POLYCYCLIC AROMATIC HYDROCARBONS IN WATER, SEDIMENT, AND SNOW, FROM LAKES IN GRAND TETON NATIONAL PARK, WYOMING

Final Report, USGS-CERC-91344

February 2005

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Abstract - Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous in the environment, and can exist at toxic concentrations in relatively remote and isolated areas. Organic chemical burdens and PAHs from anthropogenic activities in Grand Teton National Park (GRTE), Wyoming, may threaten water and sediment quality. The objective of this study was to identify current PAH concentrations in water, sediment, and snow from lakes in GRTE. Water samples were collected at 11 sites, sediment at eight sites, and snow at four sites in GRTE during 2001, 2002, and 2003, and analyzed for 27 PAHs and alkyl/methyl homologs. All samples contained very low concentrations of PAHs and the largest concentrations of total PAHs in water, sediment, and snow, were 320 ng/L[1], 480 ng/g[1], and 600 ng/L[1], respectively. There is currently little or no threat to fish, wildlife, or humans, based on concentrations of PAHs in samples collected from GRTE. Most of the water and snow samples contained primarily naphthalene and phenanthrene, indicating some anthropogenic inputs; however, retene and perylene were predominant in the sediment samples, indicating a mostly biogenic composition. The results from this investigation provide valuable baseline information on PAHs that can be used in the assessment of future threats to water and sediment quality in GRTE.

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[1] Value contains concentrations recorded at the method detection limit and method quantification limit.

Introduction

Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous in the environment, formed naturally by forest fires, volcanoes, plants, fungi and bacteria, or anthropogenically through the combustion of fossil fuels (Hoffman et al. 1985; Dickhut et al. 2000; Albers 2003). Generally, the presence of PAHs in the environment has increased over the last 100 years; however, global concentrations may have stabilized due to recent air and water quality regulations (Fernandez et al. 2000). PAH concentrations in the environment are often closely related to local and regional sources, although remote areas can be sites of PAH deposition through atmospheric processes and long range transport (Escartin and Porte 1999).

The lakes in Grand Teton National Park (GRTE), Wyoming, are relatively distant from major metropolitan areas; nevertheless, they are not necessarily devoid of organic chemicals from anthropogenic and natural sources. Visitor use in GRTE and neighboring Yellowstone National Park has increased steadily throughout the past twenty years and reached nearly 3 million total visits annually in 2003 (Sue Consolo-Murphy, GRTE, personal communication). Increasing organic chemical burdens from greater visitation and expansion of urban areas in the western United States may provide future threats to water quality in GRTE. Understanding the current amount of hydrocarbons is important in establishing baseline information for future monitoring and assessment of temporal trends in PAH accumulation in GRTE and surrounding areas.

Visitors to GRTE are allowed limited use of motorized craft on several park waters (NPS 2002). Motorized watercrafts, with the exception of personal watercrafts, are permitted on Jackson Lake, which can be accessed from three developed marinas: Colter Bay Marina, Leeks Marina, and Signal Mountain Marina. The general public is allowed to use motorized watercrafts with less than 10 horsepower on Jenny Lake, while concessionaires operating by the authority of the superintendent of GRTE are allowed to use larger engines. Visitors on snowmobiles are given limited access to Grand Teton National Park during the winter (Federal Register 2004). The Continental Divide Snowmobile Trail, a popular travel route which bisects Grand Teton National Park, has a daily quota of 50 snowmobiles, while up to 40 snowmobiles a day are allowed on Jackson Lake during periods of ice cover.

The presence and proportions of PAHs in the environment can provide some information on the scale or amount of organic contamination. Volatilization and oxidation can rapidly eliminate many common PAHs from the water column, thus PAHs generally have a short residence time in aqueous solution. Consequently, the presence of PAHs in the water column usually indicates recent or chronic pollution (Mastran et al. 1994). The incorporation of PAHs into underlying sediments reduces the effect of external or degrading forces and volatilization, thus the presence of PAHs in lake sediments can provide additional insight into deposition sources and rates.

The PAH composition in water and sediment can indicate the sources(s) from which the PAHs were derived (Simpson et al. 1998; Yan et al. 2004). Larger concentrations of lower molecular weight PAHs (e.g. acenaphthene, and fluorene) most often occur in sample matrices contaminated with naturally occurring (petrogenic) PAHs. PAHs originating from combustion (pyrolytic) sources often contain elevated concentrations of higher molecular weight and higher membered-ring PAHs (e.g.

phenanthrene, fluoranthene, pyrene) and fewer low molecular weight PAHs (Helfrich and Armstrong 1986). Some PAHs from biogenic sources, such as retene and perylene, are derived almost entirely from organic matter and can serve as markers for terrestrial derived organic inputs (Simpson et al. 1998).

Potential effects of internal and external activities on the quality of waters within GRTE are important for park managers to understand as they work to maintain the integrity of water quality in GRTE. The quality of many GRTE waters have been described previously (e.g. Farag et al. 2001; Dustin and Miller 2001); however, no studies have thoroughly investigated the presence of PAHs in any of the park's water bodies. The objectives of this study were to determine the presence and concentrations of PAHs in water, sediment, and snow samples collected in Jackson, Jenny, and Taggart lakes, and determine whether the composition of the PAH concentrations could be associated with either petrogenic or pyrolytic sources. The 16 PAHs defined as priority pollutants (Irwin et al. 1997) along with 11 additional PAHs and alkyl/methyl homologs were quantified from samples collected in 2001-2003.

Methods

Study areas

Jackson, Jenny, and Taggart lakes are located in GRTE, Wyoming along the eastern aspect of the Teton Mountain Range (Figure 1). This area of GRTE has a semi-arid mountain climate with average daily temperatures during summer (June-August) of 25° C and average annual snowfall and rainfall of 490 cm and 26 cm, respectively.

Jackson Lake, elevation 2068 m, is the largest lake in GRTE and is partially raised by Jackson Lake Dam. At full capacity, Jackson Lake has a surface area of 10,340 ha and a maximum depth of 134 m. Jackson Lake is slightly mesotrophic in the summer with temperatures that range from 15-17° C and dissolved oxygen from 8-9 mg/L in the top 5 m during August (Miller and Dustin 1997). Jenny Lake, elevation 2068 m, is a smaller natural lake with a maximum surface area of 482 ha and a maximum depth of 129 m. Jenny Lake is slightly oligotrophic to oligotrophic during the summer (Dustin and Miller 2001). Taggart Lake, elevation 2104 m, is the smallest of the three lakes studied, with a maximum surface area of 45 ha, and average depth of 25 m. Taggart Lake is slightly oligotrophic during the summer (Dustin and Miller 2001). Motorized watercraft and snowmobiles are not permitted on Taggart Lake, therefore we defined it as a "pristine" reference site for this investigation.

Water samples were collected at eight sites on Jackson Lake in August 2001, July 2002, and August 2003. Sites included open water near the Warm Springs campsite (WS), Sargents Bay (SRG), Leeks Marina (LKS), Swimmers Beach (SWB), Signal Mountain Marina (SNL), Half Moon Bay (HMB), and open water over the deepest portion of the lake (DP). Also, water samples were collected at Signal Mountain, Leeks Marina, and Swimmers Beach following "ice-off" in May 2002 and 2003. Water samples were collected from open water (OP) in Jenny Lake during August 2001, and at the commercial boat dock (BD1). Additionally, water samples were collected from Jenny Lake at the trailhead boat dock (BD2) in July 2002, and August 2003. Water samples were collected at one site on Taggart Lake near the Taggart Lake trail (TH) during 2001,

2002, and 2003. Sediment samples were collected at WS, SRG, LKS, SWB, SNL, BD1, and TH in 2001 and at BD2 during 2002 and 2003. Snow samples were collected in March 2002 and 2003 at TH, SNL, and SWB and at Flagg Ranch along the Continental Divide snowmobile trail (FLG; not shown on map ~ 6 km north of Jackson Lake) in 2003.

Three additional samples were collected to serve as "positive control" samples to compare PAH composition in samples with combustion-derived sources. One water sample was collected directly behind the exhaust port of a 4-cycle, eight cylinder, inboard/outboard boat engine (PC4), and one water sample was collected directly behind the exhaust port of a 2-cycle, one cylinder, outboard motorboat (PC2). Additionally, one snow sample was collected directly beneath the exhaust port of a 2-cycle, two cylinder, snowmobile run for approximately two minutes (PCS).

Sample collection

Water samples were collected at a depth of 3 m with a stainless steel Kemmerer bottle and transferred to a certified pre-cleaned I-chem amber glass bottle. Each bottle was rinsed thoroughly with site water prior to collection. Also, surface water samples were collected directly into sample bottles following rinsing. Sediment samples were collected at each site with a ponar grab sampler, and homogenized by stirring the sample in a stainless steel bowl with a stainless steel spoon. The stainless steel bowl and spoon used to homogenize sediment samples were rinsed with acetone and de-ionized water prior to and between collections of individual samples. Snow samples were collected as a composite of snow layers from the surface down to the snow-ice transition on the lake surface. The snow samples were collected with a stainless steel spoon and transferred into a 15 L jar covered with aluminum foil to avoid ultraviolet light penetration. Samples were allowed to melt completely while maintained below 4° C, and transferred to a 2.2 L amber bottle for shipment. Water, sediment, and snow (as water) samples were stored at 4° C (< 48 hrs) and shipped under ice, following chain of custody procedures, to the USGS-Columbia Environmental Research Center in Columbia, Missouri for analyses.

Sample analyses

Water, sediment, and snow samples were analyzed for concentrations of 25 PAHs including: naphthalene (Na), acenaphthylene (Acy), acenaphthene (Ace), fluorene (F), dibenzothiophene (DBT), phenanthrene (Pa), anthracene (A), 2-methyl anthracene (2MA), 4,5-methylene phenanthrene (45MPa), 1-methyl phenanthrene (1MPa), fluoranthene (Fl), pyrene (Py), retene (Re), 1-methyl pyrene (1MPy), benzo[b]naphtho[2,1-d]thiophene (BNTH), benzo[a]anthracene (BaA), chrysene (CHy), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[e]pyrene (BeP), benzo[a]pyrene (BaP), perylene (Per), indeno[1,2,3-c,d] pyrene (IP), dibenzo[a,h]anthracene (DA), benzo[g,h,i]perylene (Bghi), 2-methyl naphthalene (2MNa), and 1-methyl naphthalene (1MNa). Validated, performance-based methods were used to conduct the chemical analyses. Analytical standards were verified against certified standards. The extraction efficiencies and method accuracy were monitored by periodic analyses of quality control samples, including in-house reference materials.

