CHAPTER 1

Introduction

1.1 Background

Transport and deposition of atmospheric contaminants has been recognized as a possible threat to aquatic and terrestrial ecosystems for several decades. However, it was not until the 1970s and 1980s that the potential for significant regional-scale ecological impacts of long-range transport of contaminants, particularly the acidic precursors of acidic deposition, was recognized (Likens et al., 1979) and later documented and quantified across multiple spatial scales (Linthurst et al., 1986). In this case, it was demonstrated that SO_x and NO_x, byproducts of combustion, were transported thousands of kilometers in the atmosphere, transformed to acids, and deposited via precipitation on sensitive ecosystems that lacked sufficient buffering capacity to neutralize the acid (Galloway and Cowling, 1978). In addition, metals were recognized as another class of contaminants associated with the combustion of fossil fuels that could be transported great distances in the atmosphere (Galloway et al., 1982).

Once the concept of trans-boundary airborne contaminants had been demonstrated with acidic precipitation, numerous other airborne contaminant threats to ecosystems and the humans that depend upon them were identified (Perry et al., 1999). The lack of local or watershed sources of contaminants confirmed that the impacts of long-range atmospheric transport of contaminants threatened many remote ecosystems (Barrie et al., 1992; MacDonald et al., 2000). It is now well known that metals, particularly mercury and lead, are emitted by human activities and can be transported short and long distances from their sources to be deposited, retained, and, in some instances, bioaccumulated within distant ecosystems. Similarly, a vast array of persistent organic pollutants (POPs) and semi-volatile organic compounds (SOCs) are recognized as having the potential to be transported by the atmosphere (Simonich and Hites, 1995; Muir et al., 1996; Li et al., 1998; Van Drooge et al., 2002). These compounds are derived *only* from human activities and many persist in the environment for long periods of time (Gubala et al., 1995; Fernandez et al., 2000; Helm et al., 2002).

Recent studies have pointed out the atmospheric linkage between air masses traversing Eurasia and arriving in North America (Welch et al., 1991; Wania and Mackay, 1996; Jaffe et al., 1999). Although few studies have measured persistent and bioaccumulating toxics in these air masses, model output suggests that they are likely to contain a variety of contaminants (Perry et al., 1999; Koziol and Pudykiewicz, 2001). Recent studies by authors of this report (Jaffe, Simonich, and others) have demonstrated some key linkages between air masses arriving on the west coast of North America and Eurasian industrial and agricultural sources (Jaffe et al., 2005; Weiss-Penzias et al., in press). Many of the tracers used by air monitors to identify trans-Pacific air masses (e.g., CO, aerosols, O_3) are directly related to human activities and combustion sources. However, from an ecological perspective, it is very complicated to track these short lived and/or highly reactive tracers through ecosystem compartments where they are not retained as SOCs and metals are. This is particularly true in remote locations.

There is ample evidence of regional as well as long-range sources of atmospheric contamination to remote ecosystems in the western United States, but there is scant evidence in any published source that a threat to ecosystems is being realized. This is particularly true over large spatial scales. One of the major problems is that the atmospheric scientists who have identified the long-range transport across the Pacific Ocean from Eurasia have little information about deposition of inorganic and organic contaminants in these air masses. One of the few and most convincing publications regarding this issue describes the concentration of POPs in snow sampled in the Canadian Rocky Mountains during the spring of 1995 and 1996 (Blais et al., 1998). The data in this publication suggest that there is good evidence that high-elevation ecosystems are at risk with respect to SOCs for two primary reasons: (1) long-range transport of contaminants possibly being deposited with the annual snow pack and (2) cold fractionation of the lighter SOCs, resulting in migrations of these and other compounds to the higher (i.e., colder) alpine areas (Wania and Mackay, 1996). Cold fractionation appears to function at latitudinal as well as elevational gradients, putting northern ecosystems are risk. A recent publication documents the cold-trapping of POPs by vegetation in mountains in western Canada (Davidson et al., 2003).

Certainly there is sufficient scientific evidence to ponder the question of risk to high-latitude ecosystems from airborne contaminants in the western United States. The information to date, from various disciplines, published and reported independently, has generated considerable concern regarding the risk to western ecosystems, prompting the US Environmental Protection Agency (USEPA) to convene the First International Conference on Trans-Pacific Transport of Atmospheric Contaminants in Seattle, Washington, in July 2000. The meeting was attended by over 100 experts, representing disciplines that included energy and emissions, atmospheric sciences, marine sciences, biogeochemistry, biological sciences, and international environmental policy. This workshop culminated in a consensus statement published in *Science* (Wilkening et al., 2000). Three of the conclusions from this conference most pertinent to this undertaking are worth noting here:

- The nature, magnitude, and spatial distribution of the effects of airborne chemicals transported in the Pacific region, including changes in variability, are largely unknown.

- Long-range transport could have significant impacts on the chemistry of the troposphere above the Pacific Ocean, and of the ocean itself, and on contaminant concentrations in terrestrial and aquatic ecosystems.
- Some airborne chemicals, especially organochlorines and mercury, have the potential to enter food webs and biomagnify, thereby increasing the toxicological risk to top predators, including humans.

These conclusions were applied to a broad suite of contaminants, including organic contaminants, heavy metals (including mercury), and radionuclides.

1.2 Approach

In 2001, the National Park Service (NPS) convened the first of two workshops at which experts discussed how to identify a scientific approach that could be followed to quantify the risk from airborne contaminants to the national parks in the western United States. This action followed the legal mandate described in the National Park Service Organic Act (1916) that created the NPS. This federal legislation required protection of the national parks for perpetuity, "…unimpaired for the enjoyment of future generations." The Clean Air Act augmented this responsibility in 1977 by defining specific goals, objectives, and mechanisms for protecting air quality in major parks and preventing "significant deterioration" of air quality. Not only are the national parks widely distributed, but many of them have considerable elevation ranges, possibly predisposing these high-elevation locations, because of their cold alpine climates, to become long-term sinks for some classes of contaminants. Moreover, high-latitude national parks in Alaska are also perceived to be at risk of becoming sinks for air pollution, given their cold climates and the trans-continental air masses to which they are exposed.

