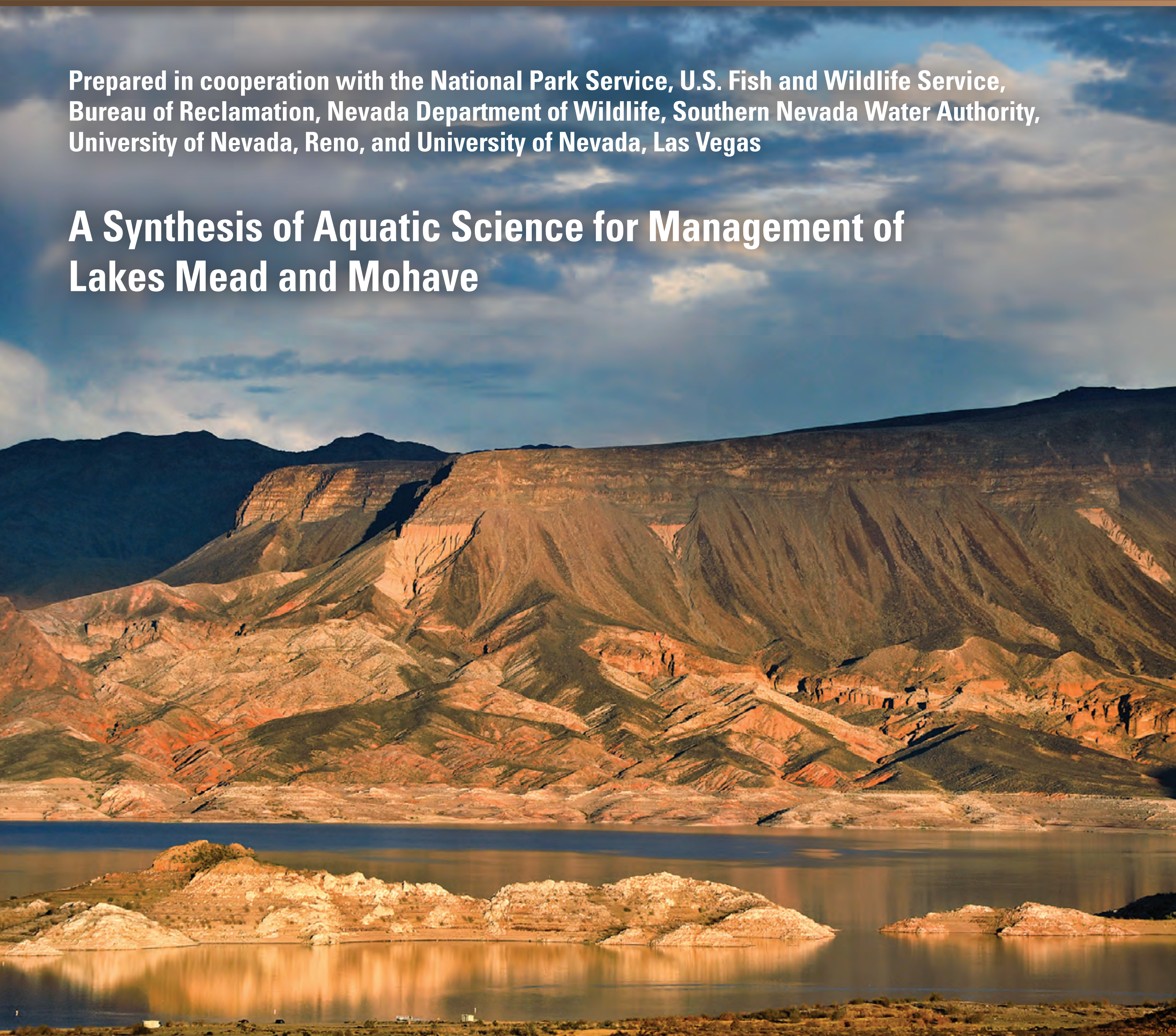
Prepared in cooperation with the National Park Service, U.S. Fish and Wildlife Service, Bureau of Reclamation, Nevada Department of Wildlife, Southern Nevada Water Authority, University of Nevada, Reno, and University of Nevada, Las Vegas

# A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave



Circular 1381

U.S. Department of the Interior
U.S. Geological Survey

# A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave

Edited by Michael R. Rosen, U.S. Geological Survey; Kent Turner, National Park Service; Steven L. Goodbred, U.S. Geological Survey; and Jennell M. Miller, University of Nevada, Las Vegas

Prepared in cooperation with the National Park Service, U.S. Fish and Wildlife Service, Bureau of Reclamation, Nevada Department of Wildlife, Southern Nevada Water Authority, University of Nevada, Reno, and University of Nevada, Las Vegas

Circular 1381

**U.S. Department of the Interior**
**U.S. Geological Survey**

**U.S. Department of the Interior**
KEN SALAZAR, Secretary

**U.S. Geological Survey**
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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# Foreword

Lake Mead provides many significant benefits that have made the modern development of the southwestern United States possible. The lake also provides important aquatic habitat for a wide variety of wildlife including endangered species, and a diversity of world-class water based recreational opportunities for more than 8 million visitors annually. It is one of the most extensively used and intensively monitored reservoirs in the United States. The largest reservoir by volume in the United States, it supplies critical storage of water supplies for more than 25 million people in three western states (California, Arizona, and Nevada). Storage within Lake Mead supplies drinking water and the hydropower to provide electricity for major cities including Las Vegas, Phoenix, Los Angeles, Tucson, and San Diego, and irrigation of greater than 2.5 million acres of croplands.