Water samples (2.00 L) were preserved with 100 ml of dichloromethane until extraction. The 2.00 L samples were separatory funnel extracted with three 100 ml portions of dichloromethane, and the extracts were combined. All water extracts were further purified by a potassium silicate preparative column and with high performance size exclusion chromatography (HPSEC).

Prior to analysis, sediment samples were homogenized and analyzed for percent moisture using a 1-5 g initial aliquant. With known moistures, sufficient sediment for each sample extraction was taken equivalent to a 10-g portion on a dry-weight basis. To each sediment sample portion, four times the amount of sediment was added as sodium sulfate to form a more granular matrix better suited for Soxhlet-extraction. Prior to instrument analysis, sediment samples were purified by KS, HP-SEC and 3 % water-deactivated Silica Gel.

Method accuracy was determined by assessing the recoveries of quality control samples. Quality control samples that were prepared and analyzed along with water, sediment, and snow samples included: perdeuterated surrogates, procedural blanks, matrix blanks, matrix spiked samples, and sample replicates.

High resolution gas chromatographic/mass spectrometric (HRGC/MS) analysis of PAHs. Sample extracts were adjusted to a final volume of ~100 µL and the instrumental internal standard p-terphenyl-d_{14} (100 ng) was added. Sixteen perdeuterated and 27 native PAHs were measured in the fractioned extracts by gas chromatography/mass spectrometry (GC/MS) in the full scan mode. Analyses were performed using a CE Instruments 8000Top GC with cool on-column capillary injection systems and an AS800 autosampler (2 µL injections) interfaced with a Voyager quadrupole mass spectrometer (Thermo-Finnigan Corp., San Jose, CA). For all analyses, a 2.5 m section of 0.53 mm i.d. uncoated and deactivated (Restek Corp., Bellefonte, PA) capillary retention gap was attached to the front of the analytical column (50 m x 0.20 mm Ultra-2, Agilent, Palo Alto, CA x 0.11 µm) by a Press-Tight® (Restek Corp., Bellefonte, PA) union.

Method detection and quantification limits were estimated from low-level standards and determined by both the signal-to-noise ratio of the peak in the quantitation ion channel and the gradual loss of unique characteristics of the background-corrected mass spectrum. Criteria for the positive identification and quantification of each PAH were established and met during this study following criteria outlined by Keith, et al. (1983; 1991). The data for PAH concentrations were censored and recorded at the method detection limit (MDL) and method quantification limit (MQL) when concentrations were below these calculated values. These censored data were used to calculate sums of total PAHs and total EPA PAHs, whereas total detectable PAHs and total detectable EPA PAHs were calculated only using concentrations above MDLs and MQLs.

Carbon analysis. Total carbon (TC), inorganic carbon (TIC), and particulate inorganic carbon (PIC) were determined using a UIC Inc. model CM5014 coulometer by determining CO_2 with different front end units. Total carbon was determined by burning all organic and inorganic carbon to CO_2 in a Whatman furnace at 925° C. Particulate organic carbon (POC) was determined by combustion at 925° C after acidification to remove inorganic carbon. Dissolved organic carbon (DOC) was determined using a Technicon AAII autoanalyzer, by measuring CO_2 colorimetrically following persulfate-

ultraviolet oxidation and diffusion through a gas-permeable membrane. Total organic carbon (TOC) was calculated as the difference between TC and TIC.

    Statistical analysis. PAHs were not statistically analyzed for any differences between sampling events or among sampling sites. Relationships between organic carbon and PAHs were evaluated using Spearman's rank correlation analysis. All analysis were conducted using Statistic Analysis System (SAS) software (SAS Institute 1999), results were considered significant at $\alpha = 0.05$.

Results

Quality assurance/quality control

    The recoveries of surrogates were consistently good across all sample sets, with most recoveries above 50% and all within the accepted range of 25-125%, allowing for accurate calculation of PAH concentrations. The isotope-dilution quantification of the native PAHs in the Mock 100% standard was excellent in all cases, and in all water, sediment and snow (water) matrix blanks, all targeted PAHs were less than 8 ng/L, and most PAHs were less than 2 ng/L. Coefficient of variation of mean concentrations of detectable PAHs in water and sediment sample triplicates were less than 25%, with the exception of one water triplicate (BD2-July 2002, 34-87%), and one sediment triplicate (LKS-Aug 2003, 27-76%). Percent correspondence in duplicate water samples with detectable PAHs were 33-150%, and in sediment samples with detectable PAHs, percent correspondence was 50-300%; however, 83% of water and sediment duplicates were within 50-150%.

PAH concentrations

    Temperature, dissolved oxygen, and conductivity measured at the surface of each lake during August 2003 were 19.8° C, 7.1 mg/L, and 149.9 µs in Jackson Lake, 19.2° C, 7.8 mg/L, and 25.8 µs in Jenny Lake, and 18.8° C, 7.4 mg/L, and 32.4 µs in Taggart Lake.

    Concentrations of PAHs in water, sediment, and snow were generally small throughout this study (Table 1; Appendix A; Appendix B; Appendix C). Water samples generally contained the smallest concentrations of PAHs, and varied among sampling events and locations. Concentrations of detectable and total PAHs were greatest in Jenny Lake versus Jackson and Taggart lakes during August 2001. The sum of detectable PAH concentrations in Jenny Lake were 41-99 ng/L, while detectable PAHs in Jackson Lake were 0.0-11 ng/L, and no PAHs were detected in Taggart Lake. Samples analyzed subsequent to 2001 benefited from lower method detection limits and method quantification limits allowing for more precise measurements of PAH concentrations in water samples. Therefore, water samples collected during 2002 and 2003 more precisely depict levels of PAHs present in GRTE. Water samples collected in May 2002 yielded total detectable PAH concentrations of 16.2 ng/L in Taggart Lake, and ranged from 13.7-222 ng/L in Jackson Lake. In July 2002, the largest concentrations of detectable PAHs were measured in water collected from Jackson Lake (15-317 ng/L), followed by Jenny Lake (111-152 ng/L) and Taggart Lake (30 ng/L). During May 2003, water samples

collected in Jackson Lake ranged from 25-53 ng/L, while water collected from Taggart Lake contained 43 ng/L of total detectable PAHs. Again, in August 2003, the largest concentrations of total detectable PAHs were measured in water collected from Jackson Lake (16-117 ng/L), with concentrations of total detectable PAHs of 28-39 ng/L in Jenny Lake and 23 ng/L in Taggart Lake. Total PAH concentrations in water from all sites were predominantly comprised of Pa and Na. Phenanthrene concentrations were the largest of the detected individual PAHs in 22 water samples, followed by Na (8 samples), 2MNa (5 samples), and Acy (2 samples).

Concentrations of PAHs in sediment samples were consistently larger than in water samples, but again varied among sampling events and locations. During August 2001, total detectable PAHs in sediment samples from marina sites in Jackson Lake ranged from 127 to 169 ng/g, while concentrations at non-marina sites ranged from 18 to 311 ng/g. Concentrations of total detectable PAHs in sediment samples collected in Jenny and Taggart Lakes were 19 and 128 ng/g, respectively. Total detectable PAHs in sediment samples from marina sites in Jackson Lake ranged from 8.0-19 ng/g in 2002 and from 32-47 ng/g in 2003, whereas sediment samples collected at non-marina sites in Jackson Lake contained detectable PAH concentrations that ranged from 40-471 ng/g in 2002 and from 41-274 ng/g in 2003. Total detectable PAHs in sediment samples collected from Jenny Lake in 2002 ranged from 66 to 139 ng/g and was 39 ng/g in 2003. Concentrations of total detectable PAHs were again consistently less in sediment samples collected at Taggart Lake, than samples collected at Jackson and Jenny lakes. Total detectable PAHs in sediment samples from Taggart Lake were 5.7ng/g in July 2002 and 19 ng/g in August 2003. Unlike water samples, a large proportion of the detectable PAH composition in sediment samples was comprised of Re and Per. Retene concentrations were largest of the detected individual PAHs most frequently occurring in 15 sediment samples, followed by Per (3 samples), Na (2 samples), 2MNa (1 sample), and Pa (1 sample).

Snow samples (as water) generally contained larger concentrations of PAHs than water samples. Taggart Lake contained 146 ng/L of total detectable PAH concentrations in snow during 2002, while samples from Jackson Lake contained 52-60 ng/L. During 2003, samples from Jackson Lake contained concentrations of total PAHs of 330-373 ng/L, while snow from Taggart Lake contained only 36 ng/L of total detectable PAHs. The snow sample collected at Flagg Ranch during 2003 contained 537 ng/L of total detectable PAHs, the largest concentration measured in GRTE. Snow samples were similar to water samples, in that the largest detected PAHs most frequently occurring in samples were Na (3 samples), Pa (3 samples), and 2MNa (2 samples).

Organic carbon concentrations

Six of twenty waters samples measured had detectable concentrations of POC, and of those samples, POC ranged from 237 to 364 µg/L. No statistical analysis of relationships between POC and PAH concentrations in water samples was conducted because samples with detectable POC concentrations did not contain detectable PAH concentrations.

Sediment samples contained relatively larger concentrations of organic carbon than did water. All 28 sediment samples analyzed for TOC had detectable levels of TOC.

There was a considerable amount of spatial variability in TOC concentrations, as TOC in sediment samples varied between 650-135,000 µg/g. Total organic carbon was significantly correlated with total detectable PAHs in sediment samples collected across all sampling events ($r = 0.7636$, $P = 0.006$). Total organic carbon was also significantly correlated with phenanthrene ($r = 0.6091$, $P = 0.047$), pyrene ($r = 0.7826$, $P = 0.004$), and perylene ($r = 0.8571$, $P = 0.014$).

Discussion

PAHs were detected at most locations in the three lakes in Grand Teton National Park, but were present at very low concentrations. Generally, of the three matrices sampled, water contained the smallest concentrations of PAHs, while snow and sediment samples contained slightly larger concentrations. PAHs generally have low solubilities and high octanol-water partition coefficients, and therefore often have a short residence time in water. Lower molecular weight PAHs (1-3 ringed) are often lost due to volatilization and microbial degradation, while larger molecular weight PAHs (4-5 ringed) can be lost due to photo-oxidation and may be incorporated into underlying sediments (Mastran et al. 1994; Miller and Olejnik 2001). The presence of PAHs in the water column of lakes in GRTE likely indicates some recent introductions; however, the identification of specific sources of the PAH contamination is hampered due to the extremely low concentrations present. Areas with chronic or prolonged contamination often have much higher PAH concentrations in the water column (Table 2). For example, PAH concentrations in a drinking water reservoir in Virginia exposed to high levels of motorboat use were considerably larger than concentrations measured in GRTE (Mastran et al. 1994). The U.S. Environmental Protection Agency has established drinking water criteria for benzo[a]pyrene, one of the more carcinogenic PAHs, not to exceed 200 ng/L (USEPA 1996). A water sample from Signal Mountain Marina in July 2002 contained the largest concentration of benzo[a]pyrene measured during this study of 1.5 ng/L, and benzo[a]pyrene concentrations in the majority of water samples were less than 0.2 ng/L or below the method detection limit. Interestingly, the positive control samples collected directly behind the exhaust ports of a four-stroke and a two-stroke engine contained 2.1 and 6.1 ng/L of benzo[a]pyrene, concentrations that are nearly two orders of magnitude below the established drinking water criteria.