The Western Airborne Contaminants Assessment Project (WACAP) was initiated by the NPS as a direct result of these workshops. In communication with a broad range of NPS personnel, the WACAP goal was finalized:

> To assess the deposition of airborne contaminants in western national parks, providing regional and local information on exposure, accumulation, impacts, and probable sources.

At this early stage, WACAP conceptually incorporated an integrated, interdisciplinary, multi-scalar scientific approach to the problem (Figure 1-1). The project was initiated, and principal investigators with expertise in a broad range of disciplines were organized to develop a research plan that was peer reviewed by an international scientific review panel, revised, published (USEPA, 2003), and implemented in 2003. The WACAP report authors are shown in Table 1-1.

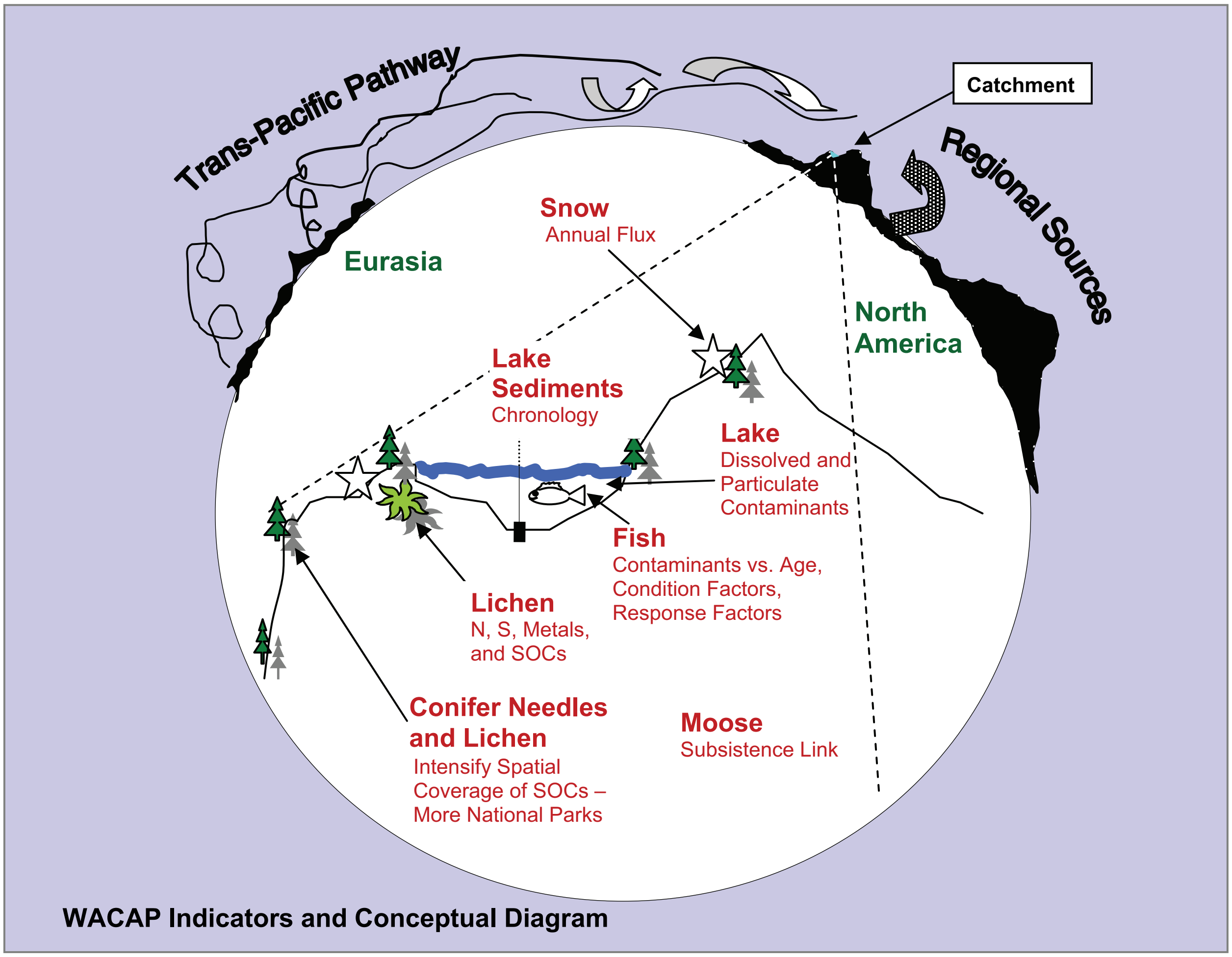


Figure 1-1. WACAP Conceptual Diagram of Airborne Contaminant Assessment Approach

Because very little was known about the contaminant concentrations and potential impacts in any of the western national parks at that time, an inventory of baseline SOCs, metals, and nutrient contaminants across various ecosystem components (i.e., snow, water, vegetation, fish, and sediment) was selected as the approach to be taken (Table 1-2). “Impacts” in the goal statement refers to evidence of accumulation in the food web—particularly animals—and does not go so far as to attempt to establish “effects,” such as reproductive or lethal responses.

The specific objectives that guided the development of WACAP were also thoroughly examined and approved by both the scientific team and the NPS:

1. Determine if contaminants are present in western national parks.
2. If contaminants are present, determine where they are accumulating (geographically and by elevation).
3. If contaminants are present, determine which ones pose a potential ecological threat.
4. Determine which indicators appear to be the most useful to assess contamination.
5. If contaminants are present, determine the source of the air masses most likely to have transported contaminants to the national parks sites.

Table 1-1. WACAP Report Authors

Name and Affiliation[1]	Project Components	Email
Luke Ackerman OSU, Corvallis, OR	Fish organic contaminants	luke.ackerman@fda.hhs.gov
Tamara Blett NPS-Air Resources Division Lakewood, CO	Project management	tamara_blett@nps.gov
Don Campbell USGS, Denver, CO	Snow	dhcampbe@usgs.gov
Marilyn Erway Dynamac Corp., Corvallis, OR	Logistics, database, QA, sediment, water	erway.marilyn@epa.gov
Linda Geiser US Forest Service Pacific NW Region Air Program, Corvallis, OR	Vegetation	lgeiser@fs.fed.us
Will Hafner University of Washington-Bothell	Atmospheric Modeling and Graphics	whafner@uwb.edu
Kim Hageman OSU, Corvallis, OR	Snow	khageman@chemistry.otago.ac.nz
Dan Jaffe University of Washington-Bothell	Atmosphere	djaffe@u.washington.edu
Michael Kent Director, Center for Fish Disease Research, OSU, Corvallis, OR	Fish pathology	michael.kent@orst.edu
Dixon Landers USEPA, Corvallis, OR	Project Director, sediment	landers.dixon@epa.gov
Neil Rose University College London, UK	Sediment SCPs	nrose@geog.ucl.ac.uk
Carl Schreck Oregon Cooperative Fish and Wildlife Research Unit, Dept. of Fisheries and Wildlife, USGS and OSU, Corvallis, OR	Fish physiology	carl.schreck@orst.edu
Jill Schrlau OSU, Corvallis, OR	Vegetation organic contaminants	schrlauj@onid.orst.edu
Adam Schwindt OSU, Corvallis, OR	Fish and Fish Sampling	ar.schwindt@gmail.com
Staci Simonich OSU, Corvallis, OR	Organic contaminants	staci.simonich@orst.edu
Howard Taylor USGS, Boulder, CO	Metals	hetaylor@usgs.gov
Sascha Usenko OSU, Corvallis, OR	Sediment and water organic contaminants	sascha_usenko@baylor.edu

[1] NPS = National Park Service, USGS = US Geological Survey, USDA-FS = US Dept. of Agriculture Forest Service, OSU = Oregon State University, USEPA = US Environmental Protection Agency

Table 1-2. Ecosystem Components Sampled for WACAP

Media	Frequency of Sampling	Purpose
Snow	Annually in the spring in each of the 14 sites in the 8 core parks	Direct measure of annual atmospheric loading; snow is 90% of annual precipitation in many alpine sites
Fish	Once in each of the 14 sites in the 8 core parks	Direct measure of food web impacts and food web bioaccumulation/biomagnification
Water	Once in each of the 14 sites in the 8 core parks	Measure of hydrophilic current-use chemicals and baseline water chemistry
Lake Sediment	Once in each of the 14 sites in the 8 core parks	Provides historic trends (~150 yrs) of contaminant loading to watershed
Vegetation	Once as elevation transects in the 8 core parks and 12 secondary parks	Direct measure (conifer and lichens) of food web bioaccumulation of nitrogen, sulfur, mercury and other metals Measure (lichens at core parks) of ecosystem exposure for SOCs; large number for statistical comparisons within and among sites, parks and elevations at a broad spatial scale
Air	Deployed PASDs (passive air sampling devices) for approximately one year in most core and secondary parks	Estimate of airborne exposure of SOCs at a site over a period of time
Moose	Once from several Alaska sites	Direct measure of subsistence food resources
Atmospheric Transport	Models developed based on 5 years of data for each park	Back trajectory models identify likely sources of contaminants

1.3 Park Selection

One of the most difficult issues was identifying which national parks should be included in the spatial design. We initially determined that we could include six parks, based on the estimated budget available for the effort, assuming that each park would have two intensive sites (i.e., lakes). However, with additional funding committed from “fee demo” sources, we were able to include 8 parks and 14 core sites. These sites, and the lakes in particular, were perceived to be natural precipitation/deposition collectors, representing some of the most remote, undisturbed remaining landscapes in the western United States. Contaminants collected at these sites were presumed not to be derived from local sources or historic land uses within the parks, given their National Park designation. However, we recognized the potential for the proximal influence of local and regional atmospheric contaminant sources and planned to interpret results with this in mind. We decided which parks to include based on the physical locations and characteristics of the parks rather than any other criteria. Through an iterative process, we identified indicators of interest, determined the number of sites in each park, set criteria for the attributes of sites within parks, and consulted with experts at each park, all with consideration for the overall spatial design and acknowledgment of budget realities.

It was clear from the outset that a strong spatial design containing enough sites to provide ample statistical power for hypothesis testing was outside the budget and scope of this project. Moreover, given the absolute lack of information of any kind regarding the impacts of airborne contaminants on the systems of interest, it seemed unwarranted and premature to pursue such a design, even if funding had been available. Rather, we decided that the first question that needed to be answered across large-scale spatial gradients appropriate to the western national parks was, “Is there a problem with respect to contaminants in the parks?” It was decided that if this policy question could be answered in a rigorous way by WACAP, then future work, if warranted, could be designed to deal with a more detailed secondary set of objectives based on the results of WACAP. These secondary objectives might include resolving the various temporal and spatial dimensions of contaminant pathways and defining and documenting specific ecological effects.

Because trans-Pacific air masses moving generally from west to east affect the west coast of the North American mainland from Alaska to California (Bailey et al., 2000; Husar et al., 2001), we selected a series of national parks ranging from Arctic Alaska south to California. Our intent was to identify a core set of western national parks along a north-south latitudinal gradient that could be affected by air masses moving across the Pacific Ocean. We wanted to accomplish this while recognizing that air masses originating in North America are also of potential interest and should be considered. We also wanted to include some parks in the interior of the western United States that could be affected by trans-Pacific air masses but that might be influenced more by regional air masses. We selected six west coast parks (NOAT, GAAR, DENA, OLYM, MORA, and SEKI) and two interior parks (GLAC and ROMO), for a total of eight core parks where all media would be sampled and evaluated. GAAR is juxtaposed to NOAT, thus we selected one site in each. As a result, 14 sites/lakes are associated with the core parks. Table 1-3 lists the locations of the lake sites in the core parks.