Due to the importance of Lake Mead, multiple agencies are actively involved in its monitoring and research. These agencies have a long history of collaboration in the assessment of water quality, water-dependent resources, and ecosystem health. In 2004, the National Park Service obtained funds from the Southern Nevada Public Lands Management Act to enhance this partnership and expand monitoring and research efforts to increase the overall understanding of Lake Mead and Lake Mohave. Participating agencies included the National Park Service, Southern Nevada Water Authority, U.S. Geological Survey, Nevada Department of Wildlife, Bureau of Reclamation, U.S. Fish and Wildlife Service, University of Nevada, Las Vegas, and University of Nevada, Reno.

Results of these important efforts have been presented in Lake Mead Science Symposia conducted in 2009 and 2012. The relationships forged by the collaboration led to the development in 2012 of the Lake Mead Ecosystem Monitoring (LaMEM) Work Group, which has formalized the partnership and documented an interagency purpose and mission statement with common objectives for protection of Lake Mead and Lake Mohave water quality and water-dependent resources. This Circular has been developed to summarize the state of the knowledge related to the interests and objectives of the LaMEM Work Group, to inform management and the public of current lake conditions, and identify future needs for monitoring and research. It is hoped that this report will provide a framework for continued long-term investigations and analysis of the environmental health of Lakes Mead and Mohave.

William H. Werkheiser
Associate Director for Water

# Preface

The purpose of this Circular is to provide a synthesis of published information and a summary of technical findings and associated implications that may affect natural resource management of Lake Mead National Recreation Area (LMNRA). Synthesized information and summarized findings should lead to a better public understanding of the natural resources of Lakes Mead and Mohave, and the issues related to maintaining their resources into the future.

# Acknowledgments

This project could not have been completed without the cooperation of all the federal, state, and local agencies, universities, and stakeholders involved in research and management of the Lakes Mead and Mohave. Special thanks to Mark Anderson (National Park Service), John Reuter (University of California, Davis), Daniel Bright (U.S. Geological Survey), and Roger Buehrer (Southern Nevada Water Authority) for their detailed reviews and suggestions that improved the clarity and presentation of this Circular. The descriptions of river operations and the water budget were improved greatly by the comments of Becky J. Blasius, Daniel A. Bunk, Christopher R. Cutler, Jeannette E. Davis, Janet Kirsch, W. Paul Miller, Shana G. Tighi, and Bruce E. Williams of the Bureau of Reclamation, Lower Colorado Region. Mark Sappington (National Park Service) is acknowledged for maps and for conceiving of and creating infographics in figs. 2-3, 2-4, and 2-6; Warren Turkett (Southern Nevada Water Authority) is acknowledged for his contribution of time to figure development within Chapter 4. Shawn L. Gerstenberger (University of Nevada, Las Vegas) and Bryan Moore (National Park Service) also are thanked for their contributions to this effort.

# Contents


Foreword ........ iii

Preface ........ iv

Acknowledgments ........ iv

Chapter 1.—**Introduction and Summary of Findings**
By Kent Turner, Michael R. Rosen, Steven L. Goodbred, and Jennell M. Miller ... 1

Chapter 2.—**Environmental Setting of Lake Mead National Recreation Area**
By Kent Turner, Michael R. Rosen, G. Chris Holdren, Steven L. Goodbred, and David C. Twichell ........ 7

Chapter 3.—**Hydrology and Management of Lakes Mead and Mohave within the Colorado River Basin**
By G. Chris Holdren, Todd Tietjen, Kent Turner, and Jennell M. Miller ........ 23

Chapter 4.—**Lake Water Quality**
By Todd Tietjen, G. Chris Holdren, Michael R. Rosen, Ronald J. Veley, Michael J. Moran, Brett Vanderford, Wai Hing Wong, and Douglas D. Drury ... 35

Chapter 5.—**Wildlife and Biological Resources**
By Sudeep Chandra, Scott R. Abella, Brandon A. Albrecht, Joseph G. Barnes, E. Cayenne Engel, Steven L. Goodbred, Paul B. Holden, Ron B. Kegerries, Jef R. Jaeger, Erik Orsak, Michael R. Rosen, John Sjöberg, and Wai Hing Wong ........ 69

Chapter 6.—**Threats and Stressors to the Health of the Ecosystems of Lakes Mead and Mohave**
By Michael R. Rosen, Steven L. Goodbred, Wai Hing Wong, Reynaldo Patiño, Kent Turner, Craig J. Palmer, and Peggy Roefer ........ 105

Chapter 7.—**Management Implications of the Science**
By Kent Turner, Steven L. Goodbred, Michael R. Rosen, and Jennell M. Miller ... 139

Glossary ........ 157

Appendix A.—List of 96 species compiled from observations made during monthly aquatic bird surveys on Lakes Mead and Mohave over a 5-year period (2004–2009) ...... 161

# Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Volume | |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |
| acre-foot (acre-ft) | 0.001233 | cubic hectometer ($hm^3$) |
| | Flow rate | |
| acre-foot per year (acre-ft/yr) | 1,233 | cubic meter per year ($m^3$/yr) |
| acre-foot per year (acre-ft/yr) | 0.001233 | cubic hectometer per year ($hm^3$/yr) |
| cubic foot per second ($ft^3$/s) | 0.02832 | cubic meter per second ($m^3$/s) |
| million gallons per day (Mgal/d) | 0.04381 | cubic meter per second ($m^3$/s) |
| inch per year (in/yr) | 25.4 | millimeter per year (mm/yr) |
| | Mass | |
| ounce, avoirdupois (oz) | 28.35 | gram (g) |
| pound, avoirdupois (lb) | 0.4536 | kilogram (kg) |
| | Energy | |
| kilowatthour (kWh) | 3,600,000 | joule (J) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Elevation, as used in this report, refers to distance above Power House Datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Chapter 1

# Introduction and Summary of Findings

By Kent Turner[1]; Michael R. Rosen[2], Steven L. Goodbred[2], and Jennell M. Miller[3]

***Lakes Mead and Mohave, which are the centerpieces of Lake Mead National Recreation Area (LMNRA), provide many significant benefits that have made the modern development of the Southwestern United States possible. Lake Mead is the largest reservoir by volume in the nation and it supplies critical storage of water supplies for more than 25 million people in three Western States (California, Arizona, and Nevada). Storage within Lake Mead supplies drinking water and the hydropower to provide electricity for major cities including Las Vegas, Phoenix, Los Angeles, Tucson, and San Diego, and irrigation of more than 2.5 million acres of croplands (National Park Service, 2010). Lake Mead is arguably the most important reservoir in the nation because of its size and the services it delivers to the Western United States (Holdren and Turner, 2010).***

Boat harbor in Boulder Basin, Lake Mead. Photograph by National Park Service.

[1]National Park Service

[2]U.S. Geological Survey

[3]University of Nevada, Las Vegas

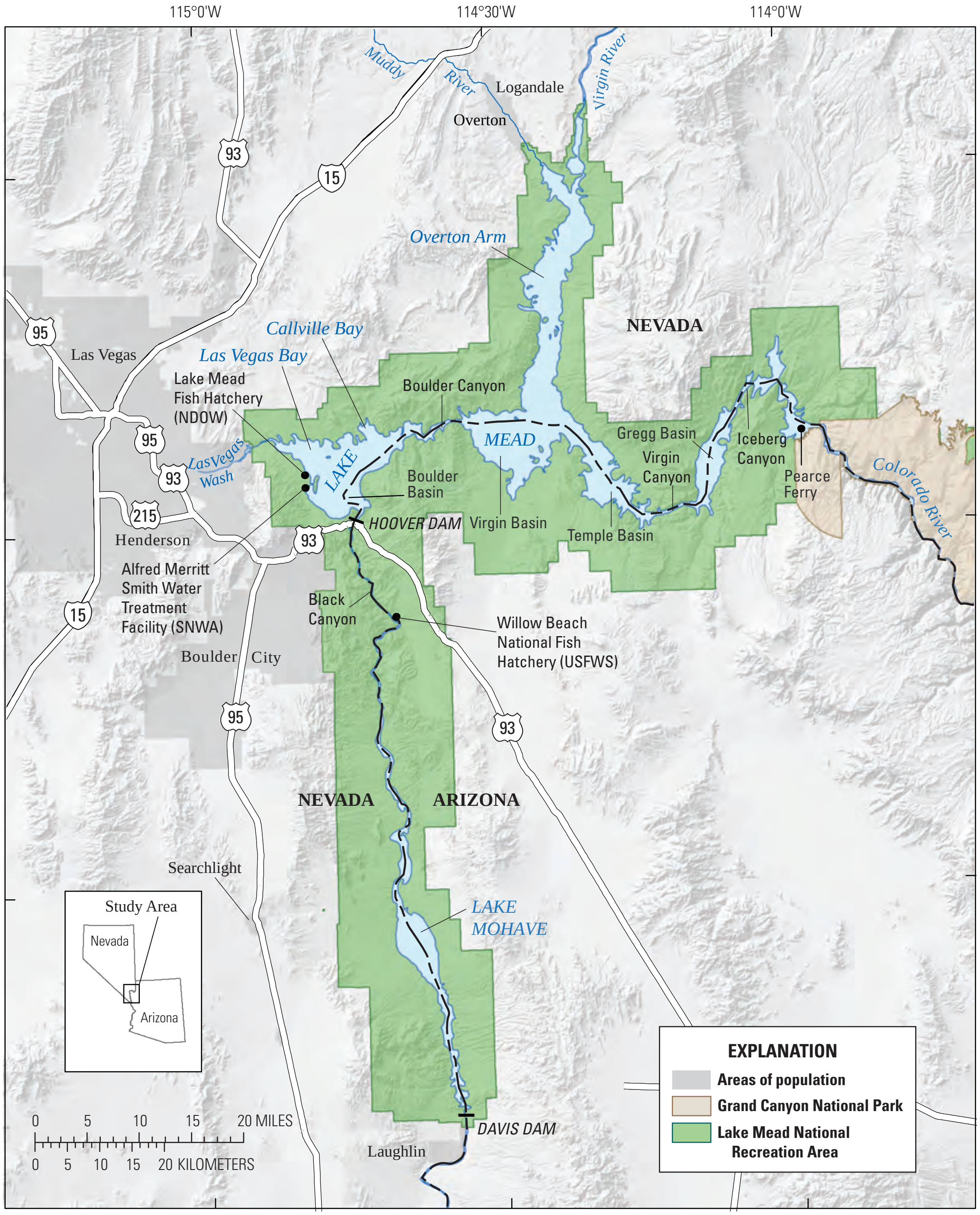
While these reservoirs and others have modified the original, free-flowing Colorado River ecosystem, Lakes Mead and Mohave still provide important habitat for a variety of fish and wildlife species. The lakes provide critical habitat for populations of the federally listed endangered razorback sucker (*Xyrauchen texanus*) (Chapter 5), as well as critical habitat for the federally listed endangered bonytail chub (*Gila elegans*). In addition, the lakes support large populations of non-native sportfish including smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), striped bass (*Morone saxatilis*), and channel catfish (*Ictalurus punctatus*). LMNRA also is a regionally important habitat for many birds, with 92 documented species of water-dependent birds (appendix A). Significant populations of peregrine falcons (*Falco peregrinus*) are present, and more than 30 eyries were documented in 2010.

