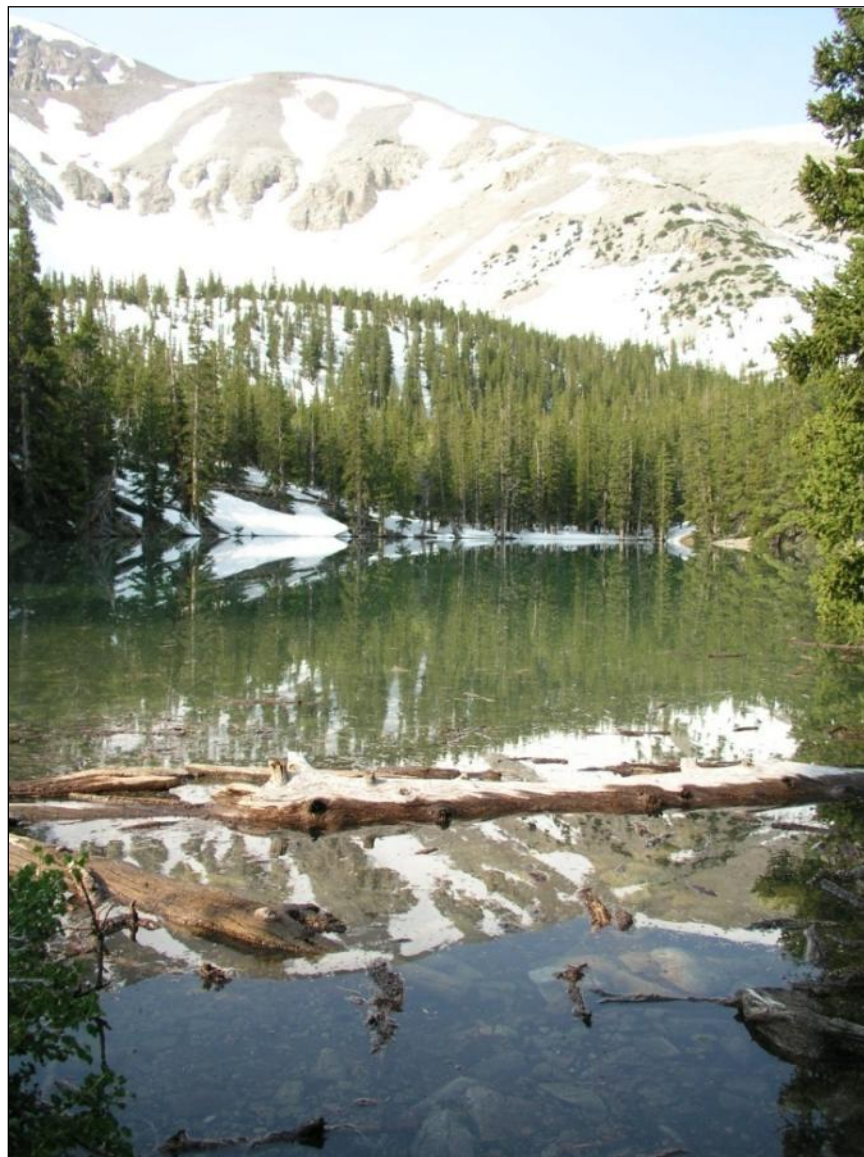




Mojave Desert Network Inventory and Monitoring Streams and Lakes Protocol

Protocol Narrative Version 1.0

Natural Resource Report NPS/MOJN/NRR—2012/593



ON THE COVER

Subalpine lake, Great Basin National Park
Photograph by: Gretchen Baker

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Natural Resource Report NPS/MOJN/NRR—2012/593

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U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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This table reflects changes to this document. Version numbers will be incremented by one (e.g., Version 1.3 to Version 2.0) each time there is a significant change in the process and/or changes are made that affect the interpretation of the data. Version numbers will be incremented after the decimal (e.g., Version 1.6 to Version 1.7...1.10....1.21) when there are changes to grammar, spelling, or formatting, or minor modifications in the process that do not affect the interpretation of the data.

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Standard Operating Procedures

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Logistics and Support

SOP 1: Safety
SOP 2: Staff Training
SOP 3: Field Season Preparations
SOP 4: Post-season Activities
SOP 5: Equipment Disinfection

Sample and Data Collection

SOP 6: Handheld Water Quality Instruments
SOP 7: Sample Handling, Storage, and Shipping
SOP 8: Regulatory Status
SOP 9: Stream Discharge
SOP 10: Lakes Field Procedures
SOP 11: Continuous Water Quality Sonde
SOP 12: Stream Chemistry and BMI Sampling
SOP 13: Laboratory Analysis of BMI
SOP 14: Laboratory Analysis of Water Chemistry

QA/QC

SOP 15: Quality Assurance Project Plan
SOP 16: Cumulative Measurement Bias

Data Management and Analysis

SOP 17: Data Analysis and Reporting
SOP 18: Database Design
SOP 19: Information Management Workflow and Tasks
SOP 20: Protocol Revision and Review

Supplementary Materials

The Supplementary Materials are on a CD (included with hardcopies of this document) with the folder structure given below. Please contact the MOJN Data Manager for a copy of the CD:

Mojave Desert Network
601 Nevada Way
Boulder City, NV 89005

http://science.nature.nps.gov/im/units/mojn/aboutus_main.cfm

Folder: Administrative Record

PDS_StreamsLakes_093008.pdf

PDS_StreamsLakes_063010.pdf

MOJN Surface Water Dynamics and Water Quality Protocol Review 1-11.doc

MOJN_Streams and Lakes_Response to Peer Review.docx

<Future location of previous versions of narratives and SOPs>

Folder: Data Management

Subfolder: Data_Dictionaries

STLK_LK_MasterDB_DataDictionary.pdf

STLK_ST_MasterDB_DataDictionary.pdf

Folder: Field Sheets

Lakes_FieldSheet.xls

Streams_Annual_Visit_FieldSheet.xls

WQ_Sonde_1st_Visit_FieldSheet.xls

WQ_Sonde_Biweekly_Visit_FieldSheet.xls

Annual_Temperature_Sensor_Test.xls

Head_to_Head_Sensor_Test.xls

Stream_Gaging_Form.pdf

Discharge_Calc.xls

Folder: Laboratory Protocols

Subfolder: CCAL

CCAL QAP Final 2010.pdf

CCAL Conductivity SOP.pdf

CCAL FAAS SOP.pdf

CCAL IC SOP.pdf

CCAL Nitrate SOP.pdf

CCAL pH_Alkalinity SOP.pdf

CCAL Total Nitrogen SOP.pdf

CCAL TP SOP.pdf

Sub-Subfolder: Previous_CCAL_Protocols

CCAL TP SOP-used on 2009 MOJN samples.pdf

Supplementary Materials (continued)

Folder: Laboratory Protocols (continued)

Subfolder: Buglab

BuglabLaboratoryStandardSampleSortingProcedures.pdf

BuglabQAQC.pdf

BuglabResultsAndReports.pdf

BuglabSampleArchiving.pdf

Folder: Lake_Benchmarks

GRBA_LakeLevel_Benchmarks.docx

Folder: Manuals

aquarius_help_manual.zip

GlobalWater.pdf

HOBOWare.pdf

pHTestr.pdf

YSI85handheld.pdf

YSI556handheld.pdf

YSI650controlunit.pdf

YSIcontinuousWQsonde.pdf

Folder: Published Protocols

Continuous_Monitoring_Wagner_et_al_2006.pdf

EMAP_Peck_et_al_2006.pdf

USGS_stream_gaging_Turnipseed_sauer_2010.pdf

Folder: Random Sites On GRBA Streams

baker_random_sites.xls

lehman_random_sites.xls

mill_random_sites.xls

pine_random_sites.xls

ridge_random_sites.xls

sfkbigwash_random_sites.xls

shingle_random_sites.xls

snake_random_sites.xls

strawberry_random_sitest.xls

williams_random_sites.xls

Folder: Safety

Accident_Report_Form.pdf

Excerpts_from_USGS_NFM.doc

GRBA-47_Employee_Backcountry_Travel_Procedures.doc

Supplementary Materials (continued)

Folder: Trend Analysis

Discharge_Trend_Analysis.doc

Kendall.exe

Kendall_Manual_Helsel_et_al_2005.pdf

Executive Summary

The mission of the National Park Service is “to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations” (NPS 1999a). To uphold this goal, the Director of the NPS approved the Natural Resource Challenge to encourage national parks to focus on the preservation of the nation’s natural heritage through science, natural resource inventories, and expanded resource monitoring (NPS 1999a). Through the Challenge, 270 parks in the national park system were organized into 32 inventory and monitoring networks. The Mojave Desert Network (MOJN) includes seven units of the National Park system: Death Valley National Park, Great Basin National Park, Joshua Tree National Park, Lake Mead National Recreation Area, Manzanar National Historic Site, Mojave National Preserve, and Grand Canyon-Parashant National Monument. Collectively, these parks comprise 3.3 million hectares or 9.7% of the total land area managed by NPS.

MOJN I&M has identified 20 priority park vital signs, indicators of ecosystem health, which represent a broad suite of ecological phenomena operating across multiple temporal and spatial scales. **This protocol addresses monitoring of Surface Water Dynamics and Chemistry in streams and lakes.** Monitoring will be restricted to streams and lakes at Great Basin National Park (GRBA) and Lake Mead National Recreation Area (LAKE) because these habitats are limited or absent at other parks and because monitoring resources are limited. Monitoring of groundwater and springs, significant aquatic resources in MOJN, are covered in a separate set of protocols. The monitoring in this protocol addresses:

1. Regulatory status of surface waters at LAKE and GRBA
2. Surface water dynamics and quality in GRBA streams and lakes

Data collected will be used to address five primary management issues: 1) regulatory status of surface waters at LAKE and GRBA, 2) water quality of GRBA streams, 3) stream discharge (water quantity) in GRBA streams, 4) water quality in GRBA subalpine lakes, and 5) lake levels, ice-over dates, and ice-out dates for GRBA subalpine lakes.

This protocol details the why, where, how, and when of the monitoring program. As recommended by Oakley et al. (2003), the protocol consists of a narrative and a set of standard operating procedures (SOPs), which detail the steps required to collect, manage, and disseminate the data representing the status and trend of water quantity and water quality parameters in the network. Collected data, in combination with other vital signs monitoring, will provide a context for the interpretation of status and trends in water resources within the network.

The protocol is intended to be a “living” document that evolves as new information emerges and methodologies are refined. Changes to the protocol are carefully documented in *SOP 20: Protocol Revision and Review*. The first few years of monitoring will address outstanding questions related to the sampling design, such as site variability, inter-annual variability, and baseline conditions. From there, the focus will shift toward trend analysis, in which ecologically meaningful declines or increases will be detected, and appropriate management strategies can be developed.

Acknowledgments

Funding for this project was provided through the National Park Service Natural Resource Challenge and the Servicewide Inventory and Monitoring Program. This protocol is the result of the work of the MOJN Water Resources Working Group (WRWG) for whose time and effort we are grateful. WRWG participants included the authors, Terry Fisk (DEVA), Bryan Moore (LAKE), Gary Rosenlieb (WRD), Luke Sabala (JOTR), Don Sada (DRI), Kyle Voyles (PARA), and Kari Yanskey (PARA). Kristina Heister's contributions as the first MOJN I&M Coordinator laid the groundwork for the water-related protocols. Passages and some tables of the introductory text were drawn from her reports on the early efforts of the WRWG. This protocol also drew inspiration and passages from the Integrated Water Resources Protocol of the Upper Columbia Basin Network and the Lakes protocol of the Sierra Nevada Network and we thank the authors of those protocols, especially Eric Starkey, Lisa Garrett, Tom Rodhouse, and Andi Heard. We thank Penny Latham (Pacific West I&M Program Manager), and Angie Evenden (Great Basin CESU coordinator) for their help in processing task agreements to fund the network water quality monitoring. Finally, we thank Gary Rosenlieb, Roy Irwin and Pete Penoyer, NPS-WRD, and especially Marie Denn, who provided technical assistance and valuable comments on early versions of the protocol.

Abbreviations

AMS+: Alternative Measurement Sensitivity Plus
ANC: Acid Neutralization Capacity
BCT: Bonneville Cutthroat Trout (*Oncorhynchus clarki* Utah)
BLM: Bureau of Land Management
BMI: Benthic Macroinvertebrates
CWA: Clean Water Act
DEVA: Death Valley National Park
DM: Data Management Plan
DO: Dissolved Oxygen
DOC: Dissolved Organic Carbon
DOI: Department of Interior
EMAP: Environmental Monitoring and Assessment Program
EPT: Ephemeroptera, Plecoptera, and Trichoptera
FGDC: Federal Geographic Data Committee
GRBA: Great Basin National Park
I&M: Inventory and Monitoring
JOTR: Joshua Tree National Park
LAKE: Lake Mead National Recreation Area
MANZ: Manzanar National Historic Site
MDL: Method Detection Limit
MOJA: Mojave National Preserve
MOJN: Mojave Desert Network Inventory and Monitoring
MQO: Method Quality Objective
NAC: Nevada Administrative Code
NPS: National Park Service
NPS WRD: National Park Service Water Resources Division
ONRW: Outstanding Natural Resource Water
PARA: Grand Canyon-Parashant National Monument
QAPP: Quality Assurance Project Plan
RAWS: Remote Automated Weather Stations program
RL: Reporting Limit
RPD: Relative Percent Difference
SNOTEL: Natural Resources Conservation Service Snowpack Telemetry Program
SOP: Standard Operating Procedure
TDN: Total Dissolved Nitrogen
TDP: Total Dissolved Phosphorus
TMDL: Total Maximum Daily Load
TN: Total Nitrogen
TP: Total Phosphorus
US EPA: United States Environmental Protection Agency
USGS: United States Geological Survey
WASO: NPS Washington Office
WRWG: Water Resources Working Group

1.0 Background and Objectives

In this chapter, we outline the legislative and scientific rationale for monitoring Mojave Desert Network Inventory and Monitoring (MOJN I&M) streams and lakes, and describe the objectives of the protocol. We also provide an overview of the natural history of the system, the ecological theory that has guided the protocol development, and background on the regulatory status of MOJN waterbodies.

1.1 Rationale for Monitoring Water Quality in the Mojave Desert Network

National Park Service enabling legislation, the 1916 Organic Act (NPS 1916), directed the NPS to “conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.” In 1999, the NPS approved the Natural Resource Challenge (NPS 1999a), which stated, “The protection of National Park waters, watersheds, and aquatic life is fundamental to maintaining the integrity of natural resources and the quality of the visitor experience in the parks. A consistent approach to identifying and measuring progress toward meeting water quality standards is essential. Protective standards, scientific monitoring, and a program to ensure the protection of water quality, natural flows, and the health of aquatic systems are required to measure and protect this critical environmental component.” However, the past availability of water quality data for the parks has been inconsistent due to the variety of agency and state efforts and protocols. The NPS goal is to conduct its own water quality monitoring when existing data are insufficient to protect this vital resource.

To that end, the intent of the NPS Inventory and Monitoring Program is to track a subset of “vital signs”, including those for water resources (Chung-MacCoubrey et al. 2008). Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, the known or hypothesized effects of stressors, or elements that have important human values or resource significance.

1.2 Rationale for Monitoring Streams and Lakes

The selection of vital signs for monitoring in MOJN parks was a multiyear, multiagency collaborative process that identified the monitoring of surface and ground water as high priorities, as documented in the MOJN Vital Signs Monitoring Plan (Chung-MacCoubrey et al. 2008). Surface water quantity and surface water chemistry ranked 4th and 14th, respectively, among all vital signs within MOJN. Aquatic and associated riparian resources are disproportionately important compared to the land area they cover because they often host endemic biota and many riparian and terrestrial species rely on aquatic habitats during part of their life cycle. For example, up to 80% of all vertebrates in the western United States depend on riparian areas for at least one-half of their life cycles, and more than half are completely dependent on riparian habitats (Chaney et al. 1993). Similarly, 70% of butterflies in the Mojave-Great Basin region are strongly associated with riparian vegetation (Brussard et al. 1998). Moreover, aquatic habitats in MOJN harbor rare and endemic aquatic taxa. Alteration of surface water and groundwater resources in desert ecosystems has profound ecological and management implications, including loss of species diversity, extinction or extirpation of special-status and endemic species, alteration in the composition and distribution of plant and animal communities, alteration of culturally significant sites, and inability of parks to meet legal and policy mandates.

Therefore, MOJN natural resource managers are very concerned about monitoring for degradation of surface water resources.

Surface water monitoring has been divided into three monitoring protocols by the MOJN I&M Program because different habitats require different sampling methods. Springs are the most common surface water feature in MOJN (Table 1.1). Monitoring of high-discharge springs will be combined with groundwater monitoring in the MOJN I&M Selected Large Springs protocol. A statistical sample of the smaller springs will be monitored in the MOJN I&M Arid Lands Springs protocol. The monitoring of perennial streams and lakes is described in this, the MOJN I&M Streams and Lakes protocol. Perennial streams and lakes are unevenly distributed within the network, with the majority occurring at Great Basin National Park (GRBA) and Lake Mead National Recreation Area (LAKE) (Table 1.1).

Consequently, monitoring of MOJN streams and lakes will be restricted to 1) monitoring the Clean Water Act status of perennial streams and lakes at GRBA and LAKE and 2) monitoring the water quality and dynamics of the perennial streams and lakes at GRBA.

The protocol will focus on surface waters in these two parks because monitoring resources are limited, perennial streams and lakes are absent in other parks, or if present, are relatively small, not specifically assessed under the CWA by states, and were considered lower priority monitoring targets by members of MOJN water resources working group and park staff during protocol development.

The overwhelming majority of surface water volume in MOJN is in the two reservoirs of the Colorado River at LAKE (Lake Mead and Lake Mohave). The surface waters at LAKE are intensively studied because they serve as water supply for and receive treated effluent from nearby municipalities. To avoid duplicating these efforts, this protocol will not collect data in LAKE surface waters. Ephemeral streams, which in the Mojave Desert flow only during major precipitation events, will not be considered because these habitats are more similar to terrestrial habitats ecosystem function and biological composition (Chung-MacCoubrey et al. 2008).

1.3 Objectives

The overarching programmatic goal of the MOJN I&M Program is to obtain information that will aid in the assessment, conservation, and restoration of surface water resources. The *management questions* given below are the overarching questions faced by park managers. The *measurable objectives* are the information that the monitoring program can provide to help address these issues. The purpose of the Streams and Lakes protocol monitoring is not to answer the management questions, but to provide some of the information required to address them.

Table 1.1. Surface water resources of Mojave Desert Network parks.

Park	Area (ha)	Elevation Range (m)	Perennial Streams	Ponds & Lakes	Reservoirs	Springs & Seeps
Death Valley NP (DEVA)	1,374,420	-86–3,368	4+ ^a	1	0	629
Great Basin NP (GRBA)	31,194	1,615–3,981	10	6	0	426
Joshua Tree NP(JOTR)	321,327	0–1,772	0	0	4 small	109
Lake Mead NRA (LAKE ^b)	521,346 ^c	152–1,719	1	0	2 very large	89
Manzanar NHS (MANZ)	329	1,168-1,221	0	0	0	0
Mojave NPRES (MOJA)	619,923	274–2,438	1	0	0	~200
Grand Canyon-Parashant NM (PARA)	424,242 ^d	366–2,447	0	0	0	206

^aIn addition to Salt Creek, Furnace Creek, Cottonwood Creek, and Darwin Creek, several short stretches of the Amargosa River are also perennial.

^bPrior to 2010, LAKE was referred to as LAME

^cExcludes 84,358 hectares of NPS-owned land currently within LAKE boundary that is now part of PARA; Total park acreage for LAKE including NPS-owned land within PARA is 605,704 hectares.

^dTotal size of PARA includes 84,358 hectares of NPS-owned land, 327,288 hectares of BLM-managed lands, and 12,595 hectares of non-federal lands.

1.3.1 Management Questions

The Streams and Lakes Protocol outlines a monitoring program that will address five primary management questions faced by park managers. These questions fall into two categories, the **regulatory status** of surface waters at LAKE and GRBA and **assessment of ecosystem condition and trend** in streams and lakes at GRBA. Regulatory status is defined as the listing status of each waterbody as 1) impaired or unimpaired, as assessed under section 303(d) of the CWA, and 2) an Outstanding National Resource Water (ONRW) or not, as defined in 40 CFR §131.12(3). ONRW status is determined by the state of Nevada. Determinations of 303(d) status are made by the State of Nevada and the State of Arizona and approved by US EPA.

Management Questions Related to Regulatory Status:

1. What is the regulatory status of the LAKE reservoirs under section 303(d) of the Clean Water Act? Which of the GRBA streams are classified as ONRWs? Do changes in listing status indicate improving or declining water quality?

Management Questions Related to GRBA Stream and Lake Ecosystems:

2. What is the status of and what are the trends in the overall health of the ecosystems in GRBA streams?

3. Is stream water quantity changing in GRBA streams? In particular, is stream discharge being affected by groundwater withdrawals, natural climatic variations, and/or climate change?
4. Is climate change affecting the physical limnology of GRBA lakes?
5. Are atmospheric deposition and/or nutrient loading affecting the chemistry of GRBA streams and lakes?

1.3.2 Measurable Objectives

In light of these questions and the broader goals outlined above, this protocol will address the following specific measurable objectives:

Regulatory Issues:

1. What is the regulatory status of 303(d)-assessed waters within LAKE? Is the number of listed water bodies or listed water quality parameters changing over time?
2. What is the regulatory status of Nevada Class A streams (the classification used by Nevada to designate ONRWs) within GRBA? What is the condition and trend in water quality of GRBA Class A streams? Specifically, is there any evidence of declining water quality that would warrant a change in regulatory status?

The measurable objectives for regulatory issues will be achieved by monitoring the listing status of all 303(d)-assessed waters and Class A streams located within LAKE and GRBA.

Condition and Trends in Streams at GRBA:

1. What are long term trends in the quantity and seasonal patterns of stream discharge?
2. What is the status of and what are the trends in stream water chemistry?
3. What is the status of and what are the trends in stream macroinvertebrate assemblages in streams? Do macroinvertebrate assemblages indicate “reference” or “stressed or impaired” water quality using regional bioassessment criteria?

Condition and Trends in Lakes at GRBA:

1. In subalpine lakes, are water levels or is the lake ice-free season changing over time?
2. What is the status of and what are the trends in lake water chemistry?

Figure 1.1 illustrates how the data collected will be used to achieve the measurable objectives, and how we anticipate that the resulting information on status and trends will be used to address monitoring questions. In the remainder of this chapter, we provide details of the geographic setting and surface water habitats of GRBA and LAKE, the conceptual models that were used to guide the selection of monitored parameters, the current regulatory status of waterbodies, and past monitoring efforts as background to the sampling design and collection methods.

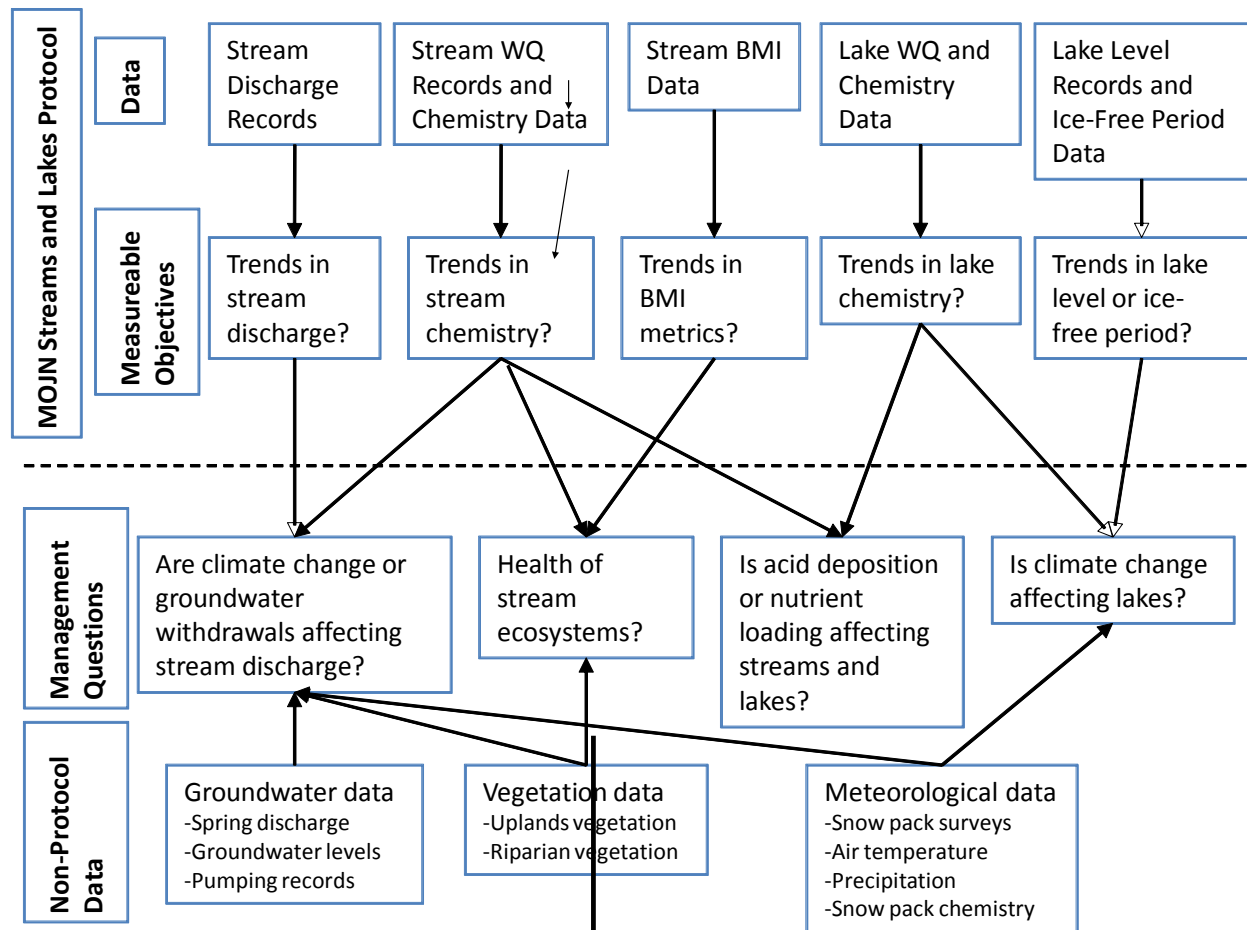


Figure 1.1. Overview of the relationships among data, measurable objectives, and management questions related to the ecological status and trend in streams and lakes of Great Basin National Park. The objective of the MOJN Streams and Lakes protocol is to collect the data and address the questions shown above the dashed line.