PAH concentrations in lake sediments provided a more comprehensive look at past and present air and water quality conditions. Like many hydrophobic organic compounds, PAHs are rapidly sorbed to particles and incorporated into aquatic sediments (Simpson et al. 1998; Fernandez et al. 2000; Yan et al. 2004). Sediment samples from lakes in GRTE contained detectable levels of nearly all PAHs during most sampling occasions. Yet, these concentrations were much lower than those reported from heavily contaminated areas (Table 2). For example, portions of the Thea Foss Waterway, Washington, contain sediments with ΣPAH (sum of 16 EPA priority pollutants) concentrations greater than 3,000,000 ng/g (Stout et al. 2003), whereas the largest ΣPAH concentration measured in GRTE was 118 ng/g[1]. Specific guidelines regarding PAH concentrations in sediments are limited, however numerous literature values are available and provide some comparison. For example, some effects-threshold concentrations as

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[1] Sum contains concentrations recorded at the method detection limit and method quantification limit

high as 1.6 to 3.6 mg/kg have been proposed for BaP in aquatic sediments. However, BaP sorbed to sediments at 0.7 mg/kg has been proposed as the lowest concentration of BaP in sediment at which biological effects (i.e. changes in benthic community composition) would occur (Irwin et al. 1997). Though the toxicological thresholds of PAHs are generally considered in terms of cumulative or summed effects of a selected set of PAHs (e.g. sum of carcinogenic PAHs), the considerable differences between concentrations observed in sediments from GRTE (BaP never exceeded 0.0076mg/kg) and those from other surveys and investigations indicate that PAH-induced toxicological effects in the lakes of GRTE are unlikely.

Snow samples (as water) from GRTE contained relatively larger concentrations of PAHs than many of the samples collected directly from the lakes, particularly those collected in March 2003 at Jackson Lake and Flagg Ranch. The concentrations of PAHs in snow samples were comparable to concentrations of similar volatile organic chemicals found in snow samples during previous investigations. Concentrations of hydrocarbons (e.g. benzene, toluene, and xylenes) ranged from 12.2 to 973 ng/L in snow samples from Yellowstone National Park and surrounding areas, including sites along trails exposed to high levels of snowmobile use; however, contamination from snowmobiles was virtually absent only 50 m from snowmobile routes (Ingersoll (1998). Due to an absence of marked snowmobile routes on the lakes in GRTE, snow samples collected during this study were not taken along designated snowmobile trails. Instead, they were collected in close proximity to snowmobile loading areas and unmarked travel routes. In the present study the variability in PAH concentrations in snow samples between years may be a result of the considerable heterogeneity in organic chemical concentrations along snowmobile travel routes (Ingersoll 1998). Therefore, it is likely that snowmobile inputs of PAHs are restricted to localized areas and contribute little to total PAH levels in Jackson, Jenny, and Taggart lakes. Further the high concentrations of PAHs in snow samples collected in March 2003 did not result in higher PAH concentrations in water samples collected in May and August 2003 compared to concentrations in earlier water samples. These results indicate the contribution of PAHs from snow and potentially snowmobiles to be low.

It is not uncommon for the deposition of atmospheric contaminants to increase during the winter, leading to increases in PAH concentrations in the environment. Franz and Eisenreich (1998) found that precipitation in the form of snow was the dominant contributor to the total PAH concentration in the snowpack due to particle scavenging. Total scavenging of PAHs from snowfall events ranged from 10^3 to 10^7, with scavenging increasing with increasing particulate matter. Some increase in overall PAH concentrations would then be expected from snowpack samples collected in GRTE due simply to atmospheric deposition during winter snowfall events.

Sources of PAH inputs in Jackson, Jenny and Taggart lakes were evaluated based on the relative concentrations of high and low molecular weight PAHs in field samples and positive control samples. Many water samples, and particularly those from marina and high use areas on Jackson and Jenny lakes, contained higher concentrations of naphthalene and phenanthrene relative to all other PAHs. For example, a water sample from Half Moon Bay collected during July 2002 contained the largest measured concentration of detectable PAHs, with 317 ng/L of total detectable PAH. Of the 317 ng/L of PAH, 308 ng/L (97%) were comprised of naphthalene, 1-methyl naphthalene,

and 2-methyl naphthalene. Saeed and Al-Mutairi (1999) identified naphthalene and methylated naphthalenes as the major component of the PAH composition of the water-soluble fraction of gasoline in seawater. Additionally, phenanthrene is generally associated with combustion, or a mixture of combustion and petroleum sources (Mastran et al. 1994; Stout et al. 2003). The composition of positive control samples was also comprised mostly of naphthalene (PC4: 55%, PC2 42%), acenaphthylene (PC4: 13%, PC2: 14%), and phenanthrene (PC4: 7%, PC2: 10%). Although 1-methyl- and 2-methyl naphthalene were not quantified in the positive control samples, the presence and relative abundance of the naphthalenes and phenanthrene indicate that some anthropogenic inputs similar to those derived from 2- and 4-stroke boat engines are likely contributing to the PAH composition in the water in lakes in GRTE.

Despite some evidence of anthropogenic inputs of PAHs into lake waters, there is little evidence that these organics are contributing to the PAH composition in lake sediments. Although there was considerable variability in sediment concentrations of PAHs, potentially indicating some localized inputs, there was a strong significant correlation between PAH concentrations and TOC. Other authors have indicated that a positive correlation between PAH and TOC is common in areas not affected by contamination, because PAHs have a high affinity for sediments rich in organic carbon (Pereira et al. 1999; Stout et al. 2003). However, areas with considerable contamination (e.g. urban runoff, mill effluents) show little or no relationship between PAH and TOC as organic matter and fine grained sediments are saturated with PAH inputs. Though multiple factors more complex than sediment-associated organic carbon affect PAH concentrations in GRTE, there is currently no evidence suggesting any major or localized anthropogenic inputs in the sedimentary record.

Sediment samples from Jackson, Jenny, and Taggart lakes contained large concentrations of retene, which has been identified as a molecular marker for the combustion of wood (Ramdahl 1983), and is often dominant in sediments impacted by runoff from coniferous forests (Simpson et al. 1998). Engelmann spruce, subalpine fir, Douglas-fir, and lodgepole pine dominate the mid-elevation forests of GRTE, which have burned periodically along the shores of Jackson, Jenny, and Taggart lakes for centuries (NPS 2004). The widespread presence of retene and the close proximity of historical fires indicates that the PAH composition in sediments is dominated by terrestrial or biogenic inputs, with some possible inputs from local anthropogenic wood burning sources.

This study provides important baseline information on water and sediment quality in GRTE under the current level of anthropogenic activities. It appears that no threats from PAH inputs currently exists for Jackson, Jenny, and Taggart lakes; however, visitor numbers and local populations may increase in the future, making it increasingly important to continually monitor the status of the park's water and sediment resources and the potential impacts of recreational and commercial uses. Though this study provides invaluable information regarding the water quality of an isolated semi-remote area, its applications can be expanded easily to include regional and global considerations. PAHs like many other environmental contaminants are easily stored and transported through the earth's atmosphere. Therefore, remote lakes far from active pollution sources can serve as indicators of air quality conditions and their effects on water and biological resources. Continued monitoring of water quality conditions in the

pristine environment of GRTE can provide both a comparison with this baseline of information and other regional air and water quality indicators. Intervals of 5-7 years between monitoring efforts in GRTE should provide adequate assessments of changes in PAH inputs and sources, although additional sampling would be beneficial following changes in management strategies and visitor numbers, or natural events (e.g. forest fires).

In summary, small concentrations of PAHs were measured in water, sediment, and snow from lakes in GRTE. While some measurable concentrations of PAHs associated with fuel and combustion sources are present near marina and higher use areas, these PAHs do not appear to be persistent. Additionally, PAHs were present in snow in areas with concentrated snowmobile use. However, these inputs did not translate into higher concentrations in lake water and sediment. Results from this study indicate that threats of PAH contamination from anthropogenic sources do not currently exist in GRTE. The precision in PAH measurements obtained from samples collected in 2002 and 2003, due to lower MDLs and MQLs, indicate some of the lowest concentrations of PAHs measured in field samples. These concentrations provide a very useful baseline for evaluating future trends in PAH concentrations in GRTE as well as numerous other similar investigations.

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Table 1. Summary of selected PAH concentrations in water, sediment, and snow from lakes in Grand Teton National Park, Wyoming (see text for abbreviations and site names). *Note: Total PAH (TPAH) concentrations are sums of PAH concentrations including values recorded at the method detection limit and method quantification limit.