Razorback sucker (*Xyrauchen texanus*) caught and released for survey of razorback sucker populations. Photograph by National Park Service.

Juvenile peregrine falcon (*Falco peregrinus*) feeding on prey along the shoreline of Lake Mead. Photograph by Joseph G. Barnes, University of Nevada, Las Vegas.

Lakes Mead and Mohave (fig. 1-1) provide a diversity of world-class, water-based recreational opportunities for more than 8 million visitors annually. Established as the nation's first National Recreation Area in 1964, LMNRA is managed by the National Park Service to meet legislative mandates to provide high-quality, water-based recreation in a manner that preserves unimpaired the area's natural and cultural resources for the enjoyment of future generations. Key objectives within those mandates include maintaining safe water for body-contact recreation, maintaining the aesthetic quality of the recreational setting, and insuring water quality to support healthy populations of fish and wildlife.

Given these benefits and uses, multiple Federal, State, and local agencies have an obvious interest in the overall water quality and environmental health of Lakes Mead and Mohave. A primary catalyst for this interest has been related to Las Vegas Wash, the main surface drainageway for Las Vegas Valley, which conveys water from four wastewater-treatment facilities. These facilities return more than 190 million gal/d of treated sewage **effluent** to Boulder Basin of Lake Mead. As a result, Lake Mead is one of the most intensively monitored reservoirs in the United States. Boulder Basin in particular has been extensively monitored by agencies with water-quality management responsibilities on Lake Mead at the Federal, State, and local levels. Moreover, that interest has generated numerous interagency partnerships and forums for the development of mutual water-quality and environmental health objectives, and desired water-resource monitoring and research programs. Ongoing partnerships include the Lake Mead Water Quality Forum facilitated by the Nevada Division of Environmental Protection; the Lake Mead Ecosystem Monitoring Work Group composed of members of Federal,




Base from National Park Service and U.S. Geological Survey digital data,1:675,000
Universal Transverse Mercator projection, Zone 11
North American Datum 1983

**Figure 1-1.** Lake Mead National Recreation Area (LMNRA) showing important features of the landscape. NDOW, Nevada Department of Wildlife; SNWA, Southern Nevada Water Authority; USFWS, U.S. Fish and Wildlife Service.

State, and local agencies and organizations concerned with understanding and protecting the ecosystems of Lakes Mead and Mohave; and the Las Vegas Valley Watershed Advisory Committee comprising water and wastewater agencies in southern Nevada working to enhance watershed management of Lake Mead and its southern Nevada tributaries.

Data collection and monitoring efforts supported by past partnerships have resulted in the recognition of new, emerging water-quality and environmental health issues within Lakes Mead and Mohave. In addition to population growth within Las Vegas Valley, urbanization has increased rapidly over the last 30 years along the Interstate-15 corridor from Overton, Nevada, through St. George, Utah, and within the tributary watersheds of the Virgin and Muddy Rivers. With population growth comes the likelihood of increased wastewater discharge from urbanized watersheds and the potential for increased **nutrient loading** and associated changes in algal production; contaminants such as industrial byproducts, volatile organic compounds, pesticides and heavy metals; endocrine disrupting compounds related to pharmaceuticals and personal care products; and human and wildlife **pathogens**. As urbanization expands in watersheds near LMNRA, it also increases the potential for non-point sources of environmental contaminants, such as herbicides and pesticides applied to golf courses, lawns, and power line rights-of-ways, as well as nutrients, such as nitrogen and phosphorous applied to lawns and golf courses. These potential water-quality effects from increased urbanization in tributary watersheds may be exacerbated by lowering lake levels caused by variations in climate or increased water demands, which reduces the amount of water available to dilute environmental contaminants. In addition, lower lake levels, as well as higher water temperatures resulting from climate change or increasingly larger shallow water areas, may result in changes to water circulation and resident biota, and potentially change the ecosystems of both lakes. **Invasive species**, such as quagga mussels (*Dreissena rostriformis bugensis*), which were discovered in Lake Mead in 2007, also have the potential to produce significant ecosystem changes that will affect water quality (National Park Service, 2010).

In recognition of these emerging threats to Lake Mead water quality, LMNRA obtained funding through the Southern Nevada Public Land Management Act in 2004 to build upon existing partnerships and enhance the understanding of water quality and natural resources throughout Lakes Mead and Mohave. This partnership program, coordinated by LMNRA, led to a number of research and monitoring products, including two Lake Mead Science Symposia, in January 2009 (http://www.lakemeadsymposium.org) and January 2012 (http://www.nvwra.org/presentations); and in 2010, the interagency development of a LMNRA Long Term Aquatic Resources Monitoring and Research Plan for Lakes Mead and Mohave (National Park Service, 2010). The plan documents six strategic objectives to maintain the quality of water within Lakes Mead and Mohave to support productive sports fisheries, healthy populations of native fish, aquatic-dependent wildlife, and aquatic and shoreline vegetation; extraordinary water-based recreation; and regional and community municipal and industrial uses including domestic water supply (National Park Service, 2010). The plan also outlines monitoring and research activities related to five ecosystem categories, including water quality and **limnology**; fish and aquatic biota; sediments; birds; and **riparian** vegetation, and suggests monitoring and research for three ecosystem stressors, including contaminants, invasive species, and climate change. A summary of key findings and management implications for these ecosystem categories and stressors are provided in table 1-1 and in more detail in table 7-1.

This Circular includes seven chapters. Chapter 2 introduces the environmental setting and characteristics of Lakes Mead and Mohave and provides a brief management context of the lakes within the Colorado River system as well as overviews of the geological bedrock and sediment accumulations of the lakes. Chapter 3 contains summaries of the operational and hydrologic characteristics of Lakes Mead and Mohave. Chapter 4 provides information on water quality, including discussion on the monitoring of contaminants and sediments within the reservoirs. Chapter 5 describes aquatic biota and wildlife, including **food-web** dynamics, plankton, invertebrates, fish, aquatic birds, and aquatic vegetation. Chapter 6 outlines threats and stressors to the health of Lake Mead aquatic ecosystems that include a range of environmental contaminants, invasive species, and climate change. Chapter 7 provides a summary of overall findings and a more detailed discussion on associated management implications, additional research, and monitoring needs.

**Table 1-1.** Summary of key scientific findings, management implications, and data and information needs for each of the ecosystem categories and stressors identified in Lake Mead National Recreational Area's Aquatic Resources Plan.

| Resource component and related goals | Scientific findings | Management implications | Recommendations for data or information needs |
|---|---|---|---|
| *Water quality and limnology* | Basic water-quality parameters are within good ranges of State standards and EPA lake criteria. Potential problems with nutrient balance, algae, and dissolved oxygen can occur at times and in some areas of Lake Mead. | Recent Lake Mead-wide scope of monitoring has provided solid baseline to characterize water quality. More information is needed for Lake Mohave. Tributary inflows provide the highest **productivity**, but also the greatest potential to cause nutrient related issues. | Maintaining existing (2012) level of Lake Mead-wide monitoring of physical and biological parameters essential to assess trends and evaluate conditions. Monitoring is the foundation to assess impacts from quagga mussels, urbanization within watersheds, and potential climate change impacts. |
| *Fish and aquatic biota* | Sport fish populations are sufficient to support important recreational fishery. Native fish within Lake Mohave are declining. Lake Mead native fish populations are small but important because they are self-recruiting. Zooplankton composition may be influenced by quagga mussels but no significant changes noted to date. | Sport fish populations appear stable and have reached a balance with reservoir operations over the past 20 years. Quagga mussels and the introduced gizzard shad (*Dorosoma cepedianum*), and wastewater treatment technologies may impact the balance. It is important to monitor status of spawning and use areas and population dynamics for razorback suckers. | Annual sport fish and shad population monitoring provides baseline to assess impacts of quagga mussels, nutrient cycling, and climate change. Native fish population monitoring is critical for assessing trends and evaluating management. Need to better understand contaminant effects on native fish and wildlife. |
| *Sediment* | Sediment deposition in Lake Mead prior to creation of Lake Powell was significant; the rate has greatly slowed since Glen Canyon Dam was completed. Low concentrations of **legacy pesticides** and some emerging organics are present in sediments mostly in Las Vegas Bay, which appears to trap many contaminants. Lake Mohave has very little sediment accumulation. | Sediment deposition may act as a sink for low levels of contaminants. Re-suspension of contaminants could occur with water-level fluctuations or increases in storm intensities New delta deposits from lowering lake levels provide bird habitat and potential new riparian habitats. | Better understanding is needed of the relationship of contaminants in sediments to food-web transfers. Characterize transport of sediments and potential re-suspension and flux of contaminants at the sediment-water interface. Monitor delta deposition in response to lowering lake levels to assess habitat potential and alteration of reservoir hydrology. |
| *Birds* | Lakes Mead and Mohave provide important migration and wintering habitat. Trends include increasing numbers of wintering bald eagles (*Haliaeetus leucocephalus*) and nesting peregrine falcons. Lake Mead fluctuations have produced a variety of shorebird habitats. Songbird habitats are limited. Contaminants documented in birds and eggs in Las Vegas Wash. | An understanding of habitats created at different water levels and different rates of water-level change, in relationship to aquatic and shorebird use is important to understand the continued role of Lake Mead in regional conservation. Understanding pathways of contaminants within the food web and to bird reproduction is needed to assess risks to population health. | Monitoring of population dynamics and relationship to available habitats needed to assess response to low water and evaluate bird responses to ecosystem changes. Monitoring of potential contaminant impacts to bird populations is warranted. Research of potential impacts of quagga mussels on bird health is needed. |
| *Riparian and aquatic vegetation* | Lake Mead riparian vegetation is mostly limited to tributary deltas. Lower lake levels resulted in new deltas at tributary confluences. Lake Mohave is ringed with shoreline riparian habitats, mostly non-native tamarisk. Mesquite groves line much of Lake Mohave's upper riparian fringe. | New deltas provide potential for riparian habitats. Newly exposed shoreline habitats have potential to spread non-native species. The near-shore band of riparian habitat of Lake Mohave requires active management. Quagga mussel infestation may alter growth of aquatic vegetation. | Early detection monitoring needed for aquatic invasive vegetation and for **littoral** and aquatic vegetation. Vegetation and community inventory and monitoring at Virgin River and Colorado River deltas is needed to assess restoration potential. |

**Table 1-1.** Summary of key scientific findings, management implications, and data and information needs for each of the ecosystem categories and stressors identified in Lake Mead National Recreational Area's Aquatic Resources Plan.—Continued

| Resource component and related goals | Scientific findings | Management implications | Recommendations for data or information needs |
|---|---|---|---|
| *Contaminants* | Legacy contaminants declining due to regulations and mitigation. Emerging contaminants, including endocrine disrupting compounds present in low concentrations, especially near Las Vegas Wash. Biomarkers of endocrine disruption documented in common carp (*Cyprinus carpio*). | Emerging contaminants of concern not seen at levels currently known to pose a threat to human health, but have been documented to cause a number of health effects to individual fish. Contaminants pose risk to fish and wildlife. | Continued monitoring of legacy contaminants and inventory and monitoring of emerging contaminants of concern in the water column is needed. Greatest new need is for information related to population level impacts to fish and wildlife and documentation of movement of contaminants through the food web. |
| *Invasive species* | Quagga mussels have become the dominant benthic organism in vast areas of the lakes. Quagga mussels are reproducing in lakes year around, with juvenile veliger larvae a significant proportion of zooplankton at certain times of the year. | Quagga mussels have potential to alter water quality and nutrient cycling, plankton composition, and food-web dynamics. They can degrade recreational setting. Quagga mussels are a significant threat to ecosystems of Lakes Mead and Mohave. | Interagency quagga mussel monitoring plan has provided quality baseline of their population. Existing adult and veliger larvae monitoring should continue. Additional work is needed to comprehensively assess ecosystem impacts and food-web dynamics. |
| *Climate change* | Climate models developed for the Colorado River watershed indicate probability of decline in watershed snowpack and thus reduced water availability. Models point to increased potential for summer thunderstorms and flash floods. | Models indicate high probability for longer periods of low water levels in Lake Mead. This would alter water circulation patterns, nutrient cycling, and food-web dynamics. Higher water surface temperatures could raise productivity, and also raise the risk of pathogenic organisms to thrive. | Information needed for Lakes Mead and Mohave relates to potential impacts of low flows, lower water levels, increased air temperatures, and increased water temperatures on limnology, ecosystems, fish and wildlife, and recreation and potential pathogens. |

## Chapter 1 References

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National Park Service, 2010, Long-term limnological and aquatic resources monitoring and research plan for Lakes Mead and Mohave: Boulder City, Nev., Lake Mead National Recreation Area and University of Nevada, Las Vegas, 94 p., accessed August 17, 2012, at http://www.nps.gov/lake/naturescience/loader.cfm?csModule=security/getfile&amp%3bpageid=431205.

Chapter 2

# Environmental Setting of Lake Mead National Recreation Area

By Kent Turner[1], Michael R. Rosen[2], G. Chris Holdren[3], Steven L. Goodbred[2], and David C. Twichell[2]

Panorama of Boulder Basin, Lake Mead. Photograph by National Park Service.

***Lakes Mead and Mohave provide opportunities for millions of regional, national, and international visitors to enjoy a wide array of water-based recreation in a spectacular desert setting. The national significance of the site's recreational opportunities and scientific values led to its designation as the nation's first National Recreation Area in 1964. The stark contrast of the deep blue lakes with spacious open water basins against a backdrop of mountain and canyon scenery creates a diversity of landscapes inviting recreation from the active to the contemplative (Maxon, 2009). The quality of the setting as a backdrop for the recreational experience has resulted in designation of approximately 200,000 acres of lands surrounding the lakes as wilderness (National Park Service, 2005).***

[1]National Park Service

[2]U.S. Geological Survey

[3]Bureau of Reclamation

Desert bighorn sheep (*Ovis canadensis nelsoni*) near Willow Beach, Arizona. Photograph by Phillip Cummingham, U.S. Fish and Wildlife Service.

LMNRA is part of a land of rugged beauty where the Colorado Plateau geologic province transitions to the Basin and Range, and where influences of three of the four North American deserts converge (Houk, 1997; Rohde, 1999). The variety of exposed geology and topography, coupled with abundant water resources in a desert land, create a diversity of wildlife habitats.

Coyote (*Canis latrans*) looking for food along Overton Arm. Photograph by Michael R. Rosen, U.S. Geological Survey.

Visitors may observe desert bighorn sheep (*Ovis canadensis nelsoni*) feeding along the shoreline ridges, be surprised by coyote (*Canis latrans*) drinking from the shoreline, and then be drawn to waterbirds feeding on fish (Maxon, 2009).

Given the multitude of societal needs met by Lakes Mead and Mohave, and their importance to water and wildlife conservation, numerous Federal, State, and local agencies have interests in direct management and providing scientific information for management decisions for the lakes. These entities include the Bureau of Reclamation, National Park Service, Southern Nevada Water Authority, Nevada Department of Wildlife, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, U.S. Geological Survey, and wastewater reclamation districts who discharge into Las Vegas Wash, representing Clark County and the cities of Henderson, Las Vegas, and North Las Vegas. These agencies coordinate management and exchange scientific information necessary to address the interests of consumptive uses and domestic water supplies, fish and wildlife conservation, and recreation. The framework for water management is established by operations of the Hoover and Davis Dams, hydrology and water supply of the Colorado River, and contributions from Las Vegas Wash, Muddy River, and Virgin River.

Davis Dam, near Bullhead City, Ariz., which created Lake Mohave, rises approximately 140 ft (42.7 m) above the level of the Colorado River. It is a zoned earthfill structure with concrete spillway, intake structure, and power plant. Photograph by Michael R. Rosen, U.S. Geological Survey.

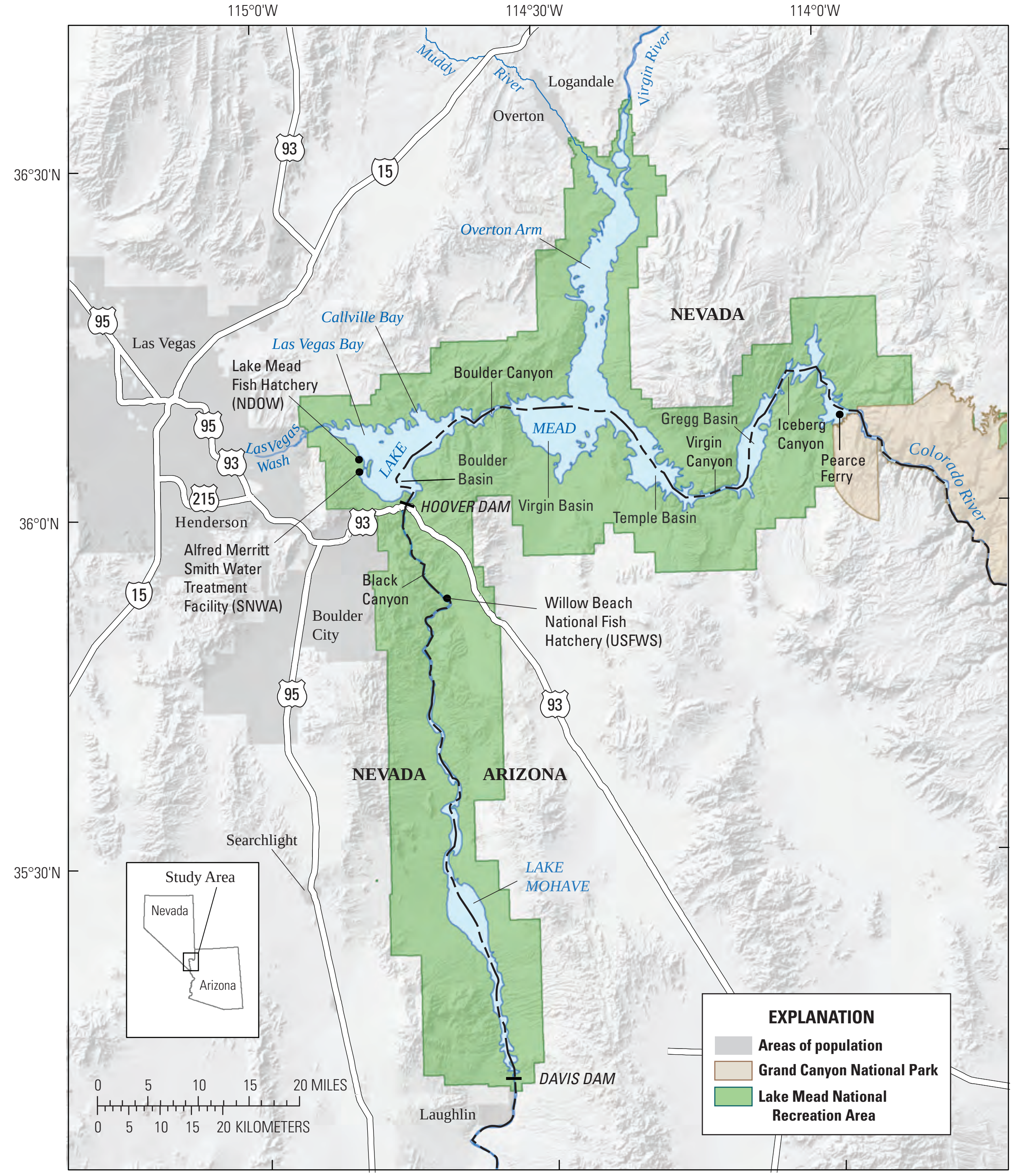
View of Hoover Dam from the new Mike O'Callaghan–Pat Tillman Memorial Bridge (Colorado River Bridge). Photograph by Michael R. Rosen, U.S. Geological Survey.

Lake Mead was formed by the completion of Hoover Dam in 1935 (Bureau of Reclamation, 2008). The dam and lake behind it were intended to provide flood control for the Colorado River, hydroelectric power for the nation, and a reliable water supply for agriculture and human consumption. In addition to these benefits, the lake and surrounding areas also have provided numerous recreational opportunities for humans and additional habitat for aquatic and terrestrial wildlife.

Lakes Mead and Mohave contain more than 140 mi (225.3 km) of former river channels, a combined 225,000 surface acres, and a wide range of water depths and **geomorphic** configurations (fig. 2-1; table 2-1). Lake Mead extends from Hoover Dam to Pearce Ferry at **full pool** and contains four large subbasins: Boulder, Virgin, Temple, and Gregg; four narrow canyons: Black, Boulder, Virgin, and Iceberg; and the 30-mi long Overton Arm, which extends from the Virgin and Muddy Rivers to the Virgin Basin. The Colorado River supplies 97 percent of the inflow into Lake Mead (Las Vegas Valley Watershed Advisory Committee, 2009). Other tributaries to Lake Mead include the Virgin River, Muddy River, and Las Vegas Wash.

Lake Mohave, which is Lake Mead's downstream neighbor (fig. 2-1), was created in 1951 by the construction of Davis Dam to stabilize flows from Hoover Dam and to help provide required water deliveries to Mexico. The Colorado River below Lake Mohave also provides water for Laughlin, Nevada, as well as up to 251 megawatts of hydroelectric power from Davis Dam. Lake Mohave extends approximately 67 mi (107.8 km) along the valley from Hoover Dam to Davis Dam, and is both narrow and shallow compared to Lake Mead (table 2-1; National Park Service, 2010). Lake Mohave also is ecologically important because it is home to the largest existing population of endangered razorback sucker (*Xyrauchen texanus*).

View of Lake Mead at Echo Bay (Overton Arm). Photograph by Michael R. Rosen, U.S. Geological Survey.




Base from National Park Service and U.S. Geological Survey digital data,1:675,000
Universal Transverse Mercator projection, Zone 11
North American Datum 1983

**Figure 2-1.** Lake Mead National Recreation Area (LMNRA) showing important locations and basins in the lakes. NDOW, Nevada Department of Wildlife; SNWA, Southern Nevada Water Authority; USFWS, U.S. Fish and Wildlife Service.

**Table 2-1.** Characteristics of Lakes Mead and Mohave.

[**Abbreviations:** acre-ft, acre-foot; ft, foot; km, kilometer; $km^2$, square kilometer; m, meter; $m^3$, cubic meter; mi, mile; yr, year]

| Lake characteristics (full pool) | [1]Lake Mead | Lake Mohave |
|---|---|---|
| | Value | Value |
| Surface area | 157,418 acres (637 $km^2$) | [2] $28.084\times10^3$ acres (114 $km^2$) |
| Volume | $28.8\times10^6$ acre-ft ($3.55\times10^{10}$ $m^3$) | [3] $1.8\times10^6$ acre-ft ($2.22\times10^9$ $m^3$) |
| Mean depth | 182 ft (55.5 m) | [4] 85 ft (25.9 m) |
| Maximum depth | 532 ft (162 m) | [4] 165 ft (50.3 m) |
| Watershed area | [5]$167\times10^3$ $mi^2$ (433×103 $km^2$) | [6] $168\times10^3$ $mi^2$ ($435\times10^3$ $km^2$) |
| Mean inflow | $10.9\times10^6$ acre-ft/yr ($1.34\times10^{10}$ $m^3$/yr) | $9.6\times10^6$ acre-ft/yr ($1.18\times10^{10}$ $m^3$/yr) |
| Hydraulic residence time | [7]2.6 yr | [7]60 days |
| Shoreline length | [2]759 mi (1,221 km) | [2]309 mi (497 km) |
| Watershed area to lake surface area ratio | 681:1 | 3,813:1 |

[1]Lake Mead values from Holdren and Turner (2010) except where noted.

[2]Computed from the U.S. Geological Survey, National Hydrographic Dataset flood polygon for Lakes Mead and Mohave.

[3]Taken from the Lake Mohave area-capacity tables (Available Capacity Table and Area-Capacity Curves for Lake Mohave, Bureau of Reclamation, October 1, 1949). Includes 8,530 acre-ft in dead storage below 533-ft elevation.

[4]Computed from fathometer readings taken by the U.S. Geological Survey in April 2002 (Lake Mohave Geophysical Survey 2002: GIS Data Release, available in Cross and others (2005). Readings were adjusted for vessel draft (1 m) and lake elevation at the time of survey (642 ft). Calculations were based on 95,216 fathometer readings taken from Willow Beach to Davis Dam.

[5]Watershed area is from the headwaters of the Colorado River to Hoover Dam.

[6]Watershed area is from the headwaters of the Colorado River to Davis Dam.

[7]Calculated from average inflow and lake volume. Actual residence time depends on reservoir operations for Lakes Mead and Powell.

## