elevated concentrations of petroleum hydrocarbons occurred at times and locations of increased motorized watercraft usage on Big Lake, including on high use weekends and near marinas, boat launches and other high traffic areas in the East Basin. Whereas petroleum hydrocarbon concentrations were below the criterion at sampling locations and times when watercraft activity was low. The hydrocarbons can come from gasoline leaks and spills but most of it likely results from the combustion process of gasoline motors, which release unburned fuel out of the exhaust into the water during combustion. This is especially the case with carbureted 2-cycle motors. More gasoline motors on the lake at any given time increases the amount of gasoline being released.

Efforts are being made to address the gasoline-related impairment in Big Lake. Most notably there is currently a coordinated effort with the Big Lake community and other local, regional and federal stakeholders implementing many actions listed in the Big Lake water quality action plan. Specific actions include development of a "Clean Boating on Big Lake" campaign, which includes a program to talk to people one-on-one about pollution prevention, signs, educational materials, and bilge pads and socks for the treatment of bilge water. Actions also include encouraging marinas to become certified in the Alaska Clean Harbors program.

2.2 Project Objectives

DEC developed the following objectives for 2013 sampling. These objectives were developed to determine if TAH concentrations continue to exceed WQC, and to provide an initial evaluation of the effectiveness of implemented education and fuel management control measures.

1. To provide the Department a sample plan for approval that addresses sample timing, locations, protocols, equipment and other logistics for evaluating the petroleum hydrocarbon impairment in the east basin of Big Lake. The sample plan will also include gathering information on motorized water craft usage on Big Lake during the sample period.

2. To provide the Department with a Quality Assurance Project Plan (QAPP) for approval for petroleum hydrocarbon sampling.
3. To coordinate and conduct field sampling events during May – early July with a focus on weekends and especially the holiday weekends of Memorial Day and Independence Day.
4. To collect motorized watercraft usage information on Big Lake during open water months and correlate this information to petroleum hydrocarbon pollutant loading in the lake.
5. To provide the Department with monitoring results specific to these sample events as well as in relation to cumulative results previously collected by the Department in 2004, 2005 and 2009 to determine if there has been an improvement in water quality. The study report will also provide a discussion of the results, conclusions and recommendations. The discussion should include descriptions of water quality standard exceedances, probable sources and loadings of petroleum hydrocarbon pollutants and potential best management practices that may address pollutants of concern.

3.0 Methods

A Quality Assurance Project Plan (QAPP) and sampling plan were developed and approved by DEC for water quality monitoring in Big Lake. The QAPP and sampling plan describe project objectives, sample collection, handling, preservation, analyses and reporting. The sampling plan was implemented in June and July of 2013.

3.1 Sampling Dates and Locations

Water samples were collected during two 4-day (96 hour) sampling events. The first sampling event was June 7, 8, 9, 10 (Friday, Saturday, Sunday, and Monday). The second sampling event was on. July 4, 5, 6, and 7 (Thursday, Friday, Saturday, and Sunday). Sampling also was conducted on Saturday June 29, 2013. Sampling occurred at 11 sampling locations within the East Basin. Sample sites were selected based on locations used in previous studies to provide continuous and comparable values (Table 1 and Figure 1). Sites included high traffic areas and sites that during previous sampling often had high and low amounts of pollution. Samples were collect throughout the day (09:00, 12:00, 15:00, 18:00, and 22:00) from two locations (BL-4, and BL-27) and once per day between 18:00 and 21:30 at the remaining sites.

3.2 Sampling Collection, Handling, and Analytical Methods

Sampling locations were accessed both by boat (4-stroke outboard or inboard motor) and by kayak. The motor was turned off for 10 minutes prior to sample collection off the bow.

Water samples were collected using the USGS-designed volatile organic carbon (VOC) sampler distributed by Wildco from 15 cm below the water surface. Prior to sample collection, the VOC sampler was decontaminated with Alconox detergent and rinsed thoroughly using the public water supply. The sampler was rinsed three times with lake water at each site prior to each sample collection.

Samples were collected in two 40 ml pre-cleaned new amber vials provided by the analytical laboratory (AM Test Laboratory Inc.). The sample was preserved with 2 drops of HCl (hydrochloric acid). Clean vinyl gloves were worn at all times when handling sampling bottles. The samples were checked to ensure that there were no air bubbles after capping. The sample bottles were labeled using adhesive labels, placed within a cooler on frozen gel-packs (<6°C) and shipped to AM Test Laboratory in Kirkland, WA for analyses. Sample temperatures were recorded by the contract laboratory upon receipt. Sealed trip blanks provided by AM Test Laboratory accompanied the sample bottles during collection, shipping, and analyses. One field blank was collected on each sampling date by submerging the VOC sampler into a bucket of hydrocarbon-free water. One replicate sample was collected from one location (BL-8 or BL-10) on all sampling dates.

Table 1. Name and description of 2013 sampling sites

Site	Description
BL-2	Major traffic lane between the east and west basins.
BL-3	Historical USGS sample site at the deepest area of the east basin.
BL-4	Near the South Shore State Recreation Site approximately 100 m from the boat launch.
BL-5	Entrance to the southeast bay.
BL-6	Site near Southport Marina and residences.
BL-7	Near where Fish Creek drains from Big Lake.
BL-8	Near Burkeshore Marina fuel station and boat launch.
BL-10	In the North Bay near the North Shore State Recreation Site. Site is approximately 150 m from the boat launch.
BL-11	In the North Bay near the mouth of Meadow Creek, the lake's major inlet.
BL-26	Site located in the middle of the North Bay near the North Shore State Recreation Site.
BL-27	Site located in the main traffic lane for users leaving North Shore State Recreation Site. Location will assess the area between the North Bay and East Basin.

Samples were analyzed in the laboratory (EPA Method 624) for the petroleum hydrocarbon compounds of benzene, ethyl-benzene, toluene, and xylene (BTEX). Total aromatic hydrocarbons (TAH) is the sum of these four compounds and is used for comparing against state water quality criteria allowed limits. The method detection limit for benzene, ethyl-benzene, and toluene is 0.5 µg/L and for total xylenes 1.0 µg/L. When concentrations are below detection limits actual values could range from 0 to 0.5 µg/L (benzene, ethyl-benzene, and toluene) or from 0 to 1.0 µg/L (xylenes). Lower TAH values will be obtained when 0 is used for concentrations below detection limits, and higher values when 0.5 or 1.0 µg/L is used. Since actual concentrations are between 0 and 0.5 or 1.0 µg/L, using a value of ½ the detection limit is an acceptable estimate. Therefore, when calculating TAH we used a concentration of 0.25 µg/L when concentrations of benzene, ethyl-benzene, or toluene were below detection limits and a value of 0.5 µg/L when concentrations of xylene were below detection limits. When all three compounds were below detection limits, TAH is equal to 1.25 µg/L (reported as 1.3 µg/L).

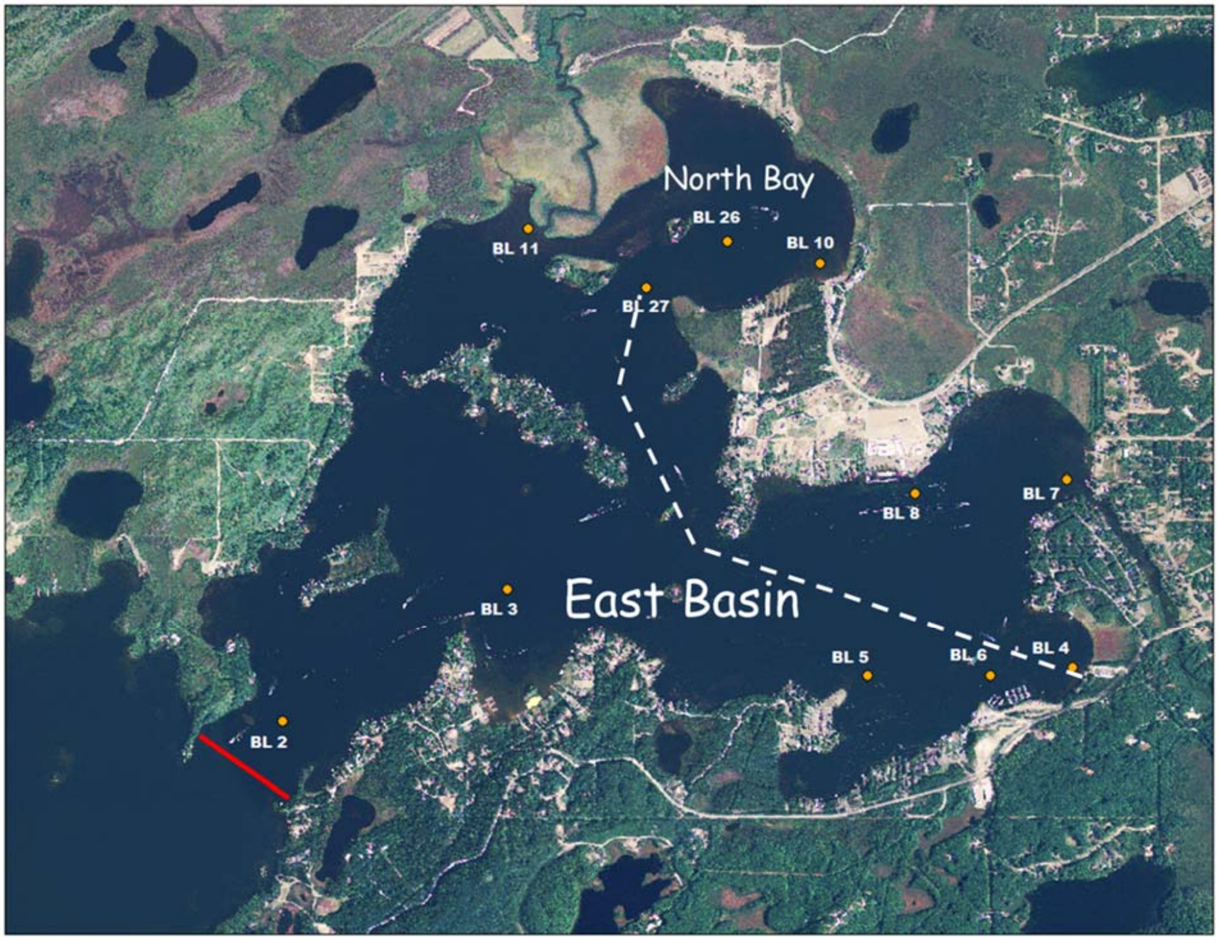

Figure 1. Aerial photograph of the East Basin and North Bay of Big Lake showing sampling sites. Red line marks the west boundary of the study area. Dashed line shows transect survey route (see Section 4.1.1).

3.3 Measures of Watercraft Use

Three different methods were used to get measurements of watercraft use, transect surveys, aerial photography, and stop action photography.

Watercrafts were counted along a transect between sites BL-27 and BL-4 at approximately 9:00 am, 12:00 pm, 3:00 pm, 6:00 pm, and 10:00 pm during sampling days (transect surveys). One observer counted all watercraft off the left side of the boat and a second observer counted all watercraft off of the right side of the boat while driving directly along the transect. The portion of total watercraft that were personal watercraft (PWC) were identified. However, we were unable to determine the portion of watercraft including personal watercraft that were using carbureted 2-stroke motors. Watercraft surveys were not conducted on three occasions, twice due to boat problems and once due to high wind and waves.

Watercrafts on the lake were counted from aerial surveys conducted on June 8, 9, and July 6, 2013. Aerial images were taken at these times of the entire east basin and North Bay and were used to obtain total motorized watercraft counts. Aerial watercraft counts were used to check the accuracy of the transect surveys conducted by boat.

Stop action photography was used to record activity at the south launch in order to determine the number of boats entering or leaving the lake throughout the day. The camera was set to take a photograph every 15 minutes during the June sampling event (June 7 – 10) and every 30 minutes during the July sampling event (July 4 – 7). The photographs were reviewed and all boats and watercraft were counted prior to each sampling event.

Surveys of watercraft use by motor type were conducted at the north boat launch on each sampling date. Surveys were conducted between 12:00 and 17:00. Counts of use by watercraft to determine type and motor type (2-cycle, 4-cycle, 2-cycle direct inject) were conducted from observations at the north boat launch on each sample date. The motor type and size of outboard motors could easily be identified. It was difficult to accurately identify motor size or type on most inboard boat motors and owners surveyed often could not provide this information. Based on review of motor specifications for the major motor types, we classified all inboard motors as 4-stoke or 2-cycle direct injection; however, we did not make any assumptions regarding motor size. Some PWC were clearly using older carbureted 2-stroke motors. However, for many PWC it was not clear and owners often could not provide information on motor type, particularly if motors were the more efficient direct injection 2-cycle motors or purge the cylinders with clear air. Therefore results for boat launch surveys are presented for total boats, 2-stroke motors plus all PWC, and for known 2-stroke motors.

Watercraft counts from transect surveys and stop action photographs were used to calculate watercraft hours. Watercraft hours are the product of the number of watercraft and hours of operation. Watercraft hours were calculated by multiplying the average number of watercraft between each sampling period by the time between each sampling period and summing these values over each day. We used the relationship between watercraft counts from stop action photography and transect survey counts to estimate the watercraft counts for transect surveys that were not completed due to boat problems or weather.

3.4 Thermal Stratification Measurements

The change in water temperature with water depth was used to determine the depth of the mixing depth or epilimnion and the presence of a thermocline. The epilimnion is the water column above the thermocline where water mixing is possible due to similar water densities. The thermocline is the portion of the water column where water temperature changes rapidly (1°C with 1 m depth) separating the dense deeper hypolimnion from the epilimnion preventing complete mixing. Water temperature was measured at 0.5-m intervals at Site BL-3, the deepest point in the lake. Measurements were collected on June 9 and 10; and on July 4, 5, 6, and 7. Water temperature was plotted as a function of water depth to determine epilimnion depth.

4.0 Results

4.1 Quality Assurance and Deviations from Sampling Plan

All data quality objectives defined with the QAPP—precisions, accuracy, and completeness were met. The maximum relative percent difference (RPD) between sample replicates was 20 due to a difference of 1.5 µg/L TAH. RPD was less than 5 for most samples. In the QAPP values below DL were to be recorded as <DL and treated as “0” in calculating TAH; however, in later discussions with DEC it was decided to treat values below DL as 0.5 DL in calculating TAH as described in the methods section of this report.

The first 4-day sampling event was scheduled to occur over the Memorial Day Weekend (May 24 – 27, 2013); however, the lake surface was still ice covered. Therefore, sampling was delayed until the second weekend in June (June 7 – 10).

Due to motor problems we used a kayak to access most sampling locations for the 18:00 sample on June 8. Sampling locations 2, 3, 5, and 11, were not sampled on June 8. In order to obtain 4 replicate samples from these sites, they were sampled twice (~15:00 and 20:00) on June 9.

Site BL-11 is located at the mouth of Meadow Creek and has been considered a reference site. However, we observed watercraft within Meadow Creek during sampling. TAH concentrations up to 15 µg/L were measured at this sampling site.

4.2 Water Quality Criteria

4.2.1 June 7 through June 10 Sampling Event (Friday – Monday)

Weather during this sampling period was favorable for water sports with clear skies and high temperatures above 70°F from Friday through Monday morning. Skies became overcast Monday afternoon, and temperatures dropped. Winds Monday afternoon caused high waves that prevented safe boating at 22:00. Water quality sampling results for the first sampling event are provided in Tables 2 through 5. Summary results are shown in Table 6 and Figure 2. TAH concentrations in initial samples at 09:00 on June 7 were 3.36 µg/L at BL-4 and 1.68 at BL-27. Concentrations in our final samples at 22:00 on June 10 were 11.50 at BL-4 and 8.93 at BL-27. TAH concentrations were highest at sites closest to boat launches, in samples collected after 18:00, and on Saturday June 9.

On Friday June 7, 2013, TAH concentrations exceeded WQC only at BL-4 at 18:00 and 22:00 (Table 2). BL-4 is located just outside of the no-wake-zone around the Big Lake South Boat Launch. TAH concentrations were between 7.0 and 10 µg/L at BL-2 and BL-7.

On Saturday June 8, TAH concentrations exceeded WQC at BL-4, BL-6, BL-8, BL-10, and BL-27. Highest concentrations were from the last two samples collected at BL-4 and the last sample (21:00) at BL-27. Concentrations at BL-10 were over 40 µg/L TAH (Table 3).

On Sunday June 9, TAH concentrations exceeded WQC at all sampling locations; however, criteria were exceeded at only 1 of 2 samples collected at BL-11 and 1 of 5 samples at BL-27 (Table 4). Both of these samples were collected at ~18:00.

On Monday June 10, TAH concentrations exceeded WQC at sites BL-4 (Big Lake South Boat Launch), BL-6 (Southport Marina), BL-8 (Burkeshore Marina) and BL-10 (Big Lake North Boat Launch) (Table 5).

Table 6 summarizes sampling event results by day and by site and provides average daily TAH concentrations using all sites, 4-day average TAH concentrations for each site, and a 4-day Lake average value (average of all sites). Average daily concentrations using all sites exceeded 10 µg/L on June 8 and June 9. Four-day average concentrations exceeded 10 µg/L at BL-4, BL-6, and BL-10. The highest values were recorded at BL-10 with a 4-day average of 25.09 µg/L.

4.2.2 June 29 Sampling Event (Saturday)

Air temperatures during sampling were in the upper 60s, with cloudy skies. TAH concentrations did not exceed WQC at any of the sampling locations on June 29, 2013 (Table 7). The highest TAH concentrations was 9.6 µg/L at BL-10. Three other sites had concentrations over 7 µg/L; BL-5, BL-8, and BL-11.

4.2.3 July 4 through 7 Sampling Event (Thursday – Sunday)

The Fourth of July weekend was cloudy and overcast. High temperatures were between 50 and 60°F with light rain on the July 4, and partial clearing on July 7. Sampling results for this event are provided in Tables 8 through 11 with a 4-day summary in Table 12. TAH concentrations at the initiation of sampling were 1.5 µg/L at BL-4 and 1.7 µg/L at BL-27. At the end of the sampling event TAH concentrations at these two intensive sampling sites were 3.6 µg/L at BL-4 and 2.3 µg/L at BL-27.

TAH concentrations did not exceed WQC at any of the sampling sites on July 4, 2013 (Table 8). Highest concentrations were at BL-7 (lake outlet) and BL-10 (Big Lake North) at 6.4 µg/L and 6.7 µg/L, respectively. Maximum daily values at the intensive sites (BL-4 and BL-27) were recorded between 18:00 and 22:00.

On Friday July 5, 2013, TAH concentrations exceeded WQC at 22:00 in BL-4 (Big Lake South) (Table 9). Concentrations at BL-7 (lake outlet) and BL-8 (Burkeshore Marina) were 10.0µg/L and 9.4 µg/L, respectively.

TAH concentrations during this sampling event were highest on Saturday, July 6. Concentrations exceeded 10 µg/L at two sampling sites, BL-8, and BL-10 (Table 10). Maximum daily values at intensive sites occurred between 18:00 and 19:00.

On Sunday, July 7, concentrations were 12.3 µg/L at BL-7 (Table 11). The next highest concentrations were recorded at BL-10 (7.3 µg/L). Maximum daily values at the intensive site BL-4 was at 19:00 and at 09:00 at BL-27.

The maximum lake average was on Saturday July 6 at 6.3 µg/L. Highest 4-day average values were for sampling sites BL-7 (lake outlet) and BL-10 (Big Lake North) at 8.2 µg/L. BL-8 4-day average concentrations were also over 7.0 µg/L (Table 12).

Table 2. Analytical results for June 7, 2013 with TAH values over 10 µg/L bolded. Key: µg/L=micrograms per liter, TAH=Total aromatic hydrocarbons. TAH calculated using 0.5 x detection limit for those values below detection limits.

Site	Time Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	20:30	<0.5	7.2	<0.5	<1.0	8.2
BL-3	20:12	<0.5	2.1	<0.5	1.0	3.6
BL-4	9:00	<0.5	1.8	<0.5	1.0	3.4
	12:00	0.6	3.2	<0.5	1.6	5.7
	15:00	0.5	2.5	<0.5	1.2	4.4
	18:00	1.2	7.5	1.0	3.3	**13.0**
	22:00	1.0	6.4	0.8	2.9	**11.1**
BL-5	20:50	<0.5	2.0	<0.5	1.1	3.6
BL-6	21:08	0.8	4.4	0.6	2.1	7.8
BL-7	19:52	<0.5	2.5	<0.5	1.2	4.2
BL-8	19:39	<0.5	2.1	<0.5	1.1	3.7
BL-8 (Dup)	19:39	<0.5	2.0	<0.5	1.1	3.5

Site	Time Sampled	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-10	18:56	0.7	3.1	<0.5	1.6	5.6
BL-11	19:14	<0.5	0.6	<0.5	<1.0	1.6
BL-26	18:40	<0.5	1.3	<0.5	<1.0	2.3
BL-27	9:00	<0.5	0.7	<0.5	<1.0	1.7
	12:00	<0.5	0<0.5	<0.5	<1.0	1.3
	15:00	<0.5	1.4	<0.5	<1.0	2.4
	18:00	<0.5	1.3	<0.5	<1.0	2.4
	22:00	<0.5	1.4	<0.5	<1.0	2.4

Table 3. Analytical results for June 8, 2013. Key: µg/L=Micrograms per liter, TAH=Total aromatic hydrocarbons, NS=Not Sampled.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2		NS	NS	NS	NS	NS
BL-3		NS	NS	NS	NS	NS
BL-4	9:00	0.5	2.3	<0.5	1.3	4.4
	12:00	<0.5	2.5	<0.5	1.3	4.2
	15:00	0.6	2.9	<0.5	1.4	5.2
	18:00	1.7	11.2	1.4	5.1	**19.4**
	22:00	2.9	19.6	2.6	9.0	**34.1**
BL-5						NS
BL-6	18:00	1.0	6.0	0.7	2.6	**10.2**
BL-7	19:30	<0.5	2.6	<0.5	1.2	4.4
BL-8	20:00	1.1	6.8	0.8	2.9	**11.6**
BL-10	20:15	4.3	26.0	3.1	10.5	**43.9**
BL-10 (Dup)	20:15	4.5	25.7	3.1	10.4	**43.7**
BL-11						NS
BL-26	20:30	0.7	3.8	<0.5	1.6	6.4
BL-27	9:00	<0.5	1.5	<0.5	<1	2.5
	12:00	<0.5	1.0	<0.5	<1	2.0
	15:00	<0.5	2.3	<0.5	1.1	3.9
	21:00	1.3	8.2	1.0	3.6	**14.2**

Table 4. Analytical results for June 9, 2013 with TAH values over 10 µg/L bolded. Key: µg/L=Micrograms per liter, TAH=Total aromatic hydrocarbons, DL=detection limit.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	16:27	1.0	6.3	0.7	2.8	**10.8**
BL-2	19:39	1.2	7.6	0.9	3.2	**13.0**
BL-3	16:45	1.2	7.6	0.9	3.2	**12.8**
BL-3	19:52	1.2	6.7	0.8	2.9	**11.6**
BL-4	9:00	1.5	10.0	1.2	4.4	**17.1**

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
	12:00	1.5	8.7	1.1	3.8	**15.1**
	15:00	1.6	10.4	1.3	4.4	**17.7**
	18:00	2.1	12.1	1.4	4.8	**20.4**
	22:00	1.8	10.8	1.3	4.4	**18.3**
BL-5	16:07	1.4	8.9	1.0	3.8	**15.1**
BL-5	21:02	1.2	6.9	0.8	2.9	**11.7**
BL-6	21:13	1.6	9.1	1.1	3.9	**15.7**
BL-7	20:40	1.4	8.9	1.0	3.7	**15.0**
BL-8	20:30	1.3	8.0	0.9	3.4	**13.6**
BL-8 (Dup)	20:30	1.3	7.6	0.9	3.3	**13.1**
BL-10	18:59	3.7	23.5	3.0	10.0	**40.1**
BL-11	15:20	0.7	3.9	<0.5	1.4	6.2
BL-11	19:15	1.5	9.0	1.1	3.5	**15.0**
BL-26	18:46	1.2	6.8	0.8	2.7	**11.5**
BL-27	9:00	0.7	4.2	<0.5	1.7	6.9
	12:00	0.9	4.8	0.6	2.1	8.3
	15:00	0.7	3.7	<0.5	1.8	6.4
	18:00	1.2	6.2	0.7	2.7	**10.8**
	22:00	0.8	4.7	0.5	2.1	8.1

Table 5. Analytical results for Sunday June 10, 2013 with TAH values over 10µg/L bolded. Key: µg/L=Micrograms per liter, TAH=Total aromatic hydrocarbons, DL=detection limit.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	19:00	0.8	4.7	0.5	2.0	8.1
BL-3	19:12	0.9	5.0	0.6	2.2	8.7
BL-4	9:00	1.4	8.6	1.1	3.8	**14.8**
	12:00	1.3	8.0	1.0	3.5	**13.8**
	15:00	1.3	7.7	0.9	3.3	**13.2**
	18:00	1.6	9.1	1.0	3.6	**15.3**
	21:00	1.3	6.6	0.8	2.8	**11.5**
BL-5	20:00	1.0	5.6	0.6	2.5	9.6
BL-6	20:10	1.2	6.6	0.8	3.0	**11.5**
BL-7	19:50	0.9	4.7	0.6	2.2	8.3
BL-8	19:30	1.0	5.8	0.7	2.6	**10.1**
BL-8 (Dup)	19:45	1.0	5.8	0.7	2.6	**10.2**
BL-10	18:24	1.1	6.4	0.8	2.8	**11.0**
BL-11	18:40	<0.5	0.5	<0.5	<1.0	1.5
BL-26	18:12	1.0	5.7	0.7	2.5	9.8

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-27	9:00	0.9	5.3	0.6	2.3	9.1
	12:00	0.9	5.3	0.6	2.2	9.0
	15:00	0.9	5.2	0.6	2.2	8.9
	18:00	0.9	4.8	0.6	2.1	8.4
	22:00	0.9	5.2	0.6	2.2	8.9

Table 6. Average daily lake TAH concentrations, daily values and 4-day averages for the sampling event. WQC were exceeded for most sites on June 8 and 9 and for 4 of the 11 sites on June 10. Four-day average values exceeded WQC at 3 of the 11 sites and for the lake average.

Sample Site	June 7, 2013	June 8, 2013	June 9, 2013	June 10, 2013	4-Day Average
	TAH (µg/L)	TAH (µg/L)	TAH (µg/L)	TAH (µg/L)	TAH (µg/L)
BL-4	7.5	**13.5**	**17.7**	**13.7**	**13.1**
BL-27	2.0	5.4	8.1	8.9	6.1
BL-2	8.2	**10.8**	**13.0**	8.1	10.0
BL-3	3.7	**12.8**	**11.6**	8.7	9.2
BL-5	3.6	**15.1**	**11.7**	9.6	10.0
BL-6	7.8	**10.2**	**15.7**	**11.5**	**11.3**
BL-7	4.2	4.4	**15.0**	8.3	8.0
BL-8	3.7	**11.6**	**13.6**	**10.1**	9.8
BL-10	5.6	**43.9**	**40.1**	**11.0**	**25.2**
BL-11	1.6	6.2	**15.0**	1.5	6.1
BL-26	2.3	6.4	**11.5**	9.8	7.5
Lake Average	4.6	**12.7**	**15.7**	9.2	**10.6**

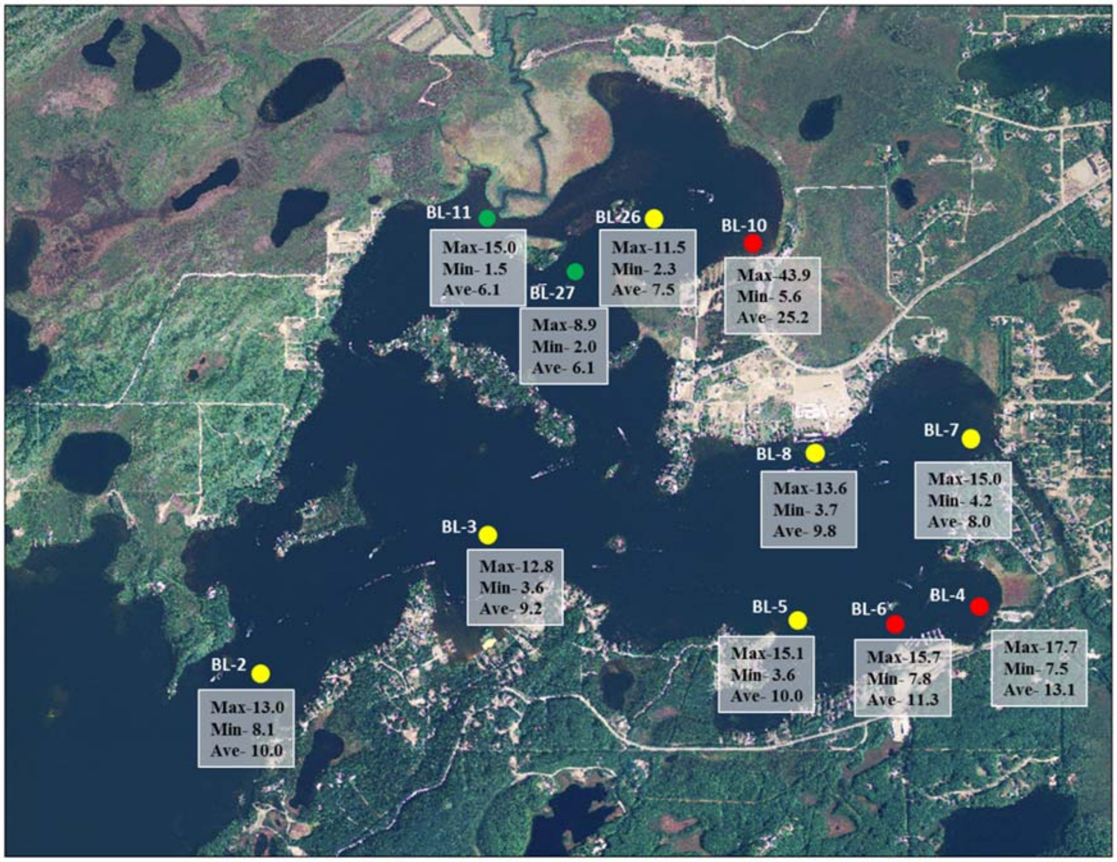

Figure 2. Maximum, minimum, and average TAH concentrations (µg/L) during the June 7 – 10 sampling event. Red circles identify those sites where 4-day (96 hour) average concentrations were > 10, yellow circles >7 but <10, and green circles sites where concentrations were < 7 µg/L.

Table 7. Analytical results for Saturday June 29, 2013. Key: µg/L=Micrograms per liter, TAH=Total aromatic hydrocarbons.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	19:55	<0.5	2.0	<0.5	<1.0	3.0
BL-3	20:09	<0.5	1.4	<0.5	<1.0	2.4
BL-4	18:37	<0.5	1.5	<0.5	<1.0	2.5
BL-5	19:10	0.6	4.4	0.5	1.8	7.3
BL-6	18:54	<0.5	1.1	<0.5	<1.0	2.1
BL-7	18:10	<0.5	1.3	<0.5	<1.0	2.3
BL-8	17:58	0.8	3.9	<0.5	1.6	6.6
BL-8 (Dup)	17:58	1.1	4.3	0.6	1.8	7.8
BL-10	20:54	1.1	5.6	0.7	2.3	9.6
BL-11	19:32	0.7	4.3	0.6	1.8	7.4
BL-26	20:40	<0.5	1.9	<0.5	<1.0	2.9
BL-27	20:25	<0.5	1.2	<0.5	<1.0	2.2

Table 8. Analytical results for Thursday July 4, 2013 with TAH values over 10 µg/L bolded. Key: µg/L=Micrograms per liter, TAH=Total aromatic hydrocarbons. TAH calculated using 0.5 x DL for those values below detection limits.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	20:14	<0.5	1.8	<0.5	<1.0	2.8
BL-3	20:31	0.6	2.0	<0.5	<1.0	3.4
BL-4	9:00	< 0.5	< 0.5	< 0.5	<1.0	1.3
	12:00	< 0.5	< 0.5	< 0.5	<1.0	1.3
	15:00	< 0.5	< 0.5	< 0.5	<1.0	1.3
	18:00	< 0.5	< 0.5	< 0.5	<1.0	1.3
	22:00	< 0.5	1.3	< 0.5	<1.0	2.3
BL-5	20:46	< 0.5	2.1	< 0.5	<1.0	3.1
BL-6	21:04	< 0.5	1.9	< 0.5	<1.0	2.9
BL-7	21:22	0.6	3.7	0.5	1.6	6.4
BL-8	21:38	0.6	3.4	< 0.5	1.4	5.6
BL-10	19:16	0.7	3.8	0.5	1.7	6.7
BL-10 (Dup)	19:17	0.8	3.9	0.5	1.8	7.0
BL-11	18:56	<0.5	0.6	<0.5	<1.0	1.6
BL-26	19:38	<0.5	<0.5	<0.5	<1.0	1.3
BL-27	9:00	<0.5	0.7	<0.5	<1.0	1.7
	12:00	<0.5	<0.5	<0.5	<1.0	1.3
	15:00	<0.5	1.2	<0.5	<1.0	2.2
	18:00	<0.5	2.8	<0.5	1.3	4.6
	22:00	<0.5	0.8	<0.5	<1.0	1.8

Table 9. Analytical results for Friday July 5, 2013 with TAH values over 10 µg/L bolded. Key: µg/L=micrograms per liter, TAH=Total aromatic hydrocarbons. TAH calculated using 0.5 x DL for those values below detection limits.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	20:30	0.5	3.1	<0.5	1.3	5.2
BL-3	20:45	0.8	4.8	0.5	1.9	8.1
BL-4	9:00	< 0.5	1.1	< 0.5	<1.0	2.1
	12:00	< 0.5	1.0	< 0.5	<1.0	2.0
	15:00	< 0.5	1.5	< 0.5	<1.0	2.5
	18:00	< 0.5	1.2	< 0.5	<1.0	2.3
	22:00	1.0	6.3	0.8	2.3	**10.4**
BL-5	21:01	0.8	4.7	0.5	1.9	7.9
BL-6	18:52	< 0.5	2.4	< 0.5	1.2	4.1
BL-7	21:18	1.0	6.0	0.7	2.3	10.0
BL-8	21:35	1.1	5.5	0.7	2.1	9.4
BL-10	19:13	0.7	3.9	0.5	1.6	6.6
BL-10 (Dup)	19:13	0.6	3.5	<0.5	1.5	5.9
BL-11	19:50	0.6	4.3	0.6	1.7	7.2
BL-26	19:35	<0.5	1.2	<0.5	<1.0	2.2
BL-27	9:00	< 0.5	< 0.5	< 0.5	<1.0	1.3

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
	12:00	< 0.5	< 0.5	< 0.5	<1.0	1.3
	15:00	< 0.5	0.8	< 0.5	<1.0	1.8
	18:00	< 0.5	0.6	< 0.5	<1.0	1.6
	22:00	< 0.5	1.3	< 0.5	<1.0	2.3

Table 10. Analytical results for Saturday July 6, 2013 with TAH values over 10 µg/L bolded. Key: µg/L=micrograms per liter, TAH=Total aromatic hydrocarbons. TAH calculated using 0.5 x DL for those values below detection limits.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	20:05	0.7	4.0	< 0.5	1.7	6.6
BL-3	20:20	0.6	2.8	< 0.5	1.3	5.0
BL-4	9:00	0.7	3.4	< 0.5	1.5	5.7
	12:00	0.7	3.1	< 0.5	1.3	5.3
	15:00	<0.5	2.2	< 0.5	1.0	3.8
	19:05	0.7	4.0	0.6	1.8	7.0
	22:00	0.6	3.3	< 0.5	1.5	5.6
BL-5	19:35	0.5	2.8	< 0.5	1.4	5.0
BL-6	19:15	0.6	3.3	0.5	1.5	5.9
BL-7	20:40	< 0.5	2.5	< 0.5	1.3	4.2
BL-8	21:00	1.1	6.6	0.7	2.7	**11.1**
BL-10	18:05	1.3	7.5	0.9	3.0	**12.7**
BL-10 (Dup)	18:05	1.2	7.4	0.9	3.0	**12.5**
BL-11	18:25	0.6	3.0	0.5	1.3	5.4
BL-26	18:00	0.5	2.5	< 0.5	1.2	4.5
BL-27	9:00	< 0.5	1.1	< 0.5	<1.0	2.1
	12:00	< 0.5	1.5	< 0.5	<1.0	2.5
	15:00	< 0.5	1.6	< 0.5	<1.0	2.6
	18:40	0.6	3.0	< 0.5	1.4	5.3
	22:00	< 0.5	2.1	< 0.5	1.0	3.6

Table 11. Analytical results for Sunday July 7, 2013 with TAH values over 10 µg/L bolded. Key: µg/L=micrograms per liter, TAH=Total aromatic hydrocarbons. TAH calculated using 0.5 x DL for those values below detection limits.

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-2	20:20	0.7	3.7	<0.5	1.7	6.3
BL-3	20:30	0.6	3.1	<0.5	1.4	5.3
BL-4	9:00	0.6	3.0	<0.5	1.5	5.3
	12:00	0.6	2.5	<0.5	1.2	4.5
	15:00	0.6	2.7	<0.5	1.2	4.7
	19:05	0.6	3.2	<0.5	1.4	5.4
	22:00	<0.5	2.1	<0.5	1.0	3.6
BL-5	19:30	0.5	2.2	<0.5	1.1	4.1

Site	Time	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Total Xylene (µg/L)	TAH (µg/L)
BL-6	19:25	0.5	2.2	<0.5	1.1	4.1
BL-7	20:45	1.0	7.5	0.8	2.9	**12.3**
BL-8	21:00	0.6	3.1	<0.5	1.5	5.4
BL-10	18:00	0.8	3.9	0.5	1.6	6.7
BL-10 (Dup)	19:50	0.9	4.0	0.6	1.8	7.3
BL-11	18:30	<0.5	0.8	<0.5	<1.0	1.8
BL-26	20:25	<0.5	1.5	<0.5	<1.0	2.5
BL-27	9:00	1.0	2.0	<0.5	1.2	4.4
	12:00	<0.5	1.2	<0.5	<1.0	2.2
	15:00	<0.5	1.9	<0.5	1.0	3.4
	18:55	<0.5	1.3	<0.5	<1.0	2.3
	22:00	<0.5	1.3	<0.5	<1.0	2.3

Table 12. Summary results for the July 4 through July 7 sampling event with samples over 10 µg/L bolded. Daily lake averages and four-day sites averages did not exceed WQC. Values for sites BL-4 and BL-27 the average of 5 samples collected through the day.

Sample Site	July 4, 2013 TAH (µg/L)	July 5, 2013 TAH (µg/L)	July 6, 2013 TAH (µg/L)	July 7, 2013 TAH (µg/L)	4-Day Average TAH (µg/L)
BL-4	1.5	3.8	5.5	4.7	3.9
BL-27	2.3	1.6	3.2	2.9	2.5
BL-2	2.8	5.2	6.6	6.3	5.2
BL-3	3.4	8.1	5.0	5.3	5.4
BL-5	3.1	7.9	5.0	4.1	5.0
BL-6	2.9	4.1	5.9	4.1	4.2
BL-7	6.4	10.0	4.2	**12.3**	8.2
BL-8	5.6	9.4	**11.1**	5.4	7.9
BL-10	6.7	6.6	**12.7**	6.7	8.2
BL-11	1.6	7.2	5.4	1.8	4.0
BL-26	1.3	2.2	4.5	2.5	2.6
Lake Average	3.4	6.0	6.3	5.1	5.2

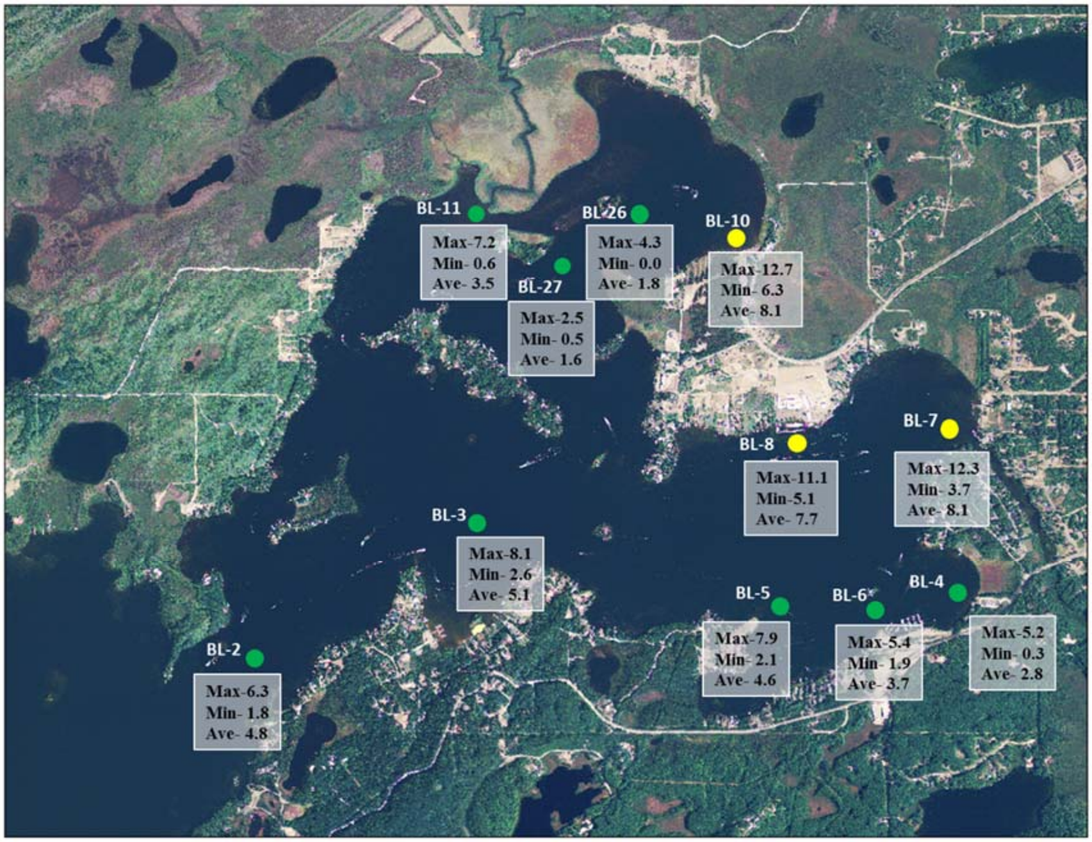

Figure 3. Maximum, minimum, and average TAH concentrations (µg/L) during the July 4 - 7 sampling event. Red circles identify those sites where 4-day average concentrations were > 10, yellow circles >7 but <10, and green circles sites where concentrations were < 7 µg/L.

4.3 Inter-Annual, Sampling Event, and Daily Variability.

Calculation of the variability in TAH concentrations over multiple time intervals is necessary to identify trends and to determine those factors that influence concentrations. The variation in TAH concentrations among and within years (inter-annual variation) was used to estimate trends in concentrations. A decreasing trend over time could indicate improvement in conditions and could be used to evaluate the success of different management approaches. Variation within a year can help identify when high TAH concentrations are likely to occur and can focus future sampling. Similarly, variability through a day or multiple days (sampling event and daily variability) can be used to identify factors related to TAH concentrations and to help identify causes. The changes in relationships between TAH concentrations and primary sources can be used to indicate improving or worsening trends over time.

4.3.1 Inter-Annual Variability

There are no obvious declines or increases in TAH concentrations over the time period sampling has been occurring (Figure 4). Average Big Lake TAH concentrations did not exceed 20 µg/L in 2004 or 2013, and once in 2005 and 2009. Maximum average TAH or TAH for BL-10 does not decrease significantly over years sampled (N = 4). The percent of days with values over 10 µg/L is lower in 2013 than in 2005 or 2009 but not 2004 (Table 13); however, the number of days sampled has not been consistent, and there is not a long enough data set to determine if this trend will persist. In addition, boat use (the primary source of TAH in Big Lake, DEC 2009) was not reported for each sampling date. Therefore, differences in concentrations among years could be due to differences in the number of watercraft on each sampling date.

Based on the abundance of ski-boats and personal water craft (jet skis), boating activity on Big Lake during the summer is largely related to water sports. Maximum air temperatures could be used as a surrogate for boat use on Big Lake. The inter-annual variability in TAH concentrations could be used to investigate relationships with air temperatures as index to boat use. There was a significant statistical relationship between average Big Lake TAH concentrations and maximum air temperatures using data from all sampling dates (Figure 5) ($p < 0.01$). There is a large variability in these data however, limiting the effectiveness at documenting changes in discharge over time.

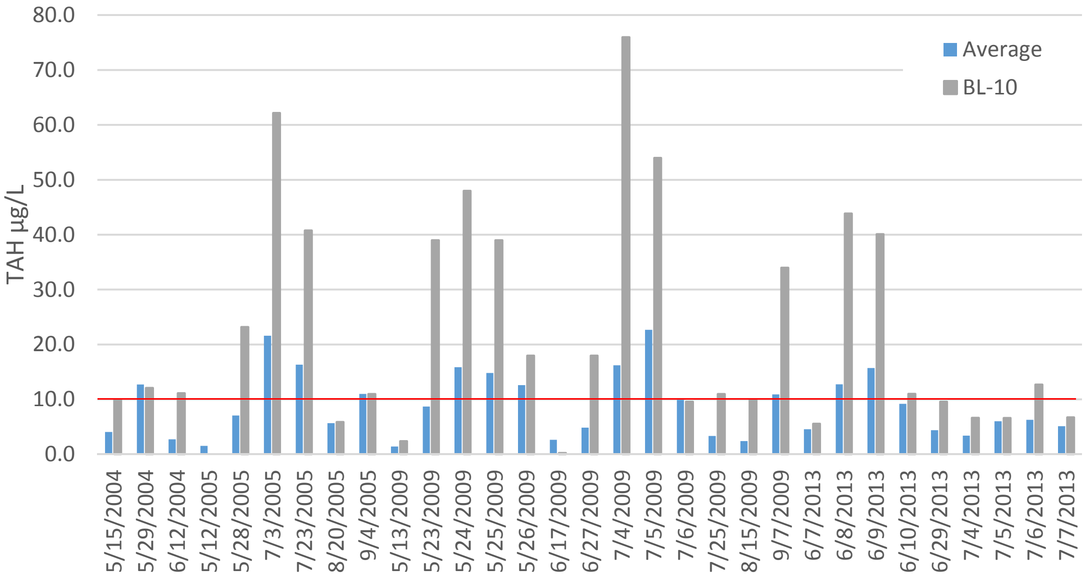

Figure 4. Average lake (average of all sampling locations) and sampling site BL-10 (Big Lake North Boat Launch) TAH concentrations for all sampling dates (2004 and 2005 data from Oasis 2006, and 2009 data from Oasis 2010).

Table 13. Summary of Big Lake TAH sampling results for the 4 years conducted. Ave is average, Min is minimum, and Max is maximum.

	2004					2005					2009					2013				
Station	Count	Min	Avg	Max	% > 10 µg/L	Count	Min	Avg	Max	% > 10 µg/L	Count	Min	Avg	Max	% > 10 µg/L	Count	Min	Avg	Max	% > 10 µg/L
BL-1	3	0.2	0.2	0.2	0	5	0.2	0.3	0.5	0	13	0.2	2.6	8.5	0	–	–	–	–	–
BL-2	3	0.2	4.1	12.0	3	–	–	–	–	–	13	0.3	6.9	16.1	38	9	9	2.8	7.1	13
BL-3	3	0.2	3.1	6.4	0	–	–	–	–	–	13	0.2	6.2	17.7	31	9	9	2.4	6.8	13
BL-4	3	0.2	3.7	8.3	0	–	–	–	–	–	12	0.2	16.2	69.6	50	9	9	1.5	7.8	18
BL-5	3	0.2	4.8	11.0	33	–	–	–	–	–	13	0.2	5.6	15.1	23	9	9	3.1	7.5	15
BL-6	3	3.0	7.0	15.0	33	5	1.1	2.8	7.1	0	13	0.2	10.5	26.7	54	9	9	2.1	7.1	16
BL-7	3	3.1	8.7	19.0	33	5	1.0	2.5	5.5	0	13	0.2	4.9	14.3	15	9	9	2.3	7.4	15
BL-8	3	3.6	9.3	17.0	33	6	0.2	5.5	13.0	33	13	0.2	9.2	20.3	54	9	9	3.7	8.6	14
BL-9	3	0.2	1.2	1.8	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BL-10	3	9.9	13.3	18.0	67	7	0.2	21.4	6.03	57	13	0.2	27.6	75.7	69	9	5.6	15.9	43.9	44
BL-11	3	0.2	0.2	0.2	0	–	–	–	–	–	13	0.2	0.8	3.5	0	9	1.5	5.3	15.0	11
BL-12	3	0.2	0.9	2.4	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BL-13	3	0.2	0.2	0.2	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BL-14	3	0.2	1.9	3.6	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BL-26	–	–	–	–	–	–	–	–	–	–	13	0.2	5.9	17.0	31	9	1.3	4.8	11.5	11
BL-27	–	–	–	–	–	–	–	–	–	–	13	0.2	6.8	16.7	38	9	1.6	4.1	8.9	0
Total	42				17	28				21	155				34	99				24

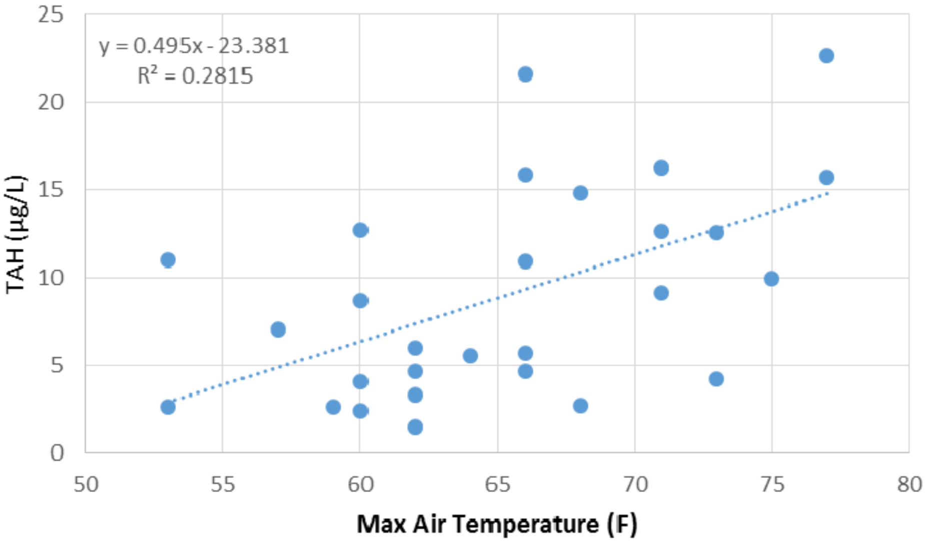

Figure 5. Relationship between average Big Lake TAH concentration and maximum air temperature at the Big Lake Airport for all sampling dates from 2004 through 2013.

4.3.2 Sampling Event Variability

The variability of TAH among sampling dates for the two 4-day sampling events is shown in Figure 6. Average TAH concentrations varied among sampling dates with the highest values occurring on weekend days, generally Saturday. Similar trends were seen for all of the other sampling sites. This daily variability was used to estimate the effects of boat use on TAH concentrations (see section 5.0).

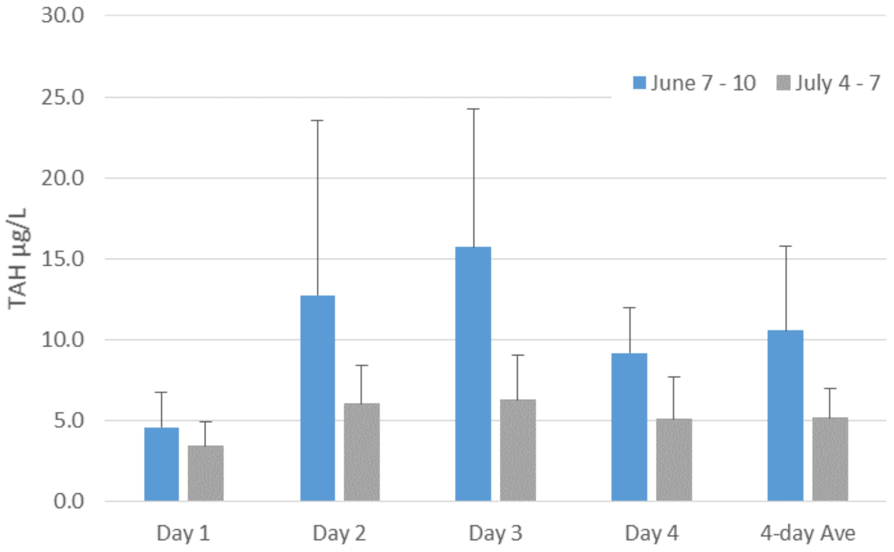

Figure 6. Average daily Big Lake TAH concentrations for the two sampling events. Highest average values during the first sampling date were on Saturday and Sunday and on the second sampling event on Friday and Saturday. Error bars are one standard deviation.

4.3.3 Daily Variability

Daily variability in TAH concentrations for the two intensive sampling sites and for the two sampling events are shown in Figures 7 and 8. Daily trends are more apparent at site BL-4. Maximum daily values generally occur between 18:00 and 22:00 and minimum values from 12:00 to 15:00. This is consistent with watercraft use which tended to be greatest during this same time period.

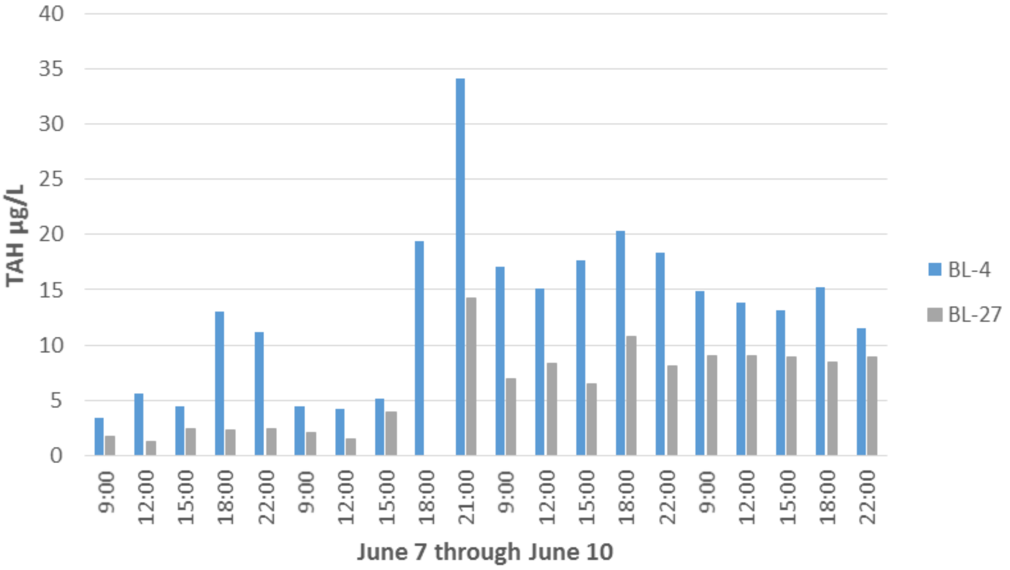

Figure 7. TAH for each sample collected at the intensive sampling sites during the first sampling event showing peak concentrations at ~18:00 to 22:00 hours and minimum concentrations at 15:00 hours.

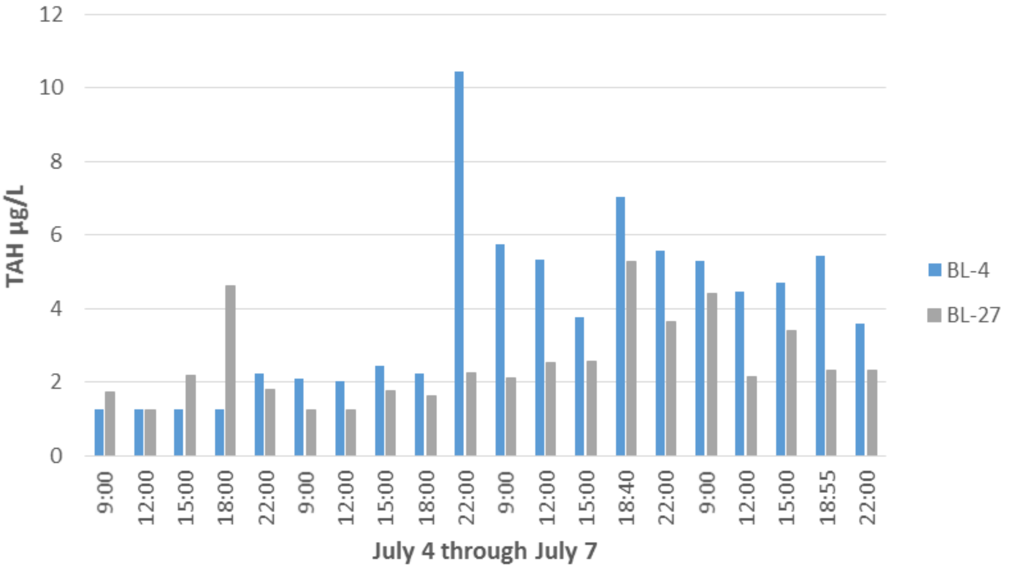

Figure 8. TAH for each sample collected at the intesive sampling sites during the second sampling event showing peak concentrations at ~18:00 hours and minimum concentrations at 12:00 to 15:00.

4.3.4 Variability among Sites

While average TAH concentrations tended to be different among sites, averages were not different statistically. We used 2-way ANOVA to test for significant differences in TAH concentrations for each site and each event. TAH concentrations were significantly higher during the first sampling event ($p < 0.001$), but concentrations were not different among sites ($p = 0.09$), even though the average at BL-10 (16 µg/L) was double the concentrations at other sites.

Sampling sites BL-8 and BL-10 had 4 samples with concentrations over 10 µg/L. BL-4 and BL-6 had 3 samples over 10 µg/L, and Sites BL-2, BL-3, BL-5 and BL-7 had 2 samples over 10 µg/L. Sites BL-11 and BL-26 had one sample that exceeded 10 µg/L and none of the samples at BL-27 exceeded this TAH concentration (Figure 9).

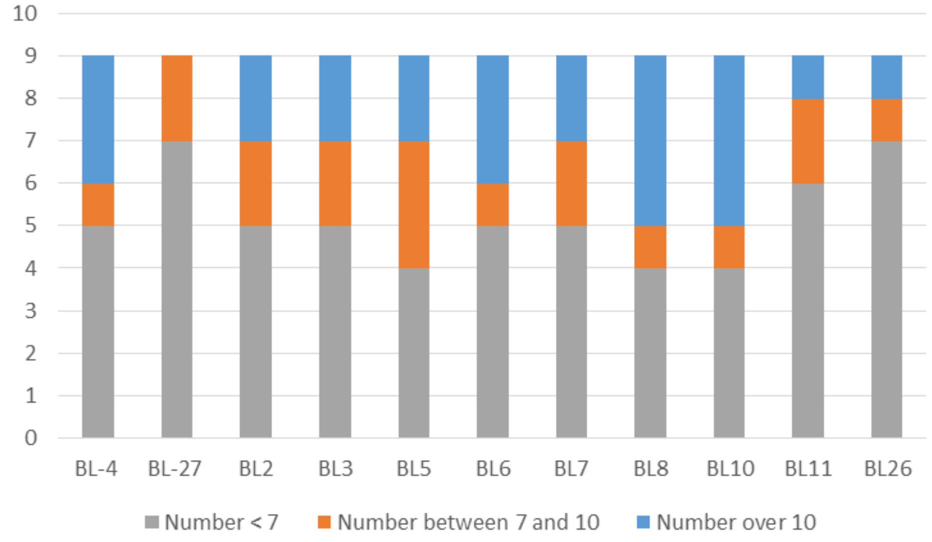

Figure 9. Number of TAH concentrations in 2013 exceeding 10 µg/L, between 7 and 9.9 µg/L, and less than 7 µg/L for each sampling site.

4.4 Watercraft Surveys

Our general observations were that watercraft were present throughout the day. Activity tended to be greater in the late afternoon to early evening (~16:00 to 20:00). Watercraft types appeared to consist primarily of pontoon boats, water ski boats, and personal watercraft. There were a few small fishing boats, sail boats, and non-motorized boats. Watercraft were active at all sampling sites. Site BL-11, at the mouth of Meadow Creek has been considered a reference site, however, we observed personal watercraft and boats operating in Meadow Creek. The level of activity at BL-11; however, was less than at most other sites. The most active locations were to and from the north boat launch (BL-10) and Burkeshore Marina (BL-8).

4.4.1 Transect Surveys

Transect surveys were conducted to obtain an index of boat use throughout each sampling day and were used to calculate boat-hours. Surveys were not conducted on two time periods during the first sampling event, due to boat engine problems and once due to unsafe boating conditions. One transect survey was not completed during the second sampling event due to unsafe boating conditions.

Total watercraft, total boat, and PWC hours for each sample period, day and event were calculated as the product of average counts between sampling events and time in hours (Table 14). This provided an index that incorporated the number of watercraft and operation time and can be used to calculate loading by watercraft hour. Watercraft counts during missed transect surveys were estimated from the relationship with watercraft counted using stop-action photography ($R^2 = 0.86$). Transect survey counts and watercraft hours were higher during the second sampling event (July 4 – 7: 1145 watercraft hours) compared to the first sampling event (June 7 – 10: 942 watercraft hours). The ratio of PWC hours to total watercraft hours was 1:3.8 during the June sampling event and 1:3.2 during the July sampling event. There was no difference in the percent of boats that were PWC between the first and second sampling events (Figure 10). Approximately 24% of all watercraft were PWC including surveys from both sampling events.

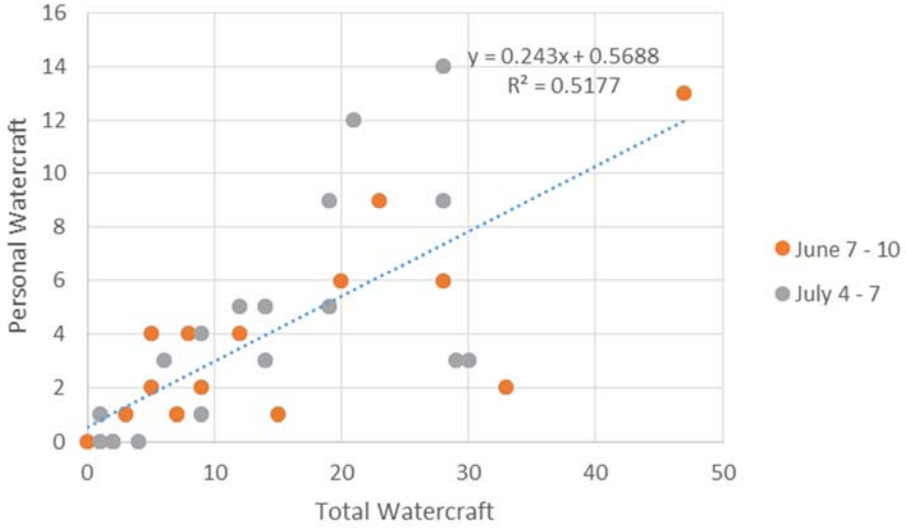

Figure 10. Relationship between total watercraft and PWC from transect surveys for the two sampling June 7 – 10 (orange circles) and July 4 – 7 sampling events.

Table 14. Calculated watercraft (WC)-hours broken down by watercraft type (PWC = personal watercraft) for each sample period for both sampling events providing values that can be compared between sampling events.

Date	Time Interval	PWC Hours	Boat Hours	WC Hours	Cum PWC Hours	Cum Boat Hours	Cum WC Hours
6/7/2013	9:00-12:00	6	4.5	10.5	6	5	11
6/7/2013	12:00-15:00	7.5	10.5	18	14	15	29
6/7/2013	15:00-18:00	7.5	15	22.5	21	30	51
6/7/2013	18:00-22:00	10	12	22	31	42	73
6/7/2013	22:00-9:00	11	44	55	42	86	128
6/8/2013	9:00-12:00	3	30	33	45	116	161
6/8/2013	12:00-15:00	15	42	57	60	158	218
6/8/2013	15:00-18:00	19.5	36	55.5	80	194	274
6/8/2013	18:00-22:00	14	38	52	94	232	326
6/8/2013	22:00-9:00	22	66	88	116	298	414
6/9/2013	9:00-12:00	10.5	37.5	48	126	336	462
6/9/2013	12:00-15:00	28.5	112	112.5	155	448	574
6/9/2013	15:00-18:00	22.5	97.5	120	177	545	694
6/9/2013	18:00-20:00	8	45	53	185	590	747
6/9/2013	20:00-9:00	39	84	130	224	674	877
6/10/2013	9:00-12:00	3	4.5	7.5	227	679	885
6/10/2013	12:00-15:00	9	16.5	25.5	236	695	910
6/10/2013	15:00-18:00	9	22.5	31.5	245	718	942
7/4/2013	9:00-12:00	6	10.5	16.5	6	11	17
7/4/2013	12:00-15:00	24	21	45	30	32	62
7/4/2013	15:00-18:00	25.5	27	52.5	56	59	114
7/4/2013	18:00-22:00	28	38	66	84	97	180
7/4/2013	22:00-9:00	66	71.5	137.5	150	168	318
7/5/2013	9:00-12:00	12	25.5	37.5	162	194	355
7/5/2013	12:00-15:00	21	49.5	70.5	183	243	426
7/5/2013	15:00-18:00	34.5	49.5	84	217	293	510
7/5/2013	18:00-22:00	40	52	92	257	345	602
7/5/2013	22:00-9:00	33	71.5	104.5	290	416	706
7/6/2013	9:00-12:00	7.5	12	19.5	298	428	726
7/6/2013	12:00-15:00	12	51	63	310	479	789
7/6/2013	15:00-18:00	12	54	88	322	533	877
7/6/2013	18:00-22:00	12	34	46	334	567	923
7/6/2013	22:00-9:00	5.5	50	60.5	339	617	983
7/7/2013	9:00-12:00	4.5	19.5	24	344	637	1007
7/7/2013	12:00-15:00	9	55.5	64.5	353	692	1072
7/7/2013	15:00-18:00	6	60	66	359	752	1138
7/7/2013	18:00-22:00	1.5	6	7.5	360	758	1145

4.4.2 Boat Launch Surveys

Surveys were conducted at Big Lake North Boat Launch from ~ 13:00 to 17:00 to obtain a measure of the relative use of motor types. Survey results are provided in Table 15. The relative numbers of 2-stroke motors (Boats and PWC) to 4-stroke motors was 1:4 during the first sampling event and 1:3 during the second sampling event. These ratios are close, but slightly lower than ratios of PWC to total watercraft obtained from transect surveys. The percent of motors that were known 2-stroke was 16% during June and 10% during the July sampling event (13% average). This is similar to the percent 2-stroke of 12% obtained during 2009 surveys (Oasis 2010).

Since the motor size for inboard motors was generally unknown, survey results very likely underestimated boat motor sizes. Average and median motor sizes for those accounted for were slightly larger during the June sampling event.

Table 15. Results of boat launch surveys conducted during the June and July 2013 sampling events.

	June 7 - 10	July 4 - 7
All Watercraft Counted	36	41
All PWC + 2-Stroke Motors	9	18
2-Stroke Motors	6	4
PWC + 2-Stroke: Total Watercraft	1:4	1:3
2-Stroke:Total Watercraft	1:6	1:10
Average Motor Size (HP)	123	63
Median Motor Size (HP)	55	50

4.4.4 Aerial Surveys

Watercraft counts from aerial surveys were used to check on the accuracy of transect surveys. Total watercraft were counted from aerial photographs that corresponded to transect survey times (Figures 11 and 12). Aerial surveys were conducted on June 8, June 9, and July 6, 2013. The difference between aerial and transect counts ranged from 1 to 5 watercraft. For example on June 8, 23 watercraft were counted by transect survey and 28 watercraft were counted by aerial survey. Accuracy (measured/actual *100) ranged from 82% to 107%.

Figure 11. Aerial photo of the East Basin taken on June 8, 2013 at 16:52. Boats are circled in red; 28 watercraft were counted. Dashed line is transect survey route.

Figure 12. Aerial photo of the East Basin taken June 9th at 16:00, 47 watercraft were counted. Dashed line is transect survey route.

4.4.5 Stop Action Photography

Counts of watercraft also were obtained from photographs taken every 15 minutes (June 7 through 10) or 30 minutes (July 4 through 7). We were unable to find a good location for the camera near Big Lake North Boat Launch, so data are only available for Big Lake South (BL-4). All watercraft were counted to provide hourly values (Table 16). Watercraft type could not be accurately obtained for all photographs; therefore, we report total watercraft only.

Total watercraft counts from stop-action photographs were lower, but consistent with transect surveys counts. Slightly higher watercraft counts were obtained during the first sample period from photographs, whereas, higher counts were obtained during the second sampling event from transect surveys.

Table 16. Cumulative watercraft counts using stop action photography for each sample event and sample period for comparison.

Date	Time	Cumulative Total Watercraft		Date	Time	Cumulative Total Watercraft
6/7/2013	12:00	0		7/4/2013	12:00	1
6/7/2013	15:00	7		7/4/2013	15:00	5
6/7/2013	18:00	13		7/4/2013	18:00	15
6/7/2013	22:00	18		7/4/2013	22:00	25
6/8/2013	9:00	18		7/5/2013	9:00	25
6/8/2013	12:00	23		7/5/2013	12:00	28
6/8/2013	15:00	42		7/5/2013	15:00	33
6/8/2013	18:00	52		7/5/2013	18:00	43
6/8/2013	22:00	60		7/5/2013	22:00	50
6/9/2013	9:00	60		7/6/2013	9:00	50
6/9/2013	12:00	64		7/6/2013	12:00	51
6/9/2013	15:00	68		7/6/2013	15:00	56
6/9/2013	18:00	96		7/6/2013	18:00	67
6/9/2013	22:00	109		7/6/2013	22:00	76
6/10/2013	9:00	109		7/7/2013	9:00	76
6/10/2013	12:00	111		7/7/2013	12:00	77
6/10/2013	15:00	115		7/7/2013	15:00	83
6/10/2013	18:00	118		7/7/2013	18:00	84

4.5 TAH Watercraft Relationships

Cumulative watercraft hours from transect surveys and stop-action photographs explained most of the variability in TAH concentrations for each sampling event. The regression relationship between cumulative watercraft counts from transect surveys and cumulative lake average TAH concentrations for the two sampling events are shown in Figure 13. Cumulative watercraft hours explained 99% of the variability in cumulative average lake TAH concentrations.

The slope of the regression equation describes the rate that TAH concentrations increase relative to watercraft hours. Regression slopes for the two sampling events were different. Slopes for the first sampling event ranged from 0.11 at BL-10 (Big Lake North) to 0.02 at BL-27, with an average of 0.04. Average regression slope for the second sampling event was 0.018, with a range from 0.008 (BL-27) to 0.028 (BL-10). R squared values describe how well the two variables are related from a low of 0 to a maximum value of 1.0. R squared values during the first sampling event ranged from 0.935 for BL-27 to 0.99 for site BL-11. For the second sampling event R squared values ranged from 0.94 for site BL-7 to 0.99 for site BL-11.

Similar relationships were obtained using watercraft hours from stop action photographs with higher regression slopes during the first sampling event (Figure 14). Using transect survey data, the change in Big Lake TAH concentrations increased at a rate of 0.043 µg/L/Watercraft hour during the first sampling event and at a rate of 0.019 µg/L/Watercraft hour during the second sampling event, a difference of 0.024 µg/L. Regression slopes between cumulative lake average TAH and watercraft hours from stop-action photography were 0.085 µg/L during the first sampling event and 0.055 µg/L during the second sampling event, a difference of 0.03 µg/L. Therefore, the difference in rates between sampling events was similar for these two methods of recording boat hours.

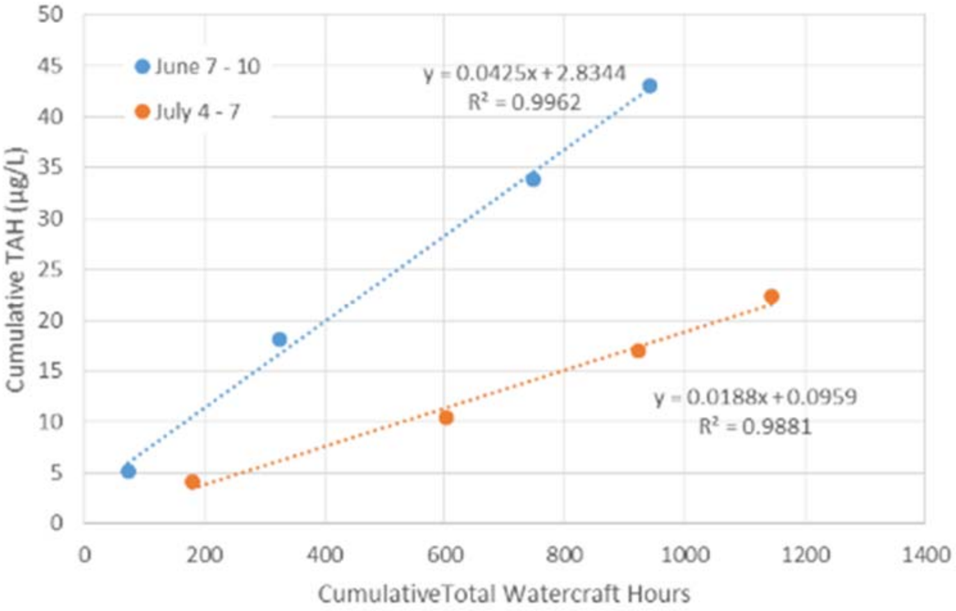

Figure 13. Relationship between cumulative watercraft hours from transect surveys and cumulative TAH concentrations for the two sampling events.

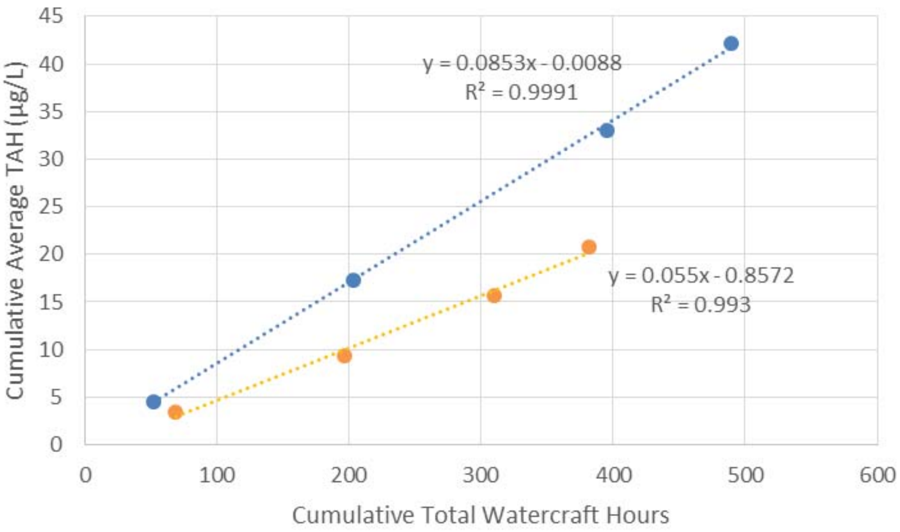

Figure 14. Regression relationships between average lake cumulative TAH concentrations and cumulative watercraft hours from stop-action photography.

4.6 TAH Loading

TAH loading was estimated for the two sampling events using BL-4 sampling results. The intensive BL-4 site was used because average daily TAH concentrations at this intensive site were very close to average lake concentrations. TAH loading over time can be defined by the following equation as:

$$C_F = C_I + Loading - Loss$$

Where C_F is final concentration and C_I is initial concentration. Loss includes TAH lost through deposition, evaporation, or dilution. TAH Loss was determined by fitting the decrease in TAH concentrations overnight (22:00 to 09:00) to an exponential decay curve.

$$C_t = C_o e^{-kt}$$

Where concentration at time *t* declines from initial concentration at a rate of –*k* times *t* in hours. The exponent –*k* is the decay constant and defines the rate at which concentrations decrease. An exponential decay curve is used because loss rate is expected to be higher when concentrations are higher and decrease as concentrations approach 0. This is consistent with TAH loss for the June and July Big Lake sampling with concentration at 21:00 explaining most of the variability in overnight loss. Fitting TAH concentrations resulted in decay constant of -0.057 (Figure 15). There were no differences in TAH loss rate coefficients between the two sampling events.

The loss coefficient can be used to estimate the time for TAH concentration to decline below WQC levels or to approach 0 (Figure 16). If initial TAH concentrations are 30 µg/L, it will take an estimated 20 hours for concentrations to drop below 10 µg/L and over 50 hours for concentrations to drop to 1.5 µg/L with no TAH discharge.

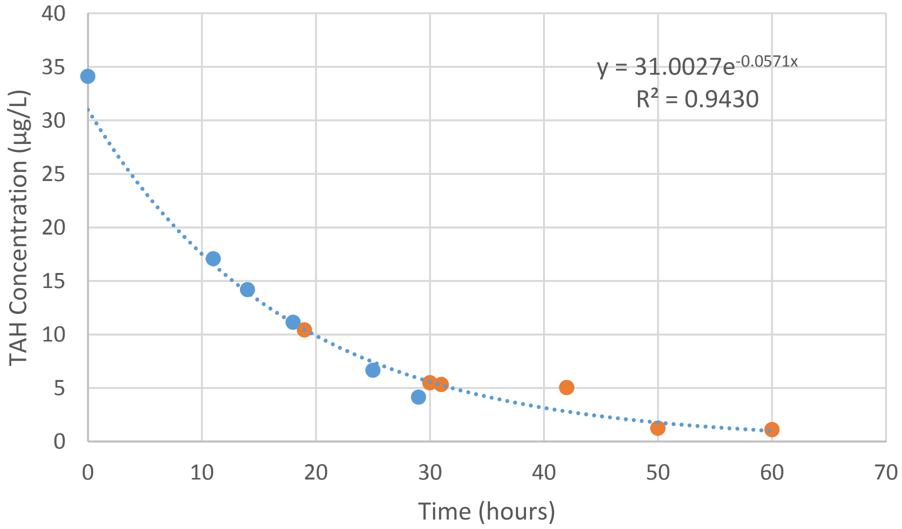

Figure 15. TAH concentrations at 21:00 and 09:00 at sampling locations during the June (blue) and July (orange) sampling events fitted to an exponential loss curve to determine the loss coefficient.

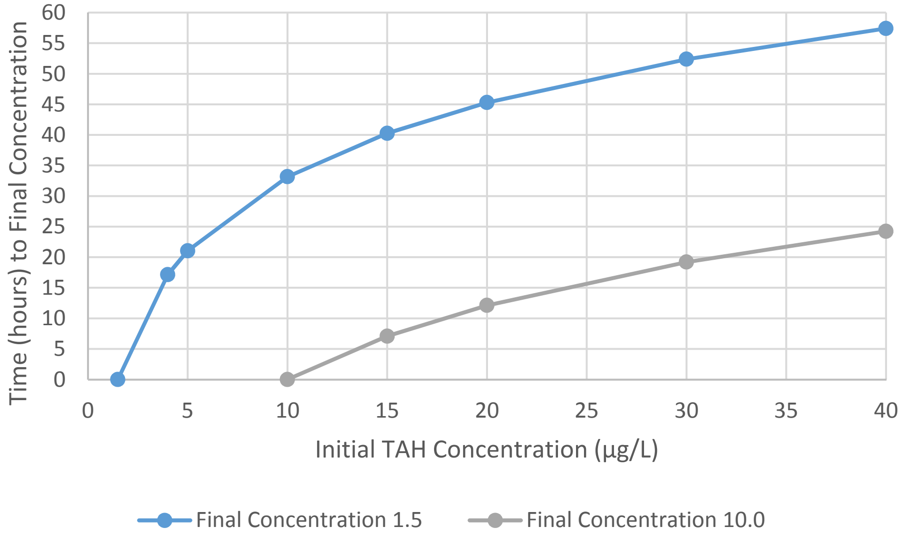

Figure 16. Time required for TAH concentrations to decline to final concentrations of 1.5 µg/L (blue line) or 10 µg/L (grey line).

Loading was calculated as the difference in concentration plus loss between each sample time (equation 1). If there was no change in concentrations between sample times, loading equaled loss. We used values from BL-4 to calculate loading. This was based on similar average BL-4 TAH concentrations and lake average TAH concentrations over the two sampling events (8.5 µg/L for BL-4 and 7.9 µg/L for lake average). There was a strong correlation between BL-4 and lake average TAH concentrations (Pearson correlation coefficient (0.93).

Cumulative daily loading was calculated for both 4-day sampling events (Table 17). Loading as TAH concentration (µg/L) was converted to mass by multiplying by the sample area and depth. Sample area included the East Basin and North Bay (Figure 1) and measured from aerial photographs using ArcGIS was 5.47 x 10^6 m^2 (1,352.38 acres). There was no clearly established mixing depth or thermocline during the June sampling event (Figure 17); however, the mixing depth was between 1 and 1.5 m. A mixing depth of 1.0 m was used for a volume of 5.37 x 10^9 L. During the second sampling event a mixing depth of 3.5 m was used based on the presence of a thermocline resulting in a volume of 19.2 x 10^9 L. TAH mass was converted to a volume by using the density of gasoline (737 g/L). Volume of gasoline was estimated by using a TAH/Gasoline ratio of 0.369 (Oasis 2009). The ratio of TAH to gasoline is variable; however, this value was used in order to be consistent with previous studies. Loading as gallons of gasoline per boat hour was calculated by plotting cumulative daily loading as a function of cumulative total watercraft hours (Figure 18).

TAH loading was estimated at 0.32 gallons (1.2 L) of gasoline per boat hour or 0.11 gallons of TAH (0.44 L) (Figure 18). This estimate was based upon measured concentrations of TAH and watercraft hours. During the first sampling event this equals a daily range of 56 to 182 gallons of gasoline added to the East Basin of Big Lake and a daily range of 34 to 200 gallons of gasoline discharged during the second sampling event.

TAH loss between sampling events was calculated from overnight loss rates from BL-4. Loss rates varied at this location, and likely among sites and with temperature, wind speed, sediment deposition, and mixing. More detailed measures of TAH loss rates among sites and due to these variables could improve calculated loss rates and loading estimates.

Table 17. TAH loading parameters and calculations as a change in concentration and by TAH mass.

Cumulative Event Totals	June 7 - 10	July 4 - 7
TAH Loss (µg/L)	61.5	17.8
TAH Loading (µg/L)	69.6	20.1
East Basin Area (m^2)	5.47 x 10^6	5.5 x 10^6
East Basin Mixing Depth (m)	1.0	3.5
East Basin Volume (m3)	5.47 x 10^6	1.92 x 10^7
East Basin Volume (L)	5.47 x 10^9	1.92 x 10^{10}
TAH Loading (mg)	3.81 x 10^8	3.86 x 10^8
TAH Loading (L)	516.7	523.1
Gasoline Loading (L)	1,400	1,418
Gasoline Loading (gallons)	368	374

The estimate of volume of water in which TAH are discharged is the largest source of potential error. We used the entire surface area of the East Basin of the lake and the depth of the thermocline. We used the entire surface area of the lake study area because we had similar TAH concentrations among sampling sites, observed watercraft activity throughout the study area, and there are no physical boundaries that would prevent TAH mixing by diffusion or convection. Previous sampling has shown little variation in TAH concentrations with depth up to 1 m (Oasis 2010). A clear thermocline was present during July sampling; however, the depth of TAH mixing during June is not clear. Differences in the mixing depth would explain differences in the regression slopes between watercraft hours and cumulative TAH concentrations from the two sampling events. Use of 1 m mixing depth in calculating lake volume for the first sampling event resulted in very similar loading estimates. However, the depth of TAH mixing was not known.

The calculated loading rate per boat hour was consistent with other studies. Using our calculated loading rate of 0.32 gal per boat hour we calculated inefficiency (fuel discharged/fuel consumed) based on different fuel consumption rates. Using a fuel consumption rate of 4.0 gallons per hour (consistent with Oasis 2010) inefficiency was ~ 8.2%. Using the same published efficiency values as Oasis (2009) for 2-stroke (27.1%) and 4 stroke (4.1%) motors we calculated combined inefficiency using different ratios of 2-stroke to 4 stroke motors. An inefficiency of 8.2% was consistent with a 2 stroke to 4-stroke ratio of 1:4.5. This is very close to the ratios we obtained from boat launch and transect survey counts, and provides further support for our calculated loading per boat-hour based on differences in mixing depth.

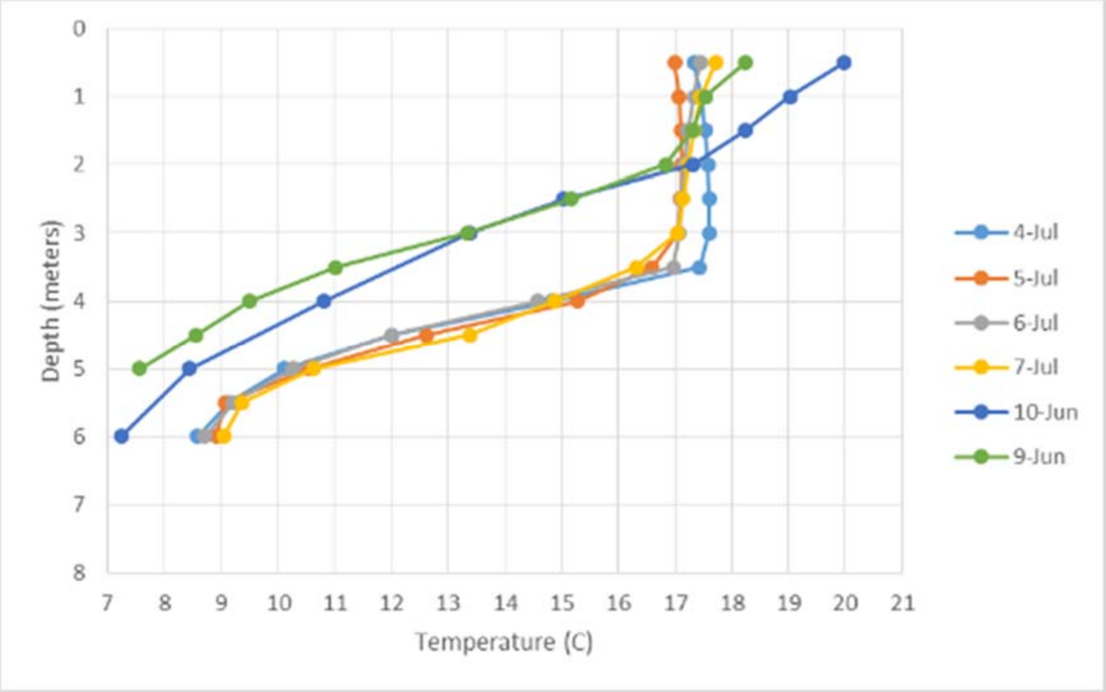

Figure 17. Water temperature at different depths on multiple sampling dates showing a shallow epilimnion during the June sampling event and an epilimnion of 3.5 m during the second sampling event.

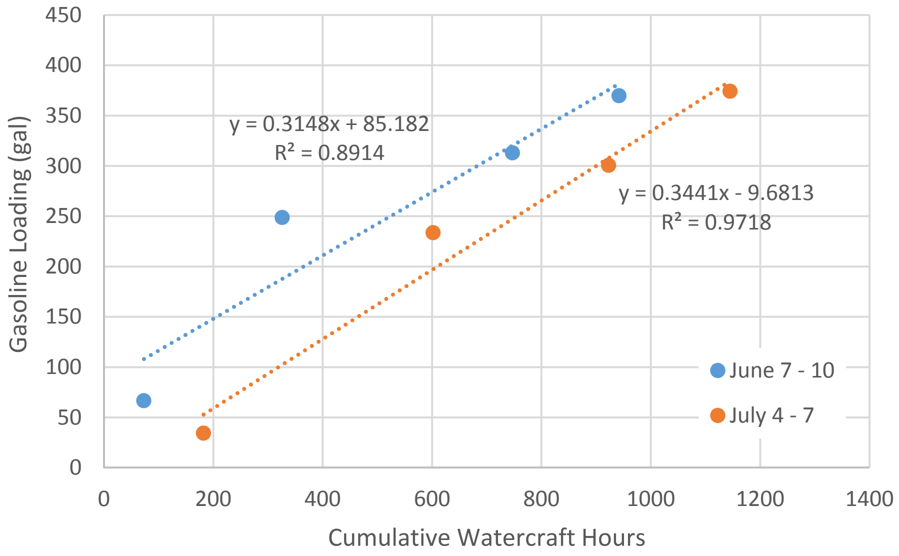

Figure 18. Loading of gasoline as a function of boat hours for the two four-day sampling events resulting in a loading rate of 0.346 gallons per boat hour.

5.0 Discussion

5.1 Water Quality Criteria

Water quality criteria values were exceeded at multiple sampling locations and on multiple sampling dates. During the first sampling event, four-day (96-hour) average TAH concentrations exceeded water quality criteria at 3 sampling sites and when using the average of all sampling sites. During the second sampling event, criteria values were only exceeded in a total of three samples and the four-day (96-hour) average was less than 10 µg/L at all sites. However, the strong relationship between watercraft hours and TAH concentrations, confirms that watercraft are the source of TAH in Big Lake. So if watercraft are the source of TAH and watercraft hours similar between the two sampling events, then why were WQC exceeded during the first sampling event and not during the second sampling event?

Big Lake TAH concentrations (µg/L) are the mass of hydrocarbons (µg) added to the lake divided by the lake mixing depth volume (L). Therefore, either the mass of TAH added to the lake was different between these two sampling events or the volume of water they were dissolved into was different between sampling events. The mass of TAH added to the lake per hour that adds to the concentration includes all TAH discharged minus the amount lost to the atmosphere or deposition. Therefore, either greater loss rate or a decrease in the discharge per watercraft are possible explanations for the differences in TAH concentrations between sampling events.

The TAH loss rate was calculated for both sampling events from the differences in TAH concentrations from 11:00 PM to 09:00 AM. The difference in loss of TAH between these two time periods was primarily due to differences in concentrations. Overnight loss was higher when initial concentrations were higher. TAH can be lost through volatilization, advection, or sorption and deposition. Volatilization and sorption increases with increasing concentrations. Warmer temperatures and winds also would increase the loss rate due to volatilization. TAH concentrations and air temperatures were higher during the first sampling event, which would suggest a higher loss rate in June. However, this would result in lower TAH concentrations during the first sampling event, which is the opposite of values obtained in this study. In addition, when we corrected for concentration, there was no difference in loss rate between the two sampling periods. Therefore, it is unlikely that differences in loss rates explains the differences in TAH concentrations between these two sampling events.

The second possibility is that loss rates were similar and TAH discharge per boat varied between these two sampling events. Multiple different factors affect TAH discharge per boat including motor inefficiency, motor size, fuel efficiency, and operating speed. Motor inefficiency is the portion of fuel lost per fuel burned. Older carbureted 2-stroke motors can be very inefficient discharging up to 30% of their fuel unburned. Inefficiency of these 2-stroke motors is greatest when idling. Larger motors generally burn more fuel than smaller motors; therefore, at the same inefficiency more fuel burned results in more fuel discharged. Fuel efficiency is greater when at cruising speed than at full throttle or during initial acceleration. Other factors including hull design, motor size to boat weight, and operation can affect fuel efficiency and TAH discharge. However, because there was little variation in discharge per boat hour within a sampling event and a large difference in discharge per boat hour between the two sampling events, we do not believe that differences in motor type or motor size can explain the differences in TAH concentrations between these two sampling events.

In order for boat motor type or motor size to explain the difference in TAH concentrations between the two 4-day sampling events there would need to be a consistent difference in watercraft use between these two events. That is, watercraft use during the first sampling event would need to have greater numbers of 2-stroke motors and consistently greater numbers of larger boats or differences in boat operation. This study was not developed to test for differences in watercraft type between sampling events. However our general observations and data on boat use collected suggest that the types of watercraft and watercraft uses were similar between the two sampling events. The portion of watercraft observed at the north boat launch using 2-stroke motors was less during the June sampling event than the July sampling event. Median and average boat motor size was greater during the June sampling event. The portion of 2-stroke motors suggests greater discharge per watercraft in July and the difference in boat motor size suggests greater discharge per watercraft in June. We believe that it is more likely that similar groups of people, were on Big Lake for similar reasons, and operated similar size and types of watercraft on June 7 – 10, 2013, as they did during July 4 – 7, 2013, and less likely for there to be large changes in use during this short time interval.

A third possibility is that TAH loss rates and discharge per watercraft were similar, but mixing depth volume varied between these two sampling events. Differences in water density with temperature prevent complete mixing. Colder denser water becomes separated from lighter surface waters forming distinct strata. The upper mixing area or epilimnion becomes separated from the deeper hypolimnion. Concentrations of dissolved gasses and solutes are different between these two strata (Goldman and Horne 1983). During the June 7 – 10 sampling event measures of water temperature with depth clearly showed rapidly changing water temperatures and incomplete surface water mixing. Whereas during the July 4 – 7 sampling event, measurements of water temperature with water depth showed complete mixing to 3.5 m (Figure 17). This difference in mixing depth of 2 to 2.5 m results in a large difference in the volume of water in which hydrocarbons are discharged (Table 17). Therefore consistent TAH discharge per boat hour and similar TAH losses between the June and July sampling events could have resulted in different TAH concentrations due to differences in mixing depth volume.

5.2 Inter-Annual Water Quality Trends

The evaluation of changes in water quality requires a consistent metric that can be used to track the effectiveness of implemented control measures. One metric is the WQC of 10 µg/L TAH. Based on this metric there was not an improvement in Big Lake water quality in 2013. However, TAH concentrations vary with the level of watercraft use, and monitoring improvements in water quality based on WQC will depend upon when samples are collected. Low TAH concentrations from samples collected when low numbers of watercraft are operating do not necessarily indicate improved water quality. In addition, there can be improvements in water quality while still not meeting WQC. Therefore, other metrics are needed to monitor improvements in water quality and the effectiveness of control measures.

Other metrics that have been used to assess improvements in Big Lake water quality including the range or maximum TAH concentration, and the number of samples or percent of samples that exceed WQC. However these metrics also vary based on the number of samples and when samples are collected. For example, watercraft hours are lower during the middle of a week or on cloudy days than on sunny weekends. If sampling were conducted only on cloudy Wednesdays, we posit that the percent or number of samples that exceed WQC would be less than the same number of samples collected on sunny Saturdays. Similarly, maximum concentrations are likely to be lower during the middle of the week than on sunny weekends. In addition, lower numbers or lower percent of samples below WQC would not necessarily indicate an improvement in water quality or the effectiveness of control measures, but could merely reflect a decrease in the number of watercraft.

Even if samples were collected every day, the number or percent of samples below WQC could not be used to assess the effectiveness of control measures. This and other studies have clearly shown the relationship between watercraft and TAH concentrations. TAH concentrations in Big Lake are a product of the number of watercraft hours and TAH discharge per watercraft. Big Lake TAH concentrations could be reduced and water quality improved by reducing the number of watercraft hours. However the objective of control measures are to reduce TAH discharge per watercraft and not to reduce the numbers of watercraft. Therefore, even if water samples were collected every day and WQC were not exceeded or the number or percent of days WQC were exceeded declined, we would not know if this reduction was due to a lower number of watercraft or a reduction in TAH discharge per watercraft. Metrics used to evaluate water quality improvement must be able to account for differences in the number of watercraft. The change in cumulative TAH concentration as a function of cumulative watercraft hours, when accounting for differences in mixing depth, developed through 2013 sampling, provides a metric that can be used to evaluate future improvements in Big Lake water quality.

5.3 TAH Loading and Watercraft Use

Results from this study showed a very strong relationship between watercraft hours and TAH concentrations for both sampling events. The percent of watercraft that were using 2-stroke engines was highly variable among sampling dates but also was within a fairly small range. Therefore, it is not possible from these data to determine how changes in the percent of watercraft using 2-stroke motors would affect TAH concentrations. However, the currently measured inefficiency of 8.2%, based on 4.0 gallons per hour consumption, could potentially be reduced to 4.1% in the absence of carbureted 2-stroke motors (based on reported inefficiencies EPA 1996, ODEQ 1999 as cited by Oasis 2010). Reducing inefficiency to 4.1% would allow for an increase in watercraft hours while still maintaining WQC. For example, at an estimated 500 watercraft hours would be required to increase TAH concentration by 10 µg/L at an inefficiency of 8.2% compared to over 900 watercraft hours at an inefficiency of 4.1% (Figure 19).

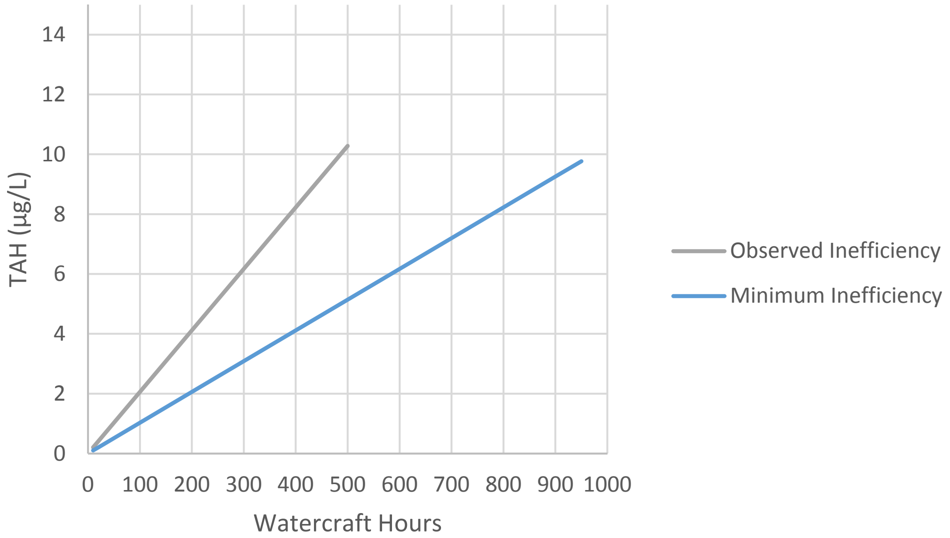

Figure 19. Estimated Big Lake TAH concentrations as a function of watercraft hours at an inefficiency of 8.2% as calculated in 2013 (observed) compared with an inefficiency of 4.1% (minimum) at a fuel burn rate of 4 gallons per hour and a 3 m mixing depth.

The calculation of TAH loading could be improved by more accurate estimates of loss rates. Our loss rates are based on 6 dates where overnight reduction in TAH concentrations allowed for calculation of loss. In order to better understand loss rates we recommend sampling every 1 or 2 hours through the night at 3 or more sampling locations to develop more accurate loss curves.

5.4 Future Water Quality Monitoring

The strong relationships between TAH concentrations and watercraft hours provides a metric that can be used to evaluate water quality improvement. A reduction in the rate of change in TAH as a function of watercraft hours would indicate reduced loading and more efficient fuel use. This metric however, varied with mixing depth. The effect of mixing depth could be potentially reduced by conducting monitoring during mid-summer when the thermocline has fully developed. However, measures of epilimnion depth should be conducted concurrent with monitoring.

Future monitoring also must include measures of watercraft use. We obtained similar results from analyses using transect survey and stop-action photography. Photography was easy to obtain, and much less expensive than boat transect surveys. However, as watercraft use from photographs is only a subset of total use, data from photographs could not be used to calculate loading rates. In addition, we could not always distinguish watercraft type from photographs.

The costs of future monitoring could be reduced by limiting the number of sites and the number of samples collected throughout each day. Results of this study showed that TAH concentrations at BL-4 were most representative of average lake values and concentrations at BL-10 often represented maximum values. Samples should be collected between 18:00 and 22:00. Sampling must be conducted over multiple consecutive days (4 or more) to determine the relationship between TAH concentrations and watercraft use or TAH loading.

Big Lake TAH concentrations are due to watercraft use and reducing motor inefficiency will result in reduced TAH discharge. Boat motor size, motor type, and operation affect TAH discharge. Therefore, consistent methods should be developed to track watercraft motor type and size over time. Obtaining accurate measures of motor size or motor type is difficult through direct observation. Inboard motor covers do not have information on motor size. In addition, it is not always easy to differentiate between PWC with 2-stroke carbureted, 2-stroke direct injection, or 4-stroke motors by observation and operators cannot always provide this information. Surveys at boat launches also may not be representative of all watercraft use. However, methods need to be developed to monitor changes in boat motor size and motor type over time.

5.5 Conclusions

- Average 4-day TAH concentrations exceeded WQC values of 10 µg/L at three sites during the June 7 – 10 sampling event, but not during the July 4 – 7 sampling event.
- TAH concentrations were highest at sites close to boat launches and marinas which is consistent with previous studies.
- Cumulative TAH concentrations over the 4 day sampling events were strongly correlated with cumulative watercraft hours and this relationship provides a metric to evaluate changes in water quality over time.
- PWC accounted for approximately 25% of all watercraft and known 2-cycle motors approximately 13% of all watercraft.
- Mixing depth in addition to boat motor size and motor type must be considered when evaluating the effects of TAH discharge from watercraft on Big Lake TAH concentrations.
- Gasoline discharge was 0.33 gallons per boat hour and, at a burn rate of 4 gallons per hour, 8.2% of the gasoline was discharged per gallon burned.
- During these two sampling events, ~34 to ~200 gallons of gasoline per day were discharged into Big Lake.
- Future monitoring should be conducted. Monitoring costs could be reduced by conducting a 4-day summer sampling event at a limited number of sampling locations and with sample collection occurring between 18:00 and 22:00 and include transect surveys of watercraft and measures of mixing depth.
- Methods should be developed to accurately track changes in watercraft motor size and type.

6.0 References

Alaska Department of Environmental Conservation. 2012. 18 AAC 70, Water Quality Standards. Juneau, Alaska.

Alaska Department of Environmental Conservation. 2012. Total maximum daily load for petroleum hydrocarbons in the waters of Big Lake in Big Lake, Alaska. Final May 2012. Anchorage, Alaska.

Alaska Department of Environmental Conservation. 2010. Alaska's Final 2010 Integrated Water Quality Monitoring and Assessment Report July 15, 2010. Juneau, Alaska.

Alaska Department of Environmental Conservation. 2007. Big Lake Petroleum Hydrocarbon Sampling Results 2004 and 2005. Nonpoint Source Water Pollution Control Program.

Oasis Environmental, Inc. 2006. Big Lake Water quality monitoring report, Big Lake Alaska, Final Report. Prepared for the Alaska Department of Environmental Conservation. Anchorage, Alaska.

Oasis Environmental, Inc. 2010. Water Quality Monitoring Big Lake, Alaska. Final Report January 2010. Prepared for the Alaska Department of Environmental Conservation. Anchorage, Alaska.

Appendix A. Project Photographs

Photograph 1. VOC sampler collecting water sample at 0.15 m depth.

Photograph 2. Water samples were preserved with hydrochloric acid.

Photograph 3. Boats launching at Big Lake South boat launch, near sampling site BL-4.

Photograph 4. Boats launching at Big Lake North boat launch, near sampling site BL-10.

Photograph 5. Burkeshore Marina, Site BL-8.