Date	Lake	Sites	N	PAHs (ng/L or ng/g dry wt.)				
				Na	Pa	BaP	Re	TPAH*
				Water				
Aug 2001	Jackson	Marina	2	< 6.0	< 40	< 0.6	-	92-93
		Non-marina	4	< 6.0-7.3	< 40	< 0.6	-	92-93
	Jenny	All	2	23-48	< 40	< 0.6	-	120-180
	Taggart	TH	1	< 6.0	< 40	< 0.6	-	92
May 2002	Jackson	All	3	3.1-110	3.3-4.9	< 0.6	< 3.3	47-250
	Taggart	TH	1	2.9	4.1	< 0.6	< 1.4	42
July 2002	Jackson	Marina	2	2.7-29	5.5-6.2	0.1-1.5	< 0.4-6.2	17-116
		Non-marina	5	R-28	4.9-16	< 0.1	< 0.9	17-320
	Jenny	All	3	38-41	6.0-9.2	< 0.1	< 0.9	114-154
	Taggart	TH	1	6.1	7.9	< 0.1	1.3	31
May 2003	Jackson	All	3	2.7-3.1	5.1-20	< 0.2-0.3	0.4-0.9	27-55
	Taggart	TH	1	2.4	16	< 0.2	1.0	45
Aug 2003	Jackson	Marina	2	3.1-41	4.7-7.9	< 0.2	0.3-1.0	24-120
		Non-marina	5	2.4-2.9	3.3-9.6	< 0.2	0.3-1.2	19-31
	Jenny	All	3	2.5-4.8	4.2-7.5	< 0.2	0.3-0.4	30-41
	Taggart	TH	1	2.7	6.8	< 0.2	2.4	26
				Sediment				
Aug 2001	Jackson	Marina	2	7.1-37	4.6-16	< 1.0	17-69	130-170
		Non-marina	4	2.7-18	1.2-18	0.3-1.7	7.8-42	18-270
	Jenny	BD1	1	6.6	1.7	0.5	0.4	20
	Taggart	TH	1	3.0	1.1	< 0.04	120	130
July 2002	Jackson	Marina	2	< 2.5-3.0	0.8-1.0	< 0.2	0.9-9.3	11-21
		Non-marina	3	3.2-32	1.3-28	< 0.1-3.7	29-180	42-480
	Jenny	All	2	1.7-1.7	0.6-23	< 0.1-7.6	12-64	70-140
	Taggart	TH	1	< 1.5	0.6	0.1	3.0	9.0
Aug 2003	Jackson	Marina	2	3.6-4.2	1.8-1.9	0.3-0.6	10-24	32-48
		Non-marina	3	3.0-18	2.0-15	0.3-2.0	25-46	42-270
	Jenny	BD1	1	4.1	1.5	1.1	15	38
	Taggart	TH	1	4.6	1.3	< 0.1	7.3	20
				Snow				
Mar 2002	Jackson	All	2	8.1-13	13-25	-	3.1-7.4	66-82
	Taggart	TH	1	77	9.5	-	8.0	160
Mar 2003	Jackson	All + FLG	3	65-110	49-98	< 0.9	< 4.7	380-600
	Taggart	TH	1	6.5	10	< 0.7	< 1.0	50

< Indicates maximum reported values of method detection and method quantification limits

Table 2. Comparison of concentrations of 16 EPA priority pollutant PAHs (ΣPAH) in surface sediment and water from this study and other investigations (see text for abbreviations and site names).

Study	Location	Comment	ΣPAH (ng/g or ng/L)
Sediment			
Present	WS (2002) BD1(2002) SRG(2001)	3 greatest concentrations	117[1] 112[1] 102[1]
Mastran et al. (1994)	Occoquan Reservoir, VA	Recreational boating Drinking water for Washington D.C.	ND-1319*
Simpson et al. (1998)	Kitimat Bay, B.C.	Aluminum smelter Pulp mill Methanol plant	1595-408,040
Pereira et al. 1999	Richardson Bay San Pablo Bay	San Francisco Bay	3665 841
Stout et al. 2003	Thea Foss Waterway, WA	Urban runoff Industrialization	14,934-3,593,882
Yan et al. 2004	New York/New Jersey Harbor	Urban runoff Industrialization	892-80,171
Water			
present	SNL (July 2002) LKS (Aug 2003) BD2 (July 2002)	3 greatest concentrations 2002-2003	134[1] 65[1] 60[1]
Mastran et al. (1994)	Occoquan Reservoir, VA	Recreational boating Drinking water for Washington D.C.	ND-4120* 18,860(s)*
Countway et al. (2003)	York River estuary		1.46-77.8**

[1]Values contain concentrations recorded at the method detection limit and method quantification limit.
* Excludes BbF, BkF, IP, DA, and Bghi
**Excludes Na, Acy, and Ace
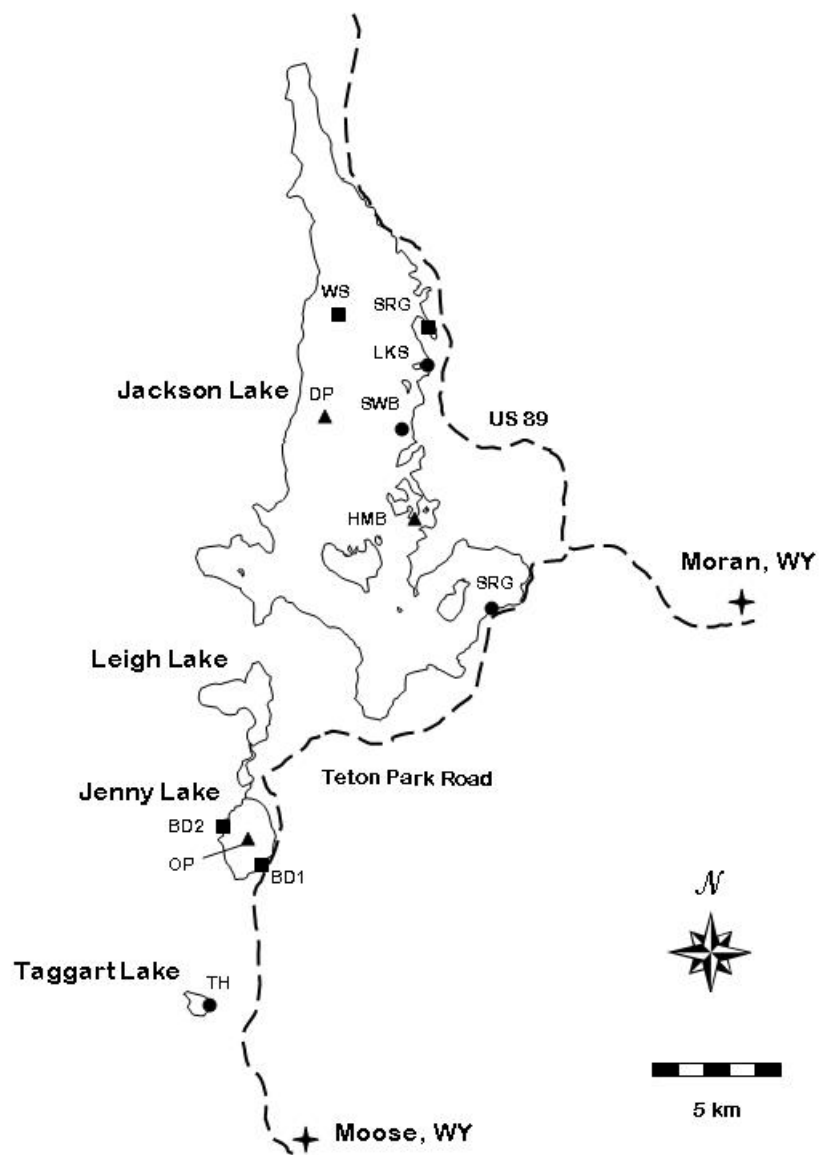
Figure 1. Map of lakes in Grand Teton National Park showing polycyclic aromatic hydrocarbon sampling locations (▲ = water, ■ = water and sediment, ● = water, sediment, and snow).

Appendix A. Polycyclic Aromatic Hydrocarbon (PAH) concentrations (ng/L) in water from lakes in Grand Teton National Park, Wyoming. Bold indicates actual measured concentrations, others represent method detection limits (†), method quantification limits (*), or no recovery of surrogate (^{R}). Values next to parentheses represent mean concentrations calculated from triplicate field samples (S.E.), S = surface water sample.

PAH	Abr.	Date/Location						
		Aug 2001 WS	Aug 2001 SNL	Aug 2001 HMB	Aug 2001 SWB	Aug 2001 SRG	Aug 2001 LKS	Aug 2001 LKS (S)
*Naphthalene	Na	$6.0^{\dagger}$	$6.0^{\dagger}$	$6.0^{\dagger}$	**7.3**	$6.0^{\dagger}$	$6.0^{\dagger}$	$6.0^{\dagger}$
2-Methyl Naphthalene	2MNa	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	**3.2**	**2.5**	**3.6 (0.4)**	$3.0^{\dagger}$
1-Methyl Naphthalene	1MNa	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$
*Acenaphthylene	Acy	$0.5^{\dagger}$	**0.6**	$0.5^{\dagger}$	$0.5^{\dagger}$	**0.6**	**1.1 (0.1)**	**0.6**
*Acenaphthene	Ace	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$
*Fluorene	F	$4.0^{\dagger}$	$4.0^{\dagger}$	$4.0^{\dagger}$	$4.0^{\dagger}$	$4.0^{\dagger}$	$4.0^{\dagger}$	$4.0^{\dagger}$
Dibenzothiophene	DBT	.	.	.	.	.	.	.
*Phenanthrene	Pa	$40.0^{\dagger}$	$40.0^{\dagger}$	$40.0^{\dagger}$	$40.0^{\dagger}$	$40.0^{\dagger}$	$40.0^{\dagger}$	$40.0^{\dagger}$
*Anthracene	A	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$
2-Methyl Anthracene	2MA	.	.	.	.	.	.	.
4,5-Methylene Phenanthrene	45MPa	.	.	.	.	.	.	.
1-Methyl Phenanthrene	1MPa	.	.	.	.	.	.	.
*Fluoranthene	Fl	$15.0^{\dagger}$	$15.0^{\dagger}$	$15.0^{\dagger}$	$15.0^{\dagger}$	$15.0^{\dagger}$	$15.0^{\dagger}$	$15.0^{\dagger}$
*Pyrene	Py	$6.0^{\dagger}$	$6.0^{\dagger}$	$6.0^{\dagger}$	$6.0^{\dagger}$	$6.0^{\dagger}$	$6.0^{\dagger}$	$6.0^{\dagger}$
1-Methyl Pyrene	1MPy	.	.	.	.	.	.	.
Benzo[b]naphtho[2,1-d] thiophene	BNTH	.	.	.	.	.	.	.
*Benz[a]anthracene	BaA	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$
*Chrysene	CHy	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$
*Benzo[b]fluoranthene	BbF	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$	$2.0^{\dagger}$
*Benzo[k]fluoranthene	BkF	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$
Benzo[e]pyrene	BeP	.	.	.	.	.	.	.
*Benzo[a]pyrene	BaP	$0.6^{\dagger}$	$0.6^{\dagger}$	$0.6^{\dagger}$	$0.6^{\dagger}$	$0.6^{\dagger}$	$0.6^{\dagger}$	$0.6^{\dagger}$
*Indeno[1,2,3-c,d] pyrene	IP	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$	$0.5^{\dagger}$
*Dibenzo[a,h]anthracene	DA	$1.0^{\dagger}$	$1.0^{\dagger}$	$1.0^{\dagger}$	$1.0^{\dagger}$	$1.0^{\dagger}$	$1.0^{\dagger}$	$1.0^{\dagger}$
*Benzo[g,h,I]perylene	Bghi	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$	$3.0^{\dagger}$
Retene	Re	.	.	.	.	.	.	.
Perylene	Per	.	.	.	.	.	.	.
Detectable PAH	DPAH	0.0	0.6	0.0	10.5	3.1	4.7	0.6
Detectable 16 EPA PAH	ΣDPAH	0.0	0.6	0.0	7.3	0.6	1.1	0.6
Total PAH[1]	TPAH	91.6	91.7	91.6	93.1	91.7	92.8	91.7
Total 16 EPA PAH[1]	ΣPAH	85.6	85.7	85.6	86.9	85.7	86.2	85.7

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[1] Includes values recorded at the method detection limits and method quantification limits

Appendix A - cont.