1.3.3 Other Monitoring Approaches Considered

Airborne Contaminants in Fish and Insects: In addition to the monitoring questions discussed above, MOJN I&M staff also considered monitoring the bioaccumulation of airborne contaminants in fish and insects in GRBA lakes. However, after consultation with outside experts, it was decided that these contaminants could not be assessed with the available resources. The rationale for not monitoring these contaminants is discussed below.

MOJN I&M considered monitoring mercury levels in the fish and insects at the top trophic level in GRBA lakes. However, the current scientific consensus is that mercury levels in aquatic biota are strongly influenced by methylation rates and trophic patterns (e.g., Landers et al. 2008, Brigham et al. 2009), so mercury levels in aquatic biota are not a good proxy for mercury deposition rates. Changes in anthropogenic mercury input can best be detected by monitoring aerial deposition rates, an activity that is outside the scope of this protocol. Fish from the lakes are not a significant source of food for any individuals, so the potential bioaccumulation of mercury in fish at GRBA is not a significant public health threat.

MOJN I&M also considered monitoring persistent organic pollutant levels in the fish and insects at the top trophic level in GRBA lakes. However, the concentrations of these compounds typically vary by an order of magnitude among fish within a lake (e.g., Landers et al. 2008, Ackerman et al. 2008). Therefore, in order to obtain data that would be representative of the status of mercury in the lake and potentially permit trends to be detected, approximately 10 fish would have to be sampled each year (Oregon State University, S. Simonich, Associate Professor of Chemistry, pers. comm., 2009). In addition, the analysis of fish and insect tissue for trace (less than 1 ng/g) levels of organic compounds remains beyond the capabilities of most commercial laboratories, and MOJN I&M could not locate a research laboratory that was willing to analyze a small number of samples each year on an ongoing basis.

DOC Quality: Dissolved organic carbon (DOC) is composed of a wide variety of different organic molecules. The term “DOC quality” refers to different methods used to characterize the different types of molecules in a specific sample. The most common way to quantify DOC quality is to measure the UV absorbance of a sample at a wavelength of 254 nm. The absorbance at this wavelength is strongly correlated with the percentage of DOC consisting of aromatic molecules, or aromaticity (Weishaar et al. 2003, Dittman et al. 2009). Dittman et al. (2010) used DOC quality (aromaticity) to track seasonal variations in the source of stream water. The network cannot sample streams and lakes frequently enough to resolve seasonal variations. However, if the quantity of DOC changes, then DOC quality data could be useful in determining if the source or sources of DOC have changed. Therefore, MOJN I&M will collect baseline DOC quality data (UV absorbance at $\lambda = 254$ nm) for all streams and lakes sampled in the 2011 and 2012 field seasons. If total DOC appears to be changing, then this data can be used to investigate the cause of the change.

Discharge of the Muddy River and the Virgin River: As noted in Section 1.9, below, the USGS operates gaging stations on the Muddy River and the Virgin River in or near LAKE. MOJN considered including the discharge of these rivers as a vital sign. No additional field work would have been required, but the USGS data would be included in the annual reports and analyzed for trends in the quadrennial trend analysis reports. However, the discharge of these rivers has not been identified as a priority by LAKE staff, so they have not been included due to limited resources. If additional resources become available, then the reporting and analysis of these data could be added to the monitoring protocol at any time.

1.4 Overview of Mojave Desert Network Water Resources

1.4.1 Geographic Setting

The seven park units in Arizona, California, and Nevada (Figure 1.2) encompass a total of nearly 3.3 million hectares of land (Table 1.1) within three contiguous semi-arid to arid desert ecosystems (the Great Basin, Mojave, and Sonoran deserts). Across these deserts there is a gradient of increasing temperature and decreasing elevation from north to south. GRBA is located northward within a high-elevation cold desert environment. LAKE is located southward, in a hot desert environment. Significant topographic relief and elevation gradients (Table 1.1) generate gradients in climate and local temperature regimes through the interaction of air density, solar radiation, precipitation, and slope. In turn, these climate gradients strongly influence the availability of surface water and the distribution of plant and animal communities.

As a result of the rain shadow created by the Sierra Nevada and the Transverse Ranges, water is scarce and a dry desert environment prevails across the MOJN area. From the Pacific Ocean, the moist air masses travel eastward, rising, cooling, and dropping the bulk of their moisture load as rain or snow once they meet mountain ranges. Precipitation gradually increases with increasing elevation and from west to east across the region, especially during the summer and fall monsoon seasons. During the monsoons, localized convective storms or tropical depressions develop, moving northward from the Gulf of California and south Pacific Ocean. The rain and snow that precipitates on the mountains ultimately enters watersheds, some of which empty in desert basins. Runoff in the mountains creates surface flows that can transport large sediment loads, which are deposited downstream in the alluvial valleys and playas. The northward location and higher elevation at GRBA result in relatively high precipitation and a higher density of surface water expressions than for LAKE and the other desert parks, which lack natural lakes or perennial headwater streams.

Lake Mead National Recreation Area encompasses 229 km of the Colorado River and is centered on two large reservoirs, Lake Mead and Lake Mojave. Because of this, it is a premier inland water recreation area in the west and a major source of drinking water for southern Nevada and Southern California. LAKE lies along the northeast boundary of the Mojave Desert and includes a portion of the high Colorado Plateau ecosystem on its eastern edge. The Colorado River reservoirs and associated lake shoreline, a reach of the Las Vegas Wash (a natural ephemeral stream used to discharge the region's treated wastewater to Lake Mead), and the park's desert springs preserve one of the southwest's most threatened habitats – the desert riparian community. As a result, there are significant populations of many species of special concern in the park (NPS 2002).

Great Basin National Park lies wholly within the Great Basin desert region and the south Snake Range in east-central Nevada. GRBA is the most mountainous MOJN desert park with nearly 10% of its land above 3,000 m, reaching the highest point in the Snake Range at Wheeler Peak (3,982 m; 13,063 ft). Due to the high elevation of the Snake Range, this range receives more moisture than many adjacent mountain ranges. Average annual precipitation in surrounding valleys is approximately 15 cm (6 in). Within the park, average annual precipitation at Lehman Cave is approximately 35 cm (14 in) but may range up to 63+ cm (25+ in) at high elevations (e.g., Wheeler Peak). GRBA is distant from urban centers and contains many relatively pristine natural resources, having one of the cleanest air quality ratings in the nation. GRBA is known for its glacial formations and karst geology producing at least 42 natural caverns harboring a variety of known and unknown cave resources. Lehman Caves is the longest and highest cave in Nevada. The combination of moisture gradients, geologic history and the isolation of higher alpine/subalpine areas in GRBA has produced several endemic plant and animal species.

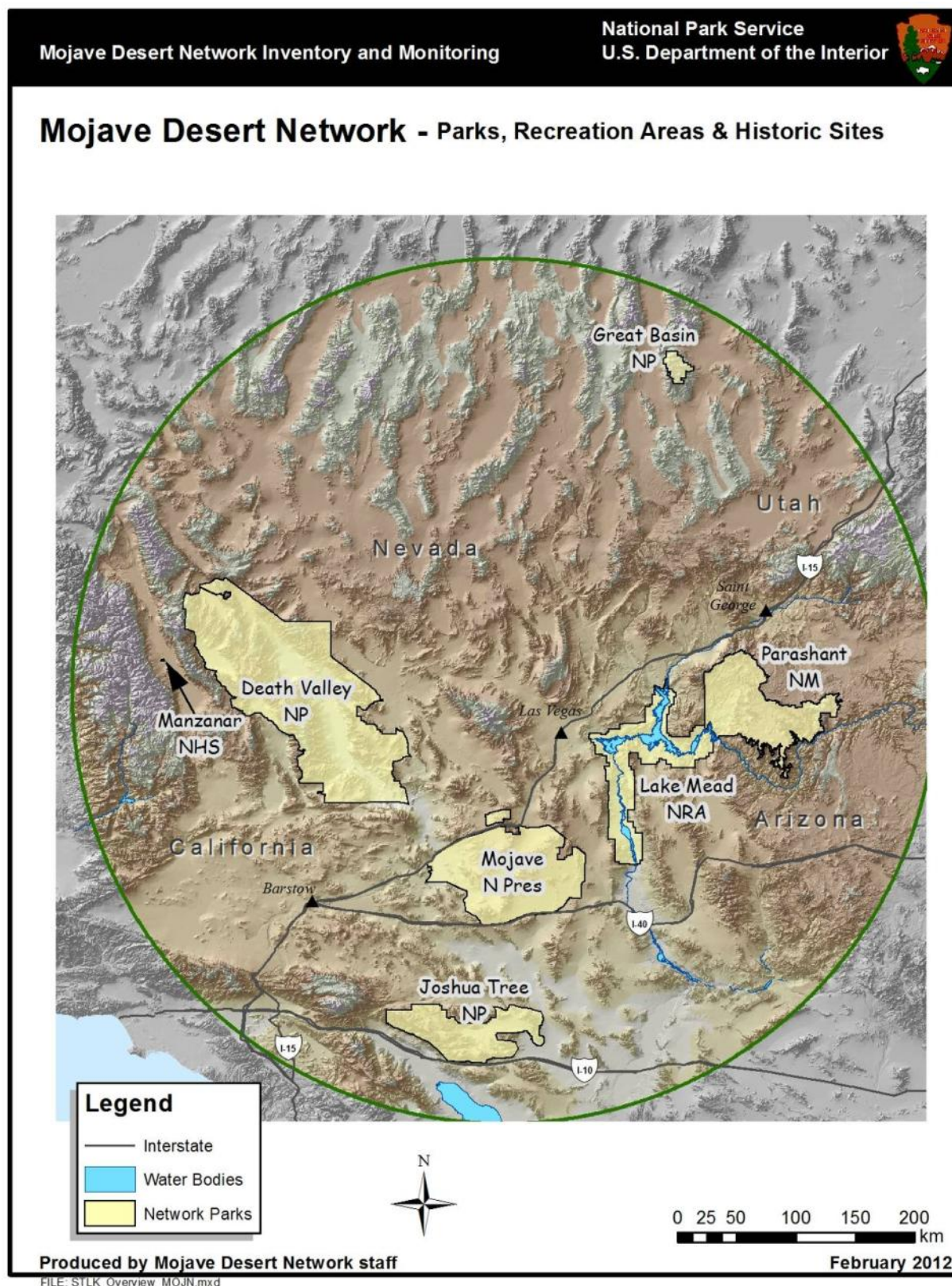


Figure 1.2. Parks in the Mojave Desert Inventory and Monitoring Network. Figure from Chung-MacCoubrey et al. (2008).

1.4.2 Perennial Streams and Lakes of the Mojave Desert Network

Lake Mead National Recreation Area encompasses two reservoirs formed by the Colorado River downstream of Glen Canyon National Recreation Area and Grand Canyon National Park (Table 1.2).

Lakes Mead and Mohave are important water resources for Nevada, Arizona, and California, and Lake Mead provides 90% of southern Nevada's water supply. Except for the extremely cold water below Hoover Dam, the lakes are ideal for swimming during the summer and fall months. Boating and water-skiing are other primary uses during the same period. Fishing in both lakes is a popular activity throughout the year. Lake levels fluctuate dramatically in response to water demand during drought conditions. The water level in Lake Mead dropped 36.3 m from January 2000 to June 2009 (USBR 2009).

The principal rivers supplying water to the recreation area are the Colorado, Virgin, and Muddy Rivers. USGS discharge data for these rivers are available at:

<http://waterdata.usgs.gov/NV/nwis/current/?type=flow>

Flows from the major source, the Colorado River, are controlled upstream by the Glen Canyon Dam, which intercepts 80-85% of the sediment which formerly entered Lake Mead. Most of the streams in the recreation area are ephemeral (i.e., they flow only after precipitation) and are subject to seasonal flash flooding primarily in the late summer and early fall months. Las Vegas Wash flows year-round and discharge has been increasing over time (Figure 1.3) because it is the outflow for treated municipal and industrial wastewater from Las Vegas. Water quality and quantity in the park is monitored intensively (Turner et al. 2010), due to the importance of Lake Mead and Lake Mohave as regional water sources and the nature of Las Vegas Wash as the wastewater outflow from a major urban area (NPS 1987a, NPS 1987b, NPS 1994a). LAKE is the only network park that includes 303(d) listed or impaired waters. The waters in and around LAKE do not meet or previously have not met regulatory standards for pH, temperature, dissolved oxygen, and a variety of inorganic constituents.

Table 1.2. Reservoirs of Lake Mead National Recreation Area.

Reservoir	Length	Area	Shoreline	Dam
Lake Mead	177 km	65,834 ha	1,323 km	Hoover
Lake Mohave	108 km	11,655 ha	409 km	Davis

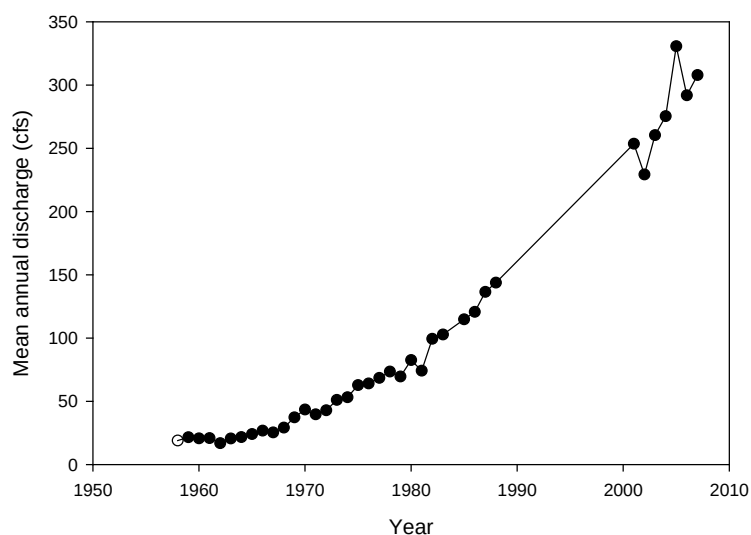


Figure 1.3. Mean annual discharge in Las Vegas Wash. Data from USGS site 9419700 Las Vegas Wash at Pabco Road, near Henderson, NV.

Great Basin National Park contains significant surface waters, including 426 perennial springs and seeps, six subalpine lakes, and ten perennial streams (Figure 1.4).

Ten perennial streams originate in the park at elevations between 1,890 to 3,353 m (6,200-11,000 ft) above sea level and are fed by springs along their courses (Table 1.3, NPS 1999b). The streams are first and second order headwater streams with an average length of 8 km (5 mi.) within the park. Six streams (Strawberry, Mill, Lehman, Baker, Snake, and South Fork Big Wash) flow eastward into Snake Valley and the Bonneville Basin. The other four streams (Shingle, Pine, Ridge, and Williams) flow westward into Spring Valley and were originally fishless. Outside park boundaries the majority of the discharge from these streams is used for irrigation; some water evaporates or percolates into the alluvium before reaching the valley bottom. Within the park a 4.8 km pipeline along Snake Creek bypasses a losing section of stream over karst. The pipeline begins at an elevation of approximately 2,300 m (7,600 ft) and ends at approximately 2,200 m (7,100 ft). Snake Creek is often dry below the pipeline from late summer until spring runoff. Water from these streams is used by public and private entities, but no water is withdrawn from them inside the park boundaries. Several GRBA streams harbor trout, including native and nonnative species. GRBA is the only network park that includes ONRWs (Nevada Class A streams) (Figure 1.4).

GRBA has six lakes (Table 1.4, Figure 1.5). All lakes lie above 2,900 m elevation and are associated with glacial moraines or cirque basins. While the areas of the lakes vary with seasonal lake level fluctuations, their average surface area in the summer months is approximately 1 ha (2.5 ac). As a result of the interannual lake level fluctuation, riparian vegetation is limited. Streams flow from the lakes seasonally. Maximum lake depth is approximately 6 m. The lakes in GRBA did not originally support fish, but trout have been introduced into Baker Lake (stocked in early 1950s with brook, cutthroat, and rainbow trout). Brook trout were removed from Johnson Lake to facilitate reintroduction of native Bonneville cutthroat trout in Snake Creek.

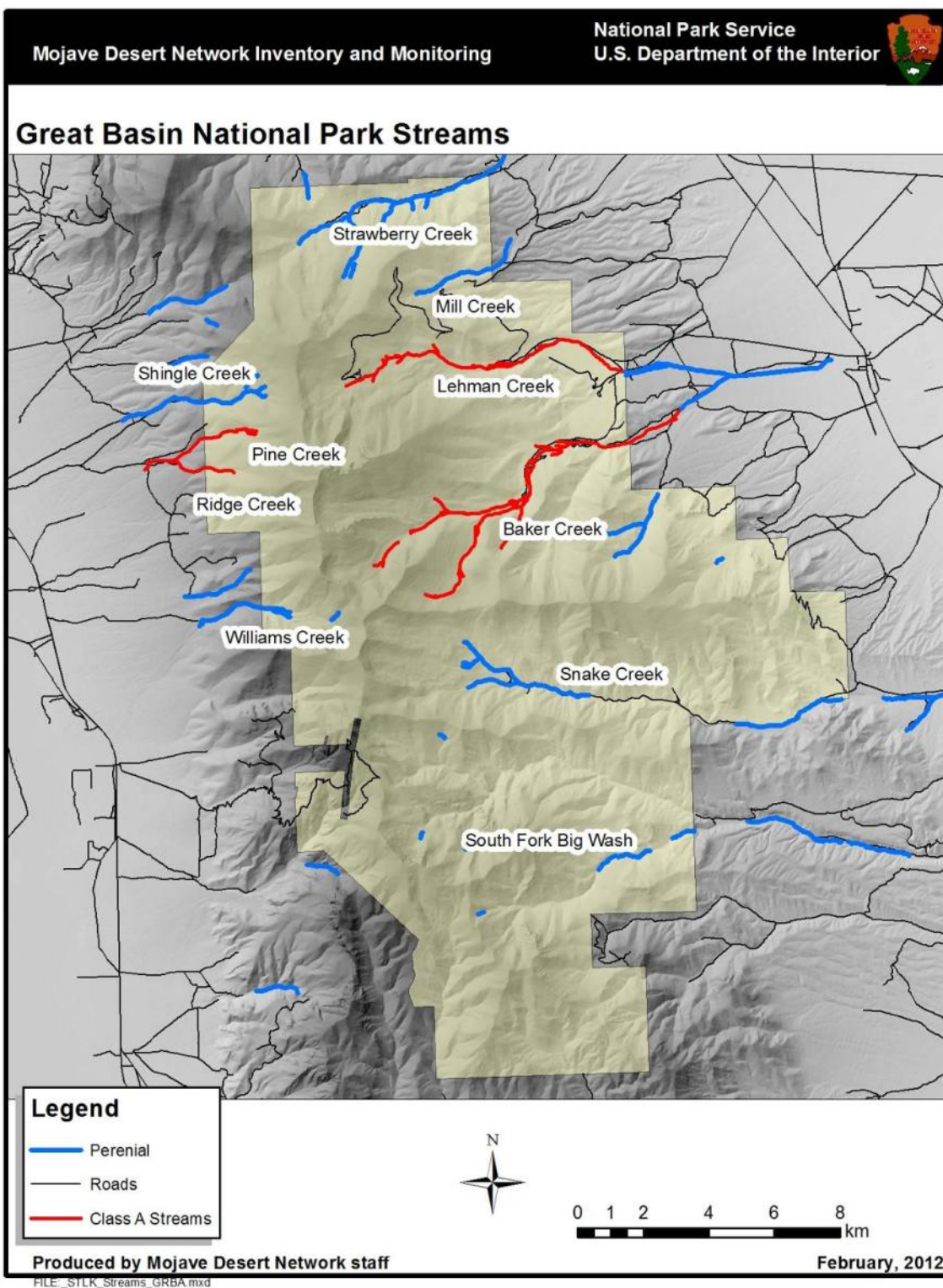


Figure 1.4. Watersheds and streams of Great Basin National Park.

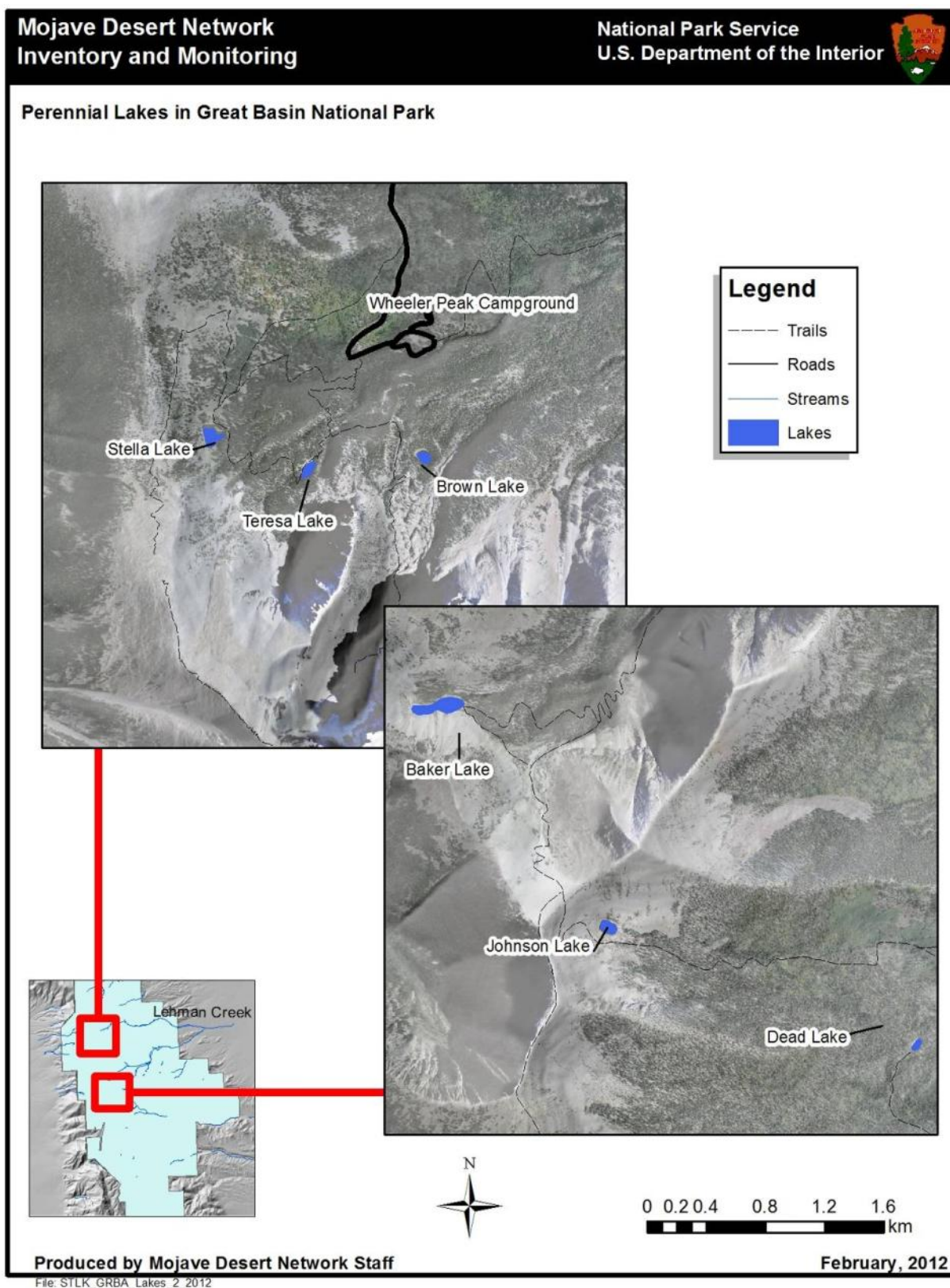


Figure 1.5. Lakes in Great Basin National Park.

