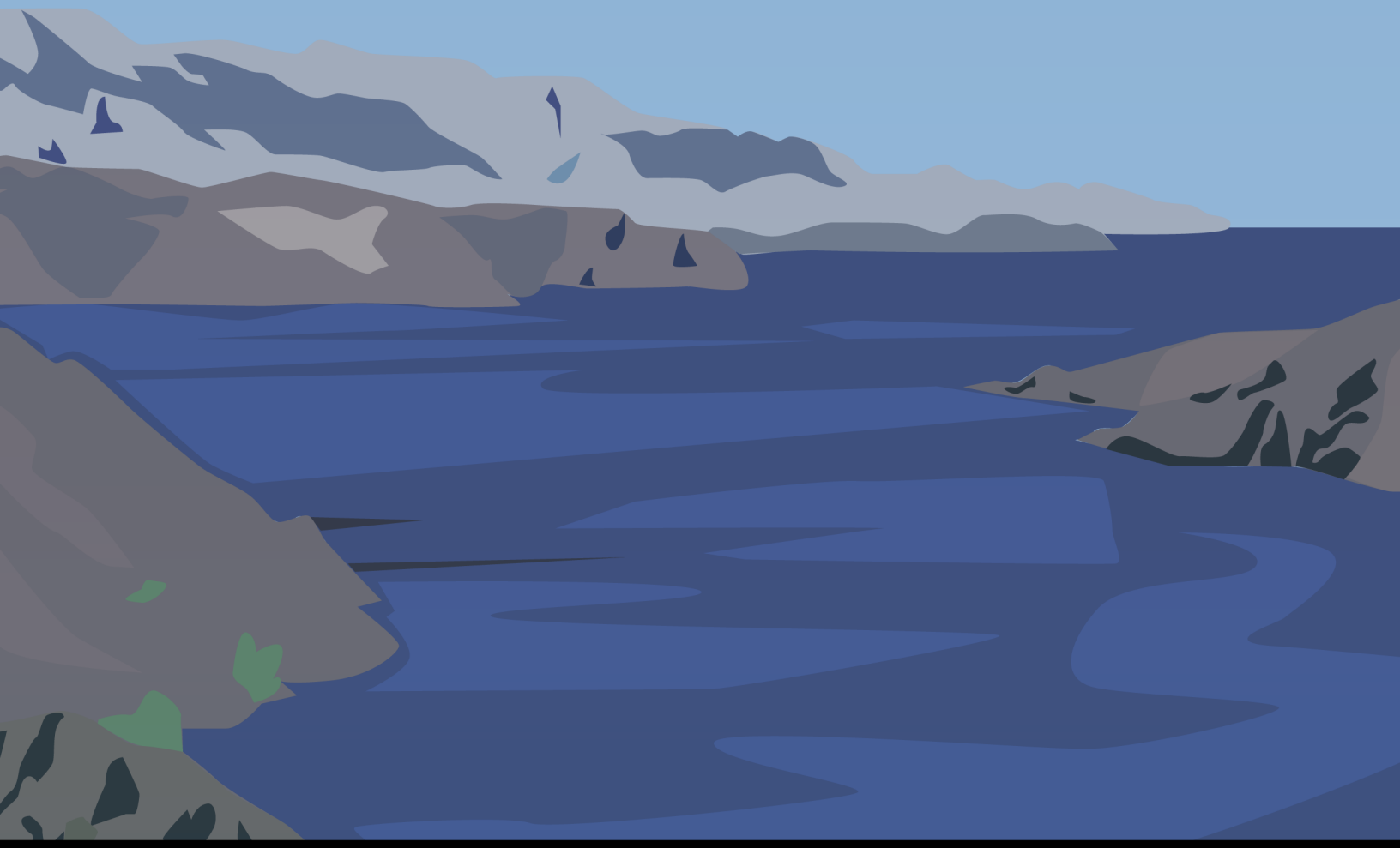
Long-Term Limnological and Aquatic Resource Monitoring and Research Plan for Lakes Mead and Mohave



Lake Mead National Recreation Area

National Park Service
U.S. Department of the Interior

Long-Term Limnological and Aquatic Resource Monitoring and Research Plan for Lakes Mead and Mohave

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ACRONYMS AND ABBREVIATIONS

AZ	Arizona
AGFD	Arizona Game and Fish Department
BBAMP	Boulder Basin Adaptive Management Plan
BMI	Basic Management, Incorporated
CCWRD	Clark County Water Reclamation District
CWC	Clean Water Coalition
ECC	emerging contaminants of concern
EDC	endocrine disrupting compound
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
FWS	U.S. Fish and Wildlife Service
IOC	Item of Concern
LCR MSCP	U.S. Bureau of Reclamation Lower Colorado River Multi-species Conservation Program
msl	mean sea level
NDOW	Nevada Department of Wildlife
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRA	National Recreation Area
NRS	Nevada Revised Statutes
NV	Nevada
PCBs	polychlorinated biphenyls
QA/QC	Quality Assurance/Quality Control
Reclamation	U.S. Bureau of Reclamation
SDWA	Safe Drinking Water Act
SNPLMA	Southern Nevada Public Land Management Act
SNWA	Southern Nevada Water Authority
TDS	total dissolved solids
TOC	total organic carbon
UNLV	University of Nevada, Las Vegas
UNR	University of Nevada, Reno
USGS	U.S. Geological Survey
VOCs	volatile organic compounds
WPRS	Water and Power Resources Service

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I. INTRODUCTION

A. Purpose of the Plan

This plan is an outgrowth of the 2009 Lake Mead Science Symposium coordinated by the National Park Service (NPS) Lake Mead National Recreation Area (Lake Mead NRA) with the assistance of the University of Nevada, Las Vegas (UNLV). Symposium technical committee chairs and other members of an interagency aquatic resources/water quality partnership for Lakes Mead and Mohave funded by the Southern Nevada Public Land Management Act (SNPLMA) contributed to the plan. The plan's purpose is to document, from an ecological perspective, a suggested long-term monitoring and research framework for the limnological and aquatic-dependent resources and drinking water quality of Lakes Mead and Mohave within Lake Mead NRA.

In many areas, suggested water-quality monitoring already occurs through the regularly funded activities of the contributing agencies. There are a number of intensive water-quality monitoring programs, particularly within the Boulder Basin, required by National Pollutant Discharge Elimination System (NPDES) wastewater discharge permits or related to the use of Lake Mead as a drinking water source. There are also ongoing regional planning initiatives, such as the U.S. Bureau of Reclamation's (Reclamation) Lower Colorado River Multi-Species Conservation Program (LCR MSCP) and the Virgin River Recovery and Habitat Conservation Program, which have an interest in the resources of Lakes Mead and Mohave. The development of this plan has also revealed where, to date, less rigorous or no monitoring has taken place.

Previously, a document did not exist that outlined a suggested holistic water quality and aquatic resource monitoring and research program for both lakes within the boundaries of Lake Mead NRA. This plan is intended to document such a program. It provides a basis for partnerships and coordination among agencies involved in the management of Lakes Mead and Mohave to carry out cooperative monitoring and research, when appropriate, and suggests a mechanism for making data and analyses available for regional planning, research, and public education. It is meant to aid in organizing interagency monitoring and research activities; coordinating monitoring that meets mutual goals; identifying gaps in existing monitoring and research; providing a framework for the periodic, cross-disciplinary interpretive analysis that takes into consideration the data collected across multiple agencies; and seeking efficiencies in providing monitoring and research that meets the documented gaps.

It is hoped that the plan will be useful to all agencies with an interest in Lakes Mead and Mohave to gain an overview of the variety of research and monitoring efforts underway, in leveraging funding opportunities to fill gaps, and help document and archive data in a means that is useful to the contributing agencies and other agencies and the public.

This document does not obligate the expenditure of funds by any of the contributing agencies nor obviate any responsibility or authority of any of the contributing agencies. It does not replace any other authorities or cause redundancies.

B. Significance

Resource Significance

With the ability to store approximately 26 million acre-ft of water, Lake Mead is the largest reservoir by volume in the United States. Lake Mead supplies three "Lower Basin States" (California, Arizona, and Nevada) and Mexico. Its uses, several of which are critical to life in the West, are diverse: drinking water for approximately 25 million people, agricultural irrigation, habitat for numerous fish and other wildlife species, world-class recreational opportunities, and hydropower generation. Lake Mead's downstream neighbor, Lake Mohave, re-regulates releases from the Hoover Dam to provide for required downstream deliveries, is the site of a national fish hatchery, serves as important habitat for fish and wildlife, including federally listed endangered species, and provides recreational opportunities. For these reasons, the health of Lakes Mead and Mohave are of interest to and the responsibility of multiple federal, state, and local agencies.

Strategy Significance

An important component of the management of Lakes Mead and Mohave is the implementation of a monitoring and research strategy to evaluate the effectiveness of current management practices and to identify emerging issues before they become widespread or difficult to solve. Multiple federal, state, and local agencies currently collect monitoring information related to water quality, limnology, emerging contaminants, fisheries, aquatic biota, riparian/shoreline resources, and other topics for a variety of existing programs. Often, these monitoring programs have been developed with specific objectives that may have limited spatial, temporal, or subject-area scopes, and do not consider ecosystem-monitoring needs for both lakes in their entirety. There is a need to develop a coordinated interagency monitoring framework with which to organize the needs, data, and information that are important to participating agencies for long-term protection of lake resources. This document is intended to assist with the development of a vision, objectives, and an approach that can lead, hopefully, to the implementation of coordinated interagency monitoring, research, and data-interpretation activities that integrate existing efforts.

Holistic Understanding for Change Detection

Issues of concern have and will continue to fluctuate in Lakes Mead and Mohave over time. Current monitoring and research should aid in the identification of appropriate management decisions to address new issues as they arise. Therefore, in the process of developing this plan, emphasis was placed on identifying monitoring and research activities that would elucidate the understanding of lake-ecosystem health as a whole. Consideration is for the best indicators of change, regardless of the specific and unique agents of change that may affect the lake over time.

Format

At the heart of this plan are fundamental objectives and key questions (**Section II**). Both monitoring and research questions have been formulated centering upon major ecosystem categories of interest to the management of Lakes Mead and Mohave and the components, drivers, and stressors inherent to each category. Each category section also includes suggested annual and periodic monitoring activities and

data analyses. A listing of suggested 5-year research priorities and 5-year data interpretation follows. Desired conditions and targets are identified, but will be further defined in the first 5-year interpretive report. It is also important to note that this plan is a living document and, as such, will change over time as information is gained and refined. Note that the amount and specificity of content is not entirely consistent from one ecosystem category to the next due to differences in the nature and extent of programs in each category.

C. Coordination

During the course of plan preparation, the interagency aquatic resources/water quality partnership group included the agencies that are listed below; summaries of their management responsibilities on Lakes Mead and/or Mohave are provided for each. These agencies participated in the partnership between 2005 and 2009 through their involvement in projects supported by SNPLMA funding in the Conservation Initiatives category awarded to NPS Lake Mead NRA. It is hoped that all other agencies with an interest in ecological monitoring and research on Lakes Mead and Mohave will join in the implementation of this plan.

National Park Service • www.nps.gov

NPS administers Lake Mead NRA under the National Park Service Organic Act of 1916 et seq. and the Lake Mead National Recreation Area Organic Act of 1964 in order to conserve the Recreation Area's scenic, natural, cultural, and wildlife resources and to provide for public enjoyment of those resources in such a manner as to leave them unimpaired for the enjoyment of future generations.

Clean Water Coalition • www.cleanwatercoalition.com

Wastewater reclamation agencies, located in the Las Vegas Valley of southern Nevada, worked together for many years on a variety of projects, including planning, engineering, and water quality studies and environmental monitoring. In November 2002, the Clean Water Coalition (CWC) was formed as a joint powers authority pursuant to chapter 277 of the Nevada Revised Statues (NRS).

Nevada Department of Wildlife • www.ndow.org

By authority of NRS 501.105 and 501.331, Nevada Department of Wildlife (NDOW) is responsible for administering the policies and regulations necessary for the preservation, protection, management, and restoration of Nevada's resident wildlife species. NRS 501.351 provides authority for the Director of NDOW to enter into cooperative agreements for the purpose of the management of native wildlife. NRS 503.584-503.589 directs NDOW to cooperate with other states and legal entities to the maximum extent practicable for the conservation, protection, restoration, and propagation of species of native fish, wildlife, and other fauna that are threatened with extinction. Nevada Administrative Code (NAC) Chapter 503 extends protected wildlife status to numerous native wildlife species.

Southern Nevada Water Authority • www.snwa.com

The Southern Nevada Water Authority (SNWA) represents seven member water and wastewater agencies in southern Nevada including Big Bend Water District, Boulder City, City of Henderson, City of Las Vegas, City of North Las Vegas, Clark County Water Reclamation District, and Las Vegas Valley Water District. SNWA is responsible for managing the regional water resources of southern Nevada and developing solutions that will ensure adequate future water supplies for the Las Vegas Valley.

U.S. Bureau of Reclamation • www.usbr.gov

Reclamation is an agency of the United States Department of the Interior, which is responsible for the management and operation of Lake Mead, Hoover Dam, and the Lower Colorado River system pursuant to the Reclamation Act of June 17, 1902 (45 Stat. 1057), and acts amendatory thereof or supplementary thereto.

U.S. Fish and Wildlife Service • www.fws.gov

The U.S. Fish and Wildlife Service (FWS) is a federal agency with the United States Department of the Interior. FWS has responsibilities and regulatory authorities under the Endangered Species Act of 1973, as amended, the Migratory Bird Treaty of 1918, as amended, the Bald and Golden Eagle Protection Act of 1940, as amended, and the Fish and Wildlife Coordination Act of 1934, as amended. Lakes Mead and Mohave, and surrounding watershed, harbor many fish, wildlife and plant species, and their habitats for which FWS is entrusted to conserve, protect, and enhance for the continuing benefit of the American people.

U.S. Geological Survey • www.usgs.gov

The U.S. Geologic Survey (USGS) is an agency of the United States Department of the Interior that serves the Nation, and Nevada (http://nevada.usgs.gov), by providing reliable, unbiased scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect the American people's quality of life.

The above-listed agencies also work with other federal, state, and local agencies in a complex variety of water-management forums and programs within Clark County. A list of such forums and programs, and their participants, can be found in Appendix 1.

D. Geographic and Resource Scope

The plan geographically covers the surface waters within Lake Mead NRA (see **Figures 1 and 2**; and **Appendix 2** for monitoring location coordinates and further details) and the basic limnological and water quality elements that relate to fulfilling the plan goals and including water-dependent natural resources such as fisheries, aquatic biota, vegetation, and shorebirds/aquatic-dependent birds.

OVERVIEW OF LAKE MEAD

Lake Mead Limnology
By G. Chris Holdren, U.S. Bureau of Reclamation

Introduction

Lake Mead is a large reservoir on the mainstem of the Colorado River. Hoover Dam, which formed Lake Mead, is located in Black Canyon approximately 30 miles east of Las Vegas, NV in the Mohave Desert, Arizona-Nevada (**Figure 1,** p. 18). At full pool, Lake Mead is the largest reservoir in the United States by volume and is second only to Lake Powell in surface area (Paulson and Baker 1983). Lake Mead has enough capacity to hold the entire flow of the Colorado River for two years [Water and Power Resources Service (WPRS) 1981]. It extends 105 km (65 mi) from Hoover Dam to Pierce Ferry at full pool. Its greatest width is 15 km (9.3 mi), and the highly irregular shoreline is 885 km (550 mi) in length (WPRS 1981). Lake Mead contains four large sub-basins: Boulder, Virgin, Temple, and Gregg; four narrow canyons: Black, Boulder, Virgin, and Iceberg; and the 30-mile long Overton Arm, which extends from the Virgin and Muddy Rivers to the Virgin Basin (Figure 1).

The construction of Lake Mead was authorized by the Boulder Canyon Project Act in 1928 (Billington et al. 2005). A site near the Narrows at the top of Boulder Canyon (**Figure 1**) was initially proposed as the site for the dam, but it was recognized early in the planning process that a site in Black Canyon would be less costly and would also lead to additional water storage and hydropower generation. Construction of Hoover Dam started in 1931 and the dam was closed in 1936 (Lara and Sanders 1970). Hoover Dam was one of the first federal, multipurpose dams. Its primary intended used were to facilitate agricultural development in the Imperial Valley and municipal growth in Los Angeles (Billington et al. 2005).

Hydropower generation was one of the major intended uses for Hoover Dam and a key factor in financing the Boulder Canyon Project. The ultimate generating capacity of more than one million horsepower represented more than 20 percent of the power generation capacity in the western states at the time of its construction. The first power was generated at Hoover Dam on October 7, 1936, and continuous, commercial power generation began in June 1937. From that time on, power generation provided the income that would pay for construction of the dam (Billington et al. 2005)

Lake Mead currently provides drinking water for the city of Las Vegas, NV, as well as drinking and irrigation water for approximately 25,000,000 downstream users. It is unlikely that the southwest could have developed as it has without the water provided by Lake Mead.

Lake Characteristics

There is considerable confusion concerning the capacity of Lake Mead. Project data reported by Reclamation (WPRS 1981) includes volumes and surface areas for water surface elevations of 1,232 ft (crest of dam), 1,229 ft (top of flood control), and 1,221.4 ft (top of spillway gates). Lake surface areas, volumes, and maximum depths have been reported based on the original construction survey in 1935 before the dam was completed, a survey undertaken in 1948-49 to determine volume losses by sedimentation (U.S. DOI 1954; USGS 1960), and a 1963-64 survey to update the capacity of the reservoir at the time of the closure of Glen Canyon Dam in March 1963 (Lara and Sanders 1970). Complete results of a recent survey undertaken by the USGS and Reclamation from 1999-2001 (Twichell et al. 2003) are not yet available.

Key characteristics of Lake Mead are summarized in **Table 1**. These data are based on Lara and Sanders (1970) at the surface elevation of 1,221.4 ft. The mean inflow used was that reported by WPRS (1981) at Hoover Dam for the period 1923-1978.

Table 1. Morphometric and Hydrologic Characteristics of Lake Mead

Parameter	Value
Surface Area	63,900 ha (157,900 acres)
Volume	3.227×10^{10} m^3 (26,159,000 acre-ft)
Mean Depth	50.1 m (167 ft)
Maximum Depth	150 m (491 ft)
Watershed Area	433,000 km^2 (167,000 mi^2)
Mean Inflow	1.55×10^{10} m^3 (12,600,000 acre-ft/yr)
Hydraulic Residence Time*	2.1 years
Shoreline Length	885 km (550 mi)
Watershed Area to Lake Surface Area Ratio	681:1

* Calculated from average inflow and lake volume. Actual residence time primarily depends upon reservoir operations for Lakes Mead and Powell

Sediment accumulation has been significant. Lara and Sanders (1970) reported that 6.21 x 1010 m^3 (1,425,900 acre-ft) of sediment accumulated in Lake Mead between 1935 and 1948-49. An additional to 1963-64 = 1,293,100 acre-ft accumulated between 1948-49 and 1963-64, for a total of (2,716,900 acre-ft), or approximately 12 percent of the original lake volume. The completion of Glen Canyon Dam greatly slowed the amount of sediment transport to Lake Mead and was estimated to increase the life of Lake Mead by 500 years (Lara and Sanders 1970).

Retention time in the reservoir averages about 3.9 years, depending on release and inflow patterns. The four major tributaries to Lake Mead are the Colorado River, which contributes about 97 percent of the annual inflow to Lake Mead, the Virgin and Muddy Rivers, and Las Vegas Wash. The annual inflow via Las Vegas Wash has increased dramatically over the past 20 years. Inflow from Las Vegas Wash has

averaged over 2.50 x 108 m^3 (203,000 acre-ft), or two percent of the total inflow, over the last five years. This is more than double the long-term average for the gauging station and is the second highest volume of inflow to Lake Mead. Discharge from Hoover Dam is from the hypolimnion[1] and occurs at elevations of 273 and 319 m (895 and 1,045 ft) above mean sea level (msl). The annual discharge is about 9 x 109 m^3 (7.3 x 106 acre-ft). Annual withdrawal through the Southern Nevada Water System in Boulder Basin is currently about 5.5 x 108 m^3 (450,000 acre-ft; Roefer et al. 1996).

Hydrology

The hydrologic budget for Lake Mead is very complex. The water level depends on inflows from its tributaries, primarily the Colorado River, and losses to downstream discharges through Hoover Dam, evaporation, and direct withdrawals for drinking water in the Las Vegas Valley. The inflows from the Colorado River depend upon the annual snowmelt and rainfall received on the west side of the Rocky Mountains in Colorado and the operation of Glen Canyon Dam.

Lake Elevation

Elevations reflect the inflow-outflow regime, and large differences in elevation are primarily a reflection of drought years. Lake Mead began filling in late 1934 and the average daily surface elevations from February 1, 1935, when elevation data began to be collected, through 2009 are shown in **Figure 2**. Note that the reservoir did not reach 1,050 ft above msl until May 10, 1937. The reservoir filled to an elevation of over 366 m (1,200 ft) above msl by mid-1941 and fluctuated annually between that elevation and 351 m (1,150 ft) through the early 1950s. The elevation dropped to just over 329 m (1,080 ft) in 1953 and remained between 329 m (1,080 ft) and 338 m (1,110 ft) until late 1957 when Lake Mead began to fill again, reaching an elevation of over 369 m (1,210 ft) in 1959 (**Figure 2**).

Glen Canyon Dam, which impounds Lake Powell, was completed in 1963 and Lake Powell began to fill. At the initial filling, Lake Mead elevations dropped significantly as inflows were reduced. Although Lake Mead gradually began filling again after Lake Powell reached full pool in 1965, full pool in Lake Mead was not reached again until 1983. Lake Mead filled to capacity (elevation >372 m [1,220 ft]) in mid-1983 and the spillway gates operated for the first time under normal operating conditions. It took 20 years for Lake Mead to fully equilibrate to the presence of Lake Powell upstream. Seasonal fluctuations due to variation in inflow were greatly reduced by the buffering capacity of Lake Powell (**Figure 2**).

Lake Inflows

Inflows to Lake Mead watershed were estimated from USGS water resources data for each of the four major tributaries to Lake Mead. Beginning with water year 2004, runoff data for Arizona and Nevada sites is only available on the internet at http://waterdata.usgs.gov/. Information on all gauging stations used to evaluate runoff is presented in **Table 2** (next page).

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[1] For definitions of lake and reservoir terminology, consult the "Water Words Glossary" published on-line by the North American Lake Management Society: at http://www.nalms.org/nalmsnew/glossary.aspx?Al=A)

Gauging stations included Colorado River above Diamond Creek near Peach Springs, AZ, located 130 miles upstream from Hoover Dam; Las Vegas Wash below Lake Las Vegas near Boulder City, NV, located approximately 0.55 miles upstream of the high water line for Lake Mead; Virgin River at Littlefield, AZ, located 36 miles upstream from Lake Mead; and Muddy River near Glendale, NV, located 16 miles upstream from Lake Mead. Two additional stations, Virgin River near Overton, NV, located 0.25 miles upstream from Lake Mead; and Muddy River at Lewis Avenue at Overton, NV, located 1.5 miles upstream from Lake Mead, were used to provide additional information on inflows to Lake Mead. Data from the Virgin River at the Overton site on the Virgin River were only available from 2003 to 2005 and from 2007 to present, and data from the Muddy River at the Lewis Avenue site were only available from 1997 to 2004 and from 2006 to present (**Table 2**).

Table 2. USGS gauging stations above Lake Mead.

Station		Location		Period of Record
Name	Number	Latitude	Longitude	
Colorado River above Diamond Creek near Peach Springs, AZ	09404200	35E 46' 25"	113E 21' 46"	6/83-12/83, 9/85-2/86, 10/89 - current year
Las Vegas Wash below Lake Las Vegas near Boulder City, NV	09419800	36E 07' 20"	114E 54' 15"	8/69-9/84, 7/02 - current year
Virgin River at Littlefield, AZ	09415000	36E 53' 30"	113E 55' 25"	10/29 - current year
Virgin River near Overton, NV	09415240	36E 34' 59"	114E 19' 27"	1/03 -11/05, 10/07 - current year
Muddy River near Glendale, NV	09419000	36E 38' 35"	114E 32' 20"	2/50-9/83, 10/84 - current year
Muddy River at Lewis Avenue at Overton, NV	09419507	36E 32' 07"	114E 25' 42"	8/97 - 9/04

The Colorado River currently enters Lake Mead at the northern end of the Gregg Basin, nearly 60 miles (97 km) upstream of Hoover Dam. For the Colorado River watershed of 149,316 mi^2 (386,727 km^2), only 3,959 mi^2 (10,250 km^2) in the Great Divide Basin in Wyoming and 697 mi^2 (1,810 km^2) on the Colorado Plateau do not contribute runoff to Lake Mead. Based on data from the gauging stations, the Colorado River contributes about 98 percent of the annual inflow to the lake. Because the Colorado River water is cold and contains a heavy sediment load, the Colorado River enters Gregg Basin as an underflow. At times, this underflow, identifiable by its lower conductivity than water from other parts of Lake Mead, can be seen all the way into Boulder Basin.

The Overton Arm collects the combined drainages of the Virgin and Muddy Rivers. These watersheds have a combined area of over 11,000 mi^2 (28,500 km^2) but less than half of the Muddy River watershed contributes runoff to Lake Mead. Runoff entering the Overton Arm through the Virgin and Muddy Rivers travels approximately 35 miles (56 km) before joining the main stem of the Colorado River in the Virgin Basin. Water from these rivers is both colder and saltier than Lake Mead and these tributaries also enter the lake as an underflow. The upper end of the Overton Arm is relatively shallow and is

usually well mixed, but at times, the interflow from the Virgin and Muddy Rivers can be identified farther downstream. Heavy flooding in 2005 produced a mass of high conductivity water that could be traced all the way to Hoover Dam. When corrected for the diversions upstream of Lake Mead, the Virgin River contributes 1.0 percent of the annual inflow and the Muddy River contributes only 0.1 percent of the annual inflow.

Boulder Basin is downstream-most basin and collects the combined flows from the Overton Arm and the main stem of the Colorado River (**Figure 1**). Additionally, it receives all drainage from the Las Vegas Valley via Las Vegas Wash into Las Vegas Bay. The total drainage area for the Las Vegas Wash watershed is 2,193 mi^2 (5,680 km^2), but only 1,586 mi^2 (4,108 km^2) contributes surface runoff to Lake Mead. This drainage includes both non-point surface and groundwater discharges, and treated effluent from the City of Las Vegas, City of Henderson, and Clark County municipal wastewater treatment facilities. As a result of the rapid development in Las Vegas, inflows from Las Vegas Wash have nearly doubled over the past 20 years and it now contributes 0.9 percent of the annual inflow to Lake Mead.

Direct precipitation on the lake surface represents an insignificant contribution to the hydologic budget. The 30-yr normal precipitation from five weather stations around Lake Mead (Las Vegas Airport, NV, Valley of Fire State Park, NV, Willow Beach, AZ, Callville Bay, NV, and Temple Bar, AZ) average 0.141 m/yr (5.53 in/yr).

Discharges through Hoover Dam are variable, but water is released as needed to meet water deliveries to Arizona, California, and Mexico that are stipulated by the Colorado River Compact. Nevada's share of Colorado River water is withdrawn directly from Lake Mead to meet water requirements for the Las Vegas Valley.

Evaporation in the area is extremely high. Pan evaporation averages 2.88 m/yr (113.53 in/yr) in Boulder City, NV, which corresponds to an evaporation rate of approximately 2.02 m/yr (79.5 in/yr from the lake surface (Farnsworth and Thompson 1982). At full pool, evaporative losses would be 1.29 x 109 m^3/yr (1,045,000 acre-ft/yr).

Water Quality

Overall, Lake Mead is mildly mesotrophic based on several classification indices (Vollenweider 1970; Carlson 1977). As with other reservoirs, dam operations exert a great influence on the water quality and ecology of the system (Thornton 1990). The hydrodynamics of such large reservoirs are complex. Each basin within Lake Mead is ecologically unique, and therefore responds differently to the inflow-outflow regime. Furthermore, the different sources of water entering Lake Mead, as in other reservoirs, often retain their identity and influence for substantial distances into the reservoir and do not necessarily mix completely with the rest of the water column (Ford 1990). The incomplete mixing of inflows to Lake Mead with the surrounding water can lead to erroneous estimates of water retention time, and the conveyance and fate of materials transported into the reservoir.

Because of the discharge through Las Vegas Wash, a large fraction of Lake Mead's nutrient loading is confined to the most downstream basin, Boulder Basin (Paulson and Baker 1981; Prentki and Paulson 1983; LaBounty and Horn 1997). This situation is unusual for a reservoir since it is opposite the normal

upstream-downstream decrease in the pattern of productivity, and results in several limnological features normally associated with upstream reaches (Kimmel et al. 1990). The combination of high concentrations of nutrients, salts, and other constituents from Las Vegas Wash and the lower concentrations, but higher flows, in Colorado River inputs combine to determine the observed conditions in Boulder Basin.

LaBounty and Burns (2005) examined water quality in Boulder Basin and concluded that Lake Mead is ecologically complex. The lake is heavily influenced by inflow and outflow patterns, with interflow layers having important impacts on lake chemistry and productivity. Lake Mead is strongly phosphorus limited, which affects nutrient concentration gradients within Boulder Basin and well-stratified. The strongest statistical relationships with decreasing Secchi transparency are with chlorophyll-*a* and total phosphorus.

Lake Mead Fishery

Sportfish

The sport fishery in Lake Mead consists entirely of exotic game species which have been either purposely stocked within the reservoir or which arrived from one of the tributaries. Principal game species, which have established self-sustaining populations, include striped bass, largemouth black bass, smallmouth black bass, black bullhead, channel catfish, crappie, green sunfish, common carp, tilapia, and bluegill. An important forage fish, first introduced into the lake in 1955, is the threadfin shad. Gizzard shad, a less desirable forage fish, was first detected in Lake Mead in 2007, and has apparently become well established. NDOW stocks rainbow trout into Lake Mead during the winter to establish a “put-and-take” sport fishery.

Base primary productivity for the waters of Lake Mead is low, in part due to nutrient deficiencies attributable to creation of the Glen Canyon Dam. Many nutrients that used to enter the lake via the Colorado River are trapped in the sediments of Lake Powell. A study of Las Vegas Wash through the USGS National Water Quality Assessment Program detected low levels of DDT within carp in Las Vegas bay. This led to follow-up assessments for DDT and in game fish within Lake Mead. These surveys found that air transport of mercury into freshwater environments is causing higher levels of mercury in top predator fish such as striped bass and largemouth bass. Lake Mead NRA is working with state officials and the Lake Mead Water Quality Forum to monitor bio-contamination in fish and assess the need for additional management responses.

The NPS works with AGFD, NDOW, Reclamation, and USFWS for cooperative fisheries management. There are regular interagency meetings to discuss fisheries management planning, attempt to coordinate activities, and achieve mutual work plans and cooperative activities for both sportfish and native fish. Sportfishing is a major activity within the recreation area: One that generates large amounts of income for the local economy. In addition to casual fishing, numerous largemouth and striped bass tournaments are held annually within the park.

Native Fish

The razorback sucker (*Xyrauchen texanus* [Abbott]) is the only native fish currently found in Lake Mead. This species is one of four endemic, large-river fish species[2] of the Colorado River Basin presently considered endangered by the U.S. Department of the Interior (USFWS 1991). Razorback suckers were historically widespread and common throughout the larger rivers of the Colorado River Basin (Minckley et al. 1991), but the distribution and abundance of this species has been greatly reduced from historic levels. These declines have been attributed to human-caused alterations in the habitat, particularly the construction of dams and the resultant cool tailwaters and reservoir habitats that replaced the relatively warm, riverine environment (Holden and Stalnaker 1975, Joseph et al. 1977, Wick et al. 1982, Minckley et al. 1991) and the introduction of numerous species of non-native fish to these newly created habitats (Minckley et al. 1991, Marsh et al. 2003).

Razorback suckers persisted in several of the reservoirs constructed in the lower Colorado River Basin; however, these populations were comprised primarily of adult fish that apparently recruited during the first few years of reservoir formation. The population of long-lived adults then disappeared 40–50 years following reservoir creation and the initial recruitment period (Minckley 1983). Riverine populations in the Upper Colorado River Basin also have declined as recruitment has not occurred at significant levels since the construction of these mainstem dams. It is thought that predation by bass (*Micropterus spp.*), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sunfish (*Lepomis spp.*), and other nonnative species is the primary reason for the lack of razorback sucker recruitment throughout the area of its original distribution (Minckley et al. 1991, Marsh et al. 2003).

The same general trend in razorback sucker decline occurred in Lake Mead as was seen throughout the rest of the Colorado River and its tributaries. Razorback sucker numbers, initially high in Lake Mead, noticeably decreased in the 1970s, and none were collected during the 1980s. However, in the early 1990s, NDOW was informed by local anglers that the species was still present in two localized areas of Lake Mead: Las Vegas Bay and Echo Bay. Limited sampling efforts initiated by NDOW soon confirmed the presence of remnant populations of razorback sucker in Lake Mead. In 1996, SNWA, in cooperation with NDOW, initiated studies in an attempt to identify some of the basic population dynamics of razorback sucker in Lake Mead. BIO-WEST, Inc. (BIO-WEST) was contracted to design and conduct the study with collaboration from the SNWA and NDOW. Other cooperating agencies included Reclamation, NPS, Colorado River Commission of Nevada, and USFWS.

It is unknown why razorback suckers have been able to persist in Lake Mead for the past 75 years without population augmentation, and why they are able to continue to recruit new adults into their population when there is no evidence that they have been able to do this anywhere else in the Colorado River System in recent years. The working hypothesis is that recruitment is taking place only in areas where high turbidity is providing adequate cover for young razorbacks to escape predators. There are essentially four areas that stand out in terms these unique cover aspects conducive to razorback sucker recruitment, namely, the Las Vegas Wash inflow, the Muddy River/Virgin River inflow, Echo Bay, and the Colorado River inflow (Golden and Holden 2001, 2002, and 2003). Currently, it is known that

[2] The others are Colorado pikeminnow (*Ptychocheilus lucius*), bonytail (*Gila elegans*), and humpback chub (*Gila cypha*).

recruiting populations occur at the Las Vegas Wash inflow, Echo Bay and the Muddy River/Virgin River inflow areas. There appears to be no reason why a razorback sucker population does not exist at the Colorado River inflow, particularly given that larval razorback suckers were identified during past sampling efforts in this area of Lake Mead as recently as 2000 and 2001. Even more recently, in 2008, AGFD captured a single large adult razorback sucker during their annual gill netting efforts in the Gregg Basin and NDOW captured two adult fish in the Virgin Basin. Although past efforts to identify a spawning population in the Colorado River inflow area have been unsuccessful to date, it may be that this area could likely harbor a spawning population of razorback sucker as well.

Lake Mead Recreation

*See also **Appendix 3** for the history of recreation on Lake Mead.*

Today, the park receives approximately eight million recreational visits with approximately 50 percent traveling from Southern California. The remaining visitors are primarily from Nevada, Arizona, Utah, and other western states. Facilities capacities were set for Lake Mead in the 2005 Lake Management Plan. At high water levels where all facilities are operational, the marina capacity for Lake Mead was established at 3,357 slips with 460 rentals boats. The public launch capacity was established at 3,000 boats. The boating capacity for Lake Mead was set at 3,295 boats at any one time.

The lowering lake levels observed between 2000 and 2010 has affected public access to Lake Mead. With the lake projected to attain an elevation of 1,076 ft in June 2010, it will be down approximately 150 vertical ft from full pool. Pearce Ferry, Government Wash, Las Vegas Bay, and Overton have been closed as lake waters have receded such that the area can no longer provide reasonable access. Boulder Harbor operations have been reduced with the removal of the Lake Mead Ferry Service and Lake Mead Marina. All other lake access points have been dramatically impacted. The park concessioners are having difficulty moving the marinas and extending utilities to keep the marinas operational at these water levels. The NPS is annually chasing the water at each of the public launch ramps, but pouring concrete to extend the ramps is limited by the water levels. These difficulties are impacting lake access and, in turn, impacting visitor use at Lake Mead.

It is anticipated that the future will include dramatic fluctuations in Lake Mead water levels and recreation facilities must be designed to operate between elevations of 1,000 to 1,220 ft. While many of the steps are underway to accommodate these changing conditions, it remains to be seen whether the NPS and its concessioners can meet the needs brought about by such changes. While the goal is to maintain the existing level of public access, it is becoming more difficult to do so with each annual 15-ft decrease in lake elevation.

OVERVIEW OF LAKE MOHAVE

Introduction

Lake Mohave (**Figure 2**, p. 20) is a reservoir on the Colorado River created in 1951 following the completion of Davis Dam near present-day Laughlin, Nevada, and Bullhead City, Arizona. Named for the Mohave Indians (Carlson 1974) who previously inhabited this region of the Colorado River valley, Lake Mohave extends approximately 67 miles along the valley from Hoover Dam to Davis Dam. The reservoir straddles the southern Nevada and northwestern Arizona border, which follows the original river channel. Construction of Davis Dam was a requirement of the 1944 Water Treaty with Mexico to regulate water released from Hoover Dam for delivery to Mexico (Treaty Series 994, 59 Stat. 1219). Lake Mohave is used for that purpose through integrated operations with Hoover Dam. Lake Mohave and surrounding lands were added to Lake Mead National Recreation Area in 1947 with a revision to the Memorandum of Agreement between the NPS and the Reclamation. The lake provides a variety of recreational opportunities, including boating, fishing, and scuba diving. Three marinas with launch ramps are located on Lake Mohave, two in Arizona (Willow Beach and Katherine Landing) and one in Nevada (Cottonwood Cove). An additional launch ramp is located at Princess Cove on the Arizona side near Katherine Landing. Lake Mohave provides aquatic and riparian habitat for a variety of native and introduced game fish, desert wildlife, and vegetative species.

Lake Mohave Characteristics

Both narrow and shallow compared to Lake Mead, Lake Mohave lies between the Black Mountains to the east in northwestern Arizona, and the Eldorado and Newberry Mountains to the west in southern Nevada. Most of the lake's length is in narrow canyons, within the steep walls of Black, Eldorado, Painted, and Pyramid canyons. The northern section of the reservoir is constrained by the steep rock walls of Black Canyon for a length of 22 miles and is narrower than 300 ft in places. This portion of the reservoir is primarily riverine. South of Black Canyon, Lake Mohave gradually widens to nearly 4 miles (Longwell 1963) in Cottonwood Basin. The transition between river and true reservoir conditions occurs in Eldorado Canyon, between Black Canyon and Cottonwood Basin. In the summer, a sharp convergence zone develops in Eldorado Canyon as the cold, nutrient-rich river water flows under the warmer lake water. Mixing at the interface promotes high phytoplankton productivity resulting in a marked change in water clarity in Eldorado Canyon (Paulson et al. 1980). The reservoir has a long north-south fetch and is subject to high winds and resulting large waves from the predominantly south/southwest summer winds and north/northeast winter winds. Small coves are formed in some areas of the basins by inundated desert washes, which are a major source of shoreline alluvial deposits that periodically are washed into the reservoir. Davis Dam is located within a narrow gorge cut into Precambrian igneous rock in Pyramid Canyon at the south end of the reservoir (Longwell 1963). At 647-foot elevation, the Lake Mohave has a total storage capacity of 1,818,300 acre-ft, a maximum depth of approximately 100 ft, and just over 28,000 surface acres with roughly half of the lake found in Arizona and half in Nevada.

With the completion of Hoover and Davis Dams, historic riverine temperature and flow cycles are no longer in place. Hoover Dam discharges water from Lake Mead's cold hypolimnion; this serves as Lake Mohave's only significant inflow. As a result, water temperatures within Black Canyon are a constant 12–13°C, and the shade provided by the steep walls of the canyon help maintain the steady low

temperatures throughout the year (Bozek et al 1984). The change in temperature cycling and modifications to the physical features of the area brought about by damming the Colorado River in the area of Lake Mohave resulted in habitat loss for aquatic insects, which are now no longer present (Bozek et al. 1984; Paulson et al. 1980). Also directly and indirectly imperiled were the razorback sucker (*Xyraychen texanus*) and bonytail chub (*Gila elegans*), two federally listed endangered fish species (U.S. Fish and Wildlife Service 1990 and 1998, respectively) for which Lake Mohave is a critical habitat. The razorback sucker population has most recently been estimated at less than 10,000 fish, which is a significant decline from previous estimates of 60,000 in the late 1980s. Once abundant throughout the Colorado River basin, Lake Mohave now contains the largest remaining population of razorback suckers. The bonytail chub presently exists in low numbers in Lake Mohave (Nevada Department of Wildlife Statewide Fisheries Management 2008).

Fishery

Lake Mohave's cold-water conditions, however, are ideal for raising rainbow trout. The Willow Beach National Fish Hatchery, built in 1962, to stock trout in Lakes Mead and Mohave, is located 11.2 miles below Davis Dam and uses and returns Lake Mohave water. The Willow Beach area of Lake Mohave is usually stocked bi-weekly throughout the year with 1,000–2,000, 12-inch rainbow trout from the hatchery. The Nevada Department of Wildlife stocks at Cottonwood Cove, Placer Cove, the Aztec Wash area, and at times, the Willow Beach and Hoover Dam areas. Today, the hatchery also rears razorback sucker and bonytail chub (http://www.fws.gov/SOUTHWEST/fisheries/ willowbeach.html).

Striped bass have become the major sport fishery; this species reproduces in the seasonally warm reaches of the reservoir and moves into cold-water areas as they become larger, and eventually prey on trout. The impact striped bass have on the stocked trout fishery has become substantial in recent years resulting in modifications to the trout-stocking program. Largemouth bass, channel catfish, and sunfish provide the remaining portion of the sport fishery. The major forage species present, other than trout, are threadfin shad, bluegill, green sunfish, and crayfish. Large striped bass are also known to prey on carp. Populations of all the forage species have remained fairly abundant with the exception of threadfin shad. Other nongame, not native fish include carp and red shiner. Predation by striped bass, among other factors, has reduced the threadfin shad population to a point where they are now difficult to detect in Lake Mohave (Nevada Department of Wildlife Statewide Fisheries Management 2008).

Other Research

Research on Lake Mohave has dealt with vegetation surrounding the lake (Tallent-Halsell and Walker 2002), fish (Bozek et al. 1990), water quality (Paulson and Baker 1983), geology (Longwell 1963), and geological hazards to recreation areas surrounding the lake associated with flash floods (Glancy and Harmsen 1975; Moosburner 1979 and 1981). The floor of Lake Mohave was mapped in 2002 when the USGS in cooperation with UNLV researchers completed a geophysical survey of this lake. The survey included collection of sidescan-sonar imagery of nearly the entire lake floor and high-resolution seismic-reflection profiles. The detailed mapping of the lake floor was used to determine the amount of sediment that had accumulated in the lake since impoundment, its distribution, and the processes of deposition (Foster et. al. 2004).

BIRDS AND LAKES MEAD AND MOHAVE

Lake Mead National Recreation Area provides valuable habitat for hundreds of bird species. Birds utilize the open water, cliffs and canyons, and the surrounding desert. Many sensitive species are attracted to, or are even dependent upon, the large tracts of riparian habitat created by the lakes' shorelines and inflow areas. The greater density and diversity of vegetation in this habitat provides cover, food, and nesting sites for breeding species as well as critical stopover areas for many migrants.

Recreational activities on the lake create disturbances to birds in the form of noise, waves and wakes, and habitat degradation. Such impacts can cause birds to avoid otherwise suitable areas when establishing territories or selecting roosting or nesting sites. During the breeding season, disturbance can result in nest abandonment at any stage of the nesting process. Birds that are repeatedly flushed from their nests are unable to effectively incubate eggs or care for young.

Active monitoring and management is necessary to preserve rare or sensitive species and protect them from inappropriate recreational activities. Additionally, some species at Lake Mead are federally listed as either threatened or endangered, so protection is necessary in order to comply with the terms of the Endangered Species Act. Since site fidelity is common in birds, with individuals returning to the same area each year to breed, the first step is to protect areas that sensitive species are known to inhabit. Critical areas include the Virgin and Muddy River inflows, the Black Canyon, and the Pearce Ferry Delta. Additional measures may be necessary in the future, as new issues arise or as new information on bird distribution becomes available.

Peregrine falcons (*Falco peregrinus*), are present year-round at Lake Mead NRA and nest on cliffs and canyon walls on both Lakes Mead and Mohave. Numerous eyrie locations have been identified in the park, and many of them are used on a yearly basis. Peregrines may lay eggs from March through June. The eggs have a 30-day incubation period, and after hatching, the young remain in the nest for 5 to 6 weeks. The period of greatest sensitivity for this species thus ranges from March through August.

The bald eagle (*Haliaeetus leucocephalus*), a federally threatened species, is a winter resident at Lake Mead NRA. Lakes Mead and Mohave provide an ample prey base for the eagles, which feed mainly on fish. Bald eagles can be found along the shorelines throughout the park. A record number of bald eagles were counted in the park during the 1999 survey. This species is most common at Lake Mead NRA from December to March.

Great blue herons (*Ardea herodias*) are year-round residents at Lake Mead NRA. Although fairly common, the species can be considered sensitive due to its habit of nesting in large groups or rookeries. Rookeries are present on both Lakes Mead and Mohave. Colonies can begin forming as early as February, with eggs being laid from March to May. Incubation takes four weeks, and young typically do not leave the colony until 60 to 90 days after hatching. Colonies could therefore be expected to be active from February through late summer.

The yellow-billed cuckoo (*Coccyzus americanus*) is a rare summer resident at Lake Mead NRA. This riparian-dependent species has experienced dramatic declines throughout its range. There are few recorded sightings at Lake Mead, although the species was recently documented in the Lower Virgin

River. Protection of breeding habitat is essential for population recovery. The species utilizes willow, cottonwood, mesquite, and tamarisk. The breeding season is fairly abbreviated. Egg-laying begins shortly after the birds' arrival in May. Incubation takes two weeks, and young fledge quickly. Yellow-billed cuckoos should be considered sensitive for the entire period they remain on the breeding grounds, from May through August.

The southwestern willow flycatcher (*Empidonax traillii extimus*), a critically endangered subspecies of the willow flycatcher, is a summer resident that occupies riparian habitat characterized by dense growths of willows, Baccharis, tamarisk, arrowweed, and other plants. The southwestern willow flycatcher has been observed at several locations on Lake Mohave, and breeding has been documented at sites in the Virgin River, Muddy River, and Lake Mead Deltas. Egg-laying begins in May and can extend into July if multiple clutches are laid. Incubation lasts approximately two weeks, and young fledge two weeks after hatching. Since the birds typically build their nests directly over or very near standing water, they can be especially susceptible to disturbance from boats or other water-based recreational activities.

The Yuma clapper rail (*Rallus longirostris yumanensis*) has recently been found in southern Nevada in areas on and adjacent to Lake Mead NRA. Yuma clapper rails occupy marshy areas with shallow water and dense vegetation including bulrush and cattails. The subspecies is listed as endangered and was previously believed to occur only in the Lower Colorado River region in Arizona and California and in parts of Mexico. Sightings in southern Nevada may indicate a range expansion, but formal surveys will be necessary to better understand the species' presence at Lake Mead NRA. If the species is found to breed in the area, eggs could be laid from March through July, followed by a three-week incubation period and a nine- to ten-week period before the young are fully independent and capable of flight. The critical period would thus extend from March until September.

A breeding colony of snowy plovers (*Charadrius alexandrines*) was discovered in 2007 along the Overton Arm. This was the first observation of snowy plovers breeding on Lake Mead and represents a large range expansion (greater than 300 miles) from previously known breeding ranges. Snowy plovers are listed as a Nevada Species of Concern and the Pacific Coast population is federally listed as threatened under the Endangered Species Act. Subsequent exploratory shoreline surveys resulted in the discovery of an additional smaller breeding colony. Monitoring surveys of these sites documented successful breeding in 2007 and 2008.

E. Current Monitoring Programs

Existing monitoring programs occur within the geographic bounds of this plan. Some programs meet regulatory requirements. For example, SNWA maintains a program for drinking water source monitoring in compliance with the Clean Water Act (1972, as amended). The water reclamation districts monitor to comply with their NPDES discharge permits, which are issued by the Nevada Division of Environmental Protection (NDEP). The CWC led the development of the Boulder Basin Adaptive Management Program (BBAMP) and selected a series of monitoring sites and parameters in response to the Environmental Impact Statement for the Systems Conveyance Operation Program (SCOP). There are also regional wildlife conservation programs that monitor within this area, such as monitoring related to

the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) by Reclamation and the Virgin River Habitat Conservation Program by FWS. Numerous agencies have statutory authorities and responsibilities for elements within this plan. Taking these efforts together, within Lake Mead there are 57 monitoring stations. Within Boulder Basin alone, there are approximately 48 monitoring stations (some are currently above water). Lake Mead is extensively monitored through a variety of programs designed for different purposes and to meet a variety of operational/regulatory needs (see **Appendix 1**).

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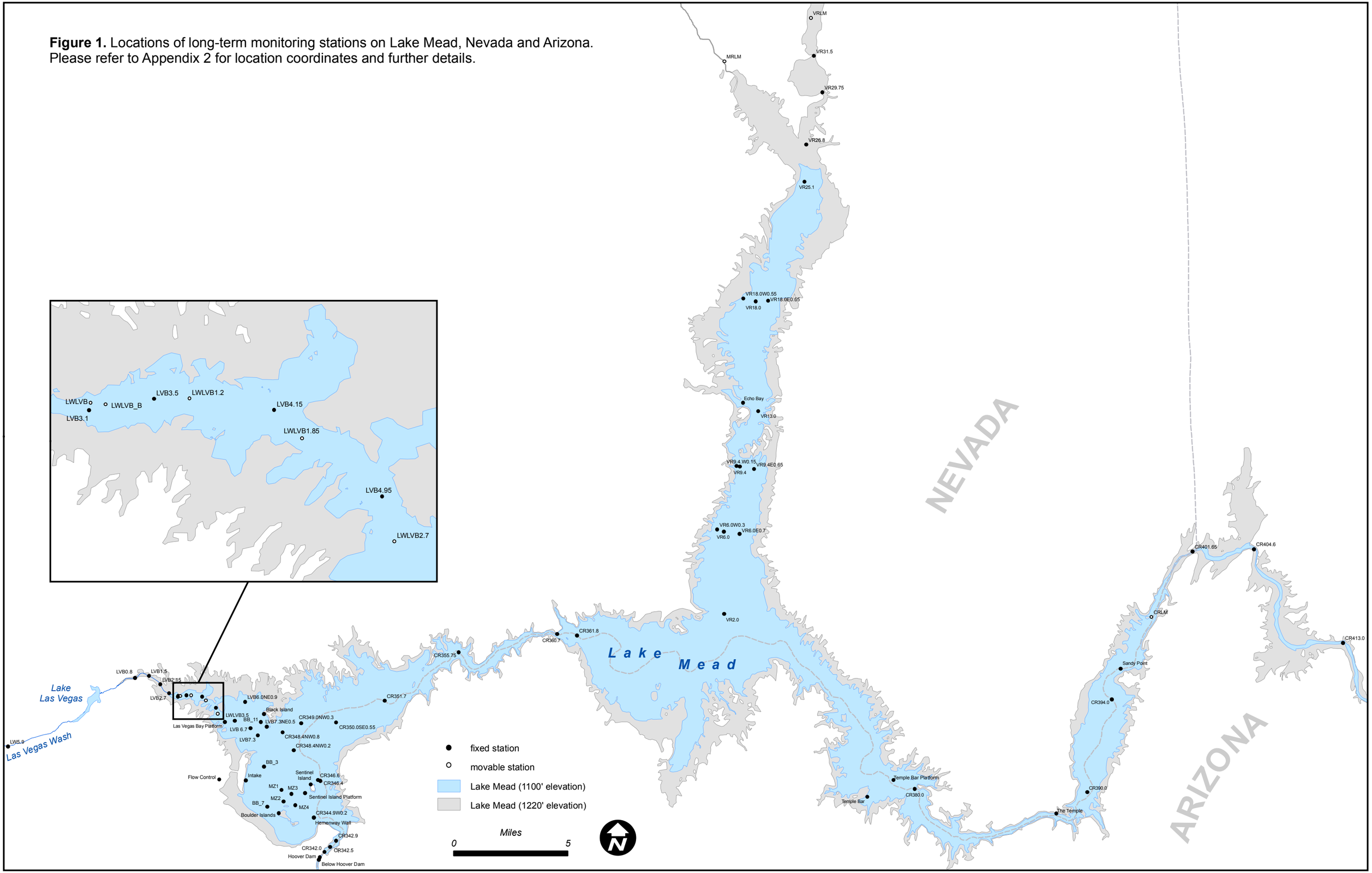
Figure 1. Locations of long-term monitoring stations on Lake Mead, Nevada and Arizona. Please refer to Appendix 2 for location coordinates and further details.



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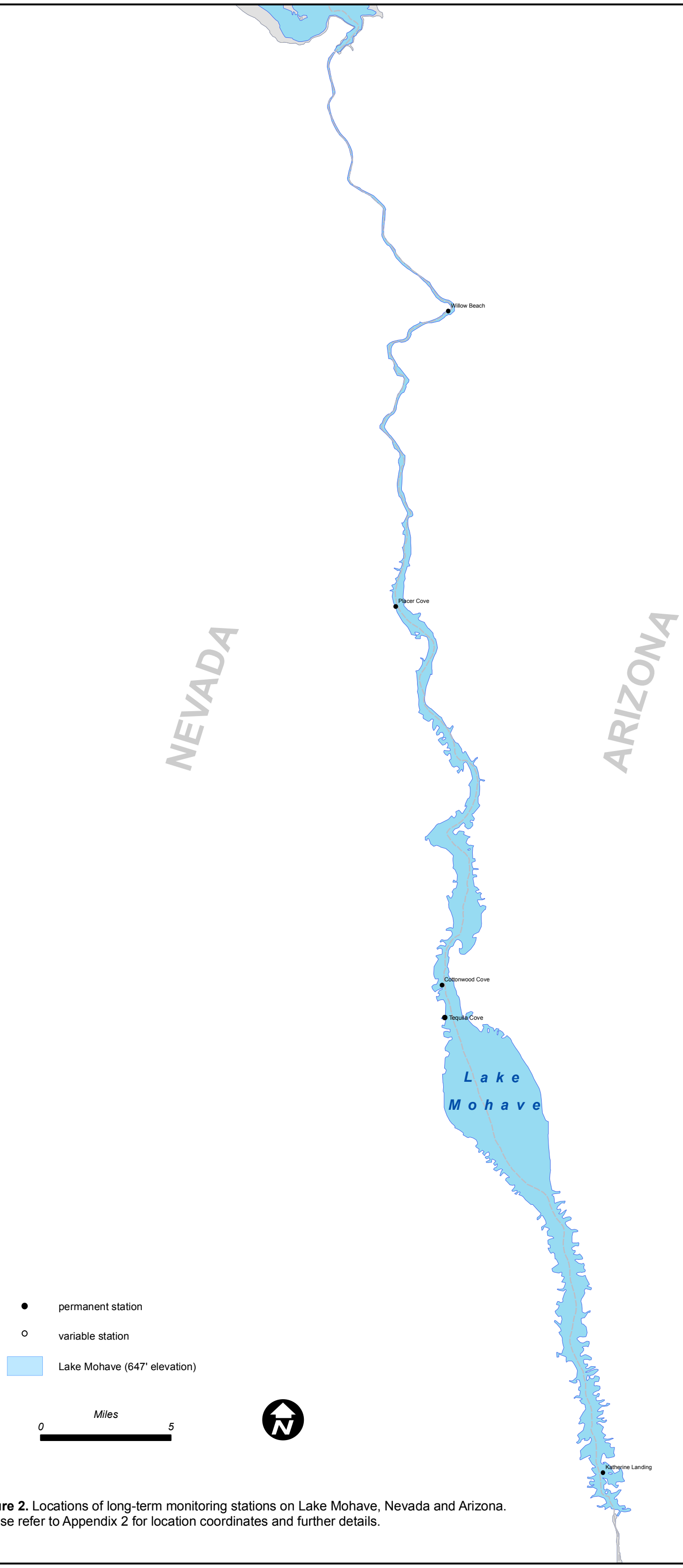

Figure 2. Locations of long-term monitoring stations on Lake Mohave, Nevada and Arizona. Please refer to Appendix 2 for location coordinates and further details.

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II. Strategic Fundamental Objectives and Ecosystem Categories

A. Strategic Fundamental Objectives

The participating agencies have agreed to the following initial set of goals to be supported by a documented comprehensive monitoring and research needs assessment. These goals were adopted as the strategic fundamental objectives of this plan.

Objective 1. Lakes Mead and Mohave maintain water quality that supports a healthy sportsfishery

Objective 2. Lakes Mead and Mohave maintain water quality that supports healthy populations of native fish

Objective 3. Lakes Mead and Mohave maintain water quality that supports healthy populations of aquatic dependent wildlife

Objective 4. Lakes Mead and Mohave maintain water quality that supports healthy populations of riparian, aquatic, and shoreline dependent native vegetation

Objective 5. Lakes Mead and Mohave maintain water quality that supports the existing high quality setting for water-based recreation

Objective 6. Lakes Mead and Mohave maintain water quality that supports regional and community needs for municipal and industrial uses, including domestic water supply and Colorado River System return flow credits.

B. Ecosystem Component Categories

The plan centers on six categories that encompass all ecosystem and limnological components of resource management interest.

Table 3. Strategic fundamental objectives addressed within each ecosystem category (as indicated by ●).

Ecosystem Category	Objective 1 Sportfishery	Objective 2 Native Fish	Objective 3 Aquatic Dependent Wildlife	Objective 4 Native Vegetation	Objective 5 Recreation	Objective 6 Community Needs
Water Quality and Limnology	●	●	●	●	●	●
Fish and Aquatic Biota	●	●	●			
Stressors	●	●	●	●	●	●
Sediment	●	●	●		●	●
Birds			●	●		
Riparian			●	●		

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Category 1. Water Quality and Limnology

Lakes Mead and Mohave are vital resources to the southwestern United States, providing drinking water for more than 25 million people, high quality water-based recreation for more than eight million people annually, including an average of 250,240 angler use days annually (NDOW 2004 – 2008 data) for recreational sport fishing. The lakes provide additional critical habitat for the federally listed endangered razorback sucker as well as key habitats along the western flyway for shorebirds and other waterfowl. Treated sewage effluent from Las Vegas, for which southern Nevada receives Colorado River return-flow credits vital to extending the community's water resources, enters Lake Mead via the Las Vegas Wash. Lake Mead, with a surface area of 157,900 acres (at full pool) and a 29-million-acre-ft storage capacity, is the largest reservoir in North America. Lake Mohave with 26,500 acres of surface area provides re-regulation of Hoover Dam release to ensure consistent volumes to meet downstream delivery. The roles of these water bodies in meeting community needs for drinking water and water management, while meeting significant regional needs for recreation and wildlife habitat, underscore the importance of maintaining water quality and understanding their limnology.

Strategic Objectives

Information related to water quality and limnology is necessary to support the following:

Strategic Fundamental Objectives

- Hhealthy sportfishery
- Healthy populations of native fish
- Healthy populations of aquatic dependent wildlife
- Healthy shoreline dependent native vegetation
- High quality setting for water-based recreation
- Regional and community needs met for municipal and industrial uses, including domestic water supply and Colorado River System return flow credits

Key Category Components

- High quality source for drinking water
- Existing high quality recreational water quality
- Water quality that supports healthy populations of fish and wildlife

Key Category System Drivers

- Volume of reservoirs as influenced by drought, climate change, and community needs
- Timing, quality, and volumes of tributary inflows related to floods and upstream tributary management
- Lake stratification
- Basic hydrology and circulation patterns related to wind, weather, and management

Key Category Stressors

- Invasion by nuisance aquatic species, specifically current concern of quagga mussels
- Urban runoff delivered by tributaries and floodwaters
- Contaminants such as industrial byproducts, organochlorine pesticides, and metals from shallow groundwater contributions to the Las Vegas Wash
- Human and wildlife pathogens (e.g., *E. coli* and fecal coliforms)
- Treated wastewater returned to Lake Mead from urban corridors along Virgin River, Moapa Valley, and Las Vegas Valley

Priority Questions

Management questions best answered by monitoring:

- What are the status and trends of physical and chemical water quality parameters (e.g., conductivity, dissolved oxygen, nutrients, temperature, transparency, pH, and water levels)?
- What are the status and trends of biological water quality parameters (e.g., plankton and chlorophyll-*a*)?
- What are the status and trends of contaminants in the water column [e.g., disinfection byproduct precursors, volatile organic compounds (VOCs), radionuclides, priority pollutants (EPA and State), and pathogens]? (See also **Category 3. Stressors**).

Management questions best answered by research:

- What are the relationships between any changes in wastewater management, tributary inflows, and climate and impacts to water quality parameters, drinking water, fish, aquatic dependent wildlife, and recreation?
- How does water column stratification affect the position or distribution of tributary inflows?
- What are the mass transport and internal cycling budgets for contaminants and nutrients?
- What is the impact of changes in operations at Glen Canyon Dam and Hoover Dam on water quality?

Suggested Monitoring

Suggested Annual Monitoring Program

Lake-wide survey of basic limnological constituents for each lake, to include no less than quarterly monitoring no fewer than 20 stations across Lake Mead, including stations in every major basin and no fewer than four stations in Lake Mohave for:

- Specific conductance
- Temperature
- pH
- Secchi disk transparency
- Dissolved oxygen
- Chlorophyll-*a*
- Nutrients: phosphorus, nitrogen; total and dissolved
- Phytoplankton and zooplankton community composition
- Human pathogens (e.g., *E. coli*, fecal coliforms)
- Lake elevations; inflows and releases
- Wind and weather in upper lake basins
- Notation of events: significant algae blooms, tributary floods, fish die offs, quagga mussel die offs, lake destratification

Suggested Annual Monitoring Program for Boulder Basin

Boulder Basin, the basin that receives urban inflows from the Las Vegas Wash and the basin from which drinking water is drawn, is the most extensively studied portion of the lake. Major indicators of water quality include clarity, pH, specific conductance, temperature, bromide, dissolved oxygen, total organic carbon (TOC), chlorophyll-*a*, and inorganic nutrients. Each of these and 29 other parameters are monitored at 53 sites across Lake Mead: 26 stations in Lake Mead's Boulder Basin are monitored on a weekly basis and an additional 27 sites (dependent on lake level) throughout Lake Mead are monitored on a monthly to quarterly basis. Water quality is continuously monitored by two automated USGS stations in Boulder Basin, and additional water quality measurements are taken at different intervals by researchers working on specific projects in the basin (and other locations in both lakes).

Since the mid 1990s the three water reclamation districts that discharge treated wastewater effluent into Las Vegas Wash have undergone a series of planning initiatives related to a concern that increasing growth in the Las Vegas Valley and corresponding increases in the volume of effluent discharges into Las Vegas Wash could result in failure to meet state water quality standards for the Las Vegas Bay. The most recent and significant of these initiatives was SCOP, which proposed an outfall pipeline to remove significant volumes of wastewater from Las Vegas Wash (see http://cleanwatercoalition.com/SCOPProject/tabid/55/Default.aspx). The SCOP planning and Environmental Impact Statement (EIS) process developed a comprehensive, three-dimensional water quality model for Boulder Basin, which was later extended to encompass the entirety of Lake Mead through a partnership of SNWA, the CWC, and the NPS. The Boulder Basin is a focal point of interest for water quality along the lower Colorado River, due to the fact that the Boulder Basin is the point of

drinking water diversion for SNWA, and that it receives the inputs of the Las Vegas Wash. Downstream Colorado River users have a great interest in the overall water quality released through the Hoover Dam. For those reasons, there is an extensive monitoring program within the Boulder Basin conducted by SNWA and the three water reclamation districts (Clark County, City of Las Vegas, and City of Henderson). See **Appendix 4** for Operational and Regulatory Monitoring Requirements for Lake Mead and **Appendix 5** for Boulder Basin "Baseline" Water Quality Conditions as described by Black & Veatch within the *Systems Conveyance and Operations Program – Final Environmental Impact Statement* (October 2006; p. 3-27)

It is anticipated that the regulatory monitoring required within the Boulder Basin will continue outside the scope of this plan. This plan does not intend to duplicate any of that monitoring, but will attempt to coordinate with those agencies for periodic review and analysis of those data to inform an understanding of the overall limnological health of the lakes. It is also anticipated that this plan may suggest other monitoring or research within the Boulder Basin beyond the scope of the regulatory monitoring, which may enhance the understanding of the overall environmental health of the Boulder Basin.

Suggested Periodic or Cyclic Return Monitoring Program

It is not necessary to monitor the following parameters annually, but they should be monitored periodically to lend to overall limnological and environmental understanding.

- Hydrology and transport – conductivity and water velocity at various depths
- Tributary characterizations and flood flows
- Bathymetry where flow enters the lake
- VOCs: NPS regulations phasing out two-stroke engines and requiring fuel-efficient technology will be in place by 2013. Once the new regulations are in place, new VOC monitoring data could be compared to the data collected in 2003 by the USGS.

Suggested Five-Year Research Priorities

- What are the relationships between any changes in wastewater management, tributary inflows, and climate and impacts to water quality parameters, drinking water, fish, aquatic dependent wildlife, and recreation?
- How does the thermocline affect the position or distribution of tributary inflows?
- What is mass transport and budget for contaminants and nutrients?
- How does change in the operations of Glen Canyon Dam and Hoover Dam affect water quality in Lake Mead?

Annual Data Analysis and Summaries

Selected water-quality constituents for summary statistics:

Specific Conductance (μS/cm)
Temperature, water, degrees Celsius and Fahrenheit
pH
Dissolved oxygen (mg/L)
Transparency, Secchi depth (m)
Chlorophyll-*a,* (μg/L)
Phytoplankton concentration (natural units/mL)
Phytoplankton biovolume (μm^3/mL)
Zooplankton (indiviuals/L)
Total phosphorus (mg/L as P)
Ortho phosphorus (mg/L as P)
Total nitrogen (mg/L as N)
Nitrogen nitrate + nitrite (mg/L as N)
Nitrogen ammonia (mg/L as N)
E. coli (MPN /100mL or cfu/100mL)
Fecal Coliform (MPN/100 mL or cfu/100 mL)
Total Organic Carbon (mg/L)
Bromide (mg/L)

Five-Year Data Interpretation

The goal of the plan, pending funding, will be to analyze for five-year and other long-term trends. It is recommended that the associated report include a discussion of water quality trends for Lakes Mead and Mohave and fulfill the following:

- Evaluates data quality
- Identifies and evaluates trends
- Depicts trends in tables, graphs, or other appropriate graphics
- Identifies water quality parameters of concern
- Identifies data gaps
- Addresses to the extent possible, the suggested 5-year research priorities for this category

Desired Future Conditions and Targets

- NDEP water-quality standards and Requirements to Maintain Higher Quality (RMHQs) for listed constituents are met.
- Water quality and associated aesthetics support existing standards for body contact recreation.
- Water quality is within ranges that support ecosystem integrity and healthy fish and wildlife populations.

Relevant Existing Monitoring

- NPDES regulatory monitoring by water reclamation districts (SNWA Members Database Project #46): The City of Las Vegas samples Lake Mead water at various locations in Boulder Basin as required by the NPDES permits of the City of Las Vegas, the Clark County Water Reclamation District (CCWRD), and the City of Henderson. Various chemical and physical parameters are measured during sampling. The samples are analyzed by the CCWRD for various chemical and microbiological parameters, and by the City of Las Vegas for zooplankton. The City of Henderson collects and analyzes samples from Las Vegas Wash.
- SNWA Safe Drinking Water Act Monitoring and monitoring of the source water in Lake Mead
- USGS platforms funded by SNPLMA
- Reclamation surface monitoring performed by Reclamation's LCR Region
- Reclamation surface monitoring funded by SNPLMA
- Reclamation water quality monitoring of Lake Mohave performed by Reclamation's LCR Region as part of a veliger monitoring program

Several fish species inhabit Lakes Mead and Mohave, including game, non-game, and endemic species that depend on clean water and high quality habitat to maintain healthy populations. Lake Mead provides a nationally recognized sport fishery with an average of 205,164 angler use days annually (NDOW 2004—2008 data; Sjöberg, J. pers. comm.), making it the most popular destination for fishing in Nevada. Lake Mohave is also a popular sport-fishing destination that supports, on average, 45,106 angler use days annually (NDOW 2004—2008 data; Sjöberg, J. pers. comm.). Predominant introduced sport fish within these lakes include largemouth bass (*Micropterus salmoides*), striped bass (*Morone saxatilis*), blue gill (*Lepomis macrochirus*), and channel catfish (*Ictalurus punctatus*), among others. The fishery is dependent primarily upon threadfin shad (forage fish) production as a food source. Rainbow trout (*Onchorhynchus mykiss*) are a regularly stocked species. Lakes Mead and Mohave also provide habitat for populations of razorback sucker (*Xyrauchen texanus*), a federally endangered fish endemic to the Colorado River system. Lake Mohave houses the National Willow Beach Fish Hatchery, which produces thousands of sport fish and raises imperiled fishes such as razorback sucker and bonytail chub for reintroduction efforts. Fish require high water quality and available food resources to maintain healthy populations. Monitoring and research are necessary to track populations and determine health status. Management of both lakes to meet recreational, wastewater, drinking water, hydropower, and flood management needs must be balanced to ensure the integrity of fish populations and their habitats are sustained.

Strategic Fundamental Objectives

Information related to fish and aquatic biota is necessary to support the following

Strategic Fundamental Objectives

- Healthy sportsfishery
- Healthy populations of native fish
- Healthy populations of aquatic dependent wildlife

Key Category Elements

- Lakes Mead and Mohave, together, support an average of 250,240 angler use days annually for sport fishing.
- Key sport fish species include black bass, striped bass, largemouth bass, and smallmouth bass; channel catfish and rainbow trout are stocked in winter months and do not reproduce.
- The key forage fish for sport fish productivity is the pelagic threadfin shad (introduced).
- Lakes Mead and Mohave are both designated critical habitat for the federally listed endangered razorback sucker; Lake Mohave is designated critical habitat for the federally listed endangered bonytail.

- The Lake Mohave population of razorbacks is the most genetically diverse and the largest spawning population on the Colorado River.
- The Lake Mead population of razorback sucker, although low in numbers, is unique as the only population that has sustained natural recruitment to the population for more than 70 years since dam construction. However, the number of offspring surviving into adulthood may not be sufficient to meet recovery goals without active management, which may include captive propagation and other strategies.

Key Category Drivers

- Lake levels and tributary flows
- Lake temperatures for spawning
- Suspended sediments
- Food source/prey base (e.g., nutrient inputs, phytoplankton/zooplankton, and shad)
- Benthic food source for benthic-driven species

Key Category Stressors

- Contaminants (point source and non-point source pollutants)
- Nutrient availability
- Viruses and pathogenic bacteria
- Invasive species such as quagga mussels
- Habitat modification
- Drought and climate change

Priority Questions

▶ **Management questions best answered by monitoring:**

- What are the status and trends of sport fish?
- What are the distributions, reproduction rates, and recruitment levels of native, non-native, and invasive fish?
- What is the biological, chemical, and physical condition of razorback sucker spawning and rearing habitat? Does water quality support recovery of razorback suckers?
- What is the status and trend of the forage base/plankton?
- What contaminants are present in native and non-native fish tissues and to what extent is fish health impaired? Which contaminants, if any, pose a risk to the public (i.e., human health)? (See also **Category 3. Stressors**).
- What are the impacts of invasive species on nutrients? (See also **Category 3. Stressors**).

- **Management questions best answered by research:**

- What factors (abiotic and biotic) influence invasive fish (e.g., tilapia) distribution and abundance?
- What food-web dynamics are in place in Lakes Mead and Mohave? How are these dynamics being altered by drought, invasive species, climate change, and other emerging threats? Are upper trophic levels being adequately maintained to support robust wildlife populations?
- What are the native and sportfish population dynamics?
- What is the ecosystem status; are the historic range and frequency of aquatic habitat conditions being maintained?
- To what extent are endocrine disruptors or hormonally active agents interfering with fish health and reproduction. What is the prevalence of intersex in fish?
- How can razorback sucker recovery in Lakes Mead and Mohave be enhanced? Are threats of (1) habitat modification/loss; (2) non-native predation; and (3) contaminants being adequately addressed?

Suggested Monitoring

Suggested Annual Monitoring Program

- Spawning areas and habitat
- Indicators of adult population numbers of razorback suckers in each reservoir
- Adult population numbers of sport fish in each reservoir
- Forage base/plankton – food sources

Suggested Periodic or Cyclic Return Monitoring Program

It is not necessary to monitor the following parameters annually, but they should be monitored periodically to lend to overall limnological and environmental understanding.

- Contaminants in native and non-native fish tissue
- Fish-condition factors and markers in relation to stressors
- Biological, chemical, and physical condition of razorback sucker spawning and rearing habitat

Suggested Five-Year Research Priorities

- Identify factors (abiotic and biotic) that influence non-native fish distribution and abundance.
- Establish what food-web dynamics are in place in Lakes Mead and Mohave. Determine whether these dynamics are being or can be altered by drought, invasive species, climate change, and other emerging threats. (See also **Category 3. Stressors**).
- Determine native and sport-fish population dynamics.

- Measure ecosystem status; determine whether the natural range and frequency of aquatic habitat conditions are being maintained.
- Assess to what extent are endocrine disruptors or hormonally active agents interfering with fish reproduction (See also **Category 3. Stressors**). What is the prevalence of intersex in fish?
- Indentify how razorback sucker recovery in Lakes Mead and Mohave can be enhanced. Are threats of (1) habitat modification/loss; (2) non-native predation; and (3) contaminants being adequately addressed? (See also **Category 3. Stressors**).
- Assess whether water quality supports recovery of razorback suckers.

Annual Data Analysis

The following constituents are recommended to be summarized annually for sport fish:

Condition of spawning areas and habitat (Lakes Mead and Mohave)	fixed transects
Adult population indicators for Lake Mead	fixed transects
Adult population indicators for Lake Mohave	fixed transects
Zooplankton and chlorophyll	Existing monitoring sites: See **Category 1. Water Quality and Limnology**

The following constituents are recommended to be summarized annually for razorback suckers and bonytail chub:

Condition of spawning areas and habitat (Lakes Mead and Mohave)	fixed transects
Adult population indicators for Lake Mead	fixed transects
Adult population indicators for Lake Mohave	fixed transects
Zooplankton and chlorophyll	Existing monitoring sites: See **Category 1. Water Quality and Limnology**

Five-Year Data Interpretation

The goal of the plan, pending funding, will be to analyze for five-year and other long-term trends. It is recommended that the associated report include a discussion of fish and aquatic biota trends for Lakes Mead and Mohave and fulfill the following:

- Evaluates data quality
- Identifies and evaluates trends
- Depicts trends in tables, graphs, or other appropriate graphics
- Identifies fish and aquatic biota parameters of concern
- Identifies data gaps
- Addresses to the extent possible, the suggested 5-year research priorities for this category

Desired Future Conditions and Targets

- Continued survival within Lakes Mead and Mohave of hatchery-reared juveniles released in accomplishment of the Conservation and Biological Goal for razorback sucker, which is defined within the Lower Colorado River Multi-Species Conservation Program's (LCR MSCP) Habitat Conservation Plan: "Create and maintain 360 acres of species habitat and rear and release up to 620,000 juvenile razorback suckers along the LCR [Lower Colorado River] over the term of LCR MSCP."
- Attainment within Lakes Mead and Mohave of recovery objectives for razorback sucker as described within the U.S. Fish and Wildlife Service (2002) Razorback Sucker (*Xyrauchen texanus*) Recovery Goals: amendment and supplement to the Razorback Sucker Recovery Plan for down-listing and de-listing.
- Maintenance of sport fish condition factors and numbers within historic ranges and in accordance with recent catch rates:

Lake Mead Overall Catch Rates Based on Creel Census Data

YEAR	FISH PER ANGLER DAY	
2003	3.69	
2004	4.50	
2005	4.74	
2006	5.20	
YEAR	FISH PER ANGLER	FISH PER HOUR
2008	5.9	1.3

Lake Mohave Overall Catch Rates Based on Creel Census Data

YEAR	FISH PER ANGLER	FISH PER HOUR
2003	2.0	0.42
2006	0.5	0.16

- To be additionally defined in the first 5-year report

Relevant Existing Monitoring and Research Projects

- **Bioassessment in the Las Vegas Wash and Tributaries - Fish Study**
  FWS and SNWA/SNWA Database Project #573

  One component of bioassessment monitoring in the Las Vegas Wash (Wash) and tributaries involves the collection of fish for contaminant analysis. Five fish are collected at six sites in the Wash and at a regional reference site. The fish are sent out for contaminant analysis for metals, organochlorine pesticides, metalloids, and perchlorate. The sites are LVB, LW0.8, LW6.05, DC_1, NP, and LW10.75. Fish from Pahranagat National Wildlife Refuge serve as control samples from a regional reference site.

- **Contaminant Biology Program**
  USGS

  See:
  Leiker, T.J., S.R. Abney, S.L. Goodbred, and M.R. Rosen. 2009. Identification of methyl triclosan and halogenated analogues in both male common carp (*Cyprinus carpio*) from Las Vegas Bay and Semipermeable Membrane Devices from Las Vegas Wash, Nevada. *Science of the Total Environment,* **407***,* 2102-2114.

- **Fish Health in Lake Mead in Lake Mead National Recreation Area**
  USGS

  See:
  http://nevada.usgs.gov/water/projects/mead_endocrine.htm
  http://pubs.er.usgs.gov/usgspubs/wri/wri964266

- **Lake Mead Larval Threadfin Shad Production Sampling**
  NDOW/SNWA Database Project #532

  Annual larval threadfin shad production sampling on Lake Mead to assess the current status of long-term trends in forage availability for pelagic sport fish species, primarily striped bass. Fixed transects are sampled by meter-net trawling using protocols developed in the 1980s by UNLV for the Lake Mead Nutrient Assessment Project. Sampling is conducted annually from mid-May through the end of June and monthly thereafter through August. Calculated relative densities of larval threadfin shad provide an indicator of juvenile and adult shad potential recruitment into the following winter and spring seasons and can be compared to past sampling for trend analysis because of the use of consistent sampling methodology since 1990.

- **Lake Mead Sport Fish Assessment**
  NDOW

  A lakewide sport fish population inventory and assessment through:
  - Gill netting – each fall; cooperatively with AGFD and Reclamation
  - Cove electrofishing – supplemental and complementary to fall gill netting for littoral species
  - Summer littoral dive transects – July-September for black bass and panfish
  - Tournament monitoring – major black bass tournaments
  - Survey of angler use and harvest – access point creel census

- **Organic Chemical Concentrations and Reproductive Biomarkers in Common Carp (*Cyprinus carpio*) Collected from Two Areas in Lake Mead, Nevada, May 1999–May 2000**
  USGS

  See:
  http://pubs.usgs.gov/ds/2007/286/

- **Organic Chemical Concentrations in Water Related to Fish Health**
  USGS

  See:
  https://www.agronomy.org/publications/jeq/view/organic-contaminants/q09-0095.pdf

- **Summary of Research Related to Fish Health in Lake Mead**
  USGS

  See:
  http://pubs.water.usgs.gov/fs20063131

- **Razorback Monitoring and Studies**
  Funded through LCR MSCP and SNWA

  Razorback sucker population studies funded by both Reclamation and SNWA have been conducted on Lake Mead since the late 1990s. The FWS has been working with the USGS for more than 10 years to assess the impacts of pollution on fish health in Lake Mead. These two efforts recently combined into a partnership to assess the reproductive health of razorback suckers.

- **Razorback Round-up**
  Multi-agency

  The Razorback Round-up is annual monitoring of Lake Mohave razorback sucker populations by an interagency team of biologists. The event takes place each March and includes collection of razorback sucker age and population data, gathering of larvae, and release of hatchery-raised fish into protected backwaters.

- **Assessment of Benthic Ecology of Lake Mead Prior to the Expansion of Adult Quagga Mussel**
  University of Nevada, Reno and USGS

  The invasive quagga mussel was discovered in Lake Mead in January 2007. In the Great Lakes, such infestation has proven to significantly alter lake-system energetics and food-web linkages. Such impacts within the Great Lakes region have included changes in phytoplankton biomass and composition, changes to pelagic fish communities, and alterations to benthic community structure. There is great potential for ecosystem wide

impacts within both Lake Mead and Lake Mohave. While there is a long history and continuous program of monitoring phytoplankton in Lake Mead, there is very little information on benthic organisms and benthic ecology, and food web energetics between open water and benthic areas upon which to base assessments of ecosystem and food web changes, and to guide future monitoring and management.

- All water-quality monitoring projects (see **Category 1 Limnology and Water Quality**) are of direct relevance to fish and aquatic biota.

Category 3. Abiotic and Biotic Stressors/Invasive Species/Climate Change

Significant alterations to the environment and community structure by abiotic and biotic stressors (i.e., contaminants, invasive species, and/or climate changes) could affect food webs and dynamics within Lakes Mead and Mohave and thereby cause profound ecosystem changes. Contaminants, invasive species, and climate change are discussed in further detail below.

Contaminants

Water quality in Lake Mead, particularly Las Vegas Bay, is affected by point and non-point sources emanating from Las Vegas Wash, an urban perennial stream that receives more than 175 million gallons per day of treated effluent from three wastewater treatment plants in Henderson, Las Vegas, and Clark County, Nevada. In addition, historic military and commercial industrial complexes located near the Wash have contributed known contaminants such as perchlorate, dichloro-diphenyltrichloroethane (DDT), and polychlorinated biphenyls (PCBs). Runoff and ground-water seepage from urban irrigation in Las Vegas also contribute organic contaminants (e.g., bacteria, oil, grease, pesticides, herbicides, nutrients from fertilizers) and metals to the Wash. Perchlorate has been detected in Lake Mead and downstream of the outlet from Hoover Dam in Lake Mohave in the area of Willow Beach. In addition, drought conditions in the region have lowered lake levels more than 100 ft, which may concentrate contaminants in some locations. Specific monitoring and research questions appear in other categories as appropriate, and are repeated within this section.

Invasive Species

The spread of invasive species is recognized as one of the major factors contributing to ecosystem change and instability throughout the world. An invasive species is "a non-native species whose introduction does, or is likely to cause, economic or environmental harm or harm to human, animal, or plant health" (Executive Order 13112, 1999).

<u>Quagga Mussels</u>

Adult quagga mussels (*Dreissena bugensis*) were detected in Lake Mead in January 2007; they subsequently spread throughout both Lakes Mead and Mohave. This invasive species has the potential to cause millions of dollars of damage by clogging engines and encrusting boats and facilities, disrupting the food chain, disrupting sport fishing, and littering beaches of Lakes Mead and Mohave. Following invasion, a standardized, cost-effective long-term quagga mussel-monitoring plan was developed for Lake Mead: the *Interagency Management Action Plan (I-MAP) for Quagga Mussels*. This document focuses monitoring of adults, juveniles, and veligers. Adults are monitored at 56 selected sampling stations locations that correspond to sub-surface rocky, sandy, and muddy areas. Veligers are monitored at 42 sampling sites. The I-MAP also suggests monitoring intervals.

Potential Noxious Aquatic Plant Invaders

The introduction of invasive plant species to United States water bodies has been escalating with widespread destructive consequences. Invasive plants are associated with significant habitat destruction, loss of animal communities, reduced fishing and water recreation opportunities, and large mitigation expenditures. Some potential aquatic plant invaders to Lakes Mead and Mohave include the following species listed below.

- Giant Reed (*Arundo donax*)
- Hydrilla (*Hydrilla verticillata*)
- Eurasian Water Millfoil and Parrotfeather (*Myriophyllum sp.*)
- Alligator Weed (*Alternanthera philoxeroides*)
- Curly Leaf Pondweed (*Potamogeton crispus*)
- Giant Salvinia (*Salvinia molesta*)

Climate Change

Colorado River water originates as spring thaws of snowpack in the Rocky Mountains; changes to snow processes in the Rockies will affect all reservoirs along the Colorado, including Lakes Mead and Mohave. Warmer temperatures may create significant water supply shortages in the Colorado River. "A warming climate is, in general, expected to increase water temperatures and modify regional patterns of precipitation, and these changes can have direct effects on water quality (Lettenmaier 2008)." Impacts to Lakes Mead and Mohave ecosystems would likely result from changes in water quantity within the Colorado River system, which would, in turn, correspond to higher probabilities of lowering lake levels, increases in surface water temperatures resulting in changes in plankton/biota and lake mixing, potential increases in urban runoff from increased probability of flash floods, and changes to shoreline vegetation and animal resources.

Strategic Objectives

Information related to abiotic and biotic stressors, invasive species, and climate change is necessary to support the following:

Strategic Fundamental Objectives

- Healthy sport fishery
- Healthy populations of native fish
- Healthy populations of aquatic dependent wildlife
- Healthy shoreline dependent native vegetation
- High quality setting for water-based recreation
- Regional and community needs met for municipal and industrial uses, including domestic water supply and Colorado River System return flow credits

Key Category Elements

- Alterations to the environment and community structure by contaminants, invasive species, and/or climate changes will affect food webs and dynamics within Lakes Mead and Mohave, likely causing profound changes to their respective ecosystems.
- Lake Mead and Lake Mohave water quality and quantity depends upon spring thaws of snowpack in the Rocky Mountains.

Key Category Drivers

- Certain characteristics of Lakes Mead and Mohave, and the surrounding environment, increase their susceptibility to invasion. For example, the temperature and limnology of the lakes is ideal for quagga mussels; being easily accessible and frequented by millions of visitors as popular recreation destinations increases the probability of import of invasive animal and aquatic plant species by humans.
- Climate change reducing snow volume on the Colorado Rocky Mountains will decrease water quantity in all reservoirs on the Colorado River; decreased volume leads to increased concentration of contaminants and other dissolved chemical constituents.
- Changes to lake temperatures due to climate change may impact limnological conditions.

Key Category Stressors

- This category describes a number of specific stressors within the broad stressors of contaminants, invasive species, and climate change.

Priority Questions

▶ **Management questions best answered by monitoring:**

- What are the status and trends of contaminants in the water column [e.g., disinfection byproduct precursors, VOCs, radionuclides, priority pollutants (EPA and State), and pathogens]? (See also **Category 1. Water Quality and Limnology**).
- What contaminants are present in native and non-native fish tissues and to what extent is fish health impaired? Which contaminants, if any, pose a risk to the public (i.e., human health)? (See also **Category 2. Fish and Aquatic Biota**).
- How effective are the new Las Vegas Wash wetlands in keeping contaminants out of Las Vegas Bay? (See also **Category 4. Sediment**).
- What is the status and trend of re-suspension and transport of contaminants and nutrients from sediments? (See also **Category 4. Sediment**).
- What is the status and trend of contaminants in sediments? (See also **Category 4. Sediment**).

- What is the effect of dredging or other maintenance activities on contaminant release from sediment? (See also **Category 4. Sediment**).
- What contaminants are present in aquatic dependant bird tissues, such as eggs? (See also **Category 5. Birds**).
- What amount and type of contaminants are in aquatic dependant bird food sources? (See also **Category 5. Birds**).
- What are the trends in aquatic invasive species (e.g., quagga mussel, Asiatic clam, New Zealand mud snail) abundance and distribution?
- What are the trends in invasive species of aquatic plant (e.g., giant reed, hydrilla, Eurasian water milfoil, and giant salvinia) abundance and distribution?
- What are the impacts of invasive species on nutrients? (See also **Category 2. Fish and Aquatic Biota**).
- What is the difference between historic lake levels and predicted lake levels due to climate change?
- What is the relationship of flows to lake levels? How does climate change relate to water availability?
- Are lake surface water temperatures changing as a result of climate change?
- What impacts are brought about by changes to waste water delivery systems to Boulder Basin?

▶ **Management questions best answered by research:**

- What are the mass transport and internal cycling budgets for contaminants? (See also **Category 1. Water Quality and Limnology**).
- To what extent are endocrine disruptors or hormonally active agents (contaminants) interfering with fish health and reproduction? (See also **Category 2. Fish and Aquatic Biota**).
- How do sediments serve as nutrient and contaminant traps or sinks and how do they affect productivity? (See also **Category 4. Sediment**).
- How do sediments and contaminants interact with the food web? (See also **Category 4. Sediment**).
- What is the relationship between sediment accumulation and contaminant accumulation? What is the fate and transport of contaminants? Is there a subsurface barrier? (See also **Category 4. Sediment**).
- What are the best management practices and treatment methods to deal with invasive species to sustain the biodiversity and function of the Lake Mead/Lake Mohave ecosystems?
- What is the life history of a selected invasive species under the environmental conditions of Lakes Mead and Mohave?

- What are impacts/potential impacts of aquatic invasive species on water quality related to drinking water and recreation?
- What are the impacts/potential impacts of invasive species on the Lake Mead and Mohave ecosystems, especially to fish and other aquatic living resources?
- What are impacts/potential impacts of climate change on water quality related to drinking water and recreation?
- What are the impacts/potential impacts of climate change on the Lake Mead and Lake Mohave ecosystems, especially to fish, other aquatic living resources, and birds?
- How are the inputs of metals changed over time and place by climate change? (See also **Category 4. Sediment**).
- What food-web dynamics are in place in Lakes Mead and Mohave? How are these dynamics being altered by drought, contaminants, invasive species, climate change, and other emerging threats? Are upper trophic levels being adequately maintained to support robust wildlife populations? (See also **Category 2. Fish and Aquatic Biota** and **Category 5. Birds**).
- Can stressors impact water quality, water security, and water delivery systems in such a way that response actions are required that affect ecosystem components?

Suggested Monitoring

Suggested Annual Monitoring Program

- Selenium, metals, endocrine disrupting chemicals (EDCs), emerging contaminants of concern (ECCs), and pathogens (within the water column and tissues)
- Continued monitoring of emerging contaminants of concern (See **Appendix 4**) and as prescribed within the BBAMP Items of Concern (IOCs)
- Selenium, metals, EDCs, and pathogens in sediments (See also **Category 3. Sediments**)
- Continued invasive vegetation monitoring by NPS Exotic Plant Management Teams
- Continued quagga mussel adult and veliger monitoring as prescribed by the I-MAP
- Documentation of lake levels and fluctuations; documentation of spring snow pack and annual Colorado River flows
- Lake temperatures at a variety of locations and depths to correspond with potential climate changes
- Air temperature and basic meteorology

Suggested Periodic or Cyclic Return Monitoring Program

It is not necessary to monitor the following parameters annually, but they should be monitored periodically to lend to overall limnological and environmental understanding.

Contaminants

- VOCs: NPS regulations phasing out two-stroke engines and requiring fuel-efficient technology will be in place by 2013. Once the new regulations are in place, new VOC

monitoring data could be compared to the data collected in 2003 by the USGS. (See **Category 1. Water Quality and Limnology**).
- Contaminants in native and non-native fish tissue. (See **Category 2. Fish and Aquatic Biota**).
- Contaminants in bird tissue, including eggs. (See **Category 4. Birds**).

Quagga Mussels
- Impacts to basic limnology and plankton/forage base/food web dynamics
- Impacts to recreation

Aquatic Invasive Plant Species
- Baseline native vegetation surveillance – following baseline assessment and analysis, subsequent periodic or cyclic return monitoring activities should be determined

Climate Change
- Baseline monitoring – following establishment of a formal climate-change monitoring program, additional periodic or cyclic return monitoring activities should be determined.
- Evaluation of lake temperature profiles in correlation to air temperatures.

Suggested Five-Year Research Priorities

Contaminants
- Assess to what extent are endocrine disruptors or hormonally active agents interfering with fish reproduction. What is the prevalence of intersex in fish? (See also **Category 2. Fish and Aquatic Biota**).
- Indentify how razorback sucker recovery in Lakes Mead and Mohave can be enhanced. Are threats of contaminants being adequately addressed? (See also **Category 2. Fish and Aquatic Biota**).
- Determine whether reproductive success and health are impaired by contaminants for wading birds, shorebirds, or other migratory birds and which contaminants, if any, pose a risk to the public (i.e., human health). Assess wintering bald eagles for contaminate burdens in tissues, and assess contaminants in eggs as well as impacts to reproductive success on breeding grounds. (See also **Category 4. Birds**).

Quagga Mussels
- Population dynamics and demographics
- Impacts to nutrient cycling and dissolved oxygen
- Impacts to Boulder Basin and drinking water and SCOP mixing zone
- Impacts to basic limnology and plankton/forage base/food web dynamics
- Impacts to recreation – mats of shells and algae

Aquatic Invasive Plant Species
- Baseline native vegetation surveillance (See also **Category 5. Riparian Resources**)
- Early detection practices to identify invasions

- Identification of early detection mechanisms for other non-native invasive species to which Lakes Mead and Mohave are vulnerable
- Effective treatment and control methods to manage invasive species within Lakes Mead and Mohave and corresponding management action monitoring activities
- Effective restoration methods to employ following invasion and treatment/control

Climate Change

- Model and monitor for the impacts of climate change or drought on water level (water quantity), and in turn, water quality.
- Establish what food-web dynamics are in place in Lakes Mead and Mohave. Determine whether these dynamics are being or can be altered by drought, invasive species, climate change, and other emerging threats. (See also **Category 2. Fish and Aquatic Biota** and **Category 5. Birds**).
- Assess whether the frequency and magnitude of invasions at Lakes Mead and Mohave are or can be influenced by climate change and, if so, in what way.

Annual Data Analysis

Contaminants

- Summarize data on selenium, metals, EDCs, ECCs, pathogens (water column, tissues, and sediments), and emerging contaminants of concern. See **Appendix 4** and as prescribed within the BBAMP Items of Concern (IOCs).

Quagga Mussels

- Summarize data collected through implementation of the Interagency Management Action Plan for Quagga Mussels (I-MAP; see p. 40 for more information).

Aquatic Invasive Plant Species

- Summarize and map annual weed surveys.

Climate Change

- Summarize water and air temperature data.
- All data collected throughout this plan are useful to monitoring the impacts of climate change; climate and weather data should be combined in the synthesis reporting to identify any interactions between climate change and ecological systems.

Five-Year Data Interpretation

The goal of the plan, pending funding, will be to analyze for five-year and other long-term trends. It is recommended that the associated report include a discussion of trends observed in relation to abiotic and biotic stressors for Lakes Mead and Mohave and fulfill the following:

- Evaluates data quality
- Identifies and evaluates trends
- Depicts trends in tables, graphs, or other appropriate graphics

- Identifies water quality parameters of concern
- Identifies data gaps
- Addresses to the extent possible, the suggested 5-year research priorities for this category

Relevant Existing Monitoring

Contaminants

- **Lake Mead Endocrine Disrupting Contaminants Investigation: Passive Sampling of Estrogenics, Method Development, and Contaminants Analyses**
  USGS

  See:
  http://nevada.usgs.gov/water/projects/mead_endocrine.htm

Invasive Species

- **Interagency Management Action Plan (I-MAP) for Quagga Mussels Implementation**
  NPS Lake Mead NRA, UNLV, and others

  The goal of I-MAP is to develop a standardized, long-term, cost-effective, and consistent monitoring plan for quagga mussels in Lake Mead to gain efficiencies from shared operations and information. The plan attempts to build upon current monitoring activities and capabilities, identifies the next steps that can occur within existing capabilities, and, finally, outlines gaps and areas of future need. The first step prescribed by the I-MAP is to identify key needs, questions, and projects related to the objectives associated with (1) infestation of quagga mussels and (2) the basic biology and ecology of quagga mussels. The approach is cost-effective in that it uses statistically determined minimum numbers of sampling stations that can represent the entire lake and an appropriate sampling frequency that will best estimate recruitment and growth of quagga mussels in Lake Mead.

- **Assessment of Benthic Ecology of Lake Mead Prior to the Expansion of Adult Quagga Mussel University of Nevada, Reno and USGS**

  There is great potential for ecosystem-wide impacts by quagga mussels within both Lake Mead and Lake Mohave. While there is a long history and continuous program of monitoring phytoplankton in Lake Mead, there is very little information on benthic organisms and benthic ecology, and food-web energetics between open water and benthic areas upon which to base assessments of ecosystem and food-web changes, and to guide future monitoring and management. This project is designed to help fill that gap.

- **Veliger Monitoring**
  Reclamation Denver Science Center

  Sampling and conducting monthly veliger counts for eight locations on Lake Mead.

- **Veliger Monitoring**
  Reclamation LCR

  Sampling and conducting monthly veliger counts for four locations on Lake Mohave.

Climate Change

- **Hourly Documentation of Reservoir Levels**
  Reclamation LCR

  See:
  http://www.usbr.gov/lc/region/g4000/hourly/hourly.html

- **Near-Real-Time Water Quality (including water temperature) and Meteorological Data Collection on Lake Mead**
  USGS

  See:
  http://nevada.usgs.gov/lmqw/instrumentation.htm#

- **NPDES studies for water temperature**

Desired Conditions and Targets

- Management of animal and vegetative invasive species at Lake Mead NRA takes place using research-supported techniques and practices.
- Natural resource vulnerabilities due to climate change and corresponding management actions are identified.

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After the completion of Hoover Dam in 1935, sediment began accumulating in the new reservoir (Lake Mead) as the flow of the Colorado River was captured. Three studies have examined the amount of sediment accumulation and the rate of sedimentation in Lake Mead: a 1948-1949 USGS and Reclamation study (Smith et al. 1960), a 1963-1964 Reclamation study after the closure of Glen Canyon Dam (Lara and Sanders 1970), and a 2001 USGS and Reclamation study. Results of the 2001 study show that post-impoundment sediment is generally distributed along the floors of the deepest parts of the lake, mainly following the paths of the former Colorado River and the tributary valleys that fed into it, rather than being deposited as a drape across the entire lake floor (Twichell et al. 2005). These sediments are thickest in the deltas that formed at the mouths of the Colorado River and its tributaries, including the Virgin and Muddy Rivers. Maximum sediment thickness exceeds 80 m where the Colorado River enters Lake Mead, thinning to 15-35 m in thickness along the remainder of the drowned Colorado River channel to Hoover Dam. Tributary valleys have a thinner sediment cover indicating the Colorado River has been the primary sediment source. Sediment cores indicated stratification of fine silt interrupted by graded beds containing as much as 30 percent sand deposited from turbidity currents, which flowed the full length of the lake. With the completion of Glen Canyon Dam in 1964, sediment volume entering Lake Mead from the Colorado River decreased to approximately one tenth of the pre-dam volume (Lara and Sanders 1970). With the lake levels dropping since 2000, delta deposits at the mouth of the Colorado River and tributaries, including Las Vegas Wash, have been eroded by the river flow and redistributed to the deeper parts of the lake.

Sediment cores taken in 1998 have been examined for anthropogenic and natural organic and inorganic contaminants (Covay and Beck 2001; Rosen and Van Metre 2009). In addition, sediment from Las Vegas Wash (the main tributary from Las Vegas) has also been examined for contaminants (Covay and Leiker 1998). These studies found numerous organic compounds associated with urban runoff, industrial contaminants from erosion of the Basic Management Incorporated (BMI) site on Las Vegas Wash, and compounds associated with tertiary treated wastewater effluent, although few compounds were greater than Canadian sediment quality guidelines (Rosen and Van Metre 2009).

In contrast to Lake Mead, remarkably little sediment has accumulated in Lake Mohave since its impoundment in 1953 (Foster 2004). Lake Powell and other upstream reservoirs trap virtually all of the sediment transported by the Colorado River. The small amount of fine-grained sediment, which has accumulated, tends to occur in the deepest parts of the lake within sheltered areas along the edges of the drowned Colorado River channel. Other post-impoundment deposits include debris flows found at the mouths of washes probably associated with flash floods and landslides along the base of steep cliffs in the northern section of the lake, which appear to be the result of cliff collapse (Foster 2004). Knowledge of any contaminants present Lake Mohave sediments is currently lacking.

Strategic Objectives

Information related to sediment is necessary to support the following:

Strategic Fundamental Objectives

- Healthy sports fishery
- Healthy populations of native fish
- Healthy populations of aquatic dependent wildlife
- Healthy shoreline dependent native vegetation
- High quality setting for water-based recreation
- Regional and community needs met for municipal and industrial uses, including domestic water supply and Colorado River System return flow credits

Key Category Components

- High quality reservoir for drinking water
- Existing high quality recreational water quality
- Water quality that supports healthy populations of fish and wildlife (including benthic organisms)

Key Category System Drivers

- Contaminant release proceeds through porewater
- Contaminant release depends upon dissolved oxygen (DO) concentration, pH, temperature, binding strength, and ionic strength of the immediately adjacent water layer
- Urban runoff and delivery by tributaries and floodwaters
- Las Vegas Wash and Bay are areas of unique sediment activity (e.g., deposition, effects to fishery, contaminant sinks)

Key Category Stressors

- Treated wastewater returned to Lake Mead from urban corridors along Virgin River, Moapa Valley, and Las Vegas Valley
- Illegal dumping into storm drains and lakes
- Human pathogens introduced via recreation
- Lifestock/wildlife pathogens introduced via grazing or other water use
- Anoxic conditions tend to result in higher release rates
- Urban runoff (including abandoned industrial sites such as the BMI site) and delivery by tributaries and floodwaters

Priority Questions

Management questions best answered by monitoring:

- What is the status and trend of re-suspension and transport of contaminants and nutrients from sediments?
- What is the status and trend of sediment delivery at tributaries?
- What is the status and trend of contaminants in sediments?
- How does sediment distribution affect spawning potential and reproductive success of sensitive species?
- How effective are the new Las Vegas Wash wetlands in keeping contaminants out of Las Vegas Bay? (See also **Category 3. Stressors**).
- What is the effect of dredging or other maintenance activities on contaminant release from sediment? (See also **Category 3. Stressors**).

Management questions best answered by research:

- How do sediments serve as nutrient and contaminant traps or sinks and how do they affect productivity?
- What happens (e.g., microbial degradation, transport, compaction etc.) to contaminants in sediment?
- Are quagga mussels and other invasive species affecting sediment dynamics or vice versa? (See also **Category 3. Stressors**).
- How do sediments and contaminants interact with the lower part of the food web? (See also **Category 2. Fish and Aquatic Biota**).
- What is the role of sediment transport in relation to native fish spawning and fish habitat? (See also **Category 2. Fish and Aquatic Biota**).
- Where do sediments accumulate in greatest abundance? Are there places where contaminants accumulate? What is the fate and transport of contaminants? Is there a subsurface barrier?
- What is the relationship between suspended sediment and the aquatic food web and success of razorback sucker? (See also **Category 2. Fish and Aquatic Biota**). How does turbidity vary seasonally?
- What pathogen/sediment associations are present and what causes pathogen remobilization into the water column?
- How are the inputs of metals changed over time and place by anthropogenic (e.g., dams, manganese mining), atmospheric (climate change), or other natural actions?
- How do wastewater delivery systems impact sediments?

Suggested Monitoring

Suggested Annual Monitoring Program

Sediments

- PONAR sampling of surface sediments in high depositions areas within a chosen geographical suite

Sediment Contaminants

- Selenium, metals, EDCs, and pathogens in sediments

Suggested Periodic or Cyclic Return Monitoring Program

It is not necessary to monitor the following parameters annually, but they should be monitored periodically to lend to overall limnological and environmental understanding.

Sediments

- Core analysis in pre-selected areas for deposition rate and environmental change

Sediment Contaminants

- Selenium, metals, EDCs, and pathogens in sediments at a broader range of sites than is done annually

Suggested Five-Year Research Priorities

Sediments

- Examine whether quagga mussels and other invasive species affect sediment dynamics or vice versa. (See also **Category 3. Stressors**).
- Trace sediment fate (e.g., microbial degradation, transport, compaction etc.).
- Determine the role of sediment transport in relation to native fish spawning and fish habitat. (See also **Category 2. Fish and Aquatic Biota**).
- Examine the relationship between suspended sediment and the aquatic food web and success of razorback sucker. (See also **Category 2. Fish and Aquatic Biota**). Assess seasonal variation in turbidity.

Sediment Contaminants

- Identify how sediments and contaminants interact with the lower part of the food web. (See also **Category 2. Fish and Aquatic Biota**).
- Assess the effect of dredging activities on contaminant release from sediment. (See also **Category 3. Stressors**).
- How effective are the new Las Vegas Wash wetlands in keeping contaminants out of Las Vegas Bay? (See also **Category 3. Stressors**).
- Determine whether sediments serve as nutrient and contaminant traps or sinks and how they affect productivity.

- Determine where sediments accumulate in greatest abundance. Are there places where contaminants accumulate? What is the fate and transport of contaminants? Is there a subsurface barrier?
- Identify what pathogen/sediment associations are present and what causes pathogen remobilization into the water column.
- Examine the change of inputs of metals over time and place by anthropogenic (e.g., dams, manganese mining), atmospheric (climate change), or other natural actions.
- How do wastewater delivery systems impact sediments?

Annual Data Analysis

- Summarize data on selenium, metals, EDCs, and pathogens in sediments

Five-Year Data Interpretation

The goal of the plan, pending funding, will be to analyze for five-year and other long-term trends. It is recommended that the associated report include a discussion of sediment and sediment-contaminant trends for Lakes Mead and Mohave and fulfill the following:

- Evaluates data quality
- Identifies and evaluates trends
- Depicts trends in tables, graphs, or other appropriate graphics
- Identifies water quality parameters of concern
- Identifies data gaps
- Addresses to the extent possible, the suggested 5-year research priorities for this category

Desired Conditions and Targets

- Sediment contaminant concentrations are below Canadian sediment-quality guidelines (McDonald et al. 2000).
- To be further defined in the 5-year report

Relevant Existing Monitoring or Research Projects

<u>Sediment Studies in Lake Mead</u>

- **2001 Lake Mead Sedimentation Survey**
  U.S. Bureau of Reclamation, February 2008

- **Comprehensive Survey of Sedimentation in Lake Mead, 1948-49**
  Geological Survey Professional Paper 295

- **Mapping the Floor of Lake Mead (Nevada and Arizona): Preliminary Discussion and Geographic Information System Data Release**
  USGS

  U.S. Geological Survey Open File Report 03-320

- **Surficial Geology of the Floor of Lake Mead (Arizona and Nevada) as Defined by Sidescan-sonar Imagery, Lake Floor Topography and Post-impoundment Sediment Thickness**
  USGS

  U.S. Geological Survey Open File Report 2009-1150

- **The 1963-64 Lake Mead Survey**
  Reclamation

  U.S. Bureau of Reclamation REC-OCE-70-21

Sediment Contaminants in Lake Mead

- **Endocrine Disruption in Lake Mead**
  USGS

  See:
  http://nevada.usgs.gov/water/projects/mead_endocrine.htm and

  Rosen M.R. and P.C. Van Metre. 2009. Assessment of multiple sources of anthropogenic and natural chemical inputs to a morphologically complex basin, Lake Mead, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology* (in press; available online).

  Covay, K.J. and D.A. Beck. 2001. Sediment-deposition rates and organic compounds in bottom sediment at four sites in Lake Mead, Nevada, May 1998. U.S. Geol. Surv. Open-File Rep. 01–282. 34 pp.

  Covay, K.J. and T.J. Leiker. 1998. Synthetic organic compounds in water and bottom sediment from streams, detention basins, and sewage-treatment plant outfalls in Las Vegas Valley, Nevada, 1997. U.S. Geol. Surv. Open-File Rep. 98–633. 15 pp.

Sediment Studies in Lake Mohave

- **Lake Mohave Geophysical Survey 2002: Geographic Information System Data Release**
  USGS

  U.S. Geological Survey Open File Report 2004-1247

- **Surficial Geology and Analysis of Post-Impoundment Sediment of Lake Mohave; Interpretation of Sidescan Sonar and Seismic-Reflection Data**
  USGS

  U.S. Geological Survey Open File Report 2004-1256

Lakes Mead and Mohave form dynamic ecosystems, in which birds play an important role both ecologically and recreationally. As significant regional aquatic habitats, Lakes Mead and Mohave support diverse populations of resident and migratory waterfowl, songbirds, shorebirds, passerines, and birds of prey. For example, cliff habitat near open water supported 52 peregrine falcons (*Falco peregrines*) in 2008 and approximately 24 breeding territories (NPS; 2008 preliminary data), constituting the largest population in southern Nevada and northwestern Arizona. Large trees and cliffs along the shorelines of both Lakes Mead and Mohave annually support approximately 75 wintering bald eagles (*Haliaeetus leucocephalus*), providing a significant stop along the Pacific Flyway. The endangered southwestern willow flycatcher (*Empidonax traillii extimus*) occurs along the shoreline of Lake Mohave and in the Virgin and Muddy River inflow areas to Lake Mead. Nearly 370 species of migratory birds have been recorded within the Recreation Area. Shorebirds include sandpipers, plovers, ibis, and others. Marsh birds include soras and rails. Waterfowl include ducks, grebes, coots, loons, and cormorants. Wading birds include herons and egrets. Birds associated with the open water include kingfishers, swallows, and terns. Birds of prey at Lake Mead include bald eagle, osprey, hawk, and owls. An aquatic bird-monitoring program has been in place at Lake Mead NRA since 2004. Through this program, more than 31,000 individual birds have been counted at Las Vegas Bay alone between 2004 and 2008 relating to the diversity of aquatic habitats to be found. Portions of Lakes Mead and Mohave, and their surrounding land areas are recognized as an "Important Bird Area (IBA)" by the Audubon Society (see http://iba.audubon.org). See **Appendix 6** for a list of avian species of concern along with their riparian/aquatic habitat uses. These diverse bird populations support a growing segment of the American public that enjoy bird watching and bird photography as popular recreational activities.

Strategic Objectives

Information related to riparian resources is necessary to support the following

Strategic Fundamental Objective

- Healthy populations of aquatic dependent wildlife

Key Category Components

- As top-predators in the food web, birds consume fish and macro-invertebrates, thereby cycling organic matter and nutrients between aquatic and terrestrial environments. Birds of prey in the area consume other terrestrial and aquatic species, including water-dependent birds in the system.

Key Category System Drivers

- Food resource abundance and quality
- Habitat availability and quality (namely water)
- Influence of weather patterns on migration patterns

Key Category Stressors

- Habitat modification (e.g., invasive plant species encroachment on shorebird nesting and foraging grounds)
- Contaminants
- Pathogenic bacteria and viruses
- Grazing by horses, cattle, and burros to include trampling of shorebird nesting sites
- Habitat destruction by wildland fire
- Climate change

Priority Questions

▶ **Management questions best answered by monitoring:**

- What are the distribution, species composition, and abundance of shorebirds, wading birds, waterfowl, and other classes of birds? What are their status and trends?
- Which bird species spend significant amounts of their life history locally or otherwise could be classified as resident species?
- What is the status and trend of shorebird habitat? What are the conditions of foraging/nesting sites? What type and degree of disturbance is present?
- What contaminants are present in bird tissues, such as eggs?
- What is the feeding ecology (prey selection) of sentinel species (e.g., snowy plovers, bald eagles, and peregrine falcons) and what amount and type of potential contaminants are in these food sources?

▶ **Management questions best answered by research:**

- What is the relationship between the food base that supports populations of shorebirds, wading birds, waterfowl, bald eagles, and peregrine falcon and contaminants?
- What are the population dynamics of shorebirds and aquatic birds? Are the population abundances changing among shorebirds and aquatic birds? If so, are these changes corresponding to changes in habitat or other environmental factors?
- What conditions put aquatic-dependent birds at risk from infection by pathogenic bacteria and viruses?

- What are the migratory patterns and breeding distribution of wintering bald eagles or other sensitive species of interest to resource managers?
- To what extent is reproductive success and health impaired by contaminants for wading birds, shorebirds, or other migratory birds? Which contaminants, if any, pose a risk to the public (i.e., human health)? Assess wintering bald eagles for contaminate burdens in tissues, and assess contaminants in eggs as well as impacts to reproductive success on breeding grounds. (See also **Category 3. Stressors**).
- What is the impact of tamarisk (and tamarisk loss due to tamarisk beetle) on breeding and distribution of aquatic dependent birds, particularly the endangered southwestern willow flycatcher (*Empidonax traillii extimus*) or other special status species?

Suggested Monitoring

Suggested Annual Monitoring Program

- Bird surveys including distribution, species composition, breeding status, and abundance of shorebirds, wading birds, waterfowl, and other classes of birds. Consider development of formal monitoring plan(s) for species for which a formal plan in not yet in place.
- Vegetation (See also **Category 6. Riparian Resources**) and associated shoreline habitat surveys.

Suggested Periodic or Cyclic Return Monitoring Program

It is not necessary to monitor the following parameters annually, but they should be monitored periodically to lend to overall limnological and environmental understanding.

- Contaminants in bird tissue, including eggs

Suggested Five-Year Research Priorities

- Identify baseline population dynamics of shorebirds and aquatic birds for future studies investigating changes in population dynamics.
- Assess risk conditions for aquatic bird development of infection by pathogenic bacteria.
- Determine migratory patterns and breeding distribution of wintering bald eagles or other sensitive species of interest to resource managers.
- Determine whether reproductive success and health are impaired by contaminants for wading birds, shorebirds, or other migratory birds and which contaminants, if any, pose a risk to the public (i.e., human health). Assess wintering bald eagles for contaminate burdens in tissues, and assess contaminants in eggs as well as impacts to reproductive success on breeding grounds.
- Determine impact of tamarisk (and tamarisk loss due to tamarisk beetle) on breeding and distribution of aquatic dependent birds, particularly the endangered southwestern willow flycatcher (*Empidonax traillii extimus*) or other special status species.

Annual Data Analysis

- Summarize number of species and individuals by month for pre-selected areas
- Summarize abundance trends by guild for pre-selected areas
- Summarize occupancy/habitat use, prey selection, breeding efforts, and reproductive success rates of peregrine falcon (and other species as yet to be determined)

Five-Year Data Interpretation

The goal of the plan, pending funding, will be to analyze for five-year and other long-term trends. It is recommended that the associated report include a discussion of bird trends observed in Lakes Mead and Mohave and fulfill the following:

- Evaluates data quality
- Identifies and evaluates trends
- Depicts trends in tables, graphs, or other appropriate graphics
- Identifies water quality parameters of concern
- Identifies data gaps
- Addresses to the extent possible, the suggested 5-year research priorities for this category

Desired Conditions and Targets

- Water quality is within ranges that support ecosystem integrity and bird populations. Shoreline habitat conditions support bird populations.
- Bird populations remain within ranges documented within relevant studies such as those conducted through the Reclamation LCR MSCP and by UNLV and others.

Relevant Existing Monitoring or Research Projects

- **Bioassessment in the Las Vegas Wash and Tributaries - Bird Egg Study**
  Reclamation Denver, FWS, SNWS, and SNWA/SNWA Database Project #572

  One component of bio-assessment monitoring in the Las Vegas Wash and tributaries involved the collection of bird eggs for contaminant analysis. Six eggs were collected in five reaches or areas in the Wash and at a regional reference site. The eggs were sent out for contaminant analysis for metals, organochlorine pesticides, metalloids, and perchlorate. Samples were collected in 2003, 2005, and 2007.

- **Shorebird Monitoring on Lakes Mead and Mohave**
  NPS/UNLV

  Monthly inventory and monitoring of aquatic birds (shorebirds, waterfowl, wading birds, gulls, terns, and raptors) from March 2004 through July 2009. This work established species composition by lake, seasonal migration, and wintering patterns, general abundances, and variation by year. Identified breeding areas of shorebirds (snowy plovers) and colonial water birds (great blue herons and double-crested cormorants). Also established were timing of

arrival and departure of wintering bald eagles, as well as collection of preliminary data concerning predation on aquatic birds.

- **Peregrine Falcon Monitoring**
  NPS/UNLV

  This work established breeding density, reproductive success rates, habitat use (breeding and non-breeding seasons), and prey selection. Preliminary data on prey selection indicate over 34 percent of peregrine falcon diet consists of aquatic birds, and likely approximately 10,000 aquatic birds are taken annually on both lakes.

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Wetland and riparian habitats associated with Lakes Mead and Mohave contain many water-dependant species such as honey mesquite, screwbean mesquite, catclaw acacia, cottonwood, true willows, wild grape, grasses, sedges, reeds, and other species. Many riparian plant species are phreatophytes whose roots extend into zone of saturation fed by groundwater, while others are species that depend on surface saturated soils such as those found in marshes. These areas are of significant biological importance to several animal species covered under the Clark County Multiple Species Habitat Conservation Plan including phainopepla, vermillion flycatcher, several species of lizards, and the sidewinder. However, many of these areas are being threatened with risk of degradation through associated human activities such as livestock grazing, off-road vehicle activity, unauthorized firewood gathering, dumping, permitted woodcutting, and groundwater withdrawals. Riparian-area integrity and health are also at risk from wildland fire and invasion of exotic species including red brome and tamarisk.

Riparian ecosystems are potentially sensitive indicators of landscape-level change because they are linked to both aquatic and upland systems, perform important ecological functions, and have high levels of biological diversity.
http://science.nature.nps.gov/im/units/ncpn/Link_Library/Web_Briefs/Riparian_Brief_2009.pdf

Strategic Objectives

Information related to riparian resources is necessary to support the following

Strategic Fundamental Objectives

- Healthy populations of aquatic dependent wildlife
- Healthy shoreline dependent native vegetation

Key Category Components

- High quality riparian and wetland habitat are necessary for protected plant and animal species

Key Category System Drivers

- Groundwater dynamics, including depth to groundwater
- Surface water dynamics
- Stream and shoreline geomorphic processes of erosion and deposition
- Pollinators and propagule dispersal mechanisms

Key Category Stressors

Tamarisk (*Tamarix*) was introduced to the United States in the 19th century as an erosion-control agent and ornamental plant. The highly invasive tamarisk rapidly spread and caused major changes to natural environments. The tamarisk is notorious for consuming large amounts of water (up to 150 gallons a day), crowding out native vegetation, displacing wildlife, and increasing the risk of fire danger. Tamarisk may also degrade rare relict leopard frog habitat found in the canyons.

- Invasion by non-native plant species, especially those that displace native riparian vegetation or alter ecosystem processes
- Grazing by horses, cattle, and burros, including defecation and trampling
- Human visitation, including trampling, illegal collection of plants and animals, and introduction of exotic fish, frogs, salamanders, etc.
- Water quantity as a response to climate change or drawdown of reservoir levels
- Water quality as a result of contamination, sedimentation, or stagnation
- Fire, especially changes in fire frequency or intensity
- Natural stochastic events, such as flash floods

Priority Questions

Management questions best answered by monitoring:

- What are the trends in distribution, connectivity, and abundance of riparian vegetation (native and non-native)?
- To what extent is shoreline tamarisk being affected by tamarisk leaf beetle advancement?

Management questions best answered by research:

- Is riparian vegetation maintained or restored to a condition that supports key riparian functions?
- Is the recruitment of native riparian and wetland plant species sufficient for these communities to persist?
- What is best mix of native/non-native vegetation to support native wildlife populations? (It is impossible to completely eradicate non-natives, so what should be the target mix?)
- What are the threats to wetland and riparian communities?
- How is riparian vegetation impacted by stressors?
- What are the best methods for mitigating threats and implementing restoration?

Suggested Monitoring

Suggested Annual Monitoring Program

- Obtain remotely sensed imagery to detect coarse-scale changes in shoreline vegetation.
- Compile geospatial records annually of fires and weed management activities in riparian areas.
- Monitor beetle activity and impacts.
- Coordinate with Reclamation and LCR MSCP to obtain habitat and vegetation cover maps developed for Lakes Mead and Mohave.

Suggested Periodic or Cyclic Return Monitoring Program

It is not necessary to monitor the following parameters annually, but they should be monitored periodically to lend to overall limnological and environmental understanding.

- Sample population structure (including seed banks) to determine recruitment and potential for recruitment.
- Coordinate with Reclamation to obtain updated imagery and vegetation mapping of shorelines and riparian areas of Lakes Mead and Mohave.

Suggested Five-Year Research Priorities

- Begin to assess whether riparian vegetation is maintained or restored to a condition that supports key riparian functions.
- Begin to assess whether the recruitment of native riparian and wetland plant species is sufficient for these communities to persist.
- Identify the best mix of native/non-native vegetation to support native wildlife populations.
- Identify the threats to wetland and riparian communities and the best methods for mitigating threats and implementing restoration.

Annual Data Analysis

- Summarize vegetation and beetle surveys conducted by NPS, LCR MSCP, or other relevant monitoring efforts. Suggested specific constituents for annual analysis remain to be determined.

Five-Year Data Interpretation

The goal of the plan, pending funding, will be to analyze for five-year and other long-term trends. It is recommended that the associated report include a discussion of vegetation trends observed in Lakes Mead and Mohave and fulfill the following:

- Evaluates data quality
- Identifies and evaluates trends
- Depicts trends in tables, graphs, or other appropriate graphics
- Identifies water quality parameters of concern

- Identifies data gaps
- Addresses to the extent possible, the suggested 5-year research priorities for this category

Desired Future Conditions and Targets

Plant communities are healthy, self-perpetuating, and contain a diverse mix of desired species in varied structural stages. These communities are resistant to rapid change from large disturbances such as floods and capable of maintaining themselves during dry periods. Although complete absence of exotic vegetative species is desired, it is recognized that these species likely cannot be eliminated at Lake Mead NRA. Therefore, the target condition is for exotic vegetative species and noxious weeds to fall within an acceptable proportion of the mix as identified through research activity.

Relevant Existing Monitoring and Research Projects

- **Frog Habitat Manipulation**
  NPS/UNLV

  Response of riparian vegetation to burning and cutting.

- **Implementation and evaluation monitoring conducted for the Lower Colorado River Multi-Species Conservation Program**
  Reclamation LCR

- **Lake Mead NRA Ecosystem Health Monitoring**
  NPS, USGS, NRCS – NV, USDA-ARS Jornada NM

  Review of historic vegetation data, development of soil and vegetation health indicators.

- **Weed Sentry – early detection of incipient exotics in targeted areas**
  NPS/UNLV

III. Data Management and Analysis

A. Information Organization and Access

As described throughout this document, numerous research efforts are carried out by a variety of entities on Lakes Mead and Mohave. Key to fulfilling specific purposes of this plan (i.e., to gain an overview of the variety of research and monitoring efforts underway, coordinate efforts, leverage funding opportunities, and prevent duplication of efforts) is the consolidation, organization, and presentation of information. The Internet provides a convenient, accessible, and easily adaptable stage for this purpose. This document, then, is the basis for a series of future web pages dedicated to limnology that will be housed on the Lake Mead NRA website (www.nps.gov/lake) and hosted by the NPS. Within these web pages, stand-alone information (e.g., summaries) and links to external data and reports, where available, will be gathered and arranged according to the framework of ecosystem categories presented herein. The Lake Mead NRA web content will not duplicate the web content of other agencies, but will serve as a portal or gateway to information associated with this living plan. On an annual basis, research conducted toward answering research and monitoring questions described within this plan can be added.

In addition to providing a living tracking system for this plan, the Internet pages will be an important central informational portal to limnological and aquatic ecosystem research activity at Lakes Mead and Mohave for the public.

B. Data Management/Archival Activity – Use of Existing Mechanisms

This plan does not develop data-management structures; it encourages the continued use of existing data management mechanisms, two of which are described below.

SNWA Members' Website

The SNWA Members Website (www.snwawatershed.org) stores data, lists events, warehouses a variety of publication types, and provides project tracking. The project tracking section of the website serves as a tool for all agencies interested in regional watershed issues. A brief narrative of each project and a listing of contact information for the project team are provided. The database allows project documents and images associated with the project to be added. Projects can be browsed and searched. A mapping function allows GPS coordinates of monitoring sites to be mapped.

Whenever possible, new projects should be added to the website. Instructions for adding and editing projects are provided at www.snwawatershed.org/members/project/

USGS Online Data and Reports

- Water-quality monitoring and meteorological data collected by the USGS platforms at Lake Mead are available online at: http://nevada.usgs.gov/lmqw/
- A list of USGS Nevada Water Science Center Publications about Lake Mead, including cooperative State publications is found at: http://nevada.usgs.gov/water/projects/regional_references.cfm?Reg=24

C. Quality Assurance and Quality Control (QA/QC) – Use of Existing Mechanisms

This plan recognizes the importance of and underscores the value of rigorous data QA/QC measures. However, this plan is intended to bring together the data and findings of multiple agencies for the purpose of broader ecological understanding. It does not provide data collection or stewardship protocols itself. It instead it recognizes that QA/QC process adherence lies with the principal investigator of each project/program. The current monitoring and research programs described within this plan have their own data stewards, which adhere to the QA/QC standards defined by the program or agency conducting them. Future monitoring and research programs implemented, as a response to this plan, must include appropriate QA/QC measures as defined by the agency conducting it.

Interagency Sampling Team Events

As described within this document, various agencies collect water-quality data from Lakes Mead and Mohave and Las Vegas Wash. Other than platform data, water-quality data are typically collected using hand-held multi-parameter water-quality profilers and other portable instrumentation made by a variety of manufacturers. Conceived as a strategy to ensure comparable, consistent data among agencies, Cooperative Interagency Sampling Events, led by SNWA, were organized starting in 2002. In 2002, the Interagency Cooperative Sampling group decided to focus a sampling event on the collection and analysis of nutrient and chlorophyll-*a* data in light of the algae bloom of 2001. In order to make the most of this effort, other physical parameters were also incorporated. Up to two events take place each year in which data-collection staff can discuss and compare field, analytical, and instrument-calibration protocols. During these events a variety of parameters are tested to ensure uniformity in results among the different equipment used and identify areas for improvement. This activity has been very useful in reducing variability. Since 2006, the events have been held, typically, in February and October aboard Forever Earth (UNLV Public Lands Institute), and have been attended by staff from the following organizations:

- SNWA (host and coordinator)
- City of Henderson
- City of Las Vegas
- City of North Las Vegas
- Clark County Water Reclamation District
- NDOW
- NPS
- Reclamation
- USFWS
- USGS

D. Data Analysis and Research Summaries

The purpose of the herein described data analysis activities and preparation of research summaries is to convert collected data into useful information. Many of the individual projects described throughout this plan have their own established requirements for data analysis and reporting, which are directly related to specific project purposes (e.g., meeting discharge-permit requirements). The analyses and summaries prescribed within this plan, however, take the broader view and seek to make use of all

available data gathered to answer questions and meet research priorities related to each ecosystem category. Research summaries for each category are suggested to be produced once per year. Summaries should correspond to the elements described within the annual monitoring section of each category, as funding allows. In addition, research summaries should be produced for the periodic/cyclic return monitoring activities completed.

E. Synthesis Reporting of Ecosystem Dynamics and Conditions

This plan recognizes the value in extracting, organizing, validating, and inter-relating relevant pieces of information contained in agency reports, published literature, and other documents to obtain a comprehensive, non-redundant report that satisfies a defined information need. It is recommended that synthesis reporting be done on a 5-year basis, pending funding. The topic areas for each synthesis report correspond to the strategic fundamental objectives stated within this plan. The approach taken in synthesis reporting may vary from one period to the next depending on the nature of the pre-determined report focus area and content. The first series of reports may include conceptual models that will comprise a written description, illustrated with results, schematic figures, and flow diagrams.

Report presentation will be designed to facilitate the use of the presented information in practice. These information syntheses are expected to include meta-analyses (statistical manipulation of findings from multiple studies).

Example Report Presentation

- Abstract / Executive Summary
- Introduction and description of the topic
- Methods
- Results
- Discussion and Implications to Management
- Refinement of desired future conditions
- References and Finders' Guide to Information Resources

IV. Relating to ELCOM/CAEDYM Model

Overview and History

ELCOM-CAEDYM couples the three-dimensional hydrodynamics **E**stuary and **L**ake **Co**mputer **M**odel (ELCOM) with the **C**omputational **A**quatic **E**cosystem **Dy**namics **M**odel (CAEDYM). This combined model system allows for investigations into the spatial and temporal relationships between physical, biological, and chemical variables in water bodies, over single events or seasonal to annual timescales. The ELCOM/CAEDYM models were originally developed at the Centre for Water Research at the University of Western Australia.

Originally, development of an ELCOM/CAEDYM model was specified as a component of the Boulder Basin Adaptive Management Plan (BBAMP). Flow Science Incorporated (Harrisburg, VA) was contracted to develop a three-dimensional ELCOM/CAEDYM model for Boulder Basin. Initially, the

model was intended to be used in two ways. First, for routine prediction of reservoir water quality and optimizing the operation of the SCOP system in order to meet the water quality goals in Boulder Basin. Second, to help define a management action plan if an item of concern had been identified. This was later expanded to become a "Whole Lake Model," comprising the entire Lake Mead, from Hoover Dam to the mouths of the Muddy, Virgin, and Colorado Rivers. The model is calibrated for years 2000 – 2007. The following parameters are included in the model: temperature, conductivity, perchlorate, bromide, chlorophyll-*a*, total phosphorus (various species), nitrate, ammonium, total organic carbon, pH, and dissolved oxygen.

Use of Model to Guide Monitoring and Assist in Planning and Education

The whole-lake model is a calibrated tool that can be used in the future management of reservoir operations as part of the BBAMP. This plan recommends that the below suggested additional uses of the model be formally discussed and considered for implementation over the next five years, as funding allows.

- Assessing the impacts of proposed operational changes at Lake Powell (e.g., changes in Colorado River inflow temperatures) on water quality in Lake Mead and Boulder Basin.
- Understanding the water quality impacts throughout the lake of lowered lake water surface elevations due to drought conditions.
- Enhancing knowledge of general water quality and transport processes through the lake, especially in the Upper Basins where field data are historically less dense or nonexistent.
- Evaluating water quality conditions at potential new intake or discharge locations.
- Understanding phosphorus processes in the Lake Mead.
- Evaluating the impact of quagga mussels in Lake Mead.

Other identified uses of the model include examination of the following questions:

- What is the connection between water quality and fish and wildlife in, and around, the lake?
- What is the impact of alternate wastewater treatment technologies and/or wastewater management policies on the water quality of Las Vegas Bay and Boulder Basin?
- Regarding climate change, what impact will increasing temperature trends, earlier runoff seasons, or even lower lake levels have on water quality in the lake?
- What is the impact of future human population growth and associated increased discharge volumes on the quality of the lake and its tributaries?

Elements needed to maintain or improve model

Some improvements (listed below) that can further enhance the model's utility are described within the Flow Science (2009) model report. This plan recommends that these improvements be formally discussed and considered for implementation, as funding allows.

- Continuous multiple year simulations over the entire modeling period. At present, the model is initialized in year 2000, and again in years 2001, 2002, 2004, and 2005. Ideally, the model would be initialized only once in year 2000, and then run continuously through all simulation years.
- Improved treatment of particulate phosphorus settling in CAEDYM would be useful to aid in the understanding of particulate settling within Lake Mead. This would require measurements of the particle size distributions of the inflows and associated modifications to CAEDYM.
- Finer grids (e.g., CAEDYM on 300-m grid, or increased vertical resolution) as computational power increases would improve resolution near the inflows.
- Statistical metrics of "goodness-of-fit" between the simulation results and measured field data. The error analysis of the model error in chlorophyll-*a* concentrations needs to be extended to include other parameters of interest.

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APPENDICES

Appendix 1 Water-management Forums and Programs within Clark County
Appendix 2 Major Monitoring Sites within Lakes Mead and Mohave
Appendix 3 Recreation on Lake Mead
Appendix 4 Overview of Operational and Regulatory Monitoring Requirements for Lake Mead
Appendix 5 Baseline Water Quality Conditions in Boulder Basin
Appendix 6 Avian Species of Interest and their Association with Riparian Resources

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APPENDIX 1

Water-management Forums and Programs within Clark County

Meeting	Lead	Participants													Schedule	Purpose
		NPS	USFWS	USBR	USGS	NRCS	NDEP	NDOW	UNLV	CWC	SNWA	CCRFCD	MWD	AGFD		
Lake Mead Water Quality Forum	NDEP	X	X	X	X	X	X	X		X	X	X	X		quarterly	Identify issues, share information, coordinate study efforts
"Water 2025"	NPS	X	X	X	X			X	X	X	X		X		quarterly	Share information about limnology research funded by SNPLMA
LVVWAC	Rotates									X	X	X			monthly	Coordinate all existing plans, policies, documents, and efforts related to water quality in the Las Vegas Valley watershed and Lake Mead
CWC	CWC															
BBAMP	↓	X	X	X					X	X	X				monthly	Plan development
- Water Quality Objectives	↓	X	X					X	X	X	X		X		monthly	Plan development
- Monitoring & Modeling	↓	X	X	X	X			X	X	X	X		X		monthly	Plan development
- Selenium Management	↓	X	X				X	X	X	X	X	X			monthly	Plan development
- Plant Operations	↓									X	X				monthly	Plan development
Board	↓									X					monthly	CWC general meetings; open to the public
Managers	↓									X	X				monthly	Program management
Steering Committee	↓									X	X				biannually	Project guidance
SNWA	SNWA															
Research/Enviro. Monitoring Study Team	↓	X	X	X	X	X	X	X	X	X	X				bimonthly	Support compliance with 404 permits through mitigation efforts; develop/coordinate long-term management and monitoring programs (fish, wildlife, invasive plant, water quality)
Admin. Study Team	↓										X				bimonthly	Public outreach effort development / grant identification / grant seeking
Operations Study Team	↓										X				bimonthly	Examination of design processes and progress
Board	↓										X				monthly	Decision-making
Managers	↓									X	X				bimonthly	Program management
Principals	↓									X	X	X			monthly	Program management
Integrated Manager	↓									X	X	X			bimonthly	Program management
Interagency Sampling	↓	X	X	X	X			X		X	X				quarterly	Coordinate monitoring and QA/QC
LVWCC	↓	X	X	X	X	X		X	X	X	X				quarterly	Implementation/coordination of the Regional Water Quality Plan
LVVWAC	↓									X	X	X			monthly	Enhancement of watershed mgmt efforts; development of Regional Water Quality Plan
CCRFCD	CCRFCD															
Storm Water Committee	↓											X			monthly	Storm water pollution monitoring, control, & outreach effort develop. & implementation
Board	↓											X			monthly	Decision-making
SWAC	Rotates									X	X	X			varies	Inform CC Commissioners on future wastewater facility requirements and demands
Interagency Quagga Mussel Meeting	NPS	X	X	X	X			X	X	X	X		X	X	quarterly	I-MAP coordination and implementation; share quagga mussel data, results, etc.
Lake Mead Fisheries Mgmt Team	NPS	X	X	X				X						X	annually	Coordinate management and monitoring
Lake Mead Razorback Study Team	SNWA/USBR	X	X	X				X			X			X	semi-annual	Coordinate implementation of Lake Mead razorback sucker study
Virgin River HCP	USFWS															
Executive Committee	↓	X	X					X			X				varies	Recovery/HCP program coordination
Technical Committee	↓	X	X	X	X	X		X			X	X			varies	Recovery/HCP program implementation
Muddy River Recovery Progam	USFWS															
Executive Committee	↓		X					X			X				varies	Recovery program coordination
Biology Committee	↓	X	X		X			X			X				varies	Recovery program implementation
Lower Colorado River MSCP	USBR	X	X	X				X			X		X	X	semi-annual	Steering committee for LCR-MSCP implementation
Relict Leopard Frog Cons. Team	NPS	X	X	X				X	X		X			X	quarterly	*Relict Leopard Frog Conservation Agreement* coordination

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APPENDIX 2

Major Monitoring Sites within Lakes Mead and Mohave

Boulder Basin, Lake Mead

Station ID	Location	USBR		BBAMP			NPDES	I-MAP		SNWA			USGS
		wq	vel.	V1.02			compliance[08]	vel.	adult	zoo.	wq	alg tox.	
LWLVB	movable	•	•					•		•		•	
LWLVB_B	movable							•		•		•	
LW5.9	36° 05' 16.2" N 114° 59' 06" W					•							
LWLVB1.2	movable			•			•						
LWLVB1.85	movable			•			•						
LWLVB2.7	movable			•			•						
LWLVB3.5	36° 06' 3.6" N 114° 48' 18.6" W	•	•	•			•						
LVB0.8	36° 07' 01.32" N 114° 52' 57.96" W	X											
LVB1.5	36° 07' 50.94" N 114° 52' 18.00" W	X											
LVB2.15	36° 07' 31.51" N 114° 51' 46.85" W	X											
LVB2.7	36° 07' 09.98" N 114° 51' 22.89" W	X											
Las Vegas Bay Platform	36° 06' 02" N 114° 48' 47" W												•
LVB3.1	36° 07' 01.99" N 114° 50' 57.30" W											•	
LVB3.5	36° 07' 04.92" N 114° 50' 33.42" W	•	•					•	•				
LVB4.15	36° 07' 00.82" N 114° 49' 49.50" W	•	•					•		•			
LVB4.95	36° 06' 34.42" N 114° 49' 10.66" W	•	•					•			•		
LVB6.0NE0.9	36° 06' 47.05" N 114° 47' 47.79" W										•		
LVB6.7	36° 05' 46.03" N 114° 47' 35.27" W							•		•			
LVB7.3	36° 05' 29.39" N 114° 47' 14.76" W	•	•					•	•		•	•	
LVB7.3NE0.5	36° 05' 48.59" N 114° 46' 48.90" W										•		
CR342.0	36° 00' 58.50" N 114° 44' 13.98" W						• BBAMP						
CR342.5	36° 01' 09.78" N 114° 43' 57.59" W	•	•					•			•		
CR342.9	36° 01' 24" N 114° 43' 40.2" W			•			• BBAMP						
CR344.9W0.2	36° 02' 18" N 114° 44' 42" W						• BBAMP						
INTAKE	36° 03' 47.05" N 114° 47' 51.32" W							•		•		•	
MZ1	36° 03' 22.8" N 114° 46' 10.8" W				•								
MZ2	36° 02' 56.4" N 114° 46' 6.6" W				•								
MZ3	36° 03' 13.2" N 114° 45' 43.2" W				•								
MZ4	36° 02' 47.4" N 114° 45' 33" W				•								
CR346.4	36° 03' 41.96" N 114° 44' 20.88" W	•	•				•	•	•	•		•	
CR346.6	36° 03' 43.8" N 114° 44' 27.6" W			•		•							
CR348.4NW0.2	36° 04' 53.45" N 114° 45' 33.92" W										•		

Station ID	Location	USBR		BBAMP			NPDES	I-MAP		SNWA			USGS
		wq	vel.	V1.02			compliance[08]	vel.	adult	zoo.	wq	alg tox.	
CR348.4NW0.8	36° 05' 34.8" N 114° 46' 04.2" W					•		•		•			
CR349.0NW0.3	36° 05' 54.62" N 114° 45' 11.08" W										•		
CR350.0SE0.55	36° 05' 54.6" N 114° 43' 32.4" W			•			•				•		
CR351.7	36° 06' 42" N 114° 41' 14" W								•		•		
CR355.75	36° 08' 28.8" N 114° 37' 41.4" W	•	•	•		•		•			•		
BB_3	36° 04' 17.4" N 114° 46' 59.4" W			•			•						
BB_7	36° 02' 45" N 114° 46' 52.2" W			•		•	•[BBAMP]						
BB_11	36° 06' 00" N 114° 47' 05" W										•		
Hemenway Wall	36° 02' 18" N 114° 44' 42"W			•									
Within Hoover Dam	36° 00' 46.8" N 114° 44' 27" W			•									
Below Hoover Dam	36° 00' 40.8" N 114° 44' 30.6" W					•							
Flow Control	36° 03' 50.4" N 114° 49' 06" W			•									
Sentinel Island Platform	36° 03' 14.5" N 114° 45' 5.4" W							•	•				•
Black Island	36° 06' 18" N 114° 46' 56" W								•				
Boulder Islands	36° 02' 30" N 114° 46' 20" W								•				

Notes: Reclamation (USBR) monitoring sites for water quality (wq) and quagga mussel veliger (vel.) are indicated; some fixed sites cannot be monitored currently due to low water (X), but will be monitored again when the water rises. BBAMP water quality monitoring sites were indicated as listed within the 2008 "version 1.02" SCOP Document. Individual sites in that column are color coded as follows: • = Regulatory Monitoring Points, • = Operational Testing Points, • = Mixing Zone, • = Endocrine Disruption. These categories are described within the 2008 document and refer to "Figure 5," a map that is not present in version 1.02, but can be found in the 2006 version and in the 2008 NPDES report. The NPDES water quality compliance column indicates sites reported upon in the 2008 NPDES Report; the BBAMP superscript appears next to sites that the report defined as "BBAMP sites." The I-MAP quagga mussel monitoring sites and SNWA zooplankton (zoo.) are indicated as shown within the 5/15/2009 draft I-MAP. The SNWA Water Quality (wq) sites are indicated as shown on the snwawatershed.org members database from the STREAM Bi-monthly project. The USGS sites monitor water quality and meteorological conditions as indicated on the USGS website.

Remainder of Lake Mead

Station ID	Location	USBR		BBAMP			NPDES	I-MAP		SNWA			USGS
		wq	vel.	V1.02			compliance[08]	vel.	adult	zoo.	wq	alg tox.	
CR361.8	36° 09' 0.6" N 114° 32' 06" W			•			• BBAMP						

Station ID	Location	USBR		I-MAP		USGS
		wq	vel.	vel.	adult	
CR360.7	36° 09' 5.11" N 114° 33' 2.48" W	•	•	•		
CR380.0	36° 02' 48.30" N 114° 16' 24.09" W	•	•	•		
CR390.0	36° 02' 29.59" N 114° 08' 17.24" W	•	•	•		
CR394.0	36° 09' 06.52" N 114° 05' 01.32" W	•	•	•		
CRLM	movable	•	•	•		
CR401.65	36° 11' 33.86" N 114° 02' 59.89" W	X				
CR404.6	36° 11' 34.91" N 114° 00' 05.94" W	X				
CR413.0	36° 07' 53.90" N 114° 56' 03.19" W	X				
MRLM	movable	•	•	•		
VR13.0	36° 17' 23.42" N 114° 23' 17.22" W	•	•	•		
VR18.0	36°21'36.09"N 114°23'15.15"W	•	•	•		
VR18.0E0.55	36° 21' 36.47" N 114° 22' 40.19" W	X				
VR18.0W0.55	36° 21' 43.27" N 114° 23' 50.18" W	X				
VR2.0	36° 09' 41.02" N 114° 25' 08.83" W	•	•	•		
VR25.1	36° 26' 06.90" N 114° 20' 48.07" W	•	•	•		
VR26.8	36° 27' 32.06" N 114° 20' 40.05" W	X				
VR29.75	36° 29' 30.88" N 114° 19' 50.55" W	X				
VR31.5	36° 30' 54.76" N 114° 20' 11.51" W	X				
VR6.0	36° 12' 50.34" N 114° 25' 03.28" W	•	•	•		
VR6.0E0.7	36° 12' 43.77" N 114° 24' 18.97" W	X				
VR6.0W0.3	36° 12' 55.44" N 114° 25' 21.86" W	X				
VR9.4	36° 15' 18.17" N 114° 24' 13.20" W	•	•	•		
VR9.4E0.65	36° 15' 11.45" N 114° 23' 33.03" W	X				
VR9.4.W0.15	36° 15' 19.62" N 114° 24' 22.75" W	X				
VRLM	movable	•		•		
Sandy Point	36° 06' 54.3" N 114° 07' 00.0" W		•			
Sandy Point	36° 06' 58" N 114° 06' 41" W			•	•	
Temple Bar	36° 02' 34.9" N 114° 18' 35.7" W		•	•		
The Temple	36° 01' 43" N 114° 09' 46" W				•	
Temple Bar Platform	36° 03' 10" N 114° 17' 23" W					•
Echo Bay	36° 17' 44.30" N 114° 23' 53.9" W		•			

Lake Mohave

Station ID	Approx. Location	USBR		I-MAP		USGS
		wq	vel.	vel.	adult	wq
Colorado River Below Hoover Dam	36° 00' 55" N 114° 44' 16" W					•
Willow Beach	35° 52' 10" N 114° 39' 53" W	•	•			
Placer Cove	35° 42' 20" N 114° 42' 20" W	•	•			
Cottonwood Cove	35° 29' 39" N 114° 40' 49" W	•	•			
Tequila Cove	35° 28' 33.4" N 114° 40' 43.94" W				•	
Katherine Landing	35° 13' 13" N 114° 34' 43" W	•	•			

APPENDIX 3

Recreation on Lake Mead

By James S. Holland, Park Planning
National Park Service
Lake Mead NRA

The National Park Service was invited to administer Lake Mead National Recreation Area as the U.S. Bureau of Reclamation began filling the reservoir in 1935 with the closing of the Hoover Dam diversion gates. A Cooperative Agreement was executed between the two agencies and the National Park Service took on the administration of the 1.9 million acre withdrawal, which as originally drawn, included the Hualapai Indian Reservation. Initially there were no recreational facilities to provide access to the rising lake waters. Early management plans identified a number of potential development sites but no formal development occurred during the period of rapidly rising waters.

Over the next 30 years, there were nine development sites on Lake Mead: five major sites and four minor sites. At the five major sites, lake access was provided through concession-operated marinas and paved public launch ramps. Overnight lodging was available at Echo Bay and Lake Mead Lodge but addition overnight capacity existed in the form of leased sites for construction of cabins and for the location of trailers. In the mid 1960s, there were 350 trailers distributed at four sites around Lake Mead.

There was an infusion of funding for recreational development in the late 1960s when much of the development was accomplished around Lake Mead. Under the Department of the Interior's Mission 66 Program, ranger stations, campgrounds, picnic areas, parking areas and visitor centers were established. This funding was available during the time the Bureau of Reclamation was filling the new reservoir behind the Glen Canyon Dam and water levels at Lake Mead dropped to approximately 1,080-ft elevation. Most of the recreation facilities established during this period are still in use today.

Visitation to Lake Mead in the 1960s was considered high with 3.5 million visitors traveling there annually. Hoover Dam was an engineering marvel and Lake Mead complimented tourism by providing outstanding boating and fishing opportunities. Las Vegas was a relatively small community during this period with less than 300,000 residents so Lake Mead was attracting visitors from a regional context.

The development of recreational facilities peaked during the period between 1980 and 2000 with each of the development areas increasing dramatically. Marina capacity increased during this time from relatively small marinas with slips numbering in the 100 to 200 range to marinas approaching or exceeding 1,000 slips. Boating was changing during this period with the development of fiberglass hauls. Boating safety improved over this period and boat sizes were increasing, affecting the size of existing marinas. In the mid 1990s, visitation to Lake Mead reached its peak and facilities were operating at capacity. Park visitation was measured at 10 million during this period.

Today, the park receives approximately eight million recreational visits with approximately 50 percent traveling from Southern California. The remaining visitors are primarily from Nevada, Arizona, Utah, and other western states. Facilities capacities were set for Lake Mead in the 2005 Lake Management Plan. At high water levels where all facilities are operational, the marina capacity for Lake Mead was established at 3,357 slips

with 460 rentals boats. The public launch capacity was established at 3,000 boats. The boating capacity for Lake Mead was set at 3,295 boats at any one time.

The lowering lake levels observed between 2000 and 2010 has affected public access to Lake Mead. With the lake projected to attain an elevation of 1,076 ft in June 2010, it will be down approximately 150 vertical ft from full pool. Pearce Ferry, Government Wash, Las Vegas Bay, and Overton have been closed as lake waters have receded such that the area can no longer provide reasonable access. Boulder Harbor operations have been reduced with the removal of the Lake Mead Ferry Service and Lake Mead Marina. All other lake access points have been dramatically impacted. The park concessioners are having difficulty moving the marinas and extending utilities to keep the marinas operational at these water levels. The National Park Service is annually chasing the water at each of the public launch ramps, but pouring concrete to extend the ramps is limited by the water levels. These difficulties are impacting lake access and, in turn, impacting visitor use at Lake Mead.

It is anticipated the future will include dramatic fluctuations in Lake Mead water levels and recreation facilities must be designed to operate between elevations of 1,000 to 1,220 ft. While many of the steps are underway to accommodate these changing conditions, it remains to be seen if such changes can be met by the NPS and its concessioners. While the goals are to maintain the existing level of public access, it is becoming more difficult with each annual 15-ft decrease in lake elevation.

APPENDIX 4

Overview of Operational and Regulatory Monitoring Requirements for Lake Mead

Environmental Protection Agency (EPA) National Pollutant Discharge Elimination System (NPDES)

http://cfpub.epa.gov/NPDES

As authorized by the Clean Water Act, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Since its introduction in 1972, the NPDES permit program has been responsible for significant improvements to U.S. water quality. In Nevada, NDEP issues NPDES permits to all facilities where water is released or discharged to the environment, and NPDES permits describe effluent limits and reporting requirements. Dischargers to Lake Mead include the Clark County Water Reclamation District, which operates the valley's largest wastewater facility and currently treats 83 million gallons per day of wastewater; the City of Las Vegas, whose facility treats more than 60 million gallons per day of wastewater; the City of Henderson, whose facility treats 18 million gallons per day; and the City of North Las Vegas whose facility will treat 25 million gallons per day when it is completed. The City of Las Vegas monitors Total Suspended Solids and turbidity at three sites and the following parameters at eight sites within Boulder Basin.

- Alkalinity Bicarbonate
- Chloride
- Chlorophyll-*a*
- Coliform, fecal
- Color units
- Conductivity
- Dissolved Oxygen
- *E. coli*
- Light
- Nitrogen Ammonia Total
- Nitrogen Nitrate Total
- Nitrogen Nitrite Total
- Nitrogen Total
- pH
- Phosphorus, dissolved
- Phosphorus Total
- Secchi
- Sulfate
- Temperature
- Temperature, water
- Total Dissolved Solids
- Wind speed
- Zooplankton Total

Boulder Basin Adaptive Management Plan (BBAMP)

www.cleanwatercoalition.com

The Clean Water Coalition (CWC) is a consortium comprising dischargers (see **NPDES**, above) in southern Nevada. In 2005, at a time when Clark County was identified as the fastest growing county in the nation, in conjunction with a prolonged drought period, a large-scale plan was created to deal with treated wastewater that historically entered Lake Mead through the Las Vegas Wash. Lowered lake levels diminish its dilution capacity, and a concentrated influx of wastewater at Las Vegas Bay would soon not be feasible. The SCOP project includes the planning, design, and construction of a conveyance system that will transport highly treated effluent from the municipal wastewater treatment facilities serving the Las Vegas urban area to a lake diffuser located in Lake Mead. The BBAMP was developed as a response to needs identified in the SCOP Environmental Impact Statement (EIS). This BBAMP addresses the operations of the SCOP, monitoring of water quality, identification of Items of Concern (IOC), and the establishment of a decision-making process for the SCOP to meet the dynamic requirements of Lake Mead. Although additional wastewater treatment measures might preclude the need for the pipeline, the water quality monitoring described by and initiated under the BBAMP is useful regardless of whether the SCOP project is completed. "Regulatory and

Operational" monitoring occurs at 13 sites at which data are collected for general water quality parameters including:

- Temperature
- Dissolved Oxygen
- Conductivity
- pH
- Br (bromide ion)
- Chlorophyll-*a*
- Chloride
- *E. coli*
- Dissolved Ortho Phosphorus
- Total Dissolved Solids
- Color
- Fecal Coliform
- NH_4 (ammonium ion)
- NO_2 (nitrite ion)
- NO_3 (nitrate ion)
- Total Coliform
- Total Nitrogen
- Total Phosphorus
- Total Suspended Solids
- Total Organic Carbon
- Sulfate
- Turbidity

Six locations are tested for endocrine disrupting compounds and other emerging contaminants of concern including:

- Atenolol
- Atorvastatin
- Atrazine
- Benzophenone
- BHA
- Bisphenol A
- Caffeine
- Carbamazepine
- DEET
- Diazepam
- Diclofenac
- Estradiol
- Estrone
- Ethynylestradiol
- Fluoxetine
- Gemfibrozil
- Ibuprofen
- Meprobamate
- Musk Ketone
- Naproxen
- Octylphenol
- Phenytoin
- Primidone
- Progesterone
- Sulfamethoxazole
- TCEP
- TCPP
- Testosterone
- Triclosan
- Trimethoprim

U.S. Bureau of Reclamation – Water Master of the Colorado

http://www.usbr.gov

The U.S. Bureau of Reclamation is delegated the responsibility of serving as Water Master of the Colorado River by the Secretary of the Interior. Investigations of the limnology of Lake Mead, with emphasis on Boulder Basin have continued since 1990 to monitor changing conditions influenced both by variance in annual inflow from the Colorado River watershed and growth of population within the lower watershed. A series of sampling locations are used to document patterns of change in limnological conditions over time. These data are used to alert public officials of any significant changes, and to document limnological conditions for use in future decision making regarding the management of water resources of the lower Colorado River basin. This program originally included 36 sites; however, sites that are currently above the water level are not being sampled, but are expected to be monitored again when the water level rises. The following parameters are currently monitored at 22 sites:

- Arsenic
- Bromide
- Chlorophyll-*a*
- Conductivity
- Dissolved Oxygen
- Dissolved Oxygen
- Nitrogen Ammonia Total
- Nitrogen Nitrate Total
- Nitrogen Total
- Nitrogen Total Kjeldahl
- Perchlorate
- pH
- Phosphate
- Phosphorus Orthophosphate Total
- Phosphorus Total
- Phytoplankton Total
- Secchi Depth
- Temperature Water
- Total Dissolved Solids
- Total Organic Carbon
- Turbidity
- Zooplankton Total

Southern Nevada Water Authority – Compliance with the Safe Drinking Water Act

www.snwa.com

The Safe Drinking Water Act (SDWA) is the main federal law that ensures the quality of America's drinking water. Under SDWA, the EPA sets standards for drinking water quality and oversees the states, localities, and water suppliers who implement those standards. In addition to testing water at the treatment facilities and following treatment, SNWA monitors water within Lake Mead. In fact, the Southern Nevada Water System tests more frequently and extensively than the SDWA requires.

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APPENDIX 5

Baseline Water Quality Conditions in Boulder Basin

(1,178 ft for year 2002 with effluent flows of 150 mgd [231 cfs] and effluent TP = 292 lbs/day)[1]

Parameter	Inner Bay (LVB1.85M)[2]	Inner Bay (LVB2.7)	Boulder Basin (CR346.4)	Boulder Beach	Hoover Dam Discharge[3]	SNWA Intake[4]
Temperature (°C) [°F]	20.3 [68.6]	20.3 [68.5]	19.6 [67.2]	19.3 [66.7]	13.2 [55.7]	13.0 [55.3]
Conductivity (μS/cm)	1085	1094	947	952	901	896
Total Dissolved Solids[5]	687	693	599	603	570	567
Dissolved Oxygen (mg/L)	8.7	8.7	8.3	8.3	7.7	7.5
Chlorophyll (μg/L)	12.4	12.4	2.0	2.1	≤0.01	≤0.01
Total Phosphorus (mg/L)	0.018	0.018	0.005	0.005	0.005	0.004
Soluble Phosphorus (mg/L)	0.009	0.009	0.003	0.003	0.004	0.004
Total Nitrogen (mg/L)	1.6	1.7	0.4	0.4	0.3	0.4
Nitrate (mg/L)	1.6	1.6	0.4	0.4	0.3	0.3
Total Ammonia Nitrogen (mg/L)	0.012	0.013	0.01	0.011	0.014	0.019
un-ionized Ammonia (mg/L)	0.0008	0.0008	0.0002	0.0004	0.0002	0.0003
Bromide (mg/L)	0.11	0.11	0.09	0.087	0.08	0.08
Sulfate (mg/L)	295	297	257	259	243	242
Chloride (mg/L)	107	108	85	85	79	78
Fecal Coliform (MPN/100mL)	1.0	1.1	0.0	0.0	0.0	0.0
pH	8.1	8.1	8.0	8.0	7.7	7.7

Notes:

[1] Sampling depth is surface to 1 m (3.3 ft) for locations other than SNWA and Hoover Dam, which were sampled at intake depths, and except for chlorophyll, which was sampled within the top 5 m (16 ft). All data are the mean annual average, except for chlorophyll, which includes the mean annual seasonal average (see note 5). These data are the 2002 calibration scenario modeling results, which are based upon actual sampling data used as input data for the model.

[2] M=Mobile. LVB1.85M is mobile and located at a depth of 16 to 18 m (52 to 59 ft) near the confluence of Las Vegas Wash and Lake Mead. All other locations are stationary.

[3] SNWA intake data are from the lower intake only.

[4] Total Dissolved Solids (TDS) are calculated from the correlation TDS (mg/L) = 0.633 Conductivity (μS/cm).

[5] Chlorophyll data include the mean annual seasonal average. Samples were taken at the top 5 m (16 ft).

[6] Most Probable Number per 100 ml (1 deciliter).

Source:

Black & Veatch 2004c as presented within *Systems Conveyance and Operations Program – Final EIS* (October 2006; p. 3-27)

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APPENDIX 6

Avian Species of Interest and their Association with Riparian Resources

Common Name/Species	Listing	Riparian / Aquatic Habitat Needs
Arizona Bell's vireo (*Vireo bellii arizonae*)	a federal species of concern	Distributed throughout the river systems of the desert southwest. It is a summer resident along the Colorado, Virgin, and Muddy Rivers, when it breeds within riparian scrub habitats. Potential habitat exists at the Las Vegas Wash. At low elevations, this species is associated with early successional cottonwood-willow.
American peregrine falcon (*Falco peregrines anatum*)	a federal species of concern and a Nevada State protected species	Tall cliffs are limiting habitat for this species; nearby water source provides a prey base of small to medium birds. The peregrine falcon is a year-round resident of southern Nevada. Breeding and nesting locations are found around Lake Mead.
Black tern (*Chlidonias niger*)	a federal species of concern	During migration the black tern frequents freshwater and saltwater, and occurs along the coast and along marshes, rivers, and lakes. The Red Rock Audubon Society (2002) reports this species to be a rare migrant to the Las Vegas Wash.
Blue grosbeak (*Guiraca caerulea*)	a federal species of concern	This species is primarily found in riparian habitat, in vegetation comprising willow, cottonwood, arrowweed, and tamarisk. Potential habitat is found at the Las Vegas Wash and along the Colorado River System, and the inflow areas of the Virgin and Muddy Rivers to Lake Mead.
Lucy's warbler (*Vermivora luciae*)	a federal species of concern	They are found in southwestern deserts, generally, in large mesquite bisques, especially along main watercourses. This species requires cavities for nesting, such as natural cavities in trees (usually mesquite but also willows). It has also been known to nest in holes in banks. The species is a common summer visitor to the Las Vegas Wash.
Summer tanager (*Piranga rubra*)	a federal species of concern	Summer tanagers breed throughout most of the southeastern and southwestern U.S. In southern Nevada, they are attracted to stands of tamarisk along the Colorado River and other tall riparian trees. Suitable habitat is present along the Las Vegas Wash.
Vermillion flycatcher (*Pyrocephalus rubinus*)	a federal species of concern	Found in the arid southwest, occurring almost exclusively near water. The species favors groves of cottonwood, willow, oak, and mesquite.
Western least bittern (*Ixobrychus elixis hesperis*)	a federal species of concern and a Nevada State protected species	This secretive bird is usually found in densely vegetated emergent wetlands near sources of fresh water and in desert riparian zones in southern California and in the Lower Colorado River Valley. The Red Rock Audubon Society (2002) reports it to be a rare migrant to the Las Vegas Wash.
White-faced ibis *(Plegadis chihi)*	*a federal species of concern*	The white-faced ibis is a common migrant in southern Nevada. It forages and nests in colonies near the ground or over water in extensive, undisturbed perennial marshes with dense stands of bulrush. Suitable habitat is available along the Las Vegas Wash.

Adapted from content within Appendix E of the System Conveyance and Operations Program – Final EIS (October 2006)