PAH	Abr.	Aug 2001 OP	Aug 2001 BD1	Aug 2001 TH	Aug 2001 TH	May 2002 TH	May 2002 SNL	May 2002 SWB
					(S)			
*Naphthalene	Na	**23.0**	**48.0**	6.0†	6.0†	**2.9**	**110.0**	**3.1**
2-Methyl Naphthalene	2MNa	**10.9**	**30.8**	3.0†	3.0†	**1.6**	**72.0**	**2.1**
1-Methyl Naphthalene	1MNa	**5.2**	**14.2**	3.0†	3.0†	**2.0**	**32.0**	**1.2**
*Acenaphthylene	Acy	**1.7**	**5.9**	0.5†	0.5†	0.0^R	0.0^R	0.0^R
*Acenaphthene	Ace	2.0†	2.0†	2.0†	2.0†	2.0†	2.0*	2.0†
*Fluorene	F	4.0†	4.0†	4.0†	4.0†	**2.0**	**1.1**	**2.0**
Dibenzothiophene	DBT	.	.	.	.	2.0*	2.0*	2.0*
*Phenanthrene	Pa	40.0†	40.0†	40.0†	40.0†	**4.1**	**4.9**	**3.3**
*Anthracene	A	2.0†	2.0†	2.0†	2.0†	0.0^R	0.0^R	0.0^R
2-Methyl Anthracene	2MA	.	.	.	.	2.0†	2.0†	2.0†
4,5-Methylene Phenanthrene	45MPa	.	.	.	.	2.0†	2.0*	2.0†
1-Methyl Phenanthrene	1MPa	.	.	.	.	2.0†	2.0*	2.0†
*Fluoranthene	Fl	15.0†	15.0†	15.0†	15.0†	**1.6**	**1.7**	**2.0**
*Pyrene	Py	6.0†	6.0†	6.0†	6.0†	**2.0**	2.0*	2.0*
1-Methyl Pyrene	1MPy	.	.	.	.	2.0†	2.0†	2.0†
Benzo[b]naphtho[2,1-d] thiophene	BNTH	.	.	.	.	2.0†	2.0†	2.0†
*Benz[a]anthracene	BaA	0.5†	0.5†	0.5†	0.5†	0.0^R	0.0^R	0.0^R
*Chrysene	CHy	2.0†	2.0†	2.0†	2.0†	2.0*	2.0*	2.0*
*Benzo[b]fluoranthene	BbF	2.0†	2.0†	2.0†	2.0†	2.0†	2.0*	2.0†
*Benzo[k]fluoranthene	BkF	0.5†	0.5†	0.5†	0.5†	2.0†	2.0*	2.0†
Benzo[e]pyrene	BeP	.	.	.	.	2.0*	2.0†	2.0†
*Benzo[a]pyrene	BaP	0.6†	0.6†	0.6†	0.6†	0.0^R	0.0^R	0.0^R
*Indeno[1,2,3-c,d] pyrene	IP	0.5†	0.5†	0.5†	0.5†	2.0†	2.0†	2.0†
*Dibenzo[a,h]anthracene	DA	1.0†	1.0†	1.0†	1.0†	0.0^R	2.0†	2.0†
*Benzo[g,h,l]perylene	Bghi	3.0†	3.0†	3.0†	3.0†	0.0^R	2.0†	2.0†
Retene	Re	.	.	.	.	1.4*	1.3*	3.3*
Perylene	Per	.	.	.	.	0.0^R	0.0^R	0.0^R
Detectable PAH	DPAH	41.1	99.3	0.0	0.0	16.2	221.7	13.7
Detectable 16 EPA PAH	ΣDPAH	25.0	54.3	0.0	0.0	12.6	117.7	10.4
Total PAH[1]	TPAH	120.2	178.4	91.6	91.6	41.6	253.0	47.0
Total 16 EPA PAH[1]	ΣPAH	104.1	133.4	85.6	85.6	22.6	133.7	26.4

[1] Includes values recorded at the method detection limits and method quantification limits

Appendix A - cont.

PAH	Abr.	May 2002 LKS	July 2002 TH	July 2002 BD2	July 2002 BD1	July 2002 OP	July 2002 SRG	July 2002 WS
*Naphthalene	Na	**5.8**	**6.1**	**40.0 (2.5)**	**41.0**	**38.0**	0.0^R	0.0^R
2-Methyl Naphthalene	2MNa	**4.8**	**5.1**	**57.0 (26.5)**	**35.0**	**44.0**	0.0^R	0.0^R
1-Methyl Naphthalene	1MNa	**2.2**	**2.8**	**33.3 (16.8)**	**18.0**	**24.5**	0.0^R	0.0^R
*Acenaphthylene	Acy	2.0†	0.1*	**2.5 (0.1)**	**3.1**	**2.5**	0.0^R	0.1*
*Acenaphthene	Ace	**2.0**	**0.8**	**0.9 (0.1)**	**0.8**	**0.9**	0.0^R	**0.6**
*Fluorene	F	2.0*	**0.8**	**2.3 (0.1)**	**2.1**	**1.9**	1.2*	**0.9**
Dibenzothiophene	DBT	2.0*	**0.4**	**0.5 (0.0)**	**0.3**	0.4*	**0.4**	**0.4**
*Phenanthrene	Pa	**3.8**	**7.9**	**9.2 (0.2)**	**6.0**	**6.3**	**9.2**	**7.6**
*Anthracene	A	0.0^R	**0.1**	**0.2 (0.0)**	**0.2**	**0.2**	**0.1**	0.1*
2-Methyl Anthracene	2MA	2.0†	0.2*	0.2*	2.0*	0.2*	0.2*	0.2*
4,5-Methylene Phenanthrene	45MPa	2.0*	**0.7**	**1.0 (0.1)**	**0.7**	**0.8**	**1.6**	**1.4**
1-Methyl Phenanthrene	1MPa	2.0*	**0.4**	**0.7 (0.1)**	**0.5**	**0.6**	**0.8**	**0.6**
*Fluoranthene	Fl	2.0*	**2.0**	**2.7 (0.1)**	**1.8**	**1.8**	**2.7**	**2.0**
*Pyrene	Py	2.0†	**0.6**	**1.0 (0.0)**	**0.7**	**0.8**	**1.1**	**0.9**
1-Methyl Pyrene	1MPy	0.0^R	**0.1**	**0.1 (0.0)**	**0.1**	**0.1**	**0.1**	**0.1**
Benzo[b]naphtho[2,1-d] thiophene	BNTH	2.0†	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*
*Benz[a]anthracene	BaA	2.0†	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*
*Chrysene	CHy	2.0*	**0.1**	**0.3 (0.0)**	**0.3**	**0.3**	**0.2**	**0.2**
*Benzo[b]fluoranthene	BbF	2.0*	0.1*	0.0*	0.2*	0.2*	0.1*	0.1*
*Benzo[k]fluoranthene	BkF	2.0*	**0.1**	0.1*	0.1*	0.1*	0.1*	0.1*
Benzo[e]pyrene	BeP	2.0†	**0.1**	**0.1 (0.0)**	**0.1**	**0.2**	**0.1**	**0.2**
*Benzo[a]pyrene	BaP	0.0^R	0.1*	**0.1 (0.0)**	0.1*	0.1*	0.1*	0.1*
*Indeno[1,2,3-c,d] pyrene	IP	1.2*	0.1*	0.1*	0.1*	0.1*	0.1†	0.1*
*Dibenzo[a,h]anthracene	DA	2.0†	0.1*	0.1*	0.1*	0.1*	0.1†	0.1*
*Benzo[g,h,I]perylene	Bghi	2.0*	**0.1**	**0.2 (0.0)**	**0.1**	**0.2**	**0.1**	**0.2**
Retene	Re	2.0*	**1.3**	0.9*	0.6*	0.9*	0.5*	0.9*
Perylene	Per	0.0^R	0.1*	0.1*	0.1*	0.1†	0.1†	0.1*
Detectable PAH	DPAH	18.6	29.6	152.2	111.1	123.1	16.4	15.1
Detectable 16 EPA PAH	ΣDPAH	11.6	18.7	59.4	56.4	52.6	13.4	12.4
Total PAH[1]	TPAH	53.8	30.5	153.8	114.3	125.0	19.1	17.2
Total 16 EPA PAH[1]	ΣPAH	32.8	19.2	59.7	56.8	53.3	15.2	13.2

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[1] Includes values recorded at the method detection limits and method quantification limits

Appendix A - cont.