To provide better coverage, we identified 12 additional (secondary) parks where vegetation samples for SOC analyses would be collected. Vegetation samples from multiple sites representing a range of elevations were taken from both the core and secondary parks (Table 1-4) to provide a better understanding of contaminant deposition in the west. In 2005, we also deployed passive air sampling devices (PASDs) for one year in both core parks and secondary parks as a means of further linking our spatial interpretations.

Table 1-3. WACAP Sites in Core Parks. All media were sampled, including water, snow, air (PASDs), vegetation (conifer needles and lichens), fish, and sediments. Parks are listed alphabetically by park code.

Park Code	Park[1]	State	Lake Site	Latitude[2] (dd)	Longitude[2] (dd)	Lake Elevation[3] (m)	Year Sampled
DENA	Denali NP and Preserve	Alaska	McLeod	63.38	-151.07	564	2004
DENA	Denali NP and Preserve	Alaska	Wonder	63.48	-150.88	605	2004
GAAR	Gates of the Arctic NP and Preserve	Alaska	Matcharak	67.75	-156.21	502	2004
GLAC	Glacier NP	Montana	Oldman	48.50	-113.46	2026	2005
GLAC	Glacier NP	Montana	Snyder	48.62	-113.79	1597	2005
MORA	Mt. Rainier NP	Washington	Golden	46.89	-121.90	1369	2005
MORA	Mt. Rainier NP	Washington	LP19	46.82	-121.89	1372	2005
NOAT	Noatak National Preserve	Alaska	Burial	68.43	-159.18	430	2004
OLYM	Olympic NP	Washington	Hoh	47.90	-123.79	1380	2005
OLYM	Olympic NP	Washington	PJ	47.95	-123.42	1384	2005
ROMO	Rocky Mountain NP	Colorado	Lone Pine	40.22	-105.73	3018	2003
ROMO	Rocky Mountain NP	Colorado	Mills	40.29	-105.64	3030	2003
SEKI	Sequoia and Kings Canyon NP	California	Emerald	36.58	-118.67	2810	2003
SEKI	Sequoia and Kings Canyon NP	California	Pear	36.60	-118.67	2908	2003

[1]NP = National Park, [2]dd= decimal degrees; [3] from drg (digital raster graphic), m = meter

The selection of the core set of national parks provides a group of 8 parks ranging over 30 degrees of latitude with 2 pairs of parks (one coastal and one interior) rather closely linked at about the same latitude (OLYM and GLAC; SEKI and ROMO). This spatial arrangement, along with the location of the secondary parks, is depicted in Figure 1-2, in association with EPA Level 1 Ecoregions (http://www.epa.gov/bioiweb1/html/usecoregions.html).

The dominant factor influencing the deposition and accumulation of SOCs in the ecosystem is temperature. This is especially true for those contaminants that demonstrate cold fractionation. Figure 1-3 depicts the mean annual air temperature one could expect at each of the WACAP sites in the eight core national parks. Temperature data were estimated from the nearest and most representative locations with long-term meteorological data. In some cases, a small correction was made to account for the difference in altitude between the meteorological and lake site (D. Jaffe, pers. comm., University of Washington, Bothel). It is useful to notice that there is general agreement in temperature for all of the sites in the conterminous United States, and that the four sites in Alaska, although lower in elevation, are significantly colder.

Table 1-4. Vegetation WACAP Sites in Core and Secondary Parks (SOCs in conifer needles, lichens, and PASDs[1]). Parks are listed alphabetically by park code, with core parks in bold.

Park Code	Park[2]	State	No. of Vegetation Sampling Sites	Minimum Elevation of Sites (m)	Maximum Elevation of Sites (m)	No. of Air Sampling Sites	Year Sampled
BAND	Bandelier National Monument	New Mexico	5	1854	2926	1	2005
BIBE	Big Bend NP	Texas	5	560	2316	4	2005
CRLA	Crater Lake NP	Oregon	5	1798	2713	1	2005
DENA	**Denali NPP**	**Alaska**	**6**	**221**	**1753**	**2**	**2004**
GAAR	**Gates of the Arctic NPP**	**Alaska**	**1**	**505**	**505**	**1**	**2004**
GLAC	**Glacier NP**	**Montana**	**5**	**961**	**2024**	**2**	**2004**
GLBA	Glacier Bay NPP	Alaska	4	8	625	1	2005
GRSA	Great Sand Dunes NPP	Colorado	5	2469	3338	1	2005
GRTE	Grand Teton NP	Wyoming	5	2073	3048	1	2005
KATM	Katmai NPP	Alaska	6	36	1112	1	2005
LAVO	Lassen Volcanic NP	California	5	1829	2713	1	2005
MORA	**Mt. Rainier NP**	**Washington**	**5**	**654**	**1809**	**2**	**2004**
NOAT	**Noatak National Preserve**	**Alaska**	**3**	**227**	**675**	**1**	**2004**
NOCA	North Cascades NP	Washington	5	198	1600	1	2005
OLYM	**Olympic NP**	**Washington**	**5**	**137**	**1850**	**2**	**2004**
ROMO	**Rocky Mountain NP**	**Colorado**	**6**	**2560**	**3451**	**5**	**2004**
SEKI	**Sequoia & Kings Canyon NPs**	**California**	**11**	**427**	**2911**	**4**	**2003 & 2004**
STLE	Stikine-LeConte Wilderness, Tongass NF	Alaska	5	1	1064	4	2005
WRST	Wrangell-St. Elias NPP	Alaska	6	7	1421	1	2005
YOSE	Yosemite NP	California	5	661	3048	1	2005

[1] PASDs = passive air sampling devices, [2]NP = National Park, NF = National Forest, NPP = National Park and Preserve

1.4 Site Selection Within Parks

Within each of the core national parks, we selected two catchments containing lakes (i.e., sites) that met the following pre-established criteria.

- Catchment is small, typical of the catchments found in the park (elevation, soils, vegetation, aspect, etc.).
- Catchment contains a lake (≥5 m deep; larger than ~0.8 hectares in surface area).
- Lake contains reproducing fish populations (preferably salmonids).
- No anadromous fish reach the lake.
- Lake is without major inlets, outlets, or glaciers in the catchment.
- Lake bathymetry is acceptable for sediment core analysis.

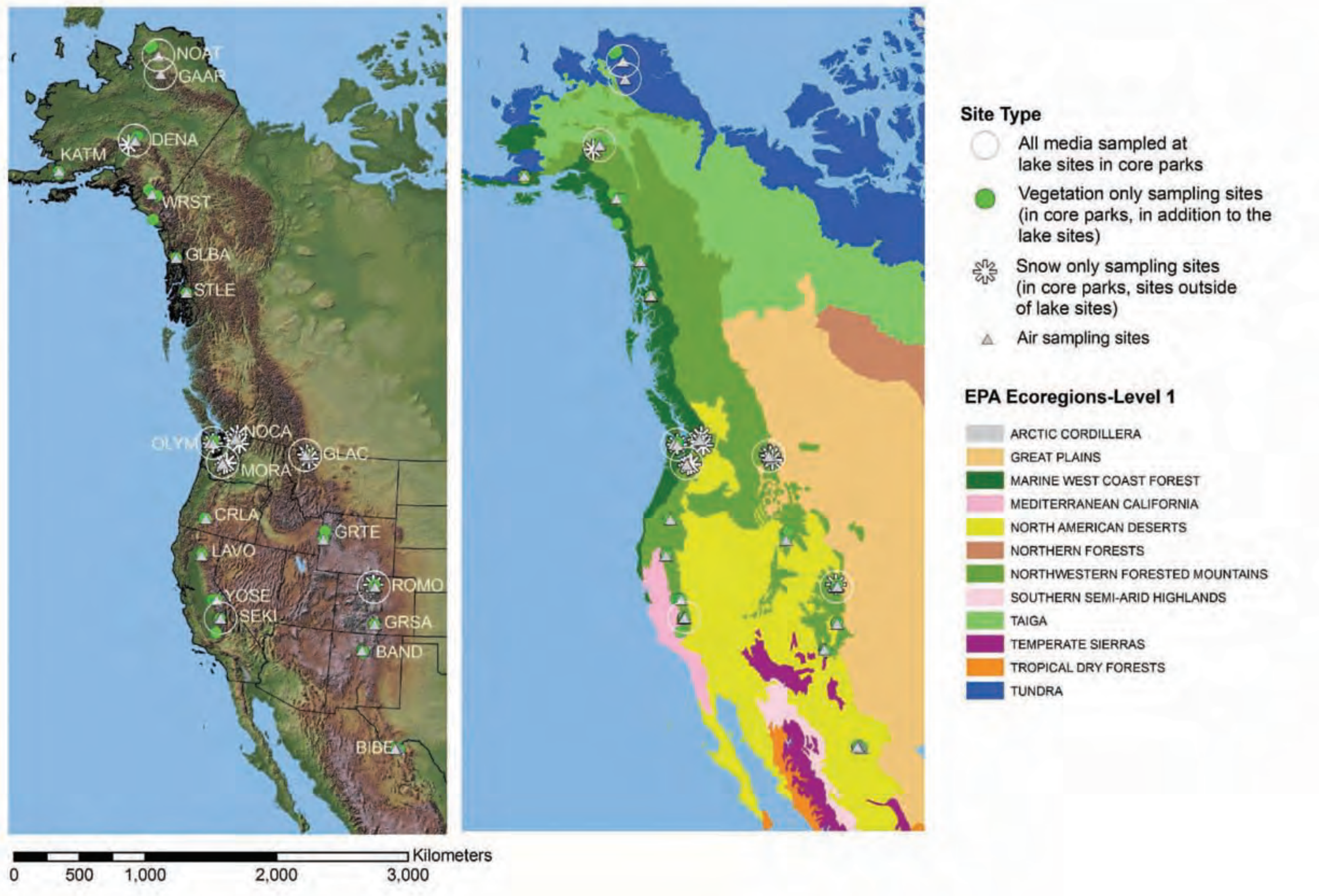


Figure 1-2. WACAP Sites Mapped on North American Shaded Relief Map and EPA Level 1 Ecoregions (Biomes). See Table 1-4 for key to national park abbreviations. Vegetation-only sampling sites in core parks designate sites used in elevational transect in addition to lake sites. Snow-only sampling sites in core parks designate alternate sampling locations when lake sites could not be reached safely.

- Safe access is possible by available means in late spring and summer.
- Gill netting of fish is acceptable.
- Catchments are located within the seasonally persistent, non-melting snowpack development for the park.
- Both catchments are located in the same general quadrant within the park.

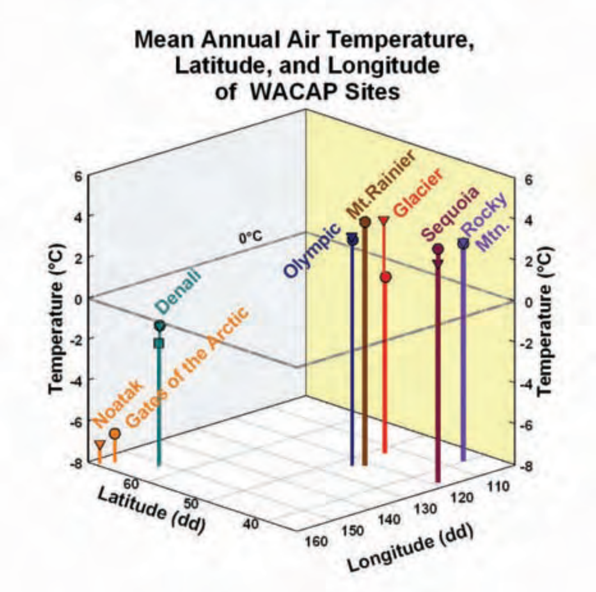


Figure 1-3. Relationships among Latitude, Longitude, and Mean Annual Temperature in the 8 National Parks and 14 Sites Sampled in WACAP.

Variability with respect to biogeophysical setting (e.g., lake and basin morphometry, vegetation, fish, etc.) was large among candidate catchments within and among parks as the WACAP research team set out to select appropriate sites. Given the large geographic scale of WACAP, several major ecological regions were included in the final selection (see Figure 1-2). We selected sites within parks that were located at similar elevations and generally in the same type of biogeophysical setting, where possible.

Candidate sites were evaluated by Dr. Dan Jaffe (WACAP atmospheric science lead) prior to final selection to maximize the possibility that atmospheric transport pathways between sites in the same park would be similar, based on available deposition and atmospheric data available only at a fairly coarse scale. The two exceptions to this strategy are in ROMO and GLAC, where the selected lakes are at almost the same elevation but on opposite sides of the Continental Divide.

Our final catchment selections in each core park represent “elevation duplicates,” in the sense that they are located at approximately the same elevation. Table 1-5 summarizes the attributes of the selected catchments/lakes for each core park. Appendix 1A contains more detailed tables of site physical and chemical characteristics for both the lake catchments in the core parks and the vegetation sites in the secondary parks. Chapter 2 provides maps showing the locations of the selected sites within each park, along with bathymetric maps of the lakes. In addition, Chapter 2 summarizes much of this site information, as well as the analytical results graphically for each site within each park within the context of the overall range of conditions found in all core WACAP parks.

Figure 1-4 depicts the relationships among WACAP indicators and the broader contaminant pathways, sources, sinks, and ecosystem components. The diagram is not all inclusive; it shows key components addressed by WACAP and some of the components and contaminant pathways that were not evaluated. The diagram should assist the unfamiliar reader with some of the complexity that WACAP examined and the ecological position and interrelationships among key areas of investigation.

Table 1-5. WACAP Lake Sites: Selected Physical and Surface (1 m) Chemical Characteristics[1] Collected during WACAP Site Visits According to Methods Listed in Chapter 3. Parks are listed by latitude, from north to south.

Park Code	Lake Name (Site)	Lake Surface Area[2] (ha)	Watershed Area (ha)	Fish Species	pH	Specific Cond. (µS/cm)	ANC (µeq/L)	DOC (mg/L)	Total P (µg/L)	Chl-a (µg/L)
NOAT	Burial	65.5	264.9	Lake trout	7.57	35.08	272.98	3.32	9.1	0.81
GAAR	Matcharak	300.7	2388.3	Lake trout	8.31	248.10	1967.03	4.71	1.1	0.96
DENA	Wonder	265.6	3212.4	Lake trout	8.18	190.10	1693.60	2.10	0.5	0.49
DENA	McLeod	35.9	236.8	Burbot Round whitefish	7.24	8.41	51.02	2.25	1.0	0.61
GLAC	Snyder	2.6	303.7	Westslope Cutthroat trout	6.42	16.80	162.08	0.65	2.7	4.73
GLAC	Oldman	18.2	230.3	Yellowstone River Cutthroat trout	8.24	159.10	1573.73	0.70	0.6	0.77
OLYM	PJ	0.8	56.2	Brook trout	8.14	127.40	1092.95	1.05	2.8	1.77
OLYM	Hoh	7.7	43.9	Brook trout	7.52	63.69	512.45	0.74	1.2	0.83
MORA	Golden	6.6	106.1	Brook trout	6.47	10.08	69.05	1.88	0.6	0.35
MORA	LP19	1.8	44.9	Brook trout	6.63	10.72	80.14	1.37	0.9	0.60
ROMO	Mills	6.1	1208.9	Rainbow Cutthroat trout	6.61	12.04	50.81	1.55	3.3	3.02
ROMO	Lone Pine	4.9	1830.0	Brook trout	6.67	14.02	91.52	1.74	2.7	1.95
SEKI	Pear	7.3	142.0	Brook trout	6.10	4.02	23.99	0.82	0.6	0.64
SEKI	Emerald	2.5	121.3	Brook trout	6.22	5.42	26.34	0.94	1.5	0.62

[1] Specific Cond.= Specific Conductance; ANC = acid neutralizing capacity, DOC= dissolved organic carbon, Total P = total phosphorus, Chl a = chlorophyll a.

[2] ha = hectare.