Table 1.3. Streams and stream flow in Great Basin National Park (discharge data from Elliott et al. 2006).

Stream Name	Stream Length in Park (km)	Source Elevation (m)	Stream Order at Park Boundary	Watershed Area in Park (km ²)	Watershed Area above Gage (km ²)	Discharge Period of Record	Aver. Annual Flow (cfs)	Trout Species**
Baker	15.9	3,113	2	43.736	43.0	10/47-09/55; 10/92-09/97; 10/02-present	9.08	Brown, Rainbow & Brook
Lehman	10.5	3,100	2	32.896	23.1	10/47-09/55; 10/92-09/97; 07/02-present	5.13	Brown, Rainbow, & Brook
Strawberry	7.9	2,591	2	19.28	19.7	10/02-06/05	0.58	Bonn. Cutthroat
Snake	17.9	2,950	2	52.084	57.0			
Snake above pipeline						10/02-06/05	2.70	Bonn. Cutthroat
Snake below pipeline						10/02-present	1.22	Brown & Brook
South Fork Big Wash	3.2	2,316	1	17.932	17.4	10/02-06/05	0.53	Bonn. Cutthroat
Shingle	2.2	2,968	1	6.424	5.2	10/02-06/05	0.84	Hybrid
Williams	1.0	2,700	1	5.944	8.5	10/02-06/05	1.13	Rainbow
Mill	3.1	2,864	1	6.8	n/a	n/a	n/a	Bonn. Cutthroat
Pine	1.3	2,773	1	6.9	n/a	n/a	n/a	Bonn. Cutthroat
Ridge	0.3	2,510	1	*	n/a	n/a	n/a	Bonn. Cutthroat

*Watershed area for Pine/Ridge combined is 6.9 km².

**The reintroduction of native fish species to GRBA streams is ongoing.

Table 1.4. Lakes of Great Basin National Park.

Lake	Date of Lake Survey	Surface Area (m ²)	Surface Area (ac)	Max. Depth (m)	Avg. Depth (m)
Dead	9/3/2002	6.1 × 10 ²	0.15	1.1	0.5
Johnson	6/19/2003	1.0 × 10 ⁴	2.5	4.9	1.9
Stella	7/24/2003	1.4 × 10 ⁴	3.4	1.2	0.7
Teresa	7/15/2003	5.7 × 10 ³	1.4	2.2	1.1
Brown	7/17/2003	5.7 × 10 ³	1.4	0.9	0.3
Baker	2004	9.3 × 10 ³	2.3	4.8	Not measured

1.5 Conceptual Models

Freshwater monitoring in the Mojave Desert Network is part of monitoring designed using an integrated, hierarchical set of ecological models to identify key drivers and stressors and select appropriate Vital Signs (Chung-MacCoubrey et al. 2008). A hierarchical framework is critical to understanding streams and lakes because ecological processes occur at multiple scales. A hierarchical ecosystem approach is also essential for integrating monitoring efforts and data across habitats within parks.

In this framework, streams and lakes, along with groundwater, are components of the wet systems. Wet systems themselves are a component nested in an overall framework model composed of wet systems, dry systems, the atmospheric system, and the human social system (Chung-MacCoubrey et al. 2008).

Perennial streams and lakes are fed by surface water and groundwater. Hydrologic inputs to both streams and lakes come from the atmospheric system as direct precipitation, and indirectly as recharge to the groundwater systems, which can then discharge to streams and lakes. Higher level organization and functioning of the overall framework model and wet systems are described in greater detail in the Mojave Desert Network Monitoring Plan (Chung-MacCoubrey et al. 2008).

Within the stream and lake submodels, drivers and stressors affect ecological processes and biological communities and may act over multiple scales. Below we describe the major drivers and stressors for stream and lake submodels and the relationships to vital signs monitoring. LAKE water bodies are not discussed in the conceptual models below because they will not be directly sampled by the monitoring program.

1.5.1 Streams

Surface water dynamics is a key driver of aquatic ecological processes in MOJN streams. The structure and function of stream habitats are driven by the flow regime—the quantity *and* variability in stream discharge (Figure 1.6, Poff et al. 1997). The annual hydrograph for a stream illustrates several key elements of the flow regime including base flow, peak flow (floods) and the 'flashiness' of the system (e.g., Figure 1.7, an example of a hydrograph influenced strongly by snowmelt run-off). The flow regime shapes habitats through disturbances, temperature and light variations, and water chemistry (including nutrient concentrations; Scott et al. 2006). The flow regime, particularly periods of base flow and flood, strongly influences aquatic species including

algae, benthic invertebrates and fishes, as well as riparian vegetation such as cottonwoods. The flow regime also determines patterns of recharge to groundwater aquifers and water availability for humans.

Groundwater recharge is a key driver to surface water dynamics in the region because a portion of the recharged water discharges to surface water bodies. This groundwater input is generally a year-round source of water, providing baseflow during the summer when there is minimal input from direct runoff. Consequently, alteration to the groundwater system, whether through aquifer drawdown or changes in watershed land-cover that affect recharge rates, can directly impact stream and riparian systems.

Water chemistry and temperature have strong effects on stream biota. Consequently, direct and indirect human alteration of stream water chemistry and temperature is associated with altered biotic communities and ecosystem processes. Water chemistry is typically a central component of any water quality monitoring program because of the direct relationship between water chemistry and biota. While temperature has been recognized as a key determinant of aquatic community structure for some time (e.g., Vannote and Sweeney 1980), the influence of land- and water-use on stream temperature regime is now better understood (e.g., Poole and Berman 2001, Sponseller et al. 2001), and the need for baseline temperature information to monitor the effects of climate change has become apparent (e.g., Kaushal et al. 2010). As with the flow regime, variation in temperature is ecologically relevant, with maximum, rather than average, temperatures limiting the distributions of some species such as trout. NPS Water Resources Division (WRD) has identified a suite of four “core parameters”—temperature, specific conductance, pH, and dissolved oxygen—that they have determined are critical to monitoring the “overall health of a water body” (Penoyer 2003).

Biotic components of streams affect ecosystem processes and provide important ecological services such as nutrient processing and recreational opportunity (e.g., fishing). Additionally, biotic communities are known to reflect physiochemical conditions and hence can be used as “bioindicators” of water quality (Karr and Chu 1999). Benthic macroinvertebrate communities are frequently used as indicators of ecosystem condition because macroinvertebrates are abundant, diverse, have strong effects on freshwater ecosystem processes, represent an important trophic linkage between primary producers and fishes, and the structure of macroinvertebrates communities reflects water quality (e.g., Karr 1999). Sampling macroinvertebrates is often more cost-effective to sample than water chemistry, algae or fishes. Additionally, macroinvertebrate communities integrate the effects of point and non-point source pollutants over spatial-temporal scales that are more appropriate to many management questions (e.g., Delong and Brusven 1998). Well-developed macroinvertebrate indices are available that can be used to assess water quality relative to unimpaired water bodies in the same region (Karr and Chu 1999, Hawkins et al. 2000, Hawkins 2006). For example, the species richness of indicator taxa (e.g. mayflies, stoneflies, and caddisflies) and measures of species evenness are two of several parameters frequently used as indices of water quality (Peck et al. 2006).

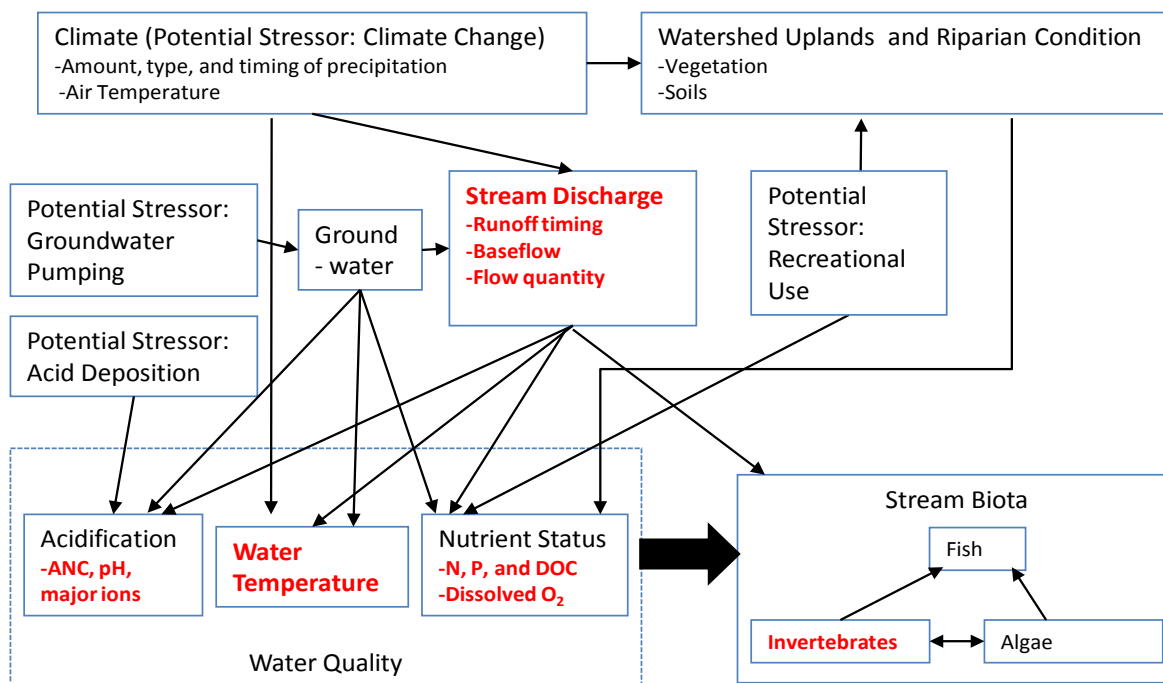


Figure 1.6. Streams submodel illustrating major drivers and potential stressors of ecosystem processes. Monitored components are shown in bold red type.

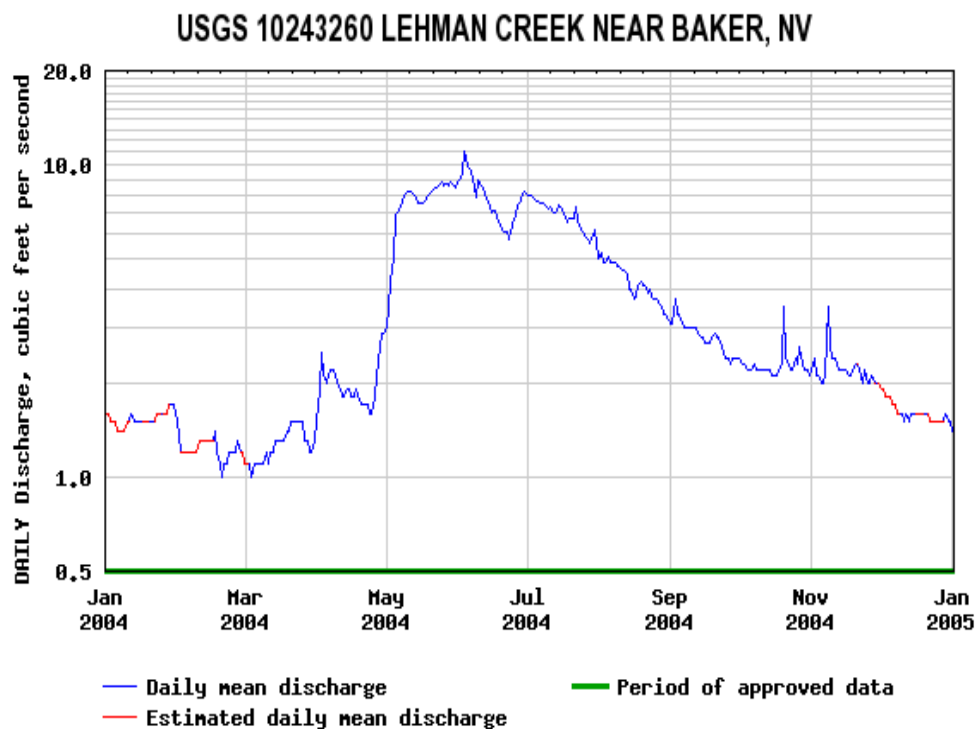


Figure 1.7. Annual hydrograph for Lehman Creek, 2004.

1.5.2 Lakes

The only perennial natural lakes in the MOJN parks are in GRBA, where shallow subalpine lakes depend on snowmelt runoff and groundwater. Global- and watershed-scale drivers include climate, basin morphometry, precipitation rates, and nutrient inputs determined by both water- and air-shed inputs (Figure 1.8). Local drivers include point sources of nutrients, bathymetry, water chemistry, and bottom type. Major stressors include alteration of nutrient status and water chemistry through cultural eutrophication, sedimentation, acid rain, input of contaminants, fishing, and the introduction of non-native species.

The character of a particular lake is strongly influenced by its hydroperiod (i.e. whether it dries and for how long), basin shape, the length of ice-free period, the water source, and nutrient concentrations. Typically, perennial ponds and lakes with sufficient depth have well developed fish communities. Temporary ponds and shallow ponds that periodically dry or “winter-kill” lack fish and have distinct invertebrate communities (Wellborn et al. 1996). At GRBA, only Baker Lake supports fish (a nonnative population of brook and rainbow trout). Overall size and depth influence both the relative ecosystem importance of benthic (bottom associated) versus pelagic (water column associated) processes and whether the water column stratifies or not. The relatively small size, shallow depth, large water level fluctuations, and short growing season in GRBA lakes results in little or no stratification, no developed littoral vegetation, and consequently, the lakes probably have strongly linked benthic and pelagic processes. Total production in lakes may be limited by the length of the growing season or the availability of nutrients or both. The magnitude and relative contribution of different water sources (precipitation, riverine or groundwater) affect water level fluctuations, flushing rate, and nutrient inputs. Finally, one of the strongest controls on biological communities in lentic habitats is nutrient status (Barbour et al. 1999, Dodson 2005). GRBA lakes have very low (oligotrophic) nutrient concentrations.

There are predictable seasonal changes in water chemistry in temperate lakes. In shallower lakes like those at GRBA, wind mixing frequently prevents strong or persistent stratification. In fall and spring, stratification breaks down as temperatures cool, and the water column mixes completely as it “turns-over”. After ice-out and spring turn-over, many lakes experience a spring bloom of phytoplankton throughout the photic zone of the lake associated with increasing light levels and the availability of nutrients released from the sediments and profundal zone during turnover (Kalff 2002, Dodson 2005). The spring bloom by phytoplankton depletes nutrient concentrations in the water column and much of this primary production settles out to the lake sediments. Depending on the degree of stratification, lake temperatures, and amount of organic deposition, oxygen concentrations below the thermocline may be depleted to hypoxic or anoxic levels by respiring bacteria (Liboriussen et al. 2009), though hypoxia and anoxia are rare in oligotrophic lakes. Secondary production of zooplankton peaks in association with the spring bloom. Planktonic and benthic invertebrates and larval, juvenile, and adult fishes consume this secondary production. Monitoring of core parameters, particularly temperature and dissolved oxygen (DO), provides important information on the physical and biological characteristics, as well as the chemical composition of lakes.

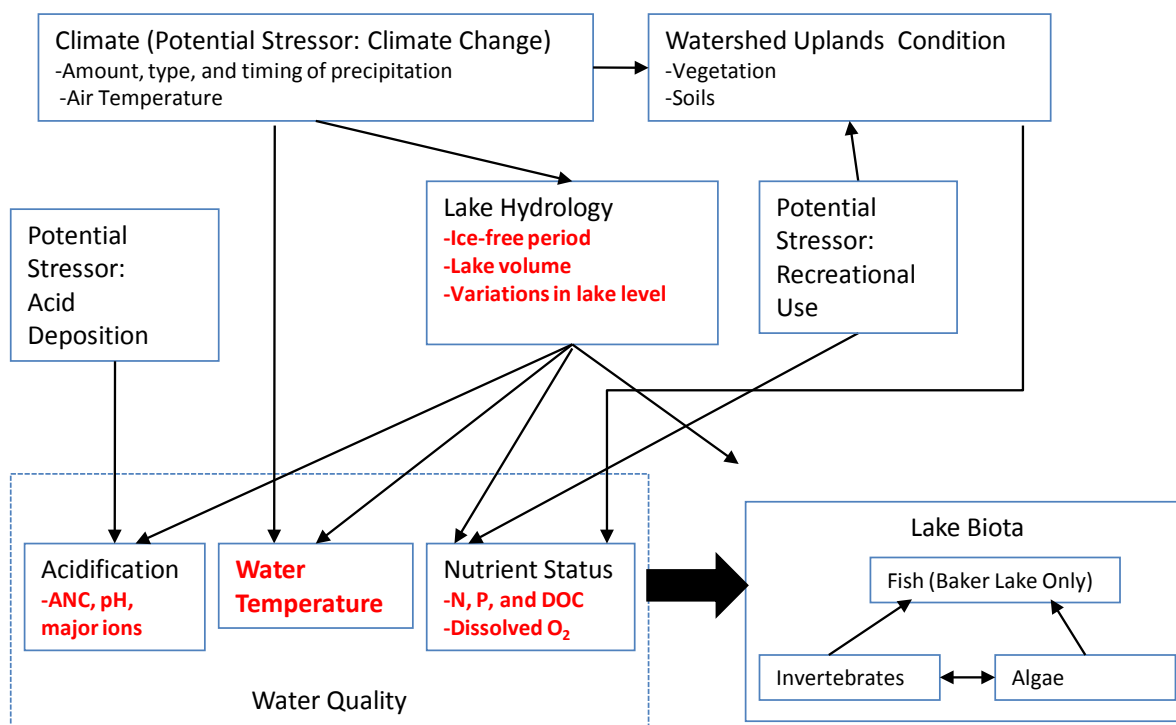


Figure 1.8. Lake submodel illustrating major drivers (solid arrows) and stressors (dashed arrows) among ecosystem components.

Stressors to lake ecosystems occur at global, regional, watershed and local scales (Williamson et al. 2008, Parker et al. 2008). Atmospheric deposition of sulfuric and nitric acids (acid rain) and other contaminants are important stressors affected by processes within the airshed. Acid rain may decrease pH and affect the nutrient status of lakes (Elser et al. 2009). Lakes such as those at GRBA with low natural buffering capacity are particularly prone to the effects of acidification (Campbell et al. 2004). The input of anthropogenic phosphorus and nitrogen may lead to cultural eutrophication through point and non-point sources, including atmospheric deposition. Cultural eutrophication leads to changes in lake food webs and fisheries, and can exacerbate hypoxia/anoxia events below the summer thermocline (Liboriussen et al. 2009). Regional and global climate changes affect precipitation patterns and the thermal regime, two strong controls on lake hydrology and physical limnology (Thompson et al. 2005).

1.6 Specific Threats and Issues

1.6.1 Lake Mead National Recreation Area

The water resources of LAKE are all highly modified from their natural state and face multiple impacts to natural ecosystem process. Lake levels in the reservoirs fluctuate seasonally and interannually in response to river input and water use needs. The level of Lake Mead has dropped markedly over the past several years during a long-term drought. In contrast, discharge in Las Vegas Wash within LAKE has been increasing through time (Figure 1.3) because it receives treated effluent and urban runoff from southern Nevada, an area that has undergone rapid urbanization. Las Vegas Wash is listed as highly contaminated or “impaired” under section 303(d) of the Clean Water Act (see Section 1.4.2) and negatively affects water quality of Las

Vegas Bay and other portions of Lake Mead. The Virgin River and Muddy River, which drain agricultural areas, are also listed as impaired. Most of the flow of these rivers is diverted during irrigation season, and the flow into Lake Mead during these times consists largely of irrigation return flow. Recently introduced non-native mollusks, along with established non-native fishes, alter community structure and threaten native biota. Current and projected future growth in human population in the region, with associated increased demands on water availability, increased recreational use, and increased point and non-point pollution will continue to threaten the ecological condition of LAKE water resources. The effects of these threats could be exacerbated by the effects of climate change.

1.6.2 Great Basin National Park

Despite its relatively remote location and current high air quality, GRBA waterbodies face several potential threats. Large-scale proposed groundwater pumping in Snake and Spring valleys adjacent to GRBA could impact park water sources in Lehman, Baker and Snake watersheds (Elliott et al. 2006). Impacts could include a reduction of water quantity, which would in turn affect water quality and the organisms that depend on it (Deacon et al. 2007). Plans to build two coal-fired power plants within 100 miles of the park near Ely, Nevada were recently shelved, but the construction of such plants in GRBA's airshed remains a possibility. Since the subalpine lakes are known to have low buffering capacity, atmospheric deposition of pollutants could potentially acidify lakes. The power plants could also become a significant source of other atmospherically deposited contaminants, particularly mercury. Mercury is also emitted into the atmosphere by many of Nevada's gold mines. Climate change is expected to alter precipitation and snowmelt patterns, affecting stream and lake hydrology. Climate change may also affect the physical limnology of lakes by changing the period and timing of the ice-free period (Magnuson et al. 2000, Thompson et al. 2005). The combined effects of past fire suppression and future climate change may result in large and catastrophic fires within the park. Large fires, particularly those burning entire watersheds, would probably represent catastrophic disturbances for aquatic biota in lakes and streams.

1.7 Outstanding National Resource Waters

The EPA water quality standards authorized by the Clean Water Act include a provision for the identification of Outstanding National Resource Waters (ONRWs) to provide protection to the Nation's most treasured water bodies. Under anti-degradation rules (40 CFR §131.12), no lowering of water quality is allowed for ONRWs.

Each state has developed its own list of ONRW waters. Nevada uses the term Class A Waters for its ORNWs, which it lists in the Nevada Administrative Code (NAC 445A.124). This list includes four stream segments in GRBA (Table 1.5). These stream segments are the only water bodies in the MOJN parks classified as ONRWs.

The NAC does not provide for regular monitoring or reporting of the status of Class A streams. However, water bodies can be reclassified by the State Environmental Commission, particularly in response to discharge permit requests.

Table 1.5. Streams in Great Basin National Park classified as Class A by the state of Nevada.

Name	Description
Baker Creek	From its origin to the national forest boundary.
Lehman Creek	From its origin to the national forest* boundary.
Pine Creek	From its origin to the first point of diversion, near the west line of section 17, T. 13 N., R. 68 E., M.D.B. & M.
Ridge Creek	From its origin to the first point of diversion, near the west line of section 17, T. 13 N., R. 68 E., M.D.B. & M.

*Since the creation of Great Basin National Park, the park boundary is the appropriate limit for the Class A segment of Lehman Creek.

1.8 Impaired Water Bodies

Section 303(d) of the Clean Water Act is meant to protect water bodies that are impaired by sources of pollution that do not violate existing effluent standards. Under Section 303(d), states are required to further regulate such pollution by developing total maximum daily loads (TMDLs) for the applicable pollutants for each impaired water body. The water quality standards used to determine if a water body has been impaired are a function of the beneficial uses of that water body. Beneficial uses are defined during an attainability analysis which determines actual use and potential future uses of a waterbody. Beneficial use status is reviewed every two years during 303(d) assessments as mandated under the Clean Water Act.

Designated or beneficial uses of 303(d)-listed waters and major surface waters include propagation of aquatic life, irrigation, industrial supply, watering of livestock, municipal or domestic supply, recreation involving or not involving contact with water, and propagation of wildlife. A table listing beneficial uses of each MOJN waterbody is included in *SOP 8: Regulatory Status*.

States are required to report water quality data to the EPA by sections 303(d), 305(b), and 314 of the CWA. These data are integrated into a single, biennial report that includes a list of impaired water bodies. EPA is currently developing a new Reporting Guidance Memo for the 2010 reporting cycle (<http://www.epa.gov/burdenreduction/pr/pr-3/w30.htm>), so the frequency of the reporting may change in the near future. The list of impaired water bodies is used for ranking of priority sites and Total Maximum Daily Load (TMDL) development in order to limit discharges of specific pollutants to the water bodies (Ledder 2003). LAKE contains the only five water bodies located in the MOJN parks that are designated as 303(d) impaired (Figure 1.8). All five water bodies are listed in the 2002, 2004, and the draft 2006 303(d) list, although the pollutants/stressors of concern have changed over time (Table 1.6). The Colorado River below the Hoover Dam was included on the State of Arizona 303(d) lists for 2004, 2006, and 2008.

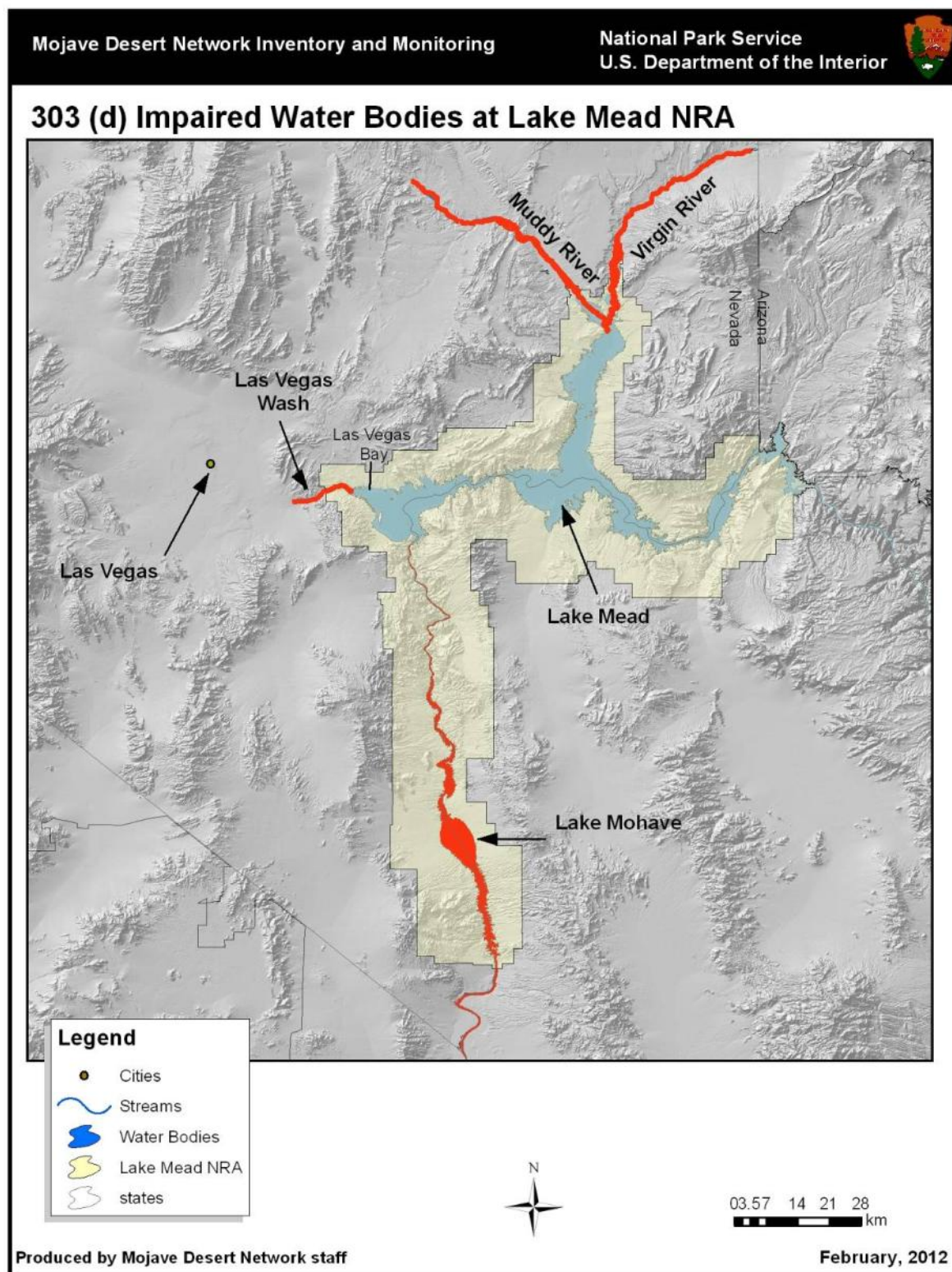


Figure 1.9. Waterbodies near or within Lake Mead National Recreation Area listed in either the Arizona or Nevada 303(d) report. Listed segments shown in red.

Table 1.6. Water bodies within and adjacent to LAKE listed as impaired by the State of Nevada and the State of Arizona.

Arizona Listings					
Waterbody Name	Reach Description	Existing TMDLs	2004 List (EPA-Approved)	2006 List (EPA-Approved)	2008 List (EPA-Approved)
Colorado River	Hoover Dam to Lake Mohave	None	Selenium	Selenium	Selenium
Nevada Listings					
Waterbody Name	Reach Description	Existing TMDLs	2002 List (EPA-Approved)	2004 List (EPA-Approved)	2006 List (Submitted to EPA)
Las Vegas Wash	Telephone Line Rd to Lake Mead	Total ammonia, Phosphorus (total)	Iron (total) Total Suspended Solids	Iron (total) Selenium	Iron Molybdenum
Virgin River	Mesquite to Lake Mead	Draft TMDL for Boron	Boron (total) Iron (total) Temperature Phosphorus (total)	Boron (total) Iron (total) Temperature Phosphorus (total) Selenium	Manganese Iron Temperature Phosphorus (total)
Muddy River	Glendale to Lake Mead	None	Boron (total) Iron (total) Temperature	Boron (total) Iron (total) Temperature	Boron Iron Temperature Manganese Molybdenum
Colorado River	Lake Mohave Inlet to CA state line	None	pH	Temperature	Temperature
Colorado River	Hoover Dam to Lake Mohave Inlet	None	pH	Zinc (total)	Dissolved oxygen Temperature

1.9 Water Resources Monitoring at LAKE and GRBA

A substantial quantity of water resource monitoring has occurred at both LAKE and GRBA. Much of the monitoring at both parks has been associated with water quality and regulatory issues, particularly to assess status of water bodies under section 303(d) of the Clean Water Act (Chung-MacCoubrey et al. 2008, *SOP 8: Regulatory Status*). Monitoring at GRBA has also collected data related to water quantity and biological resources, primarily in association with specific resource management needs. Below we provide a brief overview of the major data sources available.

1.9.1 Existing Water Quality Data

The NPS initiated a program in 1993 to characterize baseline surface water quality at all system units containing significant natural resources. The resulting reports are often referred to as the “Horizon Reports” and are available at: <http://www1.nature.nps.gov/water/horizon.htm>. With the exception of LAKE, which is intensively monitored (Turner et al. 2010), there are relatively few water quality measurements reported for the MOJN parks. Most of the reported values represent isolated samples or intensive single-year sampling efforts rather than on-going monitoring efforts. Basic information regarding data contained within these reports for LAKE and GRBA is provided in Tables 1.7 and 1.8 (NPS 1994b, NPS 2000). The reports identified potential water quality problems in each park by comparing water-quality observations to published EPA water-quality screening criteria. It was noted that the criteria may have been exceeded due to any number of factors including errors in the field, laboratory or recording procedures. Further, the data include results from areas outside of park boundaries including sampling points up to three miles upstream and one mile downstream. For these reasons, the data summarized in the Horizon reports is probably a poor representation of the general patterns of water quality in each park, but provide summaries of past water quality monitoring effort.

Table 1.7. Attributes of data retrieved from the EPA STORET database and summarized in the NPS Horizon Reports (NPS 1994b, NPS 2000).

Parameter	LAKE	GRBA
Date of STORET retrieval	08/15/93	04/19/99
Period of record	10/01/40–08/25/92	12/05/68–10/28/98
# agencies collecting data	6	5
# STORET stations in Park	318	293
# longer term stations in Park	60	1
# parameters measured	859	137
# water quality observations	445,123	6,423

Other past and on-going monitoring at LAKE focuses on regulatory water quality monitoring. A summary of water monitoring projects was compiled in 2005 for the MOJN parks, primarily through interviews with key personnel. Information regarding on-going water (quality and quantity) monitoring projects is provided in Appendix I of Chung-MacCoubrey et al. (2008). A key finding was that there are numerous ongoing efforts to monitor water quality in Lake Mead due to its importance as a regional source of drinking water, recreational value, and designation as critical habitat for several special status fish species. Currently large monitoring efforts are on-going at LAKE to determine water quality in Lake Mead and tributaries (especially Las Vegas Wash) and to monitor the spread of recently introduced exotic Quagga mussels (*Dreissena rostriformis bugensis*). Efforts are underway to coordinate the many agencies involved in monitoring Lake Mead and Lake Mohave (Turner et al. 2010). The regulatory status of the lakes, which is determined based on this monitoring, will be summarized by reporting on the 303(d) regulatory status of water bodies in LAKE.

Table 1.8. Frequency that water-quality parameters exceeded EPA water-quality criteria in Mojave Desert Network parks as reported in the Horizon Reports (NPS 1994b, NPS 2000). The EPA Criteria are taken from the Horizon Reports, and may not be current.

Water Quality Parameter	EPA Criteria	LAKE	GRBA
Dissolved oxygen	<4 mg/L	10.14%	
PH	<6.5 or >9.0	0.57%	10.49%
Turbidity	>50 JTU/FTU/NTU	25.87%	0.37%
Total coliform	>1,000 CFU/MPN per 100 ml	61.26%	5.00%
Fecal coliform	>200 MPN/CFU per 100 ml	20.50%	0.37%
Nitrite	>1 mg/L	5.08%	
Nitrate as NO ₃	>44 mg/L	1.42%	
Nitrite plus nitrate	>10 mg/L	0.55%	
Sulfate	>400 mg/L	9.08%	
Chloride	>860 mg/L	14.46%	
Selenite	>20 µg/L	0.12%	
Arsenic	>50 µg/L	15.50%	
Cadmium	>5 µg/L	4.23%	
Chromium	>100 µg/L	0.72%	
Copper	>18 µg/L	17.30%	11.11%
Lead	>82 µg/L	19.53%	29.09%
Thallium	>2.0 µg/L	14.29%	
Nickel	>100 µg/L	0.60%	
Silver	>4.1 µg/L	5.04%	
Zinc	>120 µg/L	4.56%	11.89%
Antimony	>10 µg/L	6.67%	
Selenium	>50 µg/L	1.11%	
Mercury	>2.0 µg/L	0.38%	
Methylene chloride	>5 µg/L	40.00%	
Gamma-BHC (Lindane)	>0.2 µg/L	2.94%	
Cyanide	>0.022 mg/L		
Fluoride	>4 mg/L		
Uranium	>20 µg/L		
Barium	>2 mg/L		0.83%

Historical water quality data are available for GRBA streams and lakes. Water chemistry and macroinvertebrate samples were collected in 2007 as part of a baseline water quality study (Horner et al. 2009). Water quality and aquatic macroinvertebrate communities have been studied in Strawberry, Mill, Upper Snake, and South Fork Big Wash Creeks as part of studies related to a reintroduction program for Bonneville cutthroat trout (BCT, *Oncorhynchus clarki utah*; Darby et al. 2004). The remaining six streams have had sporadic water quality measurements (Great Basin National Park, G. Baker, Ecologist, pers. comm., 2009). Across the

park, 490 invertebrate samples have been taken from 37 waterbodies during 1997-2005. The majority of samples (360) were taken at Snake and Strawberry creeks as part of the BCT reintroductions. Most other sampling occurred prior to 2001 and few samples were taken 2004-2006. In total, sampling has documented 141 distinct benthic macroinvertebrate and 8 microcrustacean (mostly zooplankton) taxa to date. The invertebrate data represent important historical data and were used in the development of the macroinvertebrate protocols presented in Chapter 2, and generally indicate high water quality (Horner et al. 2009).

1.9.2 Existing Water Quantity Data

The discharge of the Colorado River has been recorded at various locations since the early 20th century. However, the construction of the Hoover Dam and Glen Canyon Dam have had a drastic impact on the river's flow regime, and the current discharge of the Colorado River in and near LAKE is greatly impacted by dam releases and water withdrawals. The Virgin River has been gaged by the USGS since 2003. The first monitoring site (just inside the LAKE boundary) was destroyed by a flood in 2005, and the currently-used gage was established further downstream in 2006. The USGS operates three stream gages on the Muddy River, including one located just upstream of the LAKE boundary that has been in continuous operation since about 1997.

Discharge has been estimated at some GRBA streams since as early as 1947 (Table 1.3). In 2002, stream gauges were installed for two years on Baker Creek, Lehman Creek, Strawberry, Snake, South Fork Big Wash, Shingle, and Williams Creeks as part of a U.S. Geological Survey study to determine the susceptibility of park water resources to groundwater pumping in adjacent valleys (Elliott et al. 2006). The USGS has monitored the Lehman Creek gage since 2002, while the NPS has monitored Baker Creek, Strawberry Creek, and Snake Creek.

1.10 Integration with other Monitoring Efforts

The NPS Inventory and Monitoring Program, following suggestions by O'Neill et al. (1986), Noss (1990) and others (e.g. King 1993, Woodley 1993), has identified the integration of spatial, temporal, and ecological hierarchies as a key ingredient to network monitoring efforts. The Streams and Lakes protocol will provide basic hydrologic and water quality information that can be integrated with other monitoring data to answer management questions (Figure 1.1).

The Streams and Lakes protocol data will be used to interpret the results of other MOJN I&M monitoring protocols. The streams and lakes at GRBA are part of the "wet system" defined by Chung-MacCoubrey et al. (2008). Basic data on water quality and quantity are fundamental to the interpretation of any other wet system vital signs (e.g., springs, riparian vegetation, riparian birds) that MOJN I&M monitors in the future. Williamson et al. (2008) argue that streams and lakes are deeply integrated into the dry system because they provide "a spatially connected framework that ties together the terrestrial landscape." This spatial connection allows streams to transport water, nutrients, and materials across the landscape, while also providing a pathway for the spread of invasive species. Therefore, the data collected in the Streams and Lakes protocols may be crucial for the interpretation of dry-system vital signs as well.

There are many other ongoing monitoring efforts at GRBA. The monitoring programs that cover water resources closely complement the monitoring proposed in this protocol:

- There are two snowpack survey locations in GRBA monitored by the Natural Resources Conservation Service: one at Wheeler Peak and one in Baker Creek Canyon. The snow depth and snow water equivalent at the Baker Creek site are measured twice a year at the Baker Creek snow courses and on a daily basis at the Wheeler Peak site, which is part of the Snowpack Telemetry (SNOTEL) program.
- There are two weather stations in the park operated by the interagency Remote Automated Weather Stations (RAWS) program: one at Mather Overlook and one in Baker Flats near the Lehman Caves Visitor Center.
- Stream discharge at Lehman Creek is currently being monitored by USGS personnel. If long-term funding is not obtained for this effort, then Lehman Creek's discharge will be monitored under this protocol.
- The discharge at Rowland Spring has been monitored by the USGS and GRBA staff. It is anticipated that this spring will continue to be monitored by GRBA staff, with MOJN I&M providing data analysis and data management as part of the MOJN Selected Large Springs protocol.
- Several groundwater monitoring wells are planned for GRBA and the surrounding area. Upon installation, these wells will likely be monitored by USGS personnel for at least a year. In the long term, it is likely that these wells will be monitored by GRBA personnel, with the data managed by MOJN I&M as part of the Selected Large Springs protocol.

A key component to data integration is data sharing. All protocol water quality data will be uploaded to national databases (WRD STORET and EPA STORET). The taxonomic data obtained from the benthic macroinvertebrate monitoring will be integrated into GRBA's species list in the NPSpecies database. All protocol data will be made available to outside scientists.

2.0 Sampling Design

Sample design is critical to ensuring that collected data will meet program objectives in a statistically rigorous manner. Designs inherently reflect trade-offs among the priorities of the monitoring program, resources available, and the logistical considerations and constraints associated with field sampling. The sampling design for this protocol is the result of a process that included prioritization of sampling needs by the MOJN I&M Water Resources Working Group (WRWG), review of historical and on-going monitoring programs, and the identification of sampling populations, site reconnaissance, and collection of pilot data. Although the aim of the sampling design is to provide optimal statistical robustness and scientific rigor, other considerations including personnel safety, fiscal and logistical constraints, and the ability to integrate data with other vital signs were considered.

2.1 Sampling Plan

An ideal sampling plan would document the condition of the resources, (e.g., water quality and ecosystem parameters) and would be sensitive to multiple stressors, including future and unknown threats. The following suite of parameters for streams and lakes were selected on the basis of scientific, logistical, and monetary considerations. In particular, the selected parameters are the best available measures of the key ecosystem attributes identified in the conceptual models presented in Section 1.5 and are the indicators most closely connected to current and perceived future management and conservation issues. The sampling plan is summarized in Table 2.1, and the sampling locations are shown on a map in Figure 2.1. Below we provide brief descriptions of why specific parameters were chosen and how they will be monitored.

2.1.1 Stream Discharge

Importance: Monitoring of stream discharge through time quantifies the flow regime. Alteration of the flow regime—the amount and variability of discharge—by climate change or other mechanisms can affect stream morphology, chemistry, and biota (Poff et al. 1997).

Monitoring Method: Pressure transducers will be used to collect continuous records of stream stage. Approximately once a month, discharge will be measured using pygmy meters (or the floats method, at very high flows), and stage will be read from staff gages. These paired discharge measurement and staff gage readings will be used to generate rating curves, which will be used to convert the continuous stage recordings to continuous discharge records.

Monitoring Locations: The available resources and logistical issues do not allow for continuous discharge monitoring in all of the streams in Great Basin. Therefore, the discharge will be monitored in the four second-order stream reaches in the park (Baker, Lehman, Snake, and Strawberry). These streams were selected as the target population because they have the highest discharges, harbor fish, can be accessed by road, and have been identified as the highest priority monitoring targets by park staff.

Table 2.1. Overview of the sample design for streams and lakes in GRBA.

Data Type	Target Population	Measurement Location	Measured Parameters	Sampling Frequency
Stream discharge	All second order streams (Baker, Lehman, Snake, and Strawberry Creeks)	USGS-established gaging sites near park boundary; additional upstream gage on Snake Creek	Stream discharge	Monthly discharge measurements used to produce year-round hourly discharge records
Stream water quality (continuous data)	All second order streams (Baker, Lehman, Snake, and Strawberry Creeks)	Co-located with stream discharge measurements	Four core water quality parameters (dissolved oxygen, pH, temperature, specific conductance)	Hourly data from mid-June to late September
Stream water quality and chemistry (field and laboratory)	All nine accessible perennial streams (Williams Canyon inaccessible)	One randomly-chosen location per stream; the same locations will be revisited each year	Laboratory analyses listed in Table 2.2; four core parameters (listed above) measured in field	Annual sample collected in late July-to-August index period
Stream benthic macroinvertebrate (BMI) assemblages	All nine accessible perennial streams (Williams Canyon inaccessible)	Co-located with stream water chemistry sampling locations	Collected macro-invertebrates are taxonomically-identified and enumerated. Metrics are calculated from these data	Annual sample collected in late July-to-August index period
Lake water quality and chemistry (field and laboratory)	All lakes	Near the deepest point in each lake	Vertical profiles of four core parameters (listed above); Secchi depth; Laboratory analyses listed in Table 2.2	Sample collected and measurements made annually in late September.
Lake level, ice-over date, and ice-out date	All lakes	Lake level does not vary across lake; logger location determined by logistical concerns	Water pressure and temperature; atmospheric pressure and temperature	Pressure and temperature recorded every two hours; end products are year-round continuous lake level records and ice-over and ice-out dates for each lake

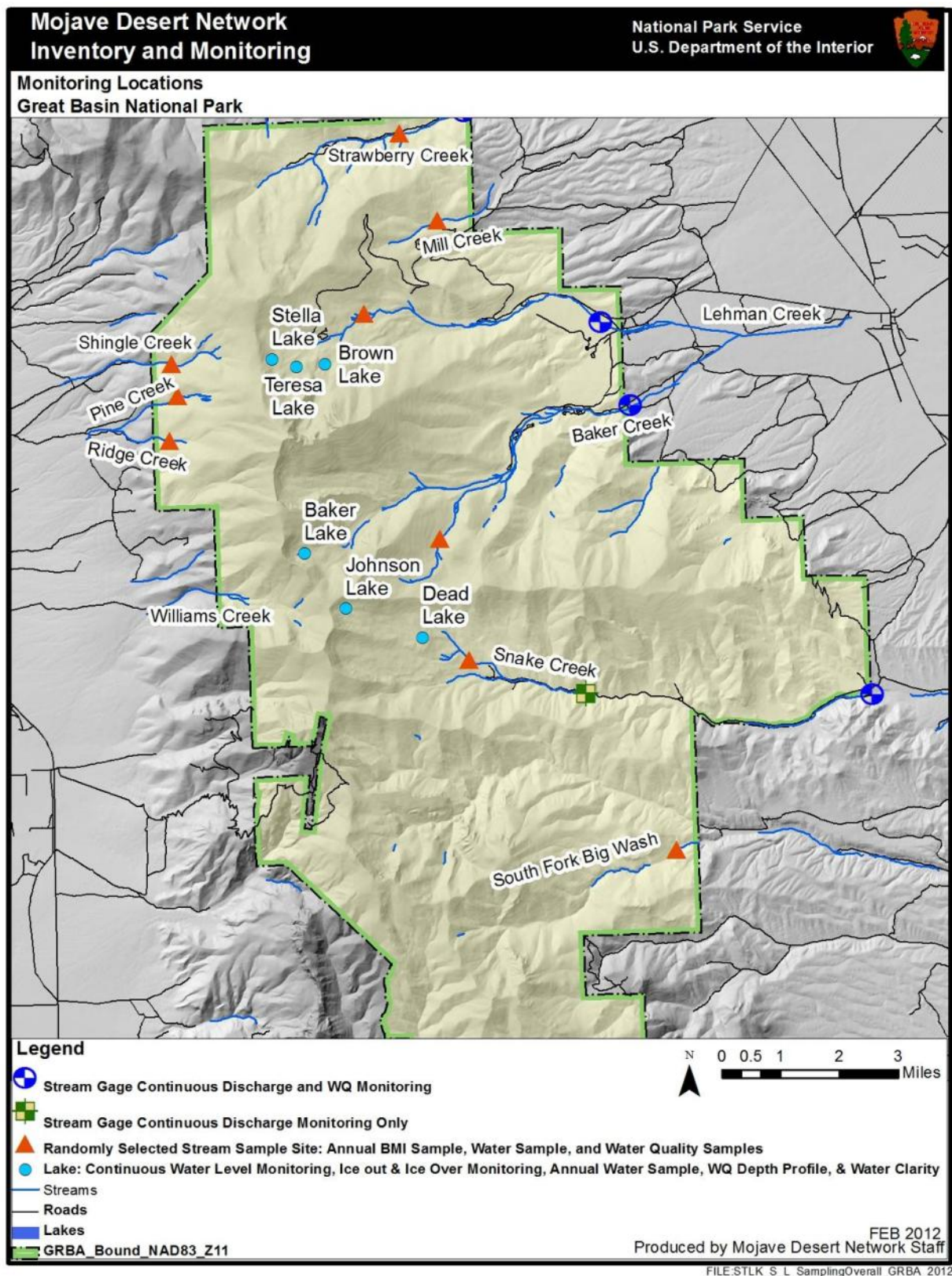


Figure 2.1. Overview of MOJN Streams and Lakes protocol sampling locations in GRBA.

The discharge monitoring sites on Lehman, Baker, Snake, and Strawberry Creeks will be the same sites selected by Elliot et al. (2006), used in historical monitoring (Section 1 of this report), and currently monitored by the USGS and GRBA (Figure 2.1). This sample design will allow future data to be compared to historical data. More importantly, all of the sites are located at or near the park boundary so that any depletion of the streams inside the park boundaries can be detected. The Snake Creek gaging site is generally dry by mid-summer, so a fifth gage has been established on the perennial portion of Snake Creek upstream of the pipeline (Figure 2.1) to provide data regarding the creek's baseflow.

Monitoring Schedule: Discharge is monitored year-round, although no data can be collected when the creeks are frozen or dry. Data is collected every 15 minutes in accordance with USGS standards.

2.1.2 Lake Level and Ice-Free Period

Importance: Lake levels fluctuate based on snowmelt timing, annual precipitation, ground water input, and evaporative demand. Lake levels may change in response to climate change (Williamson et al. 2008).

The ice-free period has a strong influence on the biological dynamics of lake systems (Williamson et al. 2008), and has been shown to be sensitive to climate change (Magnuson et al. 2000).

Monitoring Method: Lake levels will be measured with continuously-recording pressure transducers calibrated with annual direct measurements of lake stage.

Lake ice-free period will be indirectly determined from the lake level records, water temperature records, and atmospheric temperature records.

Monitoring Locations: The target population for this monitoring is all six of GRBA's lakes, and all six lakes will be monitored.

Monitoring Schedule: Water level and water temperature will be recorded continuously year-round. Data will be recorded every two hours, which field tests have shown is sufficient to characterize the magnitude of diel variations.

2.1.3 Core Water Quality Parameters (Streams and Lakes)

Importance: The NPS WRD has identified the four parameters below as critical "core parameters" to be monitored in aquatic habitats.

Water temperature is a master variable controlling many physical, chemical, and processes. For instance, water temperature affects chemical reaction rates, dissolved oxygen concentrations, algal productivity, and growth rates of aquatic organisms (Williamson et al. 2008). Water temperature is particularly sensitive to climate change (Kaushal et al. 2010).

pH is the negative logarithm (base 10) of hydrogen ion activity. pH controls many chemical and biological lake processes. It is sensitive to changes in acidic inputs and acid neutralizing capacity (Parker et al. 2008).

Specific conductance (the temperature-corrected form of electrical conductivity) is the measure of a waters' ability to conduct an electrical current and provides a broad measure of the concentration of ions in a water sample. Water bodies with low specific conductance are most sensitive and susceptible to effects from stressors such as atmospheric deposition and visitor use. A change in specific conductance, especially in the dilute waters of GRBA, may indicate a change in water chemistry that requires further investigation.

Dissolved oxygen sustains aquatic communities that respire aerobically, including zooplankton, algae, amphibians, and fish. Dissolved oxygen levels can be a good indicator of eutrophication (Liboriussen et al. 2009). As systems become more productive, biota consume oxygen from the water column at an increasing rate.

Monitoring Method: The core water quality parameters are monitored using multi-sensor instruments. In addition to the four parameters listed above, electrical conductivity will also be recorded so that values from instruments with different temperature correction algorithms can be compared.

Two methods will be used to monitor the core water quality parameters in streams: handheld water quality instruments will be used to make discrete measurements in the nine accessible streams, and continuously-recording sondes will be used to collect continuous records in the four second-order streams.

The core water quality parameters will be measured in lakes by using the handheld water quality instrument to collect depth profiles. Each parameter will be measured at the surface, near the lakebed, and at several intermediate depths.

Monitoring Locations: The target population for the continuous water quality monitoring is the four second-order streams for the reasons identified in Section 2.1.1. The sondes will be located at or near the site of the stream gages on the four second-order streams so that the water quality data can be interpreted in the context of the discharge data. Importantly, core water quality parameters vary in time and space, and selecting a representative site for sonde deployment within a given stream reach is critical to the collection of useful data. Cross-section surveys will be conducted at the beginning of each field season to select representative sonde monitoring locations (*SOP 11: Continuous Water Quality Sonde*).

The handheld water quality instrument will be used to collect readings when benthic macroinvertebrate (BMI) and water samples are collected. As described in Section 2.1.4, the target population for this component of the monitoring is the nine accessible perennial streams. The samples will be collected at one randomly-selected site on each of the nine streams. The co-location of the BMI sample, the water sample, and the discrete water quality measurement will allow the three resulting data sets to be combined in the assessment of stream health. At each site, a cross-section of measurements will be recorded to ensure that the results are not affected by heterogeneity within the stream.

The target population for water quality depth profiles is all six of GRBA's lakes. The depth profiles will be collected near the deepest point of each lake, and be co-located with the clarity measurements and the water samples.

Monitoring Schedule: In the second-order streams, the sondes will be deployed after peak runoff has occurred (mid-June) and retrieved in the fall before ice forms (late October). Eliminating the winter sampling period will reduce the possibility of damage to a sonde and reduce staff time during a period of low natural variability and biological activity. Eliminating the spring and early-summer sampling period will reduce the possibility of the loss of a sonde during peak runoff. Core parameter values will be recorded hourly, a frequency that will characterize diel variation in parameter values.

The discrete water quality measurements collected at the random locations on the nine perennial streams will be collected annually in an August 16-31 index period. Water samples and BMI samples will be collected during the same annual site visits. More frequent measurements are not feasible due to the crew time required to access remote sites and the cost of the additional laboratory analyses. Monitoring the streams during the same 16-day index period each year will minimize the effect of seasonal variations on the data set. Monitoring streams when water temperatures are near their maximum levels will permit the detection of any ecosystem degradation due to temperature stress. By late August the streams should be at baseflow conditions, so water chemistry should not be changing quickly. In order to better understand the seasonal variations in stream water chemistry, water samples from Lehman Creek will be collected every two weeks during the 2011 field season. These data will be used with the continuous water quality records to determine whether August 16-31 is an appropriate index period for stream monitoring in GRBA.

Water quality depth profiles will be collected annually in a September 15-30 index period. A U.S. Forest Service review of water quality monitoring programs found that most annual lake monitoring programs performed the monitoring in the fall, when the water chemistry of most lakes is relatively stable (Sullivan and Herlihy 2007). Further work being undertaken to better understand the annual variations in lake water quality is described in Section 2.4. For the high-elevation lakes in GRBA, late September is the latest period in which the lakes are reliably accessible. In addition, the pressure and temperature loggers used to monitor lake level and ice free period (Section 2.1.2) are installed on the same annual visit. If they are installed when lake levels are near their lowest in late September, there is no risk that they will be stranded above the water line by receding lake levels. In order to better understand the seasonal variations in lake water chemistry, water samples from Stella Lake will be collected every two weeks during the 2011 field season. These data, the continuous water level records, and the continuous temperature records will be used to determine whether September 15-30 is an appropriate index period for stream monitoring in GRBA.

2.1.4 Water Chemistry (Streams and Lakes)

Importance: The following additional water chemistry parameters will be monitored by laboratory analysis of samples collected in streams and lakes.

Acid Neutralizing Capacity (ANC) is the measure of a waters' capacity to neutralize acid. At the pH of most GRBA lakes and streams, ANC is composed primarily of the bicarbonate ion. Lakes with low ANC concentrations are more susceptible to acidification (Campbell et al. 2004). Decreases in ANC are typically observed during spring snowmelt and other high discharge events, when high discharge dilutes acid neutralizing ions and high concentrations of acids are washed into receiving waters.

Major ions (Ca^{2+} , Na^+ , Mg^{2+} , K^+ , and Cl^-) are important in understanding the geochemical evolution of surface waters. They are generally controlled by water-rock and water-soil interactions, which can vary with climate (Parker et al. 2008). The concentrations of these ions can also be indicative of external stressors such as atmospheric deposition or visitor use. The charge balance between base cations (Na^+ , Mg^{2+} , Ca^{2+} , and K^+) and acid anions (Cl^- , NO_3^- , and SO_4^{2-}) can be used to assess whether acid deposition is occurring in lakes (Campbell et al. 2004).

Sulfate is a strong acid anion that readily leaches into receiving waters. In high elevation lakes, increases in sulfate concentration can indicate acidification due to atmospheric deposition (e.g. Driscoll et al. 2001, Campbell et al. 2004). Sulfur compounds can originate from fossil fuel combustion and be deposited as wet and dry deposition or can be leached from rocks and soils. A general decreasing trend in sulfate concentrations during the past 25 years is attributed to the success of the Clean Air Act.

Dissolved Organic Carbon (DOC) is a measure of the plant- and animal-derived organic molecules present in water bodies that will pass through a filter. In some areas of the world, DOC concentrations in surface water bodies have doubled over the last two decades, presumably in response to reductions in emissions from coal-fired power plants and subsequent changes in freshwater ecology (Williamson et al. 2008). In contrast, the DOC in the Yukon River has been declining due to climate change-related changes in carbon cycling (Striegl et al. 2005). DOC cycling is intimately linked to the cycling of other nutrients (Brookshire et al. 2005). Williamson et al. (2008) strongly recommend monitoring DOC, stating that “understanding the fate of organic carbon in aquatic ecosystems is central to understanding the dynamics of climate change.”

Nutrients are essential for life. In aquatic systems, the limiting macronutrient is often N, P, or both (Elser et al. 2009). Nutrient monitoring is important for three reasons: 1) nutrient availability controls ecosystem productivity through its influence on microbial and phytoplankton growth, 2) changes in nutrient availability are likely to alter ecosystem structure (i.e., numbers and types of species present) and, 3) nutrient availability is likely to be sensitive to external stressors including atmospheric nutrient deposition and watershed drivers such as fire that are of high interest to management. Due to the relatively small changes in nutrient concentration needed to affect oligotrophic aquatic ecosystems, a suite of nutrient components were selected for monitoring: total nitrogen (TN) total dissolved nitrogen (TDN), nitrate+nitrite, total phosphorus (TP), and total dissolved phosphorus (TDP). This approach also gives MOJN I&M the flexibility to examine status and trends of nutrient ratios. For example, Elser et al. (2009) compared data from a number of alpine lakes in Norway, Sweden, and the United States and found that the impact of nutrient deposition could be detected by examining the stoichiometric ratio of TN:TP.

Total Nitrogen (TN) is a common measure in monitoring programs. TN is a measure of water quality used by most states. While TN can be less useful than other measures of nitrogen (discussed below) in assessing nutrient availability, it is commonly used to assess aerial deposition of N (e.g., Elser et al. 2009), where the total N flux is of importance.

Total Dissolved Nitrogen (TDN) is a measure of dissolved nitrogen (i.e. the N not retained by a filter). Dissolved nitrogen is a better representation of the nutrients available to phytoplankton

and algae than TN, which includes the N already incorporated into phytoplankton and algae and bound to colloids. Dissolved nitrogen consists of dissolved inorganic nitrogen, (DIN, the sum of nitrate, nitrite and ammonium), and dissolved organic nitrogen (DON, principally fulvic and humic acids). Stream ecosystems will readily uptake both DIN (Peterson et al. 2001) and DON (Brookshire et al. 2005).

Nitrate+nitrite is the sum of the concentrations of nitrate (NO_3^-) and nitrite (NO_2^-). Because ammonium (NH_4^+) is transformed so quickly in most aquatic environments that it is rarely detected at significant concentrations (Williams et al. 1995), nitrate+nitrite is a measure of DIN. Nitrate is the predominant form of DIN; nitrite is occasionally detected in hypolimnetic waters with low redox. Nitrate is a mobile anion and the form of N that most readily leaches into receiving waters during snowmelt runoff. In pristine streams and lakes such as those at GRBA, concentrations of DIN are generally much lower than those of DON (Brookshire et al. 2005). By measuring nitrate+nitrite and TDN, the ratio of DIN:DON can be estimated, allowing any changes in nitrogen cycling over time to be detected (Brookshire et al. 2005).

Total Phosphorus (TP), like total nitrogen, is a common measure in water quality monitoring programs. TP is also an indicator of eutrophication and trophic status, and is a water quality standard used by most states. Phosphates bond strongly with iron hydroxides in soil or precipitate as calcium phosphates, so they can be readily transported by either wind or water. In some montane lakes, aerial deposition is the dominant source of P (e.g., Sickman et al. 2003), while in others soil leachate is more significant (e.g., Parker et al. 2008). The source of P to the waters of GRBA is not known, although the park is located in an area of relatively high P deposition (Mahowald et al. 2005).

Total Dissolved Phosphorus (TDP) is all dissolved (i.e. not retained by a filter) organic and inorganic phosphorus (i.e., PO_4^{3-} ion). This is the phosphate that is most readily available to aquatic ecosystems.

Monitoring Method: Bottle samples will be collected using the hand-dipping method described in the USGS National Field Manual (USGS 2006). Sampling will be conducted during fixed time period (10 AM – 2 PM) at each stream and lake to minimize variability associated with diel fluctuations in water chemistry parameters.

Filtered samples are required for the analysis of TDP, TDN, nitrate+nitrite, and major ions. It is standard USGS practice to use 0.45 μm filter capsules. However, the filter media in these capsules is nitrocellulose, which can result in trace nitrogen contamination of the filtrate. Because trace contamination could significantly influence the results of TDN analyses for the low-nutrient streams and lakes in GRBA, we will use 0.7 μm glass fiber filters. The use of 0.7 μm filters avoids contamination, but results in values of TDN and TDP that are not entirely comparable to values collected under the standard USGS protocol. The filtered and unfiltered samples will be submitted to a laboratory for analysis.

Monitoring Locations: The purpose of the stream water chemistry monitoring is to provide an overall assessment of the health of the stream ecosystem. Therefore, the target population is all nine of the accessible perennial streams. One sample location was randomly chosen for each of the nine perennial streams in the park that can be accessed by a crew without an overnight stay

(i.e., all of the streams but Williams Canyon). These locations are shown on Figure 2.1, and will be revisited each year. At each sample location, a water sample and a BMI sample will be collected and the core water quality parameters will be measured.

The target population for the lake water samples is all six of GRBA's lakes. The sample will be collected with the water quality depth profiles and the clarity measurements near the deepest point in each lake. The unpublished data collected during the first two years of monitoring have shown that the lakes are well-mixed and do not exhibit stratification, so a single grab sample from arm's depth is sufficient.

Monitoring Schedule: Water samples will be collected during annual visits to the nine random sites carried out during an August 15-31 index period. The rationale for this schedule is described in Section 2.1.3.

2.1.5 Stream Benthic Macroinvertebrates

Importance: Stream benthic macroinvertebrates are an abundant, diverse, and ecologically important component of stream biological communities. Macroinvertebrates are also widely used to infer water quality because macroinvertebrate assemblages are sensitive to changing physical, chemical, and biological conditions over multiple spatial and temporal scales (Barbour et al. 1999, Karr and Chu 1999).

MOJN will report four key community metrics calculated from the BMI data: abundance, taxa richness, percent dominant taxon, and EPT taxa richness. Abundance (the total number of specimens in each sample), taxa richness (the total number of taxa observed in each sample, and percent dominant taxon (the percentage of the counted individuals in the most abundant taxon) are measures of the diversity of the BMI community in the streams. In general, the BMI communities in impaired streams are less diverse than those in less impacted streams. EPT taxa richness is the number of taxa of the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These insects are generally sensitive to ecosystem stressors, so the EPT taxa richness would be expected to decrease in response to any degradation of water quality.

Monitoring Method: BMI samples will be collected using US EPA EMAP protocols (Peck et al. 2006, Figure 2.2). The location of a reference point (the "x-site" in Figure 2.2) for each monitored stream has been randomly selected. Thereafter, 11 transects will be established as specified by US EPA EMAP protocols (Peck et al. 2006, Figure 2.2). BMI samples are taken at each transect and combined into a composite sample after a bottle sample has been collected.

Macroinvertebrate samples will be collected and preserved in the field. Samples will be processed to identify 600 randomly selected individuals to the lowest possible taxonomic level, usually species or genus. The data will be used to calculate several established measures of macroinvertebrate assemblage composition and structure for each stream.

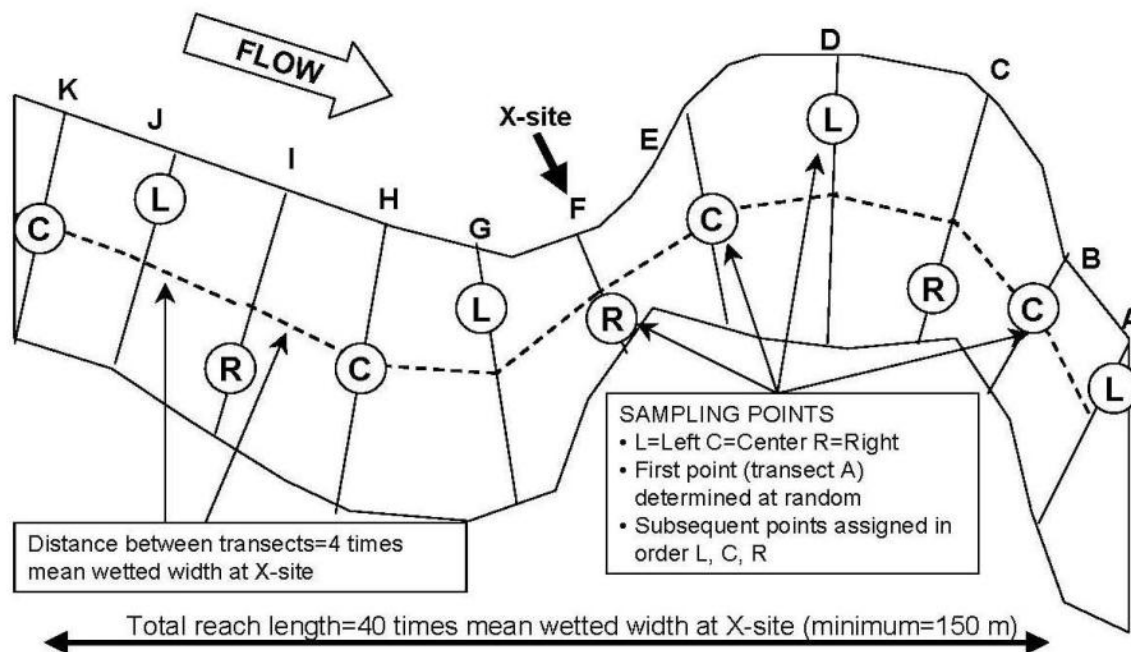


Figure 2.2. Basic layout of stream reach transects for macroinvertebrate sampling. From Peck et al. (2006).

Monitoring Locations: As described in Section 2.1.4, the target population for the BMI sampling the nine accessible perennial streams, with one randomly-selected site sampled on each of the nine accessible perennial streams. The co-location of the BMI sample, the water sample, and the discrete water quality measurement will allow the three resulting data sets to be combined in the assessment of stream health.

Monitoring Schedule: BMI samples will be collected during annual visits to the nine random sites carried out during an August 15-31 index period. The rationale for this schedule is described in Section 2.1.3.

2.1.6 Lake Water Clarity

Importance: Water clarity is a widely-used metric of lake status. In addition to its aesthetic value, clarity is also used as an indicator of trophic state (Carlson 1977). Clarity is included in virtually all lake monitoring programs, allowing data to be easily compared among lakes and to published standards.

Monitoring Method: Clarity is measured using a Secchi disk, a weighted disk of a standardized size with a standardized black and white pattern painted on it. The disk is lowered into the lake, and the depth at which it can no longer be seen is the Secchi depth. In GRBA's lakes, the disk has been visible on the lake bed each time Secchi depth has been measured, indicating that the lakes are too clear and too shallow for a Secchi depth measurement. Thus, the data will only detect changes in clarity once significant degradation has already occurred. However, clarity is not a great concern in GRBA lakes at this time, and Secchi depth can be measured easily and increases the comparability of the data with data from other monitoring programs.

Monitoring Location: The target population for the lake water clarity monitoring is all six of GRBA's lakes. The clarity measurement will be co-located with the water quality depth profiles and the water samples near the deepest point in each lake. Because the disk is generally visible on the lake bed, it is important to measure Secchi depth at the deepest point to increase the method's sensitivity to small changes in clarity.

Monitoring Schedule: Secchi depth will be measured annually in each of GRBA's lakes during a September 15-30 index period. The rationale for this schedule is described in Section 2.1.3.

2.2 Power Analyses

In statistics, power is the proportion of times that the null hypothesis is rejected in favor of the alternative hypothesis given that the alternative hypothesis is true. Power analyses are used to determine the statistical power of sampling scheme given natural variability. We have conducted preliminary power analyses using available data on discharge for GRBA streams. We will use the approach outlined below to test for trend in other parameters and assess power for those parameters once sufficient data are available (after five sampling events).

The target population for the power analysis was the two largest perennial streams at GRBA: Baker Creek and Lehman Creek. While these creeks were not randomly chosen and estimated trends from these data only represent the monitored creeks rather than a larger population, these creeks are both part of the target population for discharge monitoring.

2.2.1 Pilot Data

The pilot data consist of USGS discharge records for Baker and Lehman Creek in GRBA (Elliot et al. 2006) collected intermittently from 1947 to present (Table 2.2). These data were used to estimate the variance of the year-to-year random effect.

Table 2.2. Stream discharge data collection dates.

Stream	Data Collection Dates
Baker Creek	10/1/1947 to 9/30/1955, 10/1/1992 to 9/30/1997, 10/1/2002 to 9/30/2004
Lehman Creek	10/1/1947 to 9/30/1955, 10/1/1992 to 9/30/1997, 7/17/2002 to present

The power analyses examined trends in the three primary discharge parameters to be monitored: annual mean daily discharge, annual minimum daily discharge, and annual maximum daily discharge.

Profile plots of the pilot data are provided for Baker and Lehman Creeks from the time periods during the 1940s and 1950s (Figure 2.3) and from the past two decades (Figure 2.4). Annual variation dominates the mean and maximum discharge records, while lower frequency variation is more apparent for minimum discharge.

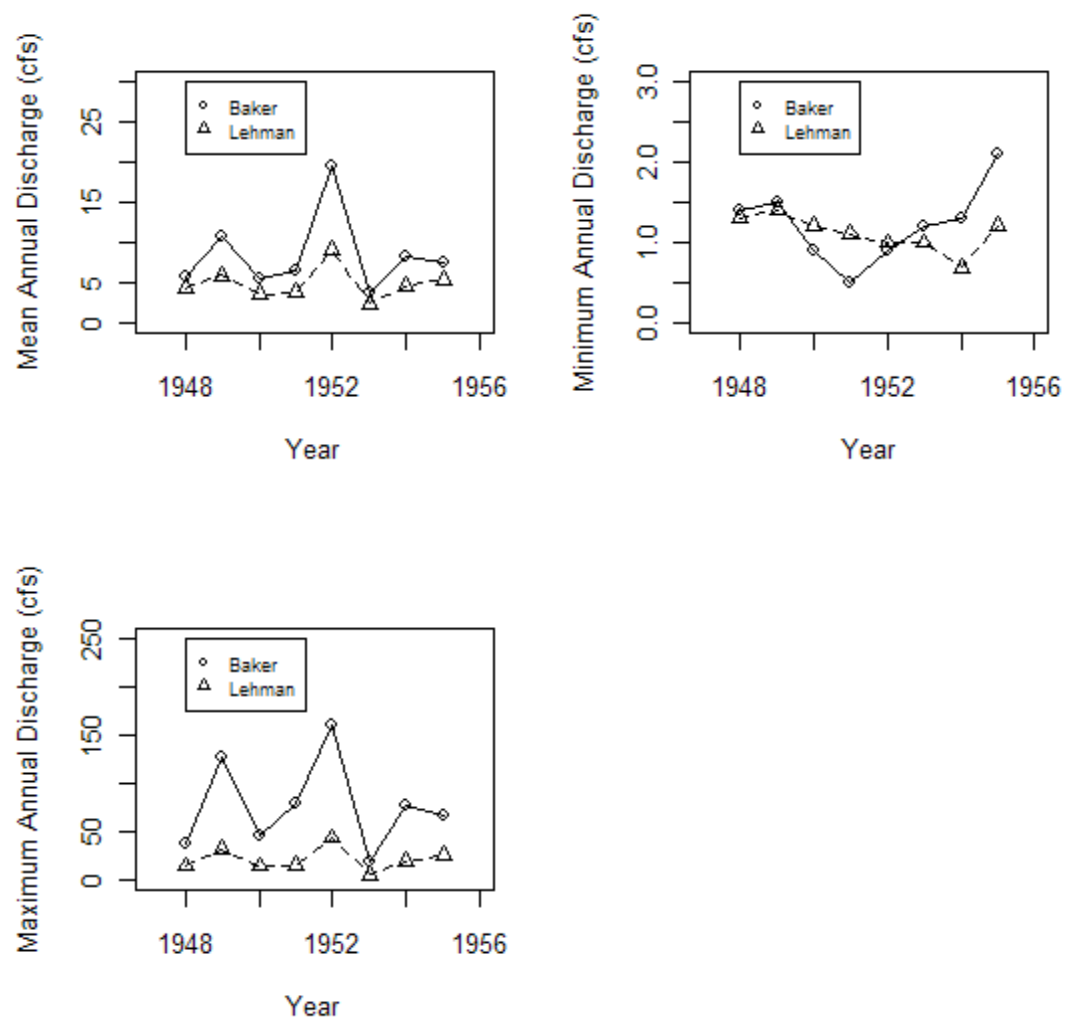


Figure 2.3. Early discharge statistics for Baker and Lehman Creeks (1947–1955).

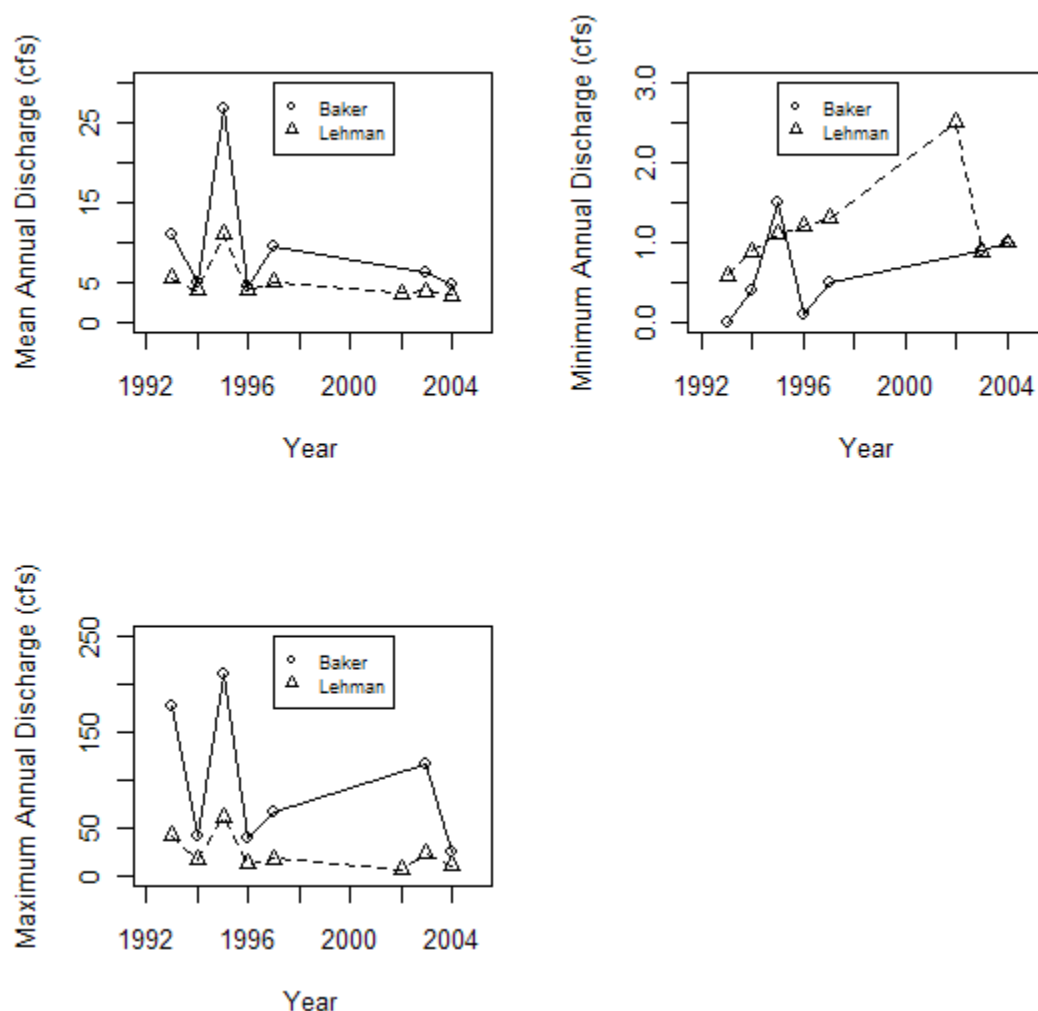


Figure 2.4. Recent discharge statistics for Baker and Lehman Creeks (1993–1997, 2003–2004).

2.2.2 Power Analyses Methods

The pilot data trend analysis used a model with two components: a fixed, underlying linear trend in stream discharge and a random year-to-year and stream-to-stream variation. More complex representations of the fixed and random components will be included in future analyses if they are required by the data.

The trend model is given by:

$$y_{ij} = \alpha_i + w_j \beta_i + e_{ij}$$

where y_{ij} is the stream discharge attribute (mean, daily maximum, or daily minimum) of creek i in calendar year j , w_j represents the number of years included in the trend analysis prior to calendar year j , α_i and β_i are the intercept and the rate of change related to the fixed linear

discharge trend for creek i , and e_{ij} is the random fluctuation in y_{ij} . In this case, no random effects will be included in the trend, and the trend analysis will involve simple linear regression of the outcomes. Two regressions were performed: one using all of the discharge data, and one using only the data collected since 1992. The regression with the data collected since 1992 had a higher estimated residual variance component (e_{ij}), so the exclusion of early data represents a more conservative approach.

Residual error and fixed effects were estimated from the pilot data in the statistical software package SAS and used in a power simulation written in the statistical software language R (R Core Development Team 2010) to compute the proportion of times the alternate hypothesis of significant trend was accurately accepted.

2.2.3 Results of Power Analyses

Figures 2.5 through 2.7 provide estimates of power as a function of the number of years surveyed. The power analyses indicated that the sampling design will provide reasonable power to detect trends in discharge parameters given a sufficient number of sampling years. Power varied depending on the parameter (mean, minimum or maximum mean annual discharge), spatial scale of sampling, assumptions about the size of the trend to be detected, and the number of years sampled.

Because the input data for the power to detect trend within Baker Creek or Lehman Creek differed only by the fixed effect of creek, the power to detect trend was identical for each analysis. The results of the power analyses for estimating the trend of stream discharge at Baker Creek or Lehman Creek (Figures 2.5-2.7) indicate that annual minimum daily discharge is the least variable outcome, and annual maximum daily discharge is the most variable outcome of the three indicators. Large trends (3% to 4% annual increases) in annual mean daily discharge within Baker or Lehman Creek may be detected with 80% power within 20 to 25 years of consecutive surveys, but smaller trends may take 30 or more years to detect at 80% power. The results of this power analysis indicate the need for consistent data collection in the long-term monitoring of streams in MOJN.

2.3 Strengths and Limitations of the Sample Design

The selected approach provides several benefits to MOJN I&M, park resource managers, and regional stakeholders. The design will provide long term data on status and trends in the measured parameters. The data will assist in the assessment of the effectiveness of management actions aimed at maintaining and improving water quality within GRBA park boundaries. The collection of lake hydrological and macroinvertebrate assemblage structure data over long periods using standardized and accepted protocols will provide a valuable record of responses to changes in human impacts and climatic conditions. The design will provide a representative picture of status and trend in GRBA streams and lakes. Reporting of regulatory status at GRBA and LAKE will provide summaries to park managers in trends in water quality as it is related to the CWA and will provide a summary estimate of conditions at LAKE (e.g., are waterbodies at LAKE being de-listed over time?)

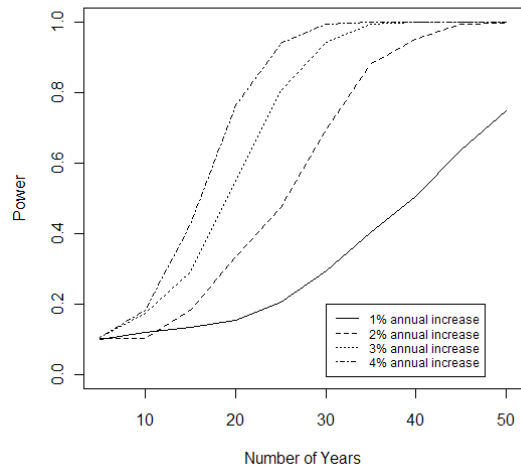


Figure 2.5. Power to detect trend in annual mean daily discharge in Baker Creek or Lehman Creek as a function of the number of survey years.

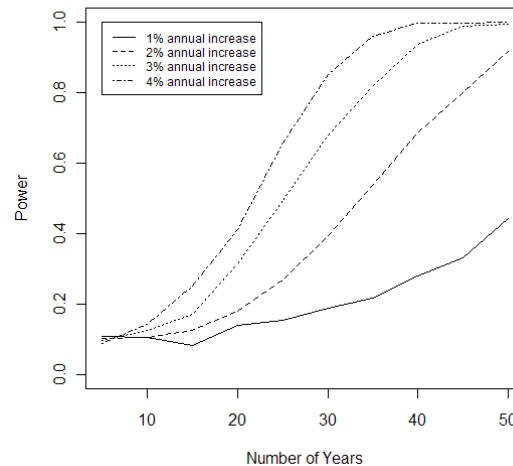


Figure 2.7. Power to detect trend in annual maximum daily discharge in Baker Creek or Lehman Creek as a function of the number of survey years.

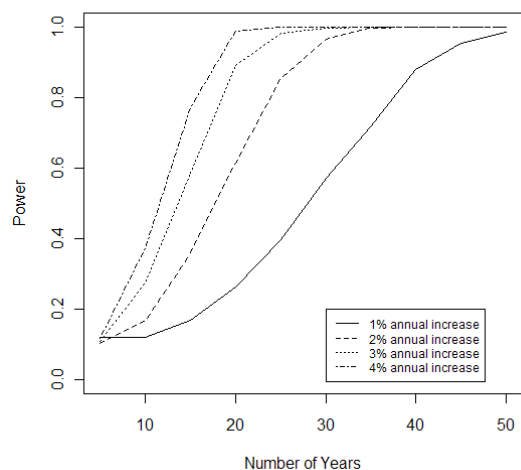


Figure 2.6. Power to detect trend in annual minimum daily discharge in Baker Creek or Lehman Creek as a function of the number of survey years.

One of the limitations of the sample design is that only a limited number of sites will be monitored. Only one location on each stream will be sampled for BMI and water chemistry. The first-order streams will not be monitored for discharge. Williams Creek will not be monitored. No direct monitoring will be conducted at LAKE.

Additionally, the parameters selected for monitoring were restricted in scope by available sampling resources. Many potentially informative important water quality parameters (mercury, bacteria, etc.) will not be estimated.

Perhaps the greatest limitation of the sample design is that many of the samples are collected annually, so the impacts of annual, diel, or other cyclical variations will not be known. These impacts are minimized by collecting samples in the same index period each year (e.g., August 15 to 31 between 10 AM and 2 PM). As discussed in Section 2.1.3, samples collected at two week intervals over the 2011 field season should clarify how the chemistry of GRBA streams and lakes changes over the course of the year. In addition, the stream discharge data, core water quality parameters in the streams, and temperatures and water depths in the lakes are collected continuously. These data can be examined to determine if cyclical variations in hydrologic processes are occurring that could impact the value of the annual samples.

Overall, the MOJN streams and lakes monitoring protocol should provide a well-documented baseline of background conditions given the modest level of funding available to conduct water quality monitoring. The status and trend data will allow the network to pursue additional funding and resources to address emerging issues through targeted research.

3.0 Field and Laboratory Methods

3.1 Standard Operating Procedures

The Standard Operating Procedures included in a companion volume to this narrative describe field collection methods in detail, including logistics, field sampling methods, QA/QC, and data analysis and reporting procedures (Table 3.1). In general, SOPs are organized by field activity and sampling trip. For example, field sampling for stream water chemistry and BMIs are combined into one SOP.

Table 3.1. Standard Operating Procedures (SOPs).

Title	Description
SOP 1: Safety	The Safety SOP provides safety information, checklists, and contact information for personnel who are involved with field activities. It covers general safety issues associated with field sampling and back-country travel.
SOP 2: Staff Training	This SOP describes the training requirements for the Streams and Lakes protocol. The MOJN I&M Hydrologist and GRBA Ecologist are responsible for providing training and ensuring the requirements are completed by all field staff.
SOP 3: Field Season Preparations	This SOP covers pre-season field preparations including hiring, training, equipment and trip preparations.
SOP 4: Post-season Activities	This SOP describes end-of-season protocols for cleaning, inventorying, and storing equipment. It discusses post-season debriefing of field crews.
SOP 5: Equipment Disinfection	Field equipment that contacts water or organisms must be disinfected between waterbodies. The purpose is to prevent the introduction and spread of non-native organisms.
SOP 6: Handheld Water Quality Instruments	This SOP describes the collection of discrete measurements of the four core water quality parameters using a handheld instrument.
SOP 7: Sample Handling, Storage, and Shipping	There are two types of samples collected under the Streams and Lakes protocol: water samples from streams and lakes and BMI samples from streams. This SOP describes how these samples should be handled, stored, and shipped.
SOP 8: Regulatory Status	Procedures for reviewing, updating and reporting the 303(d) status for LAKE and GRBA waters are described.
SOP 9: Stream Discharge	The SOP describes the methods for estimating stream discharge measurements of stream stage and discharge. It includes field procedures for the use of current meters and water level loggers.
SOP 10: Lakes Field Procedures	Methods for deploying and maintaining lake level/ temperature loggers, collecting water samples and depth profiles, and measuring water clarity are described.
SOP 11: Continuous Water Quality Sonde	This SOP describes maintenance, calibration, and operating procedures for the sondes. The sondes are used to continuously monitor specific conductance, water temperature, pH, and dissolved oxygen in the field. This SOP is based on the user manual supplied by YSI.

Table 3.1. Standard Operating Procedures (SOPs) (continued).

Title	Description
SOP 12: Stream Chemistry and BMI Sampling	Procedures for co-collection of stream water chemistry samples and benthic macroinvertebrates are described.
SOP 13: Laboratory Analysis of BMI	The protocol for enumeration and identification of benthic macroinvertebrates by a qualified taxonomy laboratory is detailed in this SOP.
SOP 14: Laboratory Analysis of Water Chemistry	This SOP describes the procedures for storing, handling, and shipping samples to a qualified laboratory for analysis. It also includes criteria for selecting laboratories including minimum MDLs.
SOP 15: Quality Assurance Project Plan	The Quality Assurance Project Plan (QAPP) describes quality assurance and quality control objectives and procedures related to data collection.
SOP 16: Cumulative Measurement Bias	This SOP describes the steps the network will take to avoid cumulative measurement bias.
SOP 17: Data Analysis and Reporting	Reporting requirements and details of data analysis, including statistical analyses, are described in this SOP.
SOP 18: Database Design	Design of databases for the protocol. There are a Master and Annual database set for the Streams data and for the Lakes data, in addition to a benthic macroinvertebrate database for original laboratory data, a geodatabase for geospatial data, and an image management database for photographs managed by Extensis software.
SOP 19: Information Management Workflow and Tasks	The information management workflow describes the numerous steps required to receive and process the data generated for the Streams and Lakes protocol.
SOP 20: Protocol Revision and Review	This SOP describes the procedures that will be followed when the protocol is revised.

3.2 Regulatory Status

There are three sources for information regarding the regulatory status of the waters in the MOJN parks: The EPA, the state of Arizona, and the state of Nevada. The EPA's water quality information portal is the Watershed Assessment, Tracking, and Environmental Results (WATERS) system. WATERS can be accessed at <http://www.epa.gov/waters/ir/index.html>. The current and historical 303(d) reports for Arizona and Nevada can be accessed from this site. However, this site only links to the final, EPA-approved reports, so it is necessary to review the reports on the state agencies' websites as well. The Arizona Department of Environmental Quality reports are available at <http://www.azdeq.gov/enviro/water/assessment/assess.html>. The Nevada Division of Environmental Protection reports are available at <http://ndep.nv.gov/bwqp/standard.htm>. The three websites should be reviewed annually at the time of report preparation.

The state of Nevada lists its Class A waters in the Nevada Administrative Code (NAC) 445A.124. These listings are not revised at regular intervals, and it is not anticipated that they will change. Therefore, an annual review of the list is appropriate. The NAC can be accessed at <http://www.leg.state.nv.us/nac/>.

SOP 8: Regulatory Status provides specific information on the background and history of regulatory status in the MOJN parks as well as guidelines for MOJN I&M Program reporting.

3.3 Permitting

GRBA personnel handle the majority of the field work for the sonde and discharge measurements, so any permission required for those activities can be handled internally. However, NPS research permits are required for water and BMI sample collection. Once these permits have been granted, Investigator Annual Reports (IARs) are due every year prior to March 31. It is crucial to the protocol that the proper channels be followed in dealing with these permits. As of 2010, permit applications and IARs can be submitted online at:

<https://science.nature.nps.gov/research>

For the Streams and Lakes protocol, compliance with permits will largely be a matter of handling the BMI samples correctly. These samples will remain GRBA property, but they will be on long term loan to the National Aquatic Monitoring (USU BugLab), a cooperative venture between Utah State University and the U.S. Bureau of Land Management. Archived samples are crucial to long term BMI monitoring efforts, as taxonomic identification can “drift” over time. GRBA, MOJN I&M, and the USU BugLab have agreed to this arrangement in principle. The record-keeping requirements related to this relationship will be in place by the end of 2011. The protocol lead will need to maintain contact with the GRBA staff member in charge of curation (currently the Cultural Resources Program Manager) to ensure that the network remains in compliance with the park’s requirements.

3.4 Before the Field Season

Key network and park staff should conduct an annual review of the protocol and SOPs prior to spring preparations. Review should include training and field procedures, data management, analysis, and reporting, as well as fundamental design issues.

Expendable supplies should be ordered well in advance of the field season to ensure their timely arrival. The required field equipment should be assembled, compared to a checklist (*SOP 3: Field Season Preparations*), and checked to ensure that it is in working order.

A full description of the tasks that must be completed prior to the beginning of the field season in June is included in *SOP 3: Field Season Preparations*.

3.5 After the Field Season

Following the June-to-September field season at GRBA, all equipment will be cleaned and stored as described in *SOP 4: Post-Season Activities*. Major equipment purchased by MOJN I&M (e.g., the YSI sondes) will be stored in MOJN I&M office between field seasons. Equipment owned by GRBA and all miscellaneous field supplies will be stored at GRBA. Electronic equipment, including; Global Positioning System (GPS) units, YSI sondes, and current meters should have the batteries removed during the winter months to prevent corrosion and leaking. Major equipment will be stored in hard plastic cases to prevent any damage.

At the end of each field season a list should be prepared detailing the amount of expendable supplies remaining and how much material should be ordered in the spring. To adequately prepare for the following sampling season, notes should be taken on where improvements to the

sampling protocol or data sheets can be made, records kept on the condition of each YSI sonde, and notes of any other problems or issues that occurred during the field season.

3.6 Site Access

Continuous water-quality and discharge will be measured at stream gages in the lower reaches of the four second-order streams. These sites are located relatively short distances from established roads. A map of the gages is given in *SOP 9: Stream Discharge*.

The stream chemistry and BMI samples will be collected at randomly selected sites (UTM coordinates given in *SOP 12: Stream Chemistry and BMI Sampling*). The accessibility of these sites varies, but most require backcountry navigation using a GPS. GRBA's backcountry safety protocols (*SOP 1: Safety*) should be followed at all times. It is anticipated that one or two samples could be collected in a day, depending on the location.

The three northern lakes are accessed using established trails from the Wheeler Peak trailhead, and can be sampled in a single day (Figure 1.5).

Baker Lake is accessed via a strenuous hike along an established trail from the Baker Creek trailhead (Figure 1.5). Due to the length of the hike, a long day (approximately 10 hours) should be planned.

Johnson Lake and Dead Lake are accessed via a strenuous hike along an established trail from the Shoshone trailhead (Figure 1.5). Due to the length of the hike, a long day (approximately 10 hours) should be planned.

3.7 Lake Level and Ice-cover

Lake level will be continuously monitored using water level loggers. Estimating lake level accurately will involve several steps. First, permanent benchmarks will be established on shore above the maximum lake level and near the deployment point. Second, the logger will be deployed at a point below the anticipated minimum lake level. Third, the elevation of the water surface relative to the benchmark will be measured using a line level at the time of each deployment.

Lake temperature will be recorded simultaneously with lake level. Seasonal temperature records will be used to reconstruct the timing of ice-out and ice-over. *SOP 10: Lakes Field Procedures* describes in detail the procedures for logger deployment, data collection, and logger retrieval.

3.8 Lake Water Quality: Vertical Profiles and Clarity

Vertical profiles of the four core water quality parameters (pH, dissolved oxygen, temperature, and specific conductance) will be measured using a handheld water quality instrument. This instrument will be calibrated according to the manufacturer's instructions using NIST-traceable standards. Measurements will be taken at several depths from a float tube near the deepest part of the lake. The method quality objectives (MQOs) for these measurements are given in Table 3.2. These values may change as personnel gain a better understanding of the performance of the instruments used to make the measurements.

Water clarity will be measured using a Secchi disk. Secchi disk depth is the average of the recorded descending reading at the point where the disk disappears from the view of an observer

and the ascending reading at the point when the disk reappears to the view of the observer. Three of these average measurements should be determined for a site during each visit and recorded on the appropriate data sheet. If the Secchi disk can be seen when resting on the bottom of the lake, then that fact is noted and the depth of the lake is recorded as the Secchi disk depth.

Table 3.2. Analytical methods and measurement quality objectives (MQOs) for parameters measured in the field.

Parameter	Instrument	Precision MQO	Bias MQO	Sensitivity MQO
		Field Stabilization Criteria	Field Calibration Check Tolerance	Alternative measurement sensitivity (AMS+) ¹
Field pH	Sonde or handheld instrument	0.1	0.1	0.1
Field Dissolved Oxygen (mg/L)	Sonde or handheld instrument	0.3 (3%, if saturation is measured)	0.3 (3%, if saturation is measured)	0.3 (3%, if saturation is measured)
Field Temperature (°C)	Sonde or handheld instrument	0.2	0.2	0.2
Field Specific Conductance (µs/cm)	Sonde or handheld instrument	5 µs/cm or 3%, whichever is greater	5 µs/cm or 3%, whichever is greater	5 µs/cm or 3%, whichever is greater

¹AMS+ is a measure of uncertainty (99% confidence interval) based on 7 in-situ measurements. AMS+ is described in detail in *SOP 15: Quality Assurance Project Plan*.

3.9 Lake Water Chemistry: Laboratory Analysis

Water samples will be collected from the lakes annually and analyzed by the Cooperative Chemical Analytical Laboratory (CCAL). CCAL is a cooperative laboratory operated by the College of Forestry at Oregon State University and the U.S. Department of Agriculture (USDA) Forest Service that specializes in high quality, trace level analysis of nutrients, ions, and physical properties of lake, stream, precipitation, and groundwater research samples. CCAL's quality assurance procedures include participation in the USGS Standard Reference Water Survey Program, an external interlaboratory QA Program, to monitor the accuracy of analytical procedures. Samples will be analyzed using the methods, method detection limits (MDLs), and minimum levels of quantitation (ML) presented in Table 3.3. All of the laboratory methods used are included in the supplementary materials.

The ANC of the samples will be measured by titrating the sample to pH 4.5 using 0.02 N (0.01 M) H₂SO₄. The total phosphorus and total dissolved phosphorus will be measured by using persulfate digestion to convert all phosphorus to orthophosphate, then using colorimetric analysis after a series of reagents have been added to determine the orthophosphorus concentration. Nitrate plus nitrite will be analyzed using the cadmium reduction method. After persulfate digestion, samples will be analyzed for total nitrogen and total dissolved nitrogen using the same method. Major cations (Ca²⁺, Na⁺, Mg²⁺, and K⁺) will be measured by flame atomic absorption spectrophotometry, and anions (Cl⁻ and SO₄²⁻) will be measured using ion chromatography.

3.10 Stream Discharge

Stream flow will be monitored using a combination of continuous stage recording devices and discrete discharge measurements following standard USGS techniques (Rantz et al., 1982). Stream gages are located at sites previously established by USGS and NPS staff (Elliott et al. 2006, Table 1.3). *SOP 9: Stream Discharge* provides guidance for technical training, including use of USGS On-Demand Web-Based Training for discharge estimates (<http://pubs.usgs.gov/fs/2007/3099/>).

3.11 Stream Water Chemistry: Core Parameters and Sonde Use

Core parameters will be measured continuously during the field season in the four second-order streams. Detailed information on how to locate and establish a sonde site is described in the *SOP 11: Continuous Water Quality Sonde*. In many cases, stream discharge is the primary control on water quality, so the sonde sites will be established in the immediate vicinity of the stream gages.

The USGS National Field Manual for the Collection of Water Quality Data (NFM) (USGS 2006) indicates that:

“In a small (usually less than 5 ft in width) and well-mixed stream, a single point at the centroid of flow may be used to represent the cross section.”

The small, fast-moving streams of GRBA are generally on the order of five feet wide, and are likely to be well-mixed. However, cross-section surveys will be conducted to ensure that the spatial variation of core water quality parameters is minimal. Given the size of the GRBA streams, one cross-section survey per monitoring site per sampling year will be sufficient to verify that the streams are well mixed. If cross-section variability is observed, or the variability appears to change with time, then more frequent surveys will be carried out.

Data will be downloaded to the YSI control unit each time the each time the sonde is visited. An initial data evaluation will be conducted to verify the accurate transfer of raw field data (sonde readings) to the database and to evaluate and identify erroneous data. The data record will be processed and plotted immediately after the service visit to confirm the accurate transfer of data and to detect instrument or sensor error.

3.12 Collection of Water Chemistry and Benthic Macroinvertebrate Samples

Field collection of bottle samples for water chemistry analysis and BMI samples will occur at sites established as described in Section 2.2.6 using EPA EMAP protocols (Peck et al. 2006). These sites have been chosen randomly, and will be permanently monumented if permits are received. After the establishment of the x-site and 11 transects, a bottle sample for water chemistry will be collected from the x-site prior to BMI sampling. Stream water chemistry samples will be processed using the same methods as lake water chemistry samples (Section 3.8).

Table 3.3. Analytical methods and measurement quality objectives (MQOs) for parameters measured in the laboratory.

Parameter	Method	Precision MQO	Bias MQOs		Sensitivity MQOs	
		Relative percent difference (RPD of duplicates) ¹	Blanks (field)	Measurement systematic error (% recovery) ²	Method detection limit (MDL) ³	Minimum level of quantitation (ML) ⁴
Laboratory pH	APHA 4500 H	+/-30%	na	90–110%	na	na
Laboratory Specific Conductance (µS/cm)	APHA 2510	+/-30%	na	90–110%	0.4	1.3
Acid Neutralization Capacity (µeq/L)	APHA 2320 with modifications ⁵	+/-30%	<MDL	90–110%	0.2	0.6
Chloride (mg/L)	APHA 4110 B	+/-30%	<MDL	90–110%	0.01	0.03
Sulfate (mg/L)	APHA 4110 B	+/-30%	<MDL	90–110%	0.02	0.06
Calcium (mg/L)	APHA 3111 D with modifications ⁵	+/-30%	<MDL	90–110%	0.06	0.019
Sodium (mg/L)	APHA 3111 B	+/-30%	<MDL	90–110%	0.01	0.03
Potassium (mg/L)	APHA 3111 B	+/-30%	<MDL	90–110%	0.03	0.10
Magnesium (mg/L)	APHA 3111 B	+/-30%	<MDL	90–110%	0.02	0.06
Nitrate+Nitrite (mg/L)		+/-30%			0.001	0.003
Total nitrogen (mg/L)	APHA 4500-NO3 F	+/-30%			0.010	0.032
Total dissolved nitrogen (mg/L)	APHA 4500-NO3 F	+/-30%	<MDL		0.010	0.032
Total phosphorus (mg/L)	APHA 4500-P B with modifications ⁵	+/-30%	<MDL		0.002	0.006
Total dissolved phosphorus (mg/L)	APHA 4500-P B with modifications ⁵	+/-30%	< MDL	90–110%	0.002	0.006
Dissolved organic carbon (mg/L)	APHA 5310 B	+/-30%	< MDL	90–110%	0.05	0.16

¹RPD is the relative percent difference between two measurements calculated as percent recovery: $RPD = (S_1 - S_2) / ((S_1 + S_2) / 2) \times 100$

Where S_1 is the larger test result value and S_2 is the smaller test result value.

²Measurement systematic error is set to 90–110% in the absence of any specific guidance for laboratory rejection criteria.

³Defined by National Environmental Methods Index (NEMI) as the lowest "measurable" concentration for an analyte by the specified method.

⁴The ML is generally the MDL multiplied by 3.18.

⁵Method modifications are described in *SOP 14: Laboratory Analysis of Water Chemistry*.

At each stream, a BMI sample will be collected using a 500 µm mesh D-net from each of the eleven cross-section transects (Transects “A” through “K”) at an assigned sampling point (Left, Center, or Right, Figure 2.2). After collecting each transect sample, the net contents will be transferred to a plastic bucket. After collecting kick net samples for all the reach-wide samples, the entire contents of the bucket is sieved and combined to create a single composite reach-wide sample for the site. Samples are then preserved in properly labeled jars filled with 95% ethanol (no headspace) so that the final concentration of ethanol is between 75 and 90%. The labeled composite samples will be stored in a container with absorbent material that is suitable for use with 95% ethanol until they are ready to be shipped to the laboratory (the USU BugLab). Ethanol is a hazardous material, so special steps must be taken to ship the samples. When a shipment of samples is ready, overnight shipping to the BugLab should be arranged. Immediately prior to sample pick-up, the ethanol should be replaced by water and the BugLab should be notified that the samples will be arriving in water so that the water can be replaced with ethanol in a timely manner. Additional details for field crews on how to collect samples is given in *SOP 12: Stream Chemistry and BMI Sampling*. Additional details on sample handling are given in *SOP 7: Sample Handling, Storage, and Shipping*.

3.13 Laboratory Analysis of Macroinvertebrate Samples

Identification of macroinvertebrates will be conducted by the USU BugLab. The sampling protocol currently specifies that the entire sample is enumerated and 600 randomly subsampled individuals are identified to lowest taxonomic level (genus for most insects). Identification to genus will be conducted for the Chironomidae, an important dipteran family with high species richness. The SOP includes detailed laboratory procedures, including subsampling methods and QA/QC criteria used by the taxonomy laboratory. *SOP 17: Data Analysis and Reporting* includes details on the indices to be calculated.

3.14 After the Field Season

Following the conclusion of the field season, most of the equipment will be stored in the GRBA headquarters. Non-electrical equipment, including nets, stakes, buckets, etc. should be stored in well-marked plastic bins. Some of this equipment may be used by other MOJN I&M protocols, so thorough organization and documentation of equipment will be important. Electronic equipment, including GPS units, should have the batteries removed during the winter months to prevent corrosion and leaking, and will be stored in plastic bins in the MOJN I&M office. The sondes will be stored at MOJN I&M headquarters in LAKE. Sondes will be cleaned and stored according to the manufacturer’s instructions in a hard plastic case to prevent any damage to the sondes. Post-season activities are summarized in *SOP 4: Post-Season Activities*.

4.0 Data Management

The following section was adapted and modified from Starkey et al. 2008 and Heard et al. 2008, as well as many other NPS network protocols that were used for guidance.

This section outlines procedures for water quality and quantity and macroinvertebrate data handling, analysis, and report development. Additional details and context for this section may be found in the MOJN Vital Signs Monitoring Plan (Chung-MacCoubrey et al. 2008), which also provides an overview of the network's data management and reporting plan. The specific procedure and details concerning data management are only briefly discussed in this section. Details and procedural steps are documented in the SOPs with the assumption that as the protocol is implemented and adjusted through its lifecycle, the SOPs will be continually updated while the narrative of the protocol can remain largely unchanged. This is particularly necessary for data management due to rapid changes in technology and data management solutions.

4.1 Project Information Management Overview

Effective data management of network protocols requires a comprehensive project information management strategy that is detailed and structured within an annual cycle, designed for refinement as needed, and is sustainable throughout the lifecycle of the protocol (Figure 4.1). Primary responsibility for the project information management resides with the Network Data Manager but is not effectively implemented without the assistance of network staff and cooperators. Detailed documentation of roles and responsibilities appears in MOJN Data and Information Management Plan (DM), *SOP Roles and Responsibilities* (Chung-MacCoubrey et al. 2008). A brief synopsis of each stage of the project management cycle follows (Siegel et al. 2007):

- *Preparation*: Training, logistics planning, printing forms and maps
- *Data acquisition*: Field trips to acquire data
- *Data entry & processing*: Data entry and uploads into the working copy of the database, GPS data processing.
- *Quality review*: Data are reviewed for quality and logical consistency
- *Metadata*: Documentation of the year's data collection and results of the quality review
- *Data certification*: Data are certified as complete for the period of record
- *Data delivery*: Certified data and metadata are delivered for archiving and uploaded to the master database
- *Data analysis*: Data are summarized and analyzed
- *Product development*: Reports, maps, and other products are developed
- *Product delivery*: Deliver reports and other products for posting and archive

- *Posting & distribution*: Distribute products as planned. Post to NPS clearinghouses as needed.
- *Archiving & records management*: Review analog and digital files for retention (or destruction) according to NPS Director's Order 19. Retained files are renamed and stored as needed
- *Season closeout*: Review and document needed improvements to project procedures or infrastructure, complete administrative reports, develop work plans for the coming season

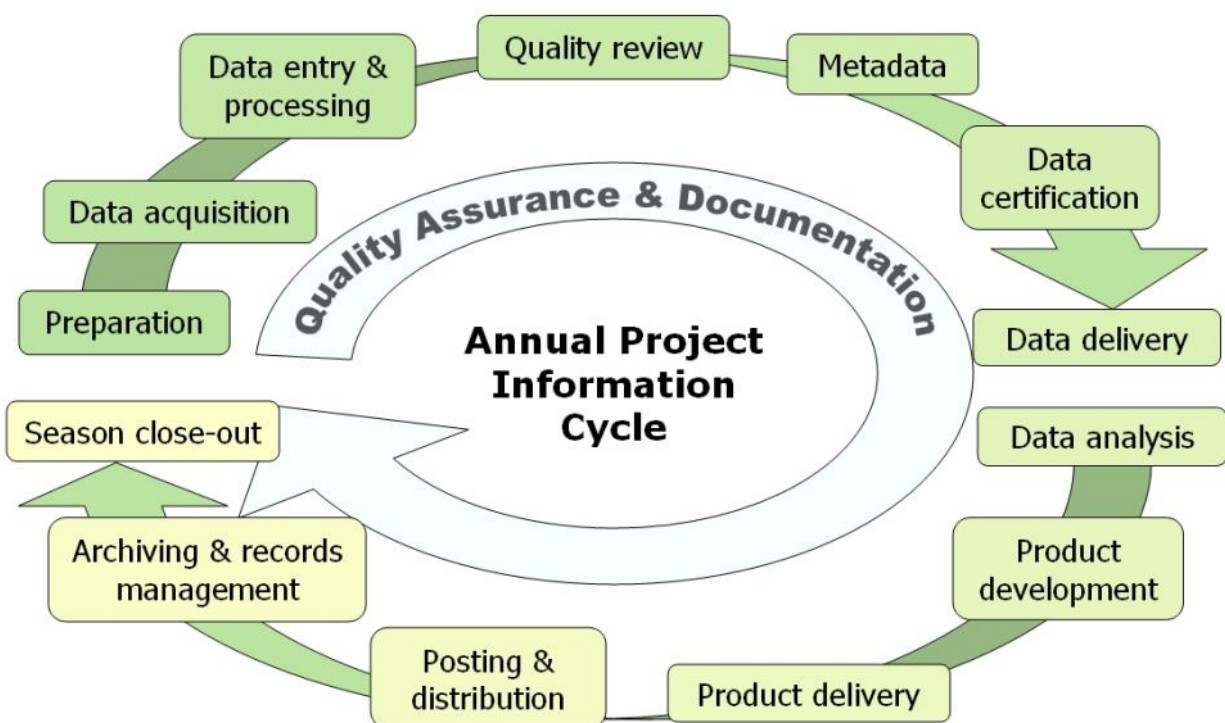


Figure 4.1. Scheme of managing project information on an annual cycle. Idealized flow schematic of the cyclical stages of project information management, from pre-season preparation to season close-out. Note: Quality assurance and documentation are thematic and not limited to any particular stage. Figure provided by North Coast and Cascades Network, J. Boetsch, Data Manager, pers. comm., 2010.

Central to project information management is an information management workflow or road map, schedule of tasks, and mechanisms or tools to manage the data, i.e. software and databases, within the structure of the Project Information Management Cycle (Figure 4.1). *SOP 19: Information Management Workflow and Tasks* presents an overall workflow of the streams and lakes data generated and managed for this protocol, and a list of detailed individual steps associated with the workflow. A list of tasks and associated schedule for project management is provided in *SOP 19: Information Management Workflow and Tasks*. The database architecture, tables, and attributes, and their features are provided in *SOP 18: Database Design*. An overview of the database management strategy is provided in the following section.

4.2 Overview of Database Design

Custom relational database management systems (DBMS) were implemented in Microsoft Access and are used to store, analyze, and report streams and lakes data. The structure and content of these databases is consistent with the standards presented in NPS I&M Natural Resource Database Template (NRDT) version 3.2 (NPS 2007). Separate DBMSs were designed for streams and lakes data. Each DBMS has a *working* database to facilitate annual data entry and quality control and assurance of field collected data and a *master* database for storing and retrieving multiple years of data. The DBMS strategy uses an empty version of the master database tables to create the working database. The working database also includes data entry forms (i.e. custom screens to input and display data) with rigorous quality controls, automated and manual functions (i.e. queries, visual basic scripts, etc.) for quality assurance reviews, summarizing the data, and generating annual report outputs. After all data in the working database have been validated and annual report elements have been generated, the data are migrated to the read-only master database. This strategy protects previously validated data from subsequent corruption, while still facilitating multi-year analyses and storage. Following the data extraction, the working databases are compressed and archived. Details of the database structures and forms, including a description of core and peripheral tables and a logical model of table relationships, are presented in *SOP 18: Database Design*. Throughout the life cycle of the monitoring protocol, all databases will undergo annual revisions to keep pace with changes in the protocol as well as changes in software and potential upgrades to new DBMS, e.g. migrating to Microsoft SQL Server. These changes will be reflected in both this protocol narrative and *SOP 18: Database Design*.

4.3 Preparation

Network protocols require a mix of applications, documents, equipment, and general field preparations before the field season is initiated. The master and working database tables may require updating if there are changes in the protocol from the previous season. Because the working database data entry forms are designed to closely resemble the field datasheets, any changes to either the protocol or the field datasheets may also require an update to the data entry forms. SOPs must be updated as needed, especially those related to field procedures that may be in response to lessons learned from the previous year's data quality review processes. Preparation for the upcoming year is an ongoing process during the previous year as the needs for changes or adjustments to the information and DBMS emerge.

4.4 Data Acquisition

The MOJN Streams and Lakes protocol integrates many different monitoring activities into a single protocol, resulting in several different types of data sources that are collected via differing methods, formats, and temporal intervals. The following list summarizes the data types for stream and lake features:

Streams:

- Continuous and discrete water quality parameter measurements
- Continuous water level
- Flow measurements

- BMI data
- Water chemistry analytical results
- GPS coordinates of sites
- Photographs

Lakes:

- Continuous water level
- Secchi depth measurements
- Core parameter depth profiles
- Water chemistry analytical results
- GPS coordinates of sites
- Photographs

Discrete water quality data, water level data, and temperature data will be uploaded to the working databases promptly after retrieval and reviewed for outliers and erroneous data. Continuous data logger sources will be uploaded to proprietary software packages promptly after retrieval to check for outliers and erroneous data. Water chemistry and macroinvertebrate identification data will be obtained from a private contractor and will be uploaded digitally if possible when submitted from the laboratory to MOJN I&M. GPS and camera images will be downloaded periodically throughout the season to the appropriate receiving folders on the network. If the data are not provided in a format that lends itself to a digital upload, then MOJN I&M staff will enter all information into the database. Other information will be entered into the working database by MOJN I&M staff from either hard copy or electronic field sheets.

4.5 Data Entry

Discrete field data collection from site visits, water quality metadata, image metadata, and laboratory sample data results are just a few examples of the data that require manual data entry procedures associated with this protocol. The data entry procedures are designed so that the data entry forms, i.e. screens, are similar in appearance to the field datasheets to ease the transcription of the data from hard copy to digital format, and to facilitate efficient quality assurance review of the data entry.

4.6 Quality Review

There are two stages of quality review associated with data acquisition. The first stage is a quality assurance review of the data entry, which follow the guidelines presented by the NPS National Data Management Plan (2008) and is detailed in Table 4.1.

Table 4.1. Data Management Quality review process for data entry.

Review Process Step	Responsibility
1. Review field datasheets for omissions or obvious errors	GRBA field crew
2. Post data entry, review 100% of the data entry values with field data sheets for errors and omissions	Data-entry technician
3. Prior to Protocol Lead validation, cross check a minimum of 10% of the data entry values with the field data sheets	Protocol Lead.
4. Prior to Protocol Lead validation, cross-reference sample events (sites and samples dates) with field datasheets to ensure all field datasheets are entered; verify sample events list with Protocol Lead	Data Manager and Protocol Lead implement and resolve discrepancies
5. Certify data	Data Manager and Protocol Lead

After Stage 1, the data must be certified by the Protocol Lead for quality, completeness, and logical consistency using a two-step process. Pre-designed queries facilitate an automated process to check for data integrity, data outliers, missing values, illogical values, and inconsistencies between related fields or tables. A report of errors is generated and the Protocol Lead may then fix these problems and document the edits. If all errors and inconsistencies cannot be fixed, the issues will be documented and included in the metadata. Once the validation is complete, the Protocol Lead must mark the data as certified in the working database. Additional quality reviews are conducted with proprietary software used to process and analyze streams and lakes water quality and water quantity data. Data correction procedures are documented by the software and archived as outlined below in the Section 4.13 Archiving and Records Management. Finally, all data are subject to the Quality Assurance Project Plan, detailed in *SOP 15: Quality Assurance Project Plan*.

Water quality data submitted to NPS WRD will also experience a final review prior to upload to EPA STORET (Figure 4.2). MOJN I&M will document data corrections, adjustments, and errors as reported from NPS WRD, data will be corrected in MOJN I&M's databases, and resubmitted to NPS WRD.

4.7 Metadata

Data documentation is a critical step toward ensuring that both spatial and non-spatial datasets are useable for their intended purposes well into the future. This involves the development of metadata, which can be defined as structured information about the content, quality, and condition of data. Additionally, metadata provides the means to catalog datasets within intranet and internet systems, making data available to a broad range of potential users. Metadata for all MOJN I&M monitoring data will conform to Federal Geographic Data Committee (FGDC) and NPS guidelines. FGDC is a federal interagency committee that “promotes the coordinated development, use, sharing, and dissemination of geospatial data on a national basis” and establishes standards for federal metadata prior to data dissemination.

For long-term projects such as this one, metadata creation is most time consuming the first time it is developed; after which most information remains static from one year to the next. Metadata records in subsequent years then only need to be updated to reflect current publications, references, taxonomic conventions, contact information, data disposition and quality, and to describe any changes in collection methods, analysis approaches or quality assurance for the project.

MOJN will also provide metadata for all measured water quality parameters that will meet the standards of EPA STORET. The Protocol Lead and the Data Manager will work together to create and update an FGDC- and NPS-compliant metadata record. The Protocol Lead should update the metadata content as changes to the protocol are made, and each year as additional data are accumulated. Edits within the document should be tracked so that any changes are obvious to those who will use it to update the metadata file. At the conclusion of the field season, the Protocol Lead will be responsible for providing a completed, up-to-date metadata interview form to the Data Manager. The Data Manager will facilitate metadata development by creating and parsing metadata records, and by posting such records to national clearinghouses as described below.

4.8 Sensitive Information

Part of metadata development includes determining whether or not the data include any sensitive information, which includes specific locations of rare, threatened, or endangered species. Prior to completing metadata, the Protocol Lead and Park Resource Manager should work together to identify any sensitive information in the data. Their findings should be documented and communicated to the Data Manager. We do not anticipate that sensitive information will be present in the water quality monitoring program at this time.

4.9 Data Certification

Data certification is a benchmark in the project information management process that indicates that 1) the data are complete for the period of record; 2) they have undergone and passed the quality assurance checks; and 3) that they are appropriately documented and in a condition for archiving, posting, and distribution. Certification is not intended to imply that the data are completely free of errors or inconsistencies which may not have been detected during quality assurance reviews. To ensure that only data of the highest possible quality are included in reports and other project deliverables, the data certification step is an annual requirement for all tabular and spatial data. The Protocol Lead is primarily responsible for completing certification with the assistance of the Data Manager..

4.10 Data Delivery

After the data are certified by the Protocol Lead, the Data Manager will transfer all data from the annual working database to the master database and deliver the data to the Protocol Lead for analyses and product development.

4.11 Data Analyses and Product Development and Delivery

Protocol Lead is responsible for data analyses, product development, and delivery of the products to the Data Manager. Analyses and products are discussed in Section 5, Data Analysis and Reporting. Reports and delivery schedules are detailed in *SOP 17: Data Analysis and*

Reporting. All documents associated with analyses and products are delivered to the Data Manager for posting and distribution.

4.12 Posting and Distribution

Data and reports are posted on the MOJN I&M SharePoint site, NPS intranet, NPS internet, and the national web-accessible secure databases supported by the NPS Washington State Office (WASO) or National I&M Program. These include:

4.12.1 Integrated Resource Management Applications

This portal is a gateway to NPS natural resource data and information available at <https://irma.nps.gov/App/Portal>.

4.12.2 WRD STORET

WRD STORET is a centralized data repository developed and maintained by NPS as a database to house ambient water quality data collected by networks. Networks may use NPSTORET or NPSEDD to transfer data for upload into WRD STORET prior to upload to EPA STORET.

4.12.3 STORET

STORET is a centralized data repository developed and maintained by EPA as a database to house ambient water quality data collected by states, federal agencies, volunteer monitoring groups, and other entities.

The water quality component of the Natural Resource Challenge (NRC) requires that networks archive all physical, chemical, and biological water quality data collected with NRC water quality funds in the National Park Service's STORET database maintained by the NPS WRD. All water quality data collected by MOJN I&M will be managed according to guidelines from the NPS WRD. This includes facilitating the transfer of park and network water quality into suitable STORET format, as requested by WRD. MOJN I&M data management staff will transfer all network water quality data, in an STORET-compatible format, at least annually to WRD for upload to the STORET database (Figure 4.2).

4.13 Archiving and Records Management

Upon certification by the Protocol Lead, digital and non-digital data will be archived. ASCII comma-delimited text fields are created for each data table within a database, and for all datasets derived from electronic data collection devices. These files are accompanied by a data dictionary that explains the contents of each file, file relationship and field definitions. *SOP 19: Information Management Workflow and Tasks* includes a detailed list of the data-related files that will be archived. Master databases and annual project deliverables and reports will be archived on the MOJN Network Attached Storage (NAS) unit which is maintained and subject to NPS Lake Mead National Recreation Area IT department back-up procedures.

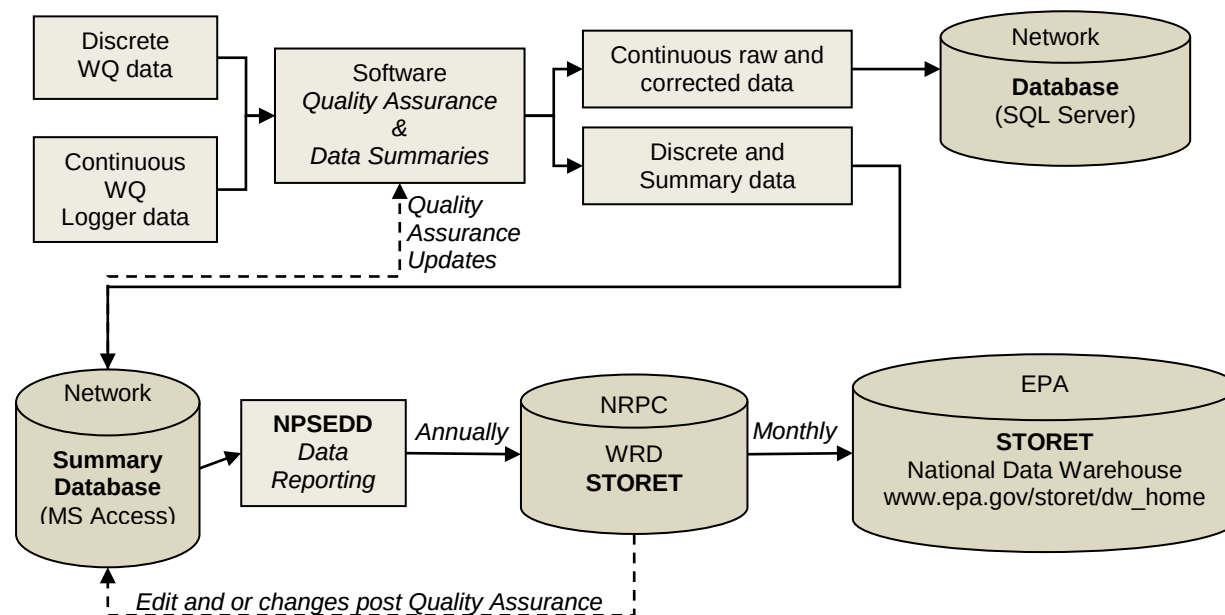


Figure 4.2. Data flow diagram for water quality data.

4.14 Season Closeout

A review of archive and expendable data products will be undertaken by the Protocol Lead and Data Manager during an annual close-out session to ensure that all data, metadata, and documents are properly organized, archived, and disseminated to the appropriate locations. Decisions on what to retain and what to destroy should be made following guidelines stipulated in NPS Director's Order 19 (NPS 2001). An example of an expendable data product is an intermediate draft of an annual report that was saved during report preparation and may be discarded once the final report is generated.

5.0 Data Analysis and Reporting

Data analysis approaches were developed in concert with sample design development and power analysis simulations. The protocol lead is responsible for performing the data analyses including descriptive statistics and statistical tests of trend through time (Table 5.1). *SOP 17: Data Analysis and Reporting* provides a detailed description of the procedures described here.

5.1 Quality Assurance/Quality Control

SOP 15: Quality Assurance Project Plan (QAPP) is the written record of the QA/QC program. *Quality assurance (QA)* refers to the overall *management system* which includes the organization, planning, data collection, quality control, documentation, evaluation, and reporting activities of the group. QA provides the information needed to ascertain the quality of data and whether it meets the requirements of the program. QA ensures that data will meet defined standards of quality with a stated level of confidence. *Quality control (QC)* refers to the routine *technical activities* whose purpose is, essentially, error control. The procedures carried out specifically for QA/QC purposes are fully described in the QAPP. The key procedures for each data type are given in Table 5.1.

Table 5.1. Key QA/QC procedures.

Data Type	Key QA/QC Procedures
Continuous and discrete water quality data	Annual cross-section surveys Annual alternative measurement sensitivity plus (AMS+) measurements Calibration and calibration checks.
Continuous stream discharge	Training field staff using standard USGS methodology Annual comparison of measurements between observers Review of rating curve each year following peak runoff
Benthic macroinvertebrates	Extensive set of procedures followed by USU BugLab
Water chemistry	Extensive set of procedures followed by CCAL Check that dissolved concentrations are $\leq$ total concentrations Submittal of duplicate samples to laboratory
Secchi depth	Use of standard disk and standard protocols
Continuous lake level monitoring	Review of data for instrument drift or battery-related problems
Continuous lake temperature monitoring	Review of data for battery-related problems

5.2 Data Processing

Some of the measurements made in this protocol require processing before they can be interpreted. While some processing is needed for nearly all of the data types collected (Table 5.2), continuous records of water quality parameters, stream discharge, lake level, and lake temperature require computationally-intensive processing. MOJN I&M will use Aquarius, a specialized software package for the analysis of hydrologic data, to process these records. Many of the data processing steps can be performed at the end of the field season. However, the continuous water quality records, which are downloaded several times during the field season, should be reviewed as soon as possible so that any problems can be remedied quickly.

Table 5.2. Annual data analysis procedures.

Data Type	Processing	Outputs for Annual Report
Continuous Stream Discharge	Stream gaging calculations (spreadsheet)	Graphs of daily mean and flow-duration plots for each 2 nd -order stream
	Data splicing, rating curve development, conversion to discharge (Aquarius software package)	Table of monthly mean, min, max for each 2 nd -order stream
Continuous Water Quality Data	Data-flagging, splicing, and drift correction (Aquarius software package)	Graphs of daily mean for all four parameters in each 2 nd -order stream
		Table of monthly mean, min, max for each parameter in each 2 nd -order stream
Benthic Macroinvertebrates	USU BugLab calculates four basic indices	Table of indices in all streams over time
Discrete Water Chemistry, Water Quality, and Secchi Depth	Convert ANC to meq/L	Table of all parameters in all streams over time
	Compute arithmetic mean of Secchi depth measurements	Comparison to regulatory standards when applicable
Continuous Lake Level Monitoring	Data-flagging, splicing, drift correction, and comparison to benchmark (Aquarius software package)	Graph of lake level for each lake
		Table of minimum, maximum, and late-season mean lake level for each lake
Continuous Lake Temperature Monitoring	Determination of ice-over and ice-out dates based on temperature and lake level data	Graph of lake temperature for each lake
		Table of ice-over date, ice-out date, and duration of ice-free period for each lake

5.2.1 Preliminary Data Analysis

The data analyses in Table 5.2 are necessary to generate the outputs for the annual report. However, it is expected that the protocol lead will perform many additional analyses to assess whether any conclusions can be drawn from the available data that would be of interest from a park management, scientific, or monitoring design perspective. Any such conclusions should be included in the annual report. The following steps are examples of the types of analyses that will

be performed by the protocol lead. A large suite of statistical parameters (for example, mean, standard error, median, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum, maximum, sum, and t-distribution confidence interval) should be calculated for continuous water quality data. The protocol lead should then inspect these parameters and determine whether any of them have changed significantly over time or differ more than expected between streams. Box-and-whisker plots may be useful in identifying outliers, both those that are true representations of the conditions of the vital sign and those caused by measurement errors.

All continuous data will be reviewed for evidence of step trends. Such changes may reflect instrument problems, but they may also be symptomatic of major changes in the watershed. Hirsch et al. (1991) emphasize that a formal analysis of the statistical significance of a step trend should not be undertaken unless the time of the change can be established from other lines of evidence. Irwin (2008) suggests that the significance of an apparent step trend can be tested as part of the data exploration process whether the cause of the step is known or not. If a major step trend is observed in the data, then park staff should be queried regarding possible causes.

After several years of continuous data have been collected, then the protocol lead will be able to identify large changes in the seasonal patterns of continuous data. If the cause of the change cannot be identified, then the change from the usual pattern should be mentioned in the annual report.

Extreme events such as floods and droughts will be easily identifiable from the discharge data. In the event of a very wet year and a very dry year, the protocol lead will discuss how each component of the monitoring system responded to the unusual conditions. Formally documenting these responses in the annual report will help future workers understand the kinds of responses that may be seen in response to long term changes in precipitation.

5.3 Trend Analysis

The data collected for the Streams and Lakes protocol will be plotted and reported annually, but there will be insufficient data for formal statistical analysis for some time. The USGS recommends that “The period of record for stations included in a trend study should be at least five years for monthly data or longer for less dense data” (Schertz et al. 1991). Trends that impact all of the streams or all of the lakes will be detectable more rapidly than trends that impact a single station. However, it will be several years before the data can be analyzed for trends using statistical methods. Trend analyses will be performed every four years once there is a minimum of five years of data, but it is expected that only the strongest trends will be detectable in the first several reports. Even if trends are detected in the first two or three reports, it may not be clear whether they are due to natural variability for some time. Trend reports may be completed more frequently if requested by NPS resource managers.

5.3.1 Visual Assessment

The first step in trend analysis is to plot the data that will be analyzed and look for apparent trends. If the data is highly variable, then a smoothed line generated using an algorithm such as LOWESS (Helsel and Hirsch 2002). While trends observed in the visual assessment step may not be statistically significant, they can provide an overview of how a parameter has changed over time. For example, if the smoothed trend lines hint that a trend has been up for 10 years and

then down for 10 years, a typical monotonic trend test might conclude “no trend” (Manly, 2001). This conclusion might be less helpful to a resource manager than a conclusion that might be had by looking at a simple plot of values vs. time.

5.3.2 Parametric vs. Non-Parametric Trend Testing

There are two general types of trend analyses that will be performed on the MOJN Streams and Lakes protocol data (Table 5.3): mixed-model parametric trend-testing and non-parametric trend testing using various Kendall tests.

The mixed-model parametric trend tests used in the Power Analysis section (Section 2.3) assume that the observed data are the sum of a linear trend and normally-distributed residuals, and use *t*-testing to evaluate the significance of the trends. Kendall-type tests assume that the data values are monotonically increasing or decreasing, but not necessarily in a linear manner, and make no assumptions regarding the distribution of the residuals.

A USGS study (Hirsch et al. 1991) compared the power of parametric and non-parametric analyses on simulated water quality data, and found that parametric trend tests were slightly more powerful than non-parametric trend tests for normally-distributed data, but much less powerful for data where the assumption of normality was not justified. The study concluded that:

“In light of these kind of results, which show that the non-parametric procedures suffer only small disadvantages (in terms of efficiency or power) in the normal case, potentially modest advantages when the data depart slightly (perhaps imperceptibly) from normality, and large advantages when they depart a great deal from normality...: we have chosen to apply non-parametric procedures routinely in studies involving multiple data sets.”

Water quality data are not generally normally-distributed, and transforming them to a normal distribution may be difficult due to the large number of extreme values (Hirsch et al. 1991). However, some measures of water quantity are less likely to vary over orders of magnitude than water quality data, and the power analyses of historical data (Section 2.3) indicate that discharge records in GRBA streams are at least somewhat amenable to parametric trend testing. In addition, the early detection of trends in discharge due to potential future groundwater withdrawals is a high priority for the Streams and Lakes protocol. Therefore, both parametric and non-parametric tests will be used to test the stream discharge data for trends (Table 5.3). This is in accordance with the recommendations of Irwin (2008), who emphasizes the importance of multiple lines of evidence in statistical inference.

5.3.3 Trend-Testing Methods

Parametric testing will be conducted using the mixed model described in Section 2.3 (VanLeeuwen et al. 1996, Piepho and Ogutu 2002). A mixed model allows some effects to be considered fixed and some to be considered random. Fixed effects contribute to the mean of the outcome and random effects contribute to the variance. Random effects are used to estimate variation of linear trends among subjects (e.g., streams) and over time. Piepho and Ogutu (2002) improve the estimator proposed by VanLeeuwen et al. (1996) by modeling the site effect as fixed or random. A random site effect may be modeled as correlated with the random slope for each site. The ability to modify the assumptions provides additional benefits of trend test invariance

and model flexibility. The mixed model will be implemented using an R script written by MOJN I&M's statistical consultant.

Table 5.3. Trend analysis procedures.

Data Type	Measureable Objective (Section 1.3.2)	Trend Analysis Method
Continuous Stream Discharge	What are the long term trends in the quantity and seasonal patterns of stream discharge?	Parametric (mixed-model) trend testing for annual maximum, minimum, and mean discharge for each stream and across all 2 nd -order streams Seasonal Kendall Test (SKT) for discharge in each stream and across all 2 nd -order streams Mann-Kendall Test (MKT) for date of peak discharge and mean late season discharge
Continuous Water Quality Data	What is the status and what are the trends in stream water chemistry parameters?	SKT for all parameters, for each stream and across all 2 nd -order streams MKT for all parameters in late June and early September index periods, for each stream and across all 2 nd -order streams
Benthic Macroinvertebrates	What is the status and what are the trends in stream macroinvertebrate assemblages?	MKT of basic indices, for each stream and across all streams
Discrete Lake Water Chemistry, Water Quality, and Secchi Depth	What is the status and what are the trends in lake water chemistry?	MKT for all parameters, for each stream or lake and across all streams or lakes
Continuous Lake Level Monitoring	In subalpine lakes, are water levels changing over time?	MKT for minimum and maximum lake level and SKT for lake level record, for each lake and across all lakes
Lake Ice-Free Period	In subalpine lakes, are the ice-free periods changing over time?	MKT for ice-over date, ice-out date, and duration of ice-free period, for each lake and across all lakes

The Mann Kendall Test (MKT) is a statistical method used to assess trends in data sets. The advantages of this test are that it is widely-used, non-parametric, and applicable to any type of monotonic trend (i.e., not just linear changes). MKT will be used for all of the parameters that are measured on an annual basis. In addition, Regional Kendall Testing (Helsel and Frans 2006) will be used to assess the trends in these parameters across all streams or all lakes.

The Seasonal Kendall Test (SKT) is used to detect trends in seasonally-variable data (e.g., Hirsch et al. 1982). The data are binned into seasons by the user, and MKT is performed for each season. The results from all seasons are then combined into a single test. Refinements to the SKT are corrections for serial correlation if 10 or more years of data are available (Hirsch and Slack 1984) and modifications to allow data from multiple sampling locations to be combined into a single test of regional trend (Helsel and Frans 2006). The SKT will be used to analyze trends in continuously-collected records of stream discharge, lake level, and water quality, both for each stream or lake and across all streams or lakes.

The statistical analyses using MKT, Regional Kendall Testing, and SKT will be conducted using *kendall.exe*, a software program available from the USGS (Helsel et al. 2006).

More details on the implementation of these methods are given in *SOP 17: Data Analysis and Reporting*.

5.3.4 Trends in Stream Discharge

The objectives of the protocol include detecting changes in both the amount of discharge and the patterns of discharge. Therefore, several different trend analyses will be performed.

Discharge in the second-order streams at GRBA is characterized by a great deal of seasonal variability (Figure 1.7). Broadly speaking, the streamflow is maintained at a relatively invariant level by groundwater, soil water, and precipitation events during the baseflow period (winter and early spring) and then rises to flood stage during the runoff period (late spring and early summer) when it is fed by snowmelt. In the late summer and early fall, discharge is a mixture of runoff and baseflow. The streams are “gaining” streams (receiving water from the surrounding alluvium) during the baseflow period and “losing” streams (recharging the surrounding alluvium) during the runoff period (Elliot et al. 2006), so the amount of discharge during the runoff period affects the amount of baseflow. In general, however, changes in precipitation patterns are likely to affect the discharge during the runoff period, while the potential effects of groundwater withdrawal would be seen during the baseflow period.

Overall trends in the amount of discharge will be tested using both a parametric and non-parametric tests: a mixed-model trend test for annual mean discharge and SKT analysis of discharge across all seasons. These tests will be carried out for each monitored stream and across all 2nd-order streams.

Changes in the pattern of discharge will be detected by analyzing trends in runoff and baseflow. Changes in runoff will be analyzed by mixed model testing of trends in maximum annual flow and MKT and Regional Kendall Test analysis of trends in the date of peak discharge. Changes in baseflow will be analyzed by mixed model testing of trends in minimum annual flow and MKT and Regional Kendall Test analysis of trends in late season (winter) discharge. These tests will be carried out for each monitored stream and across all 2nd-order streams. The possibility of serial correlation will be considered before trend analyses are performed.

5.3.5 Trends in Continuous Water Quality Data for Streams

The continuous water quality monitoring component of the protocol is intended to determine the status and trend of water quality in streams. Water quality varies seasonally, and can respond strongly to individual precipitation events. In pristine areas, the key driver of water quality is

discharge, so trends in the amount and patterns of streamflow (discussed in the previous section) would likely affect water quality. However, the water quality sondes are only deployed from after peak runoff until very early in the fall, so the water quality of baseflow cannot be directly measured.

SKT will be used to detect trends in each of the four core water quality parameters. In addition, MKT and Regional Kendall Testing will be used to test for trends in two index periods meant to represent runoff (the second half of June) and baseflow (the first half of September). These tests will be carried out for each monitored stream and across all 2nd-order streams. The possibility of serial correlation will be considered before trend analyses are performed.

5.3.6 Trends in Stream Water Chemistry and BMI Metrics

Stream water chemistry and BMI are sampled on an annual basis during a late-summer index period to determine the status and trends in stream water quality and stream macro-invertebrate assemblages. MKT and Regional Kendall Testing will be used to test for trends in the chemistry results and in the four reported BMI indices (Section 2.1.5). As these samples are collected once a year, no effort will be made correct concentrations for the effect of discharge.

5.3.7 Trends in Lake Level

One of the protocol's objectives is to determine whether lake levels are changing over time. Lake levels are highest during the early summer snowmelt runoff period, when they can oscillate in response to pulses of meltwater created by changes in the weather. Lake levels decline throughout the summer, and are lowest during the winter, when the lakes are frozen.

MKT and Regional Kendall Testing will be used to analyze trends in minimum and maximum water levels. SKT will be used to analyze the entire annual lake level record. These analyses will be performed for each lake and across all lakes.

5.3.8 Trends in Lake Ice-Free Season

One of the protocol's objectives is to determine whether the ice-free period is changing over time. Both the length of the ice-free period and its timing are important, as changes in ice-free dates can affect the timing of nutrient pulses, upsetting aquatic food webs (Winder and Schindler 2004). MKT and Regional Kendall Tests will be used to test trends in ice-over date, ice-free date, and length of ice free period.

5.3.9 Trends in Lake Water Chemistry and Clarity

Lake water chemistry and clarity are sampled on an annual basis to determine the status and trends in lake water chemistry. MKT and Regional Kendall Testing will be used to test for trends in the chemistry and clarity results.

5.4 Annual Reports

The program will produce an annual report each year following the conclusion of the field season and the completion of the laboratory analyses. The protocol lead will work with the network program manager to integrate reporting with the larger Vital Signs Monitoring Program reports and the Annual Administrative Report and Work Plan. Reports will be distributed to NPS-WRD, network staff, Resource Chiefs, MOJN Technical Committee, and the MOJN Water Resources Working Group. Reports will also be made available to interested park staff and the public via the MOJN I&M web pages.

Annual reports will be published in the NPS Natural Resource Data Series (NRDS), and will follow the required NRDS format. The reports will include the following information:

- Description of field season highlighting accomplishments
- Documentation of any deviations from the protocol, such as missed sites or samples
- Results from the field season, including raw data, summary statistics and graphics
- Quality assurance and quality control analyses
- Recommendations for future improvements.

The data summary products described in Table 5.2 will be included in the annual report. Samples of these products based on field testing conducted in 2009 are given in *SOP 17: Data Analysis and Reporting*.

5.5 Trend Analysis Reports

Trend analyses are formally reported every four years once there is a minimum of five years of data, but they may be calculated more frequently if requested by NPS resource managers. We anticipate these analyses will be supplemented by additional analyses as the program matures.

Comprehensive reports should include the following information:

- Overview of the protocol status and major accomplishments
- Status and trend analysis results
- In depth, quality assurance and quality control analysis and discussion
- Discussion of results, including management implications
- Recommendations for future improvements.
- Incorporation of resource condition status into Park Condition Reports.

5.6 Protocol Review

Protocol implementation success will be thoroughly reviewed by network staff, the Water Resources Working Group, and Science Committee following the first field season. Thereafter, the program will be formally reviewed and evaluated every four years, shortly after the preparation of the quadrennial trend analysis report has given network personnel a sense of the effectiveness of the monitoring program. At the quadrennial review, changes that should be considered included changing methods, adding or dropping monitoring components, increasing or decreasing the number of monitoring stations, and increasing or decreasing sampling frequencies. Technical protocol reviews will be accomplished according to guidance from the Inventory and Monitoring Division of Natural Resource Stewardship and Science.

6.0 Personnel Requirements and Training

6.1 Personnel Requirements

This protocol requires close collaboration between MOJN I&M staff and GRBA staff. The protocol lead will be the MOJN I&M Hydrologist. Other key staff members include the MOJN I&M Program Manager, MOJN I&M Data Manager, GRBA Ecologist, seasonal field staff at GRBA, and contract laboratories responsible for the analysis of water chemistry and macroinvertebrate samples.

MOJN I&M will require a full time Hydrologist that will serve as the protocol lead and liaison with GRBA for I&M Program aquatic resource monitoring. The Hydrologist will be supervised by the MOJN I&M Program Manager and will also frequently interact with the network Data Manager to coordinate database development and data archiving. We anticipate that approximately one third of the Hydrologist's effort will go toward implementing and refining this protocol, with the remainder of the time spent on Groundwater and Springs and Riparian Vegetation protocols. The duty station for the position will be the MOJN I&M office at LAKE.

6.2 Roles and Responsibilities

As protocol lead, the Hydrologist will coordinate data collection, sample processing, archiving of data, and perform data analysis and reporting. The protocol lead will visit GRBA annually before the beginning of the season (late-May) to provide training and pre-season support and to perform the pre-season QA/QC tests for the water quality instruments. During the field season, the protocol lead is responsible for ensuring that the required field work occurs. Additional visits to GRBA may be necessary to coordinate with park personnel and assist with field work. The GRBA Ecologist will work with the protocol lead to implement the field program, and will be responsible for scheduling the regular site visits required to collect discharge and water quality data. The current program budget includes funds to support the hiring of seasonal technicians for field work at GRBA under supervision of the GRBA Ecologist. The MOJN I&M Data Manager will develop and maintain the databases for the water quality monitoring data generated by this protocol and upload water quality data to national databases (e.g., EPA STORET). The roles and responsibilities of all personnel are summarized in Table 6.1.

6.3 Qualifications and Training

We anticipate that the protocol lead will meet the basic requirements for a GS-9/11 Hydrologist. Education and/or experience in field sampling and water quality assessment are required. Experience with wilderness travel, wilderness field sampling, high physical fitness, and proficient swimming abilities are desired.

Details on training for safety, the protocol methods, and park specific training requirements are outlined in *SOP 1: Safety* and *SOP 2: Staff Training*.

Table 6.1. Roles and responsibilities for implementing the Mojave Desert Network Streams and Lakes protocol.

Role	Responsibilities	Name/Position
Protocol Lead	• Manages project oversight and administration. • Collaborates with Program Manager on tracking project objectives, budget, personnel requirements, and progress toward meeting monitoring objectives. • Facilitates communications between NPS resource managers and field crew. • Coordinates and ratifies changes to protocol. • Assists in training and auditing of field crews. • Provides training to GRBA Ecologist and Biotechs on sonde operation. • Coordinates field work. • Provides periodic assistance with field data collection. • Supervises macroinvertebrate sample processing. • Performs data summaries and analyses. • Maintains and archives project records. • Manages project operations and implementation. • Certifies each season's data for quality and completeness. • Completes reports, metadata, and other products according to schedule.	MOJN I&M Hydrologist
Park-based Lead	• Ensures safe field practices. • Supervises or conducts sample collection in absence of protocol lead, including: - o Calibration and maintenance of sondes, including data downloads - o Collection of water chemistry samples from streams and lakes - o Vertical profiling of core parameters in lakes & Secchi depth measurements - o Deployment and maintenance of lake level loggers - o Macroinvertebrate sampling - o Monthly discharge measurements	GRBA Ecologist
Technicians	• Assists GRBA Ecologist with field collections, as described above. • Assists with data compilation, data entry, field QA/QC, and field equipment management. •	GRBA seasonal employees
Taxonomists & Chemistry Labs	• Identifies and enumerates macroinvertebrates, according to MOJN I&M protocols. • Performs water chemistry analyses. • Certifies QA/QC.	Independent contractors
Data Manager	• Consults on data management activities. • Facilitates check-in, review, and posting of data, metadata, reports and other products to national databases (e.g., EPA STORET) according to schedule. • Maintains and updates database application. • Provide database training as needed. • Serves as primary steward of Access database and GIS data and products.	MOJN I&M data manager

Table 6.1. Roles and responsibilities for implementing the Mojave Desert Network Streams and Lakes protocol (continued).

Role	Responsibilities	Name/Position
Program Manager	• Provides supervision and oversight of protocol lead. • Manages administration and budget. • Consults on all phases of protocol review and implementation. • Reviews annual and 4-year reports.	MOJN I&M Program Manager

6.4 Facilities, Equipment, and Vehicles

The only facilities needed to support the protocol field work consist of a locking cabinet for the sondes and a freezer where water samples can be stored. GRBA Resource Management is able to supply these facilities.

The equipment for the protocol consists of five sondes (four owned by MOJN I&M, one owned by GRBA), handheld water quality meters (GRBA), four vented pressure transducers (GRBA), a current meter (GRBA), and six pressure/temperature loggers (MOJN I&M). The protocol lead will take responsibility for providing miscellaneous hardware (e.g., logger housings, fence-posts used for sonde installation). Miscellaneous field equipment such as waders, GPS units, backpacks, etc. will generally be provided by GRBA.

MOJN I&M personnel will use a MOJN I&M vehicle for transportation to and from GRBA. GRBA 4WD vehicles will generally be used for transportation to and from monitoring sites and trailheads.

7.0 Operational Requirements

7.1 Annual Workload and Schedule

The annual workload of this monitoring protocol is outlined by the responsibilities listed above in Table 6.1. The annual start-up for water quality monitoring begins in January with the final reporting, review and other close-out activities for the previous year. An evaluation of the protocol and any necessary changes must be made by April. Sondes are deployed in late May or early June after spring runoff subsides and core water chemistry parameter monitoring continues in streams throughout the summer by GRBA staff. GRBA staff also collects lake and stream samples after early season training by the MOJN I&M Hydrologist and/or GRBA Ecologist.

The schedule (Table 7.1) is coordinated with the anticipated annual schedules for the Selected Large Springs and Arid Lands Springs protocols. Specifically, low activity periods in the Streams and Lakes protocol correspond to the periods of intensive field preparation and field work in the desert parks (winter and early spring).

Table 7.1. Annual implementation schedule for water quality monitoring. Review of regulatory status is included as a task under Data Management/Reporting. Tasks are performed by the MOJN I&M Hydrologist (MH) except where noted (GE = GRBA Ecologist).

Month	Administration	Lakes	Streams	Data Management
January	Review laboratory results. Draft Streams and Lakes Annual Report.			Reconcile and upload laboratory results to Master database
February	Submit draft Annual Report to MOJN I&M Program Manager and WRWG.	GE posts job ads for seasonal bio-techs.		Season close-out
March	Complete required permitting reports (IARs).			Update protocol and data management SOPs
April	Finalize any modifications to protocol and SOP(s).			Compile data needs for IARs
May	Arrange for water chemistry and BMI sample processing.			Compile and submit data to WRD STORET
June	Training of field seasonal crews (MH and GE).		GRBA staff begin sonde deployment rotations and stream gaging.	Coordinate data acquisition Initiate data entry – hire/train technician Upload device data

Table 7.1. Annual implementation schedule for water quality monitoring. Review of regulatory status is included as a task under Data Management/Reporting. Tasks are performed by the MOJN I&M Hydrologist (MH) except where noted (GE = GRBA Ecologist) (continued).

Month	Administration	Lakes	Streams	Data Management
July	Supervise the analysis of water chemistry and BMI samples.		GRBA Staff collect water chemistry samples and BMI samples. Sonde calibration and stream gaging continue.	Coordinate data acquisition Continue data entry Upload device data
August	Submit water chemistry and BMI samples for analysis.		Water chemistry and BMI sampling continues. Sonde calibration and stream gaging continue.	Coordinate data acquisition Continue data entry Upload device data
September		GRBA Staff +/- MH measure lake level, collect vertical profiles, collect bottle samples, and download lake level and temperature data in the six lakes.	Sonde calibration and stream gaging continue.	Coordinate data acquisition Continue data entry Upload device data
October			GRBA staff remove sondes, prepare for winter storage and pass full dataset and all MOJN equipment (including sondes) from GE to MH (timing will vary from year to year depending on weather).	Coordinate data acquisition Continue data entry Upload device data Close out MOJN I&M field gear Compile discrete data for Project Lead
November				Certify data Transition data to Master dbs and geodatabases
December				Upload summary data to Master db

7.2 Budget

The estimated annual operating budget for the Streams and Lakes protocol is given below (Table 7.2).

Table 7.2. Estimated protocol budget.

Annual Estimates		Annual Cost
Analyses and Equipment		
Laboratory analyses	Lake Water Chemistry	1,500
	Stream Water Chemistry	2,300
	BMI	2,700
	Shipping & Supplies	1,000
Lake level logger/temp logger replacement (replace 1 / year)		1,000
Equip replacement costs/year (~50% cost of one sonde)		3,500
Sonde maintenance and standards		500
Total for Analyses and Equipment		12,500
Labor		
Hydrologist (0.33 time/year)		21,450
GS-5 Biotech (seasonal) at GRBA (4 pay periods)		5,440
GRBA Staff (In-kind contribution from park)		10,000
Statistician (25% of quadrennial cost)		1,250
Data Management		
Data Manager (321 hrs)		13,771
Data Management Technician (64 hrs)		1,469
GIS Specialist (68 hrs)		2,156
Travel		3,000
Total Annual Cost		71,036

8.0 Literature Cited

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