PAH	Abr.	July 2002 DP	July 2002 LKS	July 2002 HMB	July 2002 SWB	July 2002 SNL	May 2003 TH	May 2003 SWB	May 2003 LKS
					Date/Location				
*Naphthalene	Na	0.0^R	2.7	28.0	5.1	29.0	2.4	3.1	2.7
2-Methyl Naphthalene	2MNa	0.0^R	1.9	160.0	4.3	28.0	1.7	2.9	2.2
1-Methyl Naphthalene	1MNa	0.0^R	1.1	120.0	2.4	20.0	1.0	1.8	1.2
*Acenaphthylene	Acy	0.0^R	$0.1^†$	0.2*	0.1*	0.4*	0.2*	0.2*	0.2*
*Acenaphthene	Ace	$0.1^†$	0.4	0.8	0.9	0.6	0.5	0.4	0.6
*Fluorene	F	1.3	0.5	0.9	1.1	0.8	0.8	0.5	1.5
Dibenzothiophene	DBT	0.7	0.3	0.2*	0.6	0.3	0.9	0.3	1.1
*Phenanthrene	Pa	16.0	5.5	4.9	11.0	6.2	16.0	5.1	20.0
*Anthracene	A	0.3	0.1*	0.1*	0.1*	0.3*	0.4	0.3	0.5
2-Methyl Anthracene	2MA	0.2*	0.1*	0.1*	0.1	$0.1^†$	0.2*	0.2*	0.2*
4,5-Methylene Phenanthrene	45MPa	1.6	0.4	0.5*	0.6	0.5	1.0	0.3	1.2
1-Methyl Phenanthrene	1MPa	1.5	0.3	0.3	0.5	0.7*	1.4	0.6	1.7
*Fluoranthene	Fl	4.0	1.6	1.4	2.5	2.9	11.0	4.9	13.0
*Pyrene	Py	1.4	0.7	0.5	0.9	1.7	4.3	2.0	5.0
1-Methyl Pyrene	1MPy	0.1	0.1	0.1	0.1	0.2	0.2*	0.2*	0.2*
Benzo[b]naphtho[2,1-d] thiophene	BNTH	0.1*	0.1*	$0.1^†$	0.1*	0.2*	0.2*	0.2*	0.2*
*Benz[a]anthracene	BaA	0.1*	0.1*	$0.1^†$	0.1*	0.9	0.2*	0.2*	0.2*
*Chrysene	CHy	0.2	0.2	0.1	0.2	0.9	0.3	0.5	0.6
*Benzo[b]fluoranthene	BbF	0.1*	0.1*	0.1*	0.1*	1.0	0.2	0.4	0.3
*Benzo[k]fluoranthene	BkF	0.1*	0.1*	0.1*	0.1*	0.8	0.2*	0.3	0.2*
Benzo[e]pyrene	BeP	0.1	0.1	0.1*	0.1*	8.6	0.2*	0.4	0.2*
*Benzo[a]pyrene	BaP	0.1*	$0.1^†$	0.1*	0.1*	1.5	0.2*	0.3	0.2*
*Indeno[1,2,3-c,d] pyrene	IP	0.1*	0.1*	$0.1^†$	$0.1^†$	0.9	0.2*	0.3	0.2*
*Dibenzo[a,h]anthracene	DA	0.1*	0.1*	$0.1^†$	$0.1^†$	0.2	0.2*	0.2*	0.2*
*Benzo[g,h,l]perylene	Bghi	0.1	0.1	0.1	0.1*	1.1	0.3	0.5	0.3
Retene	Re	0.7*	0.4*	0.4*	0.4*	6.2	1.0	0.4	0.8
Perylene	Per	$0.1^†$	$0.1^†$	$0.1^†$	$0.1^†$	2.0	0.2*	0.2*	0.2*
Detectable PAH	DPAH	27.3	15.9	317.1	30.3	114.3	43.2	25.3	52.7
Detectable 16 EPA PAH	ΣDPAH	23.3	11.7	36.7	21.7	48.5	36.2	18.6	44.5
Total PAH[1]	TPAH	29.1	17.4	319.5	31.9	116.0	45.4	26.7	54.9
Total 16 EPA PAH[1]	ΣPAH	24.0	12.5	37.6	22.6	49.2	37.4	19.2	45.7

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[1] Includes values recorded at the method detection limits and method quantification limits

Appendix A – cont.

PAH	Abr.	May 2003 SNL	Aug 2003 WS	Aug 2003 DP	Aug 2003 SRG	Aug 2003 SNL	Aug 2003 HMB	Aug 2003 LKS	Aug 2003 SWB
					Date/Location				
*Naphthalene	Na	**2.7**	**2.9**	**2.7**	**2.4**	**3.1**	**2.6**^{R}	**41.0**	**2.5**
2-Methyl Naphthalene	2MNa	**1.9**	**2.4**	**1.7**	**1.4**	**3.0**	**0.9**^{R}	**33.0**	**1.7**
1-Methyl Naphthalene	1MNa	**1.1**	**1.4**	**1.0**	**0.8**	**2.2**	**0.6**^{R}	**16.0**	**0.9**
*Acenaphthylene	Acy	0.2*	0.2*	0.2*	0.2*	0.2*	0.2†	**2.7**	0.2*
*Acenaphthene	Ace	**0.4**	**0.7**	**0.4**	**0.3**	**0.4**	0.3†	**1.4**	**0.3**
*Fluorene	F	**0.5**	**2.7**	**2.0**	**1.8**	**1.8**	**2.0**	**3.2**	**1.7**
Dibenzothiophene	DBT	**0.5**	**0.7**	**0.4**	**0.4**	**0.3**	**0.4**	**0.6**	0.2*
*Phenanthrene	Pa	**7.5**	**9.6**	**6.2**	**6.5**	**4.7**	**8.5**	**7.9**	**3.3**
*Anthracene	A	0.2*	0.2*	0.2*	**0.3**	0.2*	**0.3**	**0.3**	0.2*
2-Methyl Anthracene	2MA	**0.2**	0.2*	0.2*	0.2*	0.2*	0.2*	**0.3**	0.2*
4,5-Methylene Phenanthrene	45MPa	**0.4**	**0.6**	**0.5**	**0.6**	**0.5**	0.2†	**0.9**	**0.3**
1-Methyl Phenanthrene	1MPa	**0.9**	**0.7**	**0.4**	**0.4**	**0.4**	**0.7**	**1.0**	**0.3**
*Fluoranthene	Fl	**7.0**	**2.6**	**2.4**	**3.1**	**2.3**	**1.6**	**2.7**	**1.4**
*Pyrene	Py	**2.8**	**1.3**	**1.1**	**1.6**	**1.3**	**2.7**	**2.3**	**0.9**
1-Methyl Pyrene	1MPy	0.2*	0.2*	0.2*	0.2*	0.2*	0.4*	0.2*	0.2*
Benzo[b]naphtho[2,1-d] thiophene	BNTH	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*
*Benz[a]anthracene	BaA	0.2*	0.2*	**0.3**	0.2*	0.2*	0.2*	0.2*	0.2*
*Chrysene	CHy	**0.5**	**0.9**	**0.8**	**0.8**	**0.6**	**0.6**	**0.8**	**0.6**
*Benzo[b]fluoranthene	BbF	**0.5**	**0.3**	**0.4**	**0.4**	**0.3**	**0.3**	**0.4**	**0.4**
*Benzo[k]fluoranthene	BkF	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*
Benzo[e]pyrene	BeP	**0.4**	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*
*Benzo[a]pyrene	BaP	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*
*Indeno[1,2,3-c,d] pyrene	IP	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	**0.3**	0.2*
*Dibenzo[a,h]anthracene	DA	0.2*	0.2*	**0.5**	0.2*	0.2*	0.2*	0.2*	0.2*
*Benzo[g,h,l]perylene	Bghi	**0.4**	**0.7**	**0.4**	**2.9**	**0.6**	**0.6**	**0.8**	**1.3**
Retene	Re	**0.9**	**1.2**	**0.3**	**0.3**	**0.3**	**1.0**	**1.0**	**0.3**
Perylene	Per	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*	0.2*
Detectable PAH	DPAH	28.6	28.7	21.5	24.0	21.8	23.5	116.6	15.9
Detectable 16 EPA PAH	ΣDPAH	22.3	21.7	17.2	20.1	15.1	19.4	63.8	12.4
Total PAH[1]	TPAH	30.6	31.1	23.5	26.2	24.2	25.3	118.2	18.5
Total 16 EPA PAH[1]	ΣPAH	23.7	23.1	18.2	21.3	16.5	20.4	64.6	13.8

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[1] Includes values recorded at the method detection limits and method quantification limits

Appendix A – cont.

PAH	Abr.	Date/Location					
		Aug 2003 BD1	Aug 2003 BD2	Aug 2003 OP	Aug 2003 TH	Aug 2001 PC4	Aug 2001 PC2
*Naphthalene	Na	**4.8**	**2.5**	**3.9**	**2.7**	**1,700**	**790**
2-Methyl Naphthalene	2MNa	**3.4**	**1.6**	**3.5**	**1.4**	.	.
1-Methyl Naphthalene	1MNa	**1.9**	**0.9**	**2.4**	**0.8**	.	.
*Acenaphthylene	Acy	**1.7**	0.2*	**0.7**	0.2*	**390**	**260**
*Acenaphthene	Ace	**0.9**	**0.5**	**0.7**	**0.3**	**170**	**130**
*Fluorene	F	**4.9**	**3.0**	**3.9**	**1.9**	**230**	**210**
Dibenzothiophene	DBT	**0.4**	**0.4**	**0.3**	**0.4**	.	.
*Phenanthrene	Pa	**7.5**	**7.3**	**4.2**	**6.8**	**230**	**180**
*Anthracene	A	**0.9**	**0.3**	**0.3**	0.2*	**82**	**78**
2-Methyl Anthracene	2MA	0.2*	0.2*	0.2*	0.2*	.	.
4,5-Methylene Phenanthrene	45MPa	**1.6**	**1.2**	**1.2**	**0.4**	.	.
1-Methyl Phenanthrene	1MPa	**1.6**	**1.6**	**1.8**	**0.6**	.	.
*Fluoranthene	Fl	**4.1**	**4.3**	**3.0**	**3.4**	**104**	**68**
*Pyrene	Py	**2.3**	**1.9**	**1.7**	**1.4**	**190**	**121**
1-Methyl Pyrene	1MPy	0.2*	0.2*	0.2*	0.2*	.	.
Benzo[b]naphtho[2,1-d] thiophene	BNTH	0.2*	0.2*	0.2*	0.2*	.	.
*Benz[a]anthracene	BaA	**0.3**	0.2*	0.4*	0.2*	**2.3**	**8.1**
*Chrysene	CHy	**0.9**	**0.9**	**0.8**	**0.4**	**2.8**	**9.2**
*Benzo[b]fluoranthene	BbF	**0.5**	**0.5**	**0.5**	0.2*	**2.9**	**7.6**
*Benzo[k]fluoranthene	BkF	0.2*	0.2*	0.2*	0.2*	**0.8**	**6.5**
Benzo[e]pyrene	BeP	0.2*	0.2*	0.2*	0.2*	.	.
*Benzo[a]pyrene	BaP	0.2*	0.2*	0.2*	0.2*	**2.1**	**6.1**
*Indeno[1,2,3-c,d] pyrene	IP	0.3*	0.2*	0.2*	0.2*	**2.0**	**4.7**
*Dibenzo[a,h]anthracene	DA	0.2*	0.2*	0.2*	0.2*	**1.0**	**1.0**
*Benzo[g,h,l]perylene	Bghi	**0.7**	**0.9**	**0.7**	**0.5**	**9.3**	**19**
Retene	Re	**0.3**	**0.3**	**0.4**	**2.4**	.	.
Perylene	Per	0.2*	0.2*	0.2*	0.2*	.	.
Detectable PAH	DPAH	38.7	28.1	30.0	23.4	3119	1898
Detectable 16 EPA PAH	ΣDPAH	29.5	22.1	20.4	17.4	3119	1898
Total PAH[1]	TPAH	40.6	30.3	32.0	26.0	3119	1898
Total 16 EPA PAH[1]	ΣPAH	30.4	23.3	21.4	19.0	3119	1898

[1] Includes values recorded at the method detection limits and method quantification limits

Appendix B. Polycyclic Aromatic Hydrocarbon (PAH) concentrations (ng/g) in sediment from lakes in Grand Teton National Park, Wyoming. Bold indicates actual measured concentrations, others represent method detection limits ([†]), method quantification limits (*), or no recovery of surrogate ([R]). Values next to parentheses represent mean concentrations calculated from triplicate field samples (S.E.).

		Date/Location						
		Aug 2001	Aug 2001	Aug 2001	Aug 2001	Aug 2001	Aug 2001	Aug 2001
PAH	Abr.	WS	SNL	SWB	SRG	WS	LKS	BD1
*Naphthalene	Na	**18.3 (0.9)**	**37.0**	**2.7**	**20.5**	**19.0**	**7.1**	**6.6**
2-Methyl Naphthalene	2MNa	**34.7 (2.9)**	**27.0**	**1.1**	**27.5**	**37.0**	**11.0**	**3.0**
1-Methyl Naphthalene	1MNa	**30.7 (2.2)**	**20.0**	**0.7**	**23.5**	**33.0**	**6.8**	**1.3**
*Acenaphthylene	Acy	0.1*	0.3*	0.3*	0.4*	0.1*	0.2*	0.1*
*Acenaphthene	Ace	1.3*	**12.0**	0.1*	1.8*	1.3*	0.4*	0.2*
*Fluorene	F	**1.7 (0.1)**	**16.0**	**0.1**	**4.8**	**1.6**	0.7*	**0.2**
Dibenzothiophene	DBT	**1.0 (0.0)**	**2.9**	**0.04**	**2.0**	**1.5**	**0.3**	**0.1**
*Phenanthrene	Pa	**15.0 (1.0)**	**16.0**	**1.2**	**15.0**	**18.0**	**4.6**	**1.7**
*Anthracene	A	**1.1 (0.1)**	2.6*	**0.1**	0.6[R]	1.6*	**0.8**	**0.1**
2-Methyl Anthracene	2MA	**1.5 (0.1)**	**0.3**	0.02*	0.7[R]	1.5*	0.2*	0.04*
4,5-Methylene Phenanthrene	45MPa	**0.5 (0.0)**	**1.1**	0.05*	**3.0**	0.8*	0.5*	0.09*
1-Methyl Phenanthrene	1MPa	**8.37 (0.4)**	**1.3**	**0.5**	**7.3**	**9.1**	**2.5**	**0.2**
*Fluoranthene	Fl	**3.8 (0.2)**	**3.1**	**0.5**	**8.1**	**4.5**	**3.1**	**0.7**
*Pyrene	Py	**5.5 (0.3)**	**2.4**	**0.5**	**8.2**	**6.1**	4.8*	**0.6**
1-Methyl Pyrene	1MPy	**2.4 (0.1)**	**0.3**	**0.1**	**2.2**	**2.5**	**0.9**	**0.1**
Benzo[b]naphtho[2,1-d]thiophene	BNTH	**1.4 (0.2)**	**0.2**	**0.1**	**2.0**	**2.1**	**0.7**	**0.03**
*Benz[a]anthracene	BaA	**2.3 (0.2)**	**0.6**	**0.2**	**3.3**	**2.4**	**1.6**	**0.1**
*Chrysene	CHy	**6.6 (0.4)**	**1.2**	**0.4**	**9.1**	**7.7**	**3.2**	**0.3**
*Benzo[b]fluoranthene	BbF	**3.9 (0.3)**	**1.0**	**0.2**	**7.1**	**4.5**	**2.4**	**0.4**
*Benzo[k]fluoranthene	BkF	**1.5 (0.2)**	**0.7**	**0.2**	**3.3**	**1.6**	**1.7**	**0.2**
Benzo[e]pyrene	BeP	**7.4 (0.7)**	**1.5**	**0.3**	**11.5**	**9.0**	**3.6**	**0.5**
*Benzo[a]pyrene	BaP	1.6[R]	**1.0**	**0.3**	3.4[R]	0.0[R]	0.0[R]	**0.5**
*Indeno[1,2,3-c,d]pyrene	IP	**1.7 (0.2)**	**1.1**	**0.2**	**4.5**	**1.7**	**1.9**	**0.4**
*Dibenzo[a,h]anthracene	DA	**0.8 (0.1)**	**0.2**	**0.1**	**1.6**	**0.9**	**0.5**	**0.04**
*Benzo[g,h,l]perylene	Bghi	**5.7 (0.4)**	**4.2**	**0.3**	**10.2**	**6.7**	**5.7**	**1.6**
Retene	Re	**42.0 (4.1)**	**17.0**	**7.8**	**40.0**	**31.0**	**69.0**	**0.4**
Perylene	Per	8.7[R]	**0.7**	**0.1**	91.0[R]	0.0[R]	0.0[R]	**0.02**
Detectable PAH	DPAH	213.3	168.8	17.5	311.3	199.9	127.4	19.0
Detectable 16 EPA PAH	ΣDPAH	70.3	96.5	6.9	100.0	74.7	32.6	13.4
Total PAH[1]	TPAH	214.7	171.7	18.0	313.4	205.2	134.2	19.5
Total 16 EPA PAH[1]	ΣPAH	71.7	99.4	7.3	102.1	77.7	38.7	13.7

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[1] Includes values recorded at the method detection limits and method quantification limits

Appendix B - cont.

PAH	Abr.	Aug 2001 TH	July 2002 SRG	July 2002 WS	July 2002 LKS	July 2002 SWB	July 2002 SNL	July 2002 TH
				Date/Location				
*Naphthalene	Na	**3.0**	**13.0**	**32.0**	2.5*	3.2*	**3.0 (0.4)**	1.5*
2-Methyl Naphthalene	2MNa	**1.5**	**23.0**	**79.0**	**1.4**	**1.9**	**2.0 (0.1)**	**0.7**
1-Methyl Naphthalene	1MNa	**0.8**	**18.0**	**61.0**	**0.8**	**1.4**	**1.0 (0.0)**	**0.4**
*Acenaphthylene	Acy	**0.06**	0.2*	0.1*	0.1*	0.1*	0.1*	0.1*
*Acenaphthene	Ace	**0.1**	1.1*	2.0*	0.1*	0.2*	0.1*	0.1*
*Fluorene	F	**0.1**	**3.9**	3.3*	0.1*	**0.3**	0.1*	0.1*
Dibenzothiophene	DBT	**0.05**	**1.1**	**1.9**	0.1*	0.1*	0.1*	0.1*
*Phenanthrene	Pa	**1.1**	**12.0**	**28.0**	**0.8**	**1.3**	**1.0 (0.0)**	**0.6**
*Anthracene	A	**0.08**	1.0*	**1.6**	0.7†	0.1†	0.1*	0.1†
2-Methyl Anthracene	2MA	**0.02**	0.3*	0.6*	0.7†	0.1†	0.1 †	0.1†
4,5-Methylene Phenanthrene	45MPa	**0.08**	1.5*	0.2*	0.1†	0.1*	0.1*	0.1†
1-Methyl Phenanthrene	1MPa	**0.3**	**6.7**	**15.0**	**0.2**	**1.0**	**0.4 (0.0)**	**0.2**
*Fluoranthene	Fl	**0.3**	**6.5**	**5.5**	**0.4**	0.5*	**0.5 (0.0)**	0.4*
*Pyrene	Py	**0.2**	**6.0**	**8.4**	**0.3**	**0.3**	**0.5 (0.0)**	**0.2**
1-Methyl Pyrene	1MPy	0.03*	**1.7**	**3.4**	0.1*	0.1*	0.1*	0.1*
Benzo[b]naphtho[2,1-d]thiophene	BNTH	0.02*	**1.5**	**2.2**	0.1*	0.1*	0.1*	0.1*
*Benz[a]anthracene	BaA	0.03*	**2.1**	**3.0**	0.1*	0.1*	0.1*	0.1†
*Chrysene	CHy	**0.1**	**6.7**	**11.0**	**0.2**	**0.3**	**0.3 (0.0)**	**0.2**
*Benzo[b]fluoranthene	BbF	0.07*	**6.1**	**5.6**	0.2*	**0.3**	0.3*	**0.2**
*Benzo[k]fluoranthene	BkF	0.05*	**2.7**	**2.0**	0.1†	0.1†	0.1 †	0.1*
Benzo[e]pyrene	BeP	**0.07**	**6.5**	**8.6**	**0.2**	**0.3**	**0.4 (0.0)**	**0.1**
*Benzo[a]pyrene	BaP	0.04*	**3.6**	**3.7**	0.0^R	0.1*	0.2*	**0.1**
*Indeno[1,2,3-c,d]pyrene	IP	0.05*	0.8*	**2.2**	0.1*	0.2*	0.2*	0.1*
*Dibenzo[a,h]anthracene	DA	0.02*	0.9*	**0.9**	0.1*	0.1*	0.1 †	0.1†
*Benzo[g,h,l]perylene	Bghi	**0.07**	**8.7**	**8.5**	**0.3**	**0.3**	**0.7 (0.1)**	0.2*
Retene	Re	**120.0**	**41.0**	**180.0**	**0.9**	**29.0**	**9.3 (1.1)**	**3.0**
Perylene	Per	0.02*	**65.0**	**9.5**	0.1*	**0.3**	0.1*	0.1†
Detectable PAH	DPAH	127.9	233.1	471.0	8.0	39.9	19.1	5.7
Detectable 16 EPA PAH	ΣDPAH	5.1	68.6	110.4	4.5	6.0	6.0	1.3
Total PAH[1]	TPAH	128.3	241.6	479.2	10.8	41.9	21.1	9.2
Total 16 EPA PAH[1]	ΣPAH	5.4	75.3	117.8	6.1	7.5	7.4	4.2

[1] Includes values recorded at the method detection limits and method quantification limits

Appendix B - cont.

PAH (*16 EPA PAH)	Abr.	July 2002 BD2	July 2002 BD1	Aug 2003 WS	Aug 2003 SRG	Aug 2003 SNL	Aug 2003 LKS	Aug 2003 SWB
*Naphthalene	Na	1.7*	1.7*	13.0	18.0	3.6	4.2 (0.3)	3.0
2-Methyl Naphthalene	2MNa	0.8	1.4	26.0	23.0	6.0	3.2 (0.1)	2.0
1-Methyl Naphthalene	1MNa	0.4	1.2	21.0	19.0	2.7	1.7 (0.0)	1.6
*Acenaphthylene	Acy	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*	0.1*
*Acenaphthene	Ace	0.1*	3.3	1.1	1.6	0.2	0.2 (0.0)	0.2
*Fluorene	F	0.1*	2.7	1.9	4.5	0.3	0.2 (0.0)	0.2
Dibenzothiophene	DBT	0.1*	1.2	1.3	1.2	0.2	0.2 (0.0)	0.1
*Phenanthrene	Pa	0.6	23.0	15.0	13.0	1.8	1.9 (0.1)	2.0
*Anthracene	A	0.1†	4.3	1.0	1.4	0.2	0.2 (0.0)	0.2
2-Methyl Anthracene	2MA	0.1†	0.7	0.7	0.9	0.1*	0.1 (0.0)	0.1*
4,5-Methylene Phenanthrene	45MPa	0.1*	2.7	0.7	0.8	0.1	0.1 (0.0)	0.1
1-Methyl Phenanthrene	1MPa	0.2	2.1	7.4	11.0	1.0	0.7 (0.0)	1.2
*Fluoranthene	Fl	0.4*	19.0	3.5	6.7	0.9	0.8 (0.1)	0.8
*Pyrene	Py	0.4	16.0	4.5	6.2	1.0	1.1 (0.1)	0.7
1-Methyl Pyrene	1MPy	0.1*	1.0	1.9	4.2	0.1*	0.3 (0.1)	0.2*
Benzo[b]naphtho[2,1-d] thiophene	BNTH	0.1*	0.9	1.3	0.8	0.2	0.2 (0.0)	0.1
*Benz[a]anthracene	BaA	0.1*	6.6	1.9	2.3	0.2	0.3 (0.1)	0.2
*Chrysene	CHy	0.1	7.7	5.5	8.6	0.7	1.0 (0.1)	0.8
*Benzo[b]fluoranthene	BbF	0.1*	5.5	3.1	2.5	0.6	0.6 (0.1)	0.5
*Benzo[k]fluoranthene	BkF	0.1*	5.5	1.1	6.0	0.3	0.4 (0.2)	0.3
Benzo[e]pyrene	BeP	0.2	4.3	4.7	4.6	0.7	0.9 (0.1)	0.6
*Benzo[a]pyrene	BaP	0.1*	7.6	2.0	1.7	0.3	0.6 (0.3)	0.3
*Indeno[1,2,3-c,d] pyrene	IP	0.1*	4.3	1.3	1.2	0.5	0.6 (0.3)	0.2
*Dibenzo[a,h]anthracene	DA	0.1†	0.9	0.7	0.3	0.1*	0.1 (0.0)	0.1*
*Benzo[g,h,l]perylene	Bghi	0.2	4.4	5.1	6.4	1.3	1.7 (0.3)	0.7
Retene	Re	63.5	12.0	26.0	46.0	24.0	10.4 (1.7)	25.0
Perylene	Per	0.2	0.8	51.0	82.0	0.3	0.5 (0.0)	0.3
Detectable PAH	DPAH	66.4	139.3	202.7	273.9	47.1	32.2	41.1
Detectable 16 EPA PAH	ΣDPAH	1.3	111.0	60.7	80.4	11.9	14.0	10.1
Total PAH[1]	TPAH	70.0	141.1	202.8	274.0	47.5	32.3	41.6
Total 16 EPA PAH[1]	ΣPAH	4.3	112.8	60.8	80.5	12.1	14.1	10.3

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[1] Includes values recorded at the method detection limits and method quantification limits

Appendix B - cont.

PAH	Abr.	Date/Location	
		Aug 2003 BD1	Aug 2003 TH
*Naphthalene	Na	**4.1**	**4.6**
2-Methyl Naphthalene	2MNa	**2.2**	**1.2**
1-Methyl Naphthalene	1MNa	**1.0**	**0.9**
*Acenaphthylene	Acy	0.1*	0.1*
*Acenaphthene	Ace	0.1*	0.1*
*Fluorene	F	**0.2**	**0.2**
Dibenzothiophene	DBT	**0.1**	**0.1**
*Phenanthrene	Pa	**1.5**	**1.3**
*Anthracene	A	**0.2**	**0.1**
2-Methyl Anthracene	2MA	**0.1**	0.1†
4,5-Methylene Phenanthrene	45MPa	**0.2**	**0.1**
1-Methyl Phenanthrene	1MPa	**0.6**	**0.3**
*Fluoranthene	Fl	**1.9**	**0.6**
*Pyrene	Py	**2.1**	**0.4**
1-Methyl Pyrene	1MPy	**0.3**	0.1*
Benzo[b]naphtho[2,1-d] thiophene	BNTH	**0.3**	0.1*
*Benz[a]anthracene	BaA	**0.9**	**0.1**
*Chrysene	CHy	**1.7**	**0.3**
*Benzo[b]fluoranthene	BbF	**0.9**	**0.2**
*Benzo[k]fluoranthene	BkF	**1.0**	**0.2**
Benzo[e]pyrene	BeP	**0.9**	0.1*
*Benzo[a]pyrene	BaP	**1.1**	0.1*
*Indeno[1,2,3-c,d] pyrene	IP	**0.9**	0.1*
*Dibenzo[a,h]anthracene	DA	**0.2**	0.1*
*Benzo[g,h,l]perylene	Bghi	**1.0**	**0.2**
Retene	Re	**14.5**	**7.3**
Perylene	Per	**0.4**	**0.8**
Detectable PAH	DPAH	37.9	18.9
Detectable 16 EPA PAH	ΣDPAH	17.4	8.2
Total PAH[1]	TPAH	38.1	19.8
Total 16 EPA PAH[1]	ΣPAH	17.6	8.7

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[1] Includes values recorded at the method detection limits and method quantification limits

Appendix C. Polycyclic Aromatic Hydrocarbon (PAH) concentrations (ng/L) in snow from Grand Teton National Park, Wyoming. Bold indicates actual measured concentrations, others represent method detection limits (†), method quantification limits (*), or no recovery of surrogate (^{R}).

		Date/Location						
		Mar 2002	Mar 2002	Mar 2002	Mar 2003	Mar 2003	Mar 2003	Mar 2003
PAH	Abr.	TH	SWB	SNL	TH	SWB	SNL	FLG
*Naphthalene	Na	**77.0**	**13.0**	**8.1**	**6.5**	**110.0**	**65.0**	**100.0**
2-Methyl Naphthalene	2MNa	**31.0**	**6.6**	**5.5**	**5.2**	**110.0**	**88.0**	**170.0**
1-Methyl Naphthalene	1MNa	**13.0**	**3.5**	**2.4**	**2.2**	**56.0**	**42.0**	**87.0**
*Acenaphthylene	Acy	0.0^R	0.0^R	0.0^R	0.9^*	**2.1**	**1.5**	**2.1**
*Acenaphthene	Ace	0.0^R	0.0^R	$2.0^†$	0.8^*	5.2^*	3.0^*	5.4^*
*Fluorene	F	**2.0**	**1.6**	**2.0**	**1.3**	**14.0**	**12.0**	**13.0**
Dibenzothiophene	DBT	2.0^*	2.0^*	2.0^*	**0.9**	**2.3**	**3.7**	**4.2**
*Phenanthrene	Pa	**9.5**	**13.0**	**25.0**	**10.0**	**49.0**	**71.0**	**98.0**
*Anthracene	A	0.0^R	0.0^R	0.0^R	0.9^*	3.7^*	3.8^*	4.2^*
2-Methyl Anthracene	2MA	$2.0^†$	$2.0^†$	$2.0^†$	0.2^*	1.6^*	0.8^*	3.7^*
4,5-Methylene Phenanthrene	45MPa	2.0^*	2.0^*	**2.0**	0.8^*	3.3^*	5.2^*	6.6^*
1-Methyl Phenanthrene	1MPa	2.0^*	**1.1**	**1.3**	**0.9**	**10.0**	**18.0**	**28.0**
*Fluoranthene	Fl	**3.7**	**3.7**	**6.8**	8.1^*	21.0^*	28.0^*	33.0^*
*Pyrene	Py	0.0^R	0.0^R	$5.0^†$	**2.3**	**6.7**	**8.1**	**16.0**
1-Methyl Pyrene	1MPy	0.0^R	0.0^R	$2.0^†$	0.1^*	0.3^*	0.5^*	0.9^*
Benzo[b]naphtho[2,1-d] thiophene	BNTH	$2.0^†$	$2.0^†$	$2.0^†$	0.2^*	0.6^*	**1.1**	**1.4**
*Benz[a]anthracene	BaA	0.0^R	0.0^R	0.0^R	**0.3**	0.3^*	0.7^*	0.5^*
*Chrysene	CHy	**2.0**	**2.0**	**2.0**	**0.9**	**3.3**	**5.9**	**6.5**
*Benzo[b]fluoranthene	BbF	2.0^*	$2.0^†$	2.0^*	**0.9**	**2.1**	**3.0**	**2.5**
*Benzo[k]fluoranthene	BkF	**0.0**	2.2^*	2.4^*	0.6^*	1.0^*	1.8^*	1.4^*
Benzo[e]pyrene	BeP	2.0^*	$2.0^†$	**2.0**	**2.4**	**4.6**	**5.2**	**5.4**
*Benzo[a]pyrene	BaP	0.0^R	0.0^R	0.0^R	0.7^*	$0.1^†$	0.6^*	0.9^*
*Indeno[1,2,3-c,d] pyrene	IP	0.0^R	0.0^R	$2.0^†$	**0.7**	**1.0**	**1.7**	**1.2**
*Dibenzo[a,h]anthracene	DA	0.0^R	0.0^R	0.0^R	0.1^*	0.1^*	0.2^*	0.2^*
*Benzo[g,h,l]perylene	Bghi	0.0^R	0.0^R	0.0^R	**1.4**	**2.0**	**3.4**	**2.1**
Retene	Re	**8.0**	**7.4**	**3.1**	1.0^*	2.2^*	4.7^*	4.3^*
Perylene	Per	0.0^R	0.0^R	0.0^R	$0.1^†$	$0.1^†$	$0.1^†$	$0.1^†$
Detectable PAH	DPAH	146.2	51.9	60.2	35.9	373.1	329.6	537.4
Detectable 16 EPA PAH	ΣDPAH	94.2	33.3	43.9	24.3	190.2	171.6	241.4
Total PAH[1]	TPAH	160.2	66.1	81.6	50.4	412.6	379.0	598.6
Total 16 EPA PAH[1]	ΣPAH	96.2	37.5	57.3	36.4	221.6	209.7	287.0

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[1] Includes values recorded at the method detection limits and method quantification limits