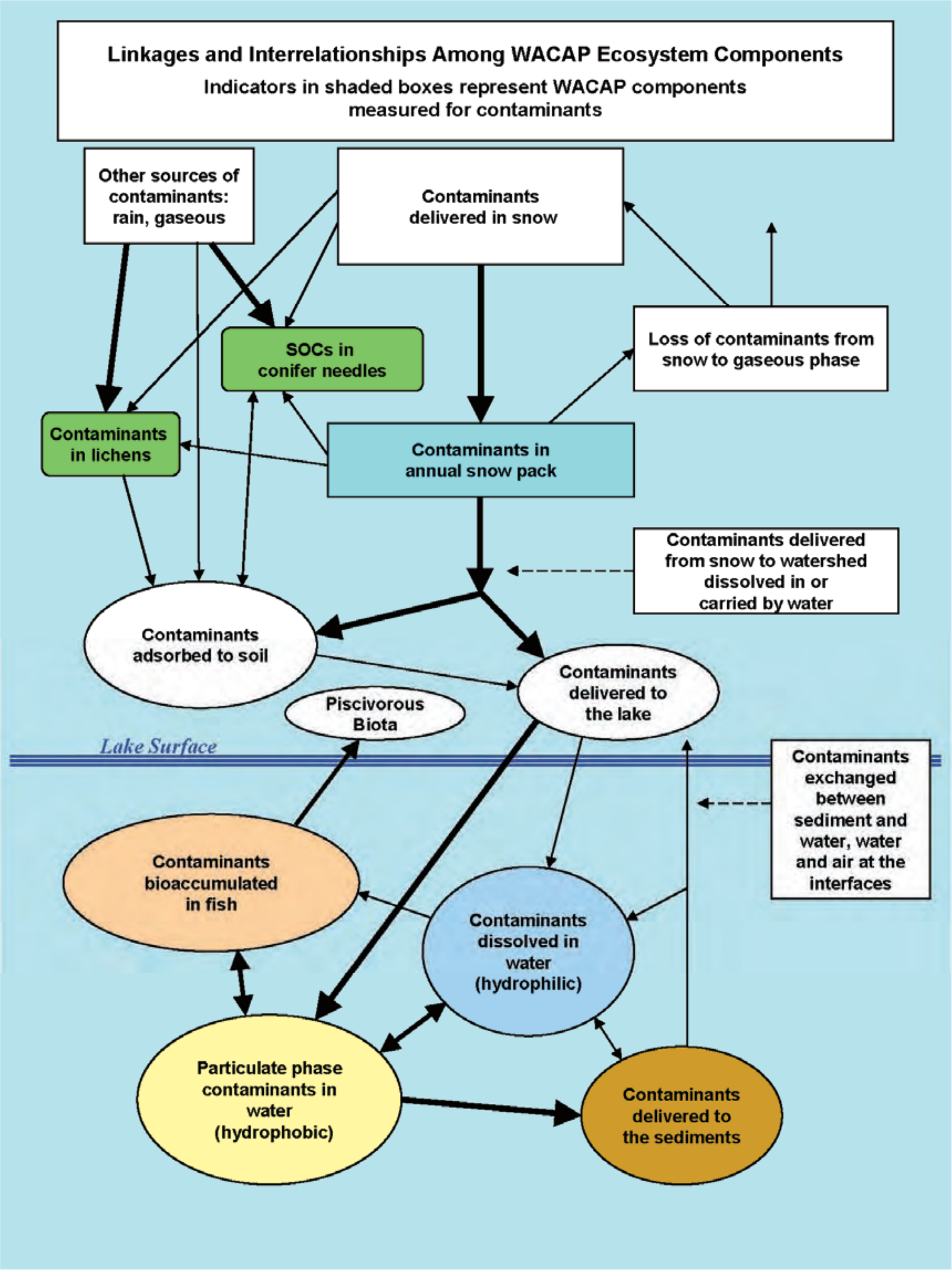


Figure 1-4. Linkages among Major WACAP and Ecosystem Components, Contaminant Pools, and Pathways. Colored components indicate those investigated for contaminants as part of WACAP.

1.5 Measurements and Contaminants

A wide variety of measurements could be used to provide information regarding the degree to which airborne contaminants have become entrained in national park ecosystems. Similarly, a large group of contaminants could be measured. One of the early WACAP design tasks was to winnow the expansive list of possible measurements, as well as contaminants, down to a manageable and affordable number. In doing this, we frequently referred back to the WACAP goal and objectives to ensure that selected indicators collectively fulfilled broad, and in some cases, multiple, purposes. Moreover, a secondary concern was to select indicators that would compare to other similar ongoing and historic studies (e.g., the European Union EMERGE program; Livingstone, 2005) regarding contaminant impacts in remote alpine and arctic locations. Chapter 3 in this report identifies the contaminants of interest and discusses the methods used in their analyses.

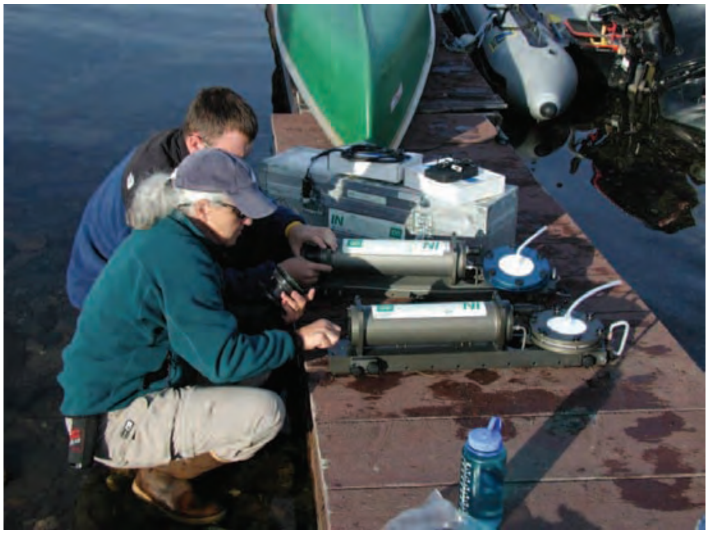
1.6 Timeline, Implementation, and Reporting

The 6-year WACAP began in fiscal year 2002 (October 2001 through September 2002) and continued through fiscal year 2007. Year 1 was a pilot year devoted to design, organization, funding for principal investigators, and methods development for the project. Some methods development continued into fiscal year 2003. Fieldwork and associated laboratory work were conducted during fiscal years 2003, 2004, and 2005. The final two years, 2006–2007, were devoted to finishing analytical work, analyzing data, writing the final report, preparing and publishing the final WACAP database, and publishing the results in the peer literature. Table 1-6 depicts the sequencing and timing of field collections acquired as part of WACAP.

Table 1-6. WACAP Timeline and Site Sampling Strategy.

Year	Activity			
Year 1 (2002)	Design, organization, methods development, written research plan, peer review, quality assurance plan			
	Annual snow sampling	***Intensive Study Year (fish, water, sediment)***	***Vegetation/Air Sampling***	***Moose Sampling***
Year 2 (2003)	All 8 parks (14 sites)	SEKI, ROMO (4 sites)	Pilot study to choose target vegetation & needle age	
Year 3 (2004)	All 8 parks (14 sites)	NOAT, DENA, and GAAR (4 sites)	Lichen and conifer needle sampling in 8 core parks (14 sites)	Moose from DENA
Year 4 (2005)	All 8 parks (14 sites)	OLYM, MORA, and GLAC (6 sites)	Lichen and conifer needle sampling in 12 secondary parks (61 sites); PASD installation in all parks	Moose from DENA
Year 5 (2006)	Data analyses, synthesis, publications, PASD retrieval in all parks			
Year 6 (2007)	Final NPS report, final database			

1.7 Data Management and Quality Assurance/Quality Control



Data management occurred at several levels throughout the project. Laboratory analyses were summarized, along with all QA/QC results at the batch level. This data management activity was guided by the QAPP (Quality Assurance Project Plan available on the WACAP web site: http://www2.nature.nps.gov/air/Studies/air_toxics/wacap.cfm. In this document, we use the term "media" to describe the major environmental compartments we analyzed (e.g., snow, water, fish). Batches of data were combined for each medium/indicator and forwarded to the appropriate principal investigators. Copies of these data were maintained by the analytical laboratories and a copy was sent to the WACAP coordination group at EPA (Corvallis). The coordination group confirmed laboratory QA/QC procedures and worked with each laboratory group to verify and validate the data on a batch-by-batch basis. The overall objective was to incorporate these data, along with metadata derived from a variety of sources (e.g., reconnaissance, field work, principal investigators, laboratories, park resources), into a working, integrated database. Modeled and GIS-derived data were also entered into this database. The database was combined into a final master database of the WACAP data in 2007. The final database is intended as a final repository for the data resulting from the work conducted during WACAP and will contain all data and associated QA/QC information. The final database will be published as a peer reviewed EPA report and made available to the public via several government website locations. It will also be stored permanently in NPS and USEPA searchable data archival systems. The general website address for the NPS Data Store is http://science.nature.nps.gov/nrdata/ and the general website address for the EPA location is http://www.epa.gov/nheerl/wacap/.

We participated in four levels of reporting for the WACAP data:

1. Professional papers (journal articles, dissertations, theses) generated by individual principal investigators
2. Synthesis journal articles prepared by various combinations of principal investigators
3. Annual information summaries prepared as NPS brochures
4. Final report

In addition, principal investigators and other key WACAP personnel have been active in their disciplinary societies by making oral presentations at annual national and international meetings.

1.8 WACAP Direction and Funding

WACAP was administered and funded primarily by the Air Resources Division (ARD) of the NPS, directed by Ms. Christine Shaver, in Lakewood, Colorado. Funding was derived from a variety of sources (base funding, competitive, and fee-demo) within ARD and NPS that varied among years and funding cycles. In this context, interagency agreements between the NPS and the US Geological Survey (USGS), the USEPA, and the US Forest Service (USFS) facilitated funding. Supplemental funding with in-kind services was provided by these federal agencies, the Oregon Cooperative Fish and Wildlife Research Unit and the Center for Fish Disease Research, OSU. NPS funding for university participants was accomplished through the NPS Cooperative Ecosystem Studies Unit (CESU) Cooperative Agreements process. In addition, several principal investigators have sought and received funding from a variety of sources external to the NPS to supplement funding they receive from ARD/NPS. These funds have been targeted to support graduate students, supply research equipment, and provide supplemental technical support. The USGS has contributed additional funding for the snow contaminants work. The success of WACAP depended upon continued funding from the NPS and its collaborators at annual levels sufficient to support the core WACAP efforts described in the research plan (USEPA, 2003). Funding was forthcoming and WACAP proceeded to completion as planned.

1.9 Organization of this Report

This final WACAP interpretive report is organized into six major chapters. An overview of each chapter and the name of the chapter organizer follow.

Chapter 1. Introduction (Dixon Landers)

Chapter 1 (this chapter) provides the background, goals, objectives, approach, and design considerations for WACAP.

Chapter 2. Park Summaries (Dixon Landers)

The park-by-park summaries provide a quick but in-depth graphical overview of the key results from the two sites within each core park and show how key variables associated with these sites compare with each other and among results from all other parks. The two-page graphical summary for each park is followed by a one-page written summary that identifies key findings for the sites and the specific park, along with major differences and similarities among the various measurements and the group of WACAP parks as a whole.

Chapter 3. Contaminants Studied and Methods Used (Staci Simonich)

In this chapter, all contaminants are identified and discussed regarding their occurrence in the environment and the methods used to sample, extract, and quantify them in the various media, or components, of the ecosystems sampled.

Chapter 4. Contaminant Distribution (Dan Jaffe)

This chapter interprets results of the WACAP effort for all components spatially, vertically, and temporally. Media-specific spatial results are evaluated across the geographic area encompassing the entire project. Vertical evaluations are limited to vegetation results among both core and secondary parks and among all contaminants. Snow and sediment analyses are used to evaluate inter-annual variation (snow) and decennial resolution and trends (sediment).

Chapter 5. Biological and Ecological Effects (Linda Geiser)

In this chapter, a variety of results that lend themselves to evaluation of the impacts and effects of contaminants in various media are examined. For fish, accepted pathological and physiological indicators of contaminant exposure are related to contaminant concentrations. Inferences on reproductive and overall health are made based on these relationships.

Chapter 6. Conclusions and Recommendations

Chapter 6 contains recommendations to the National Park Service that respond to the question, “What did you learn in this project that could help guide or focus future work within the NPS on contaminants in western U.S. parks?” These recommendations are specific to the original five project objectives. Also included is a list of additional research questions posed by WACAP scientists. These questions define fertile areas for future research into processes, mechanisms, and ecological interactions of contaminants in western ecosystems.

Volume II. Appendices

The appendices provide supplemental information about the WACAP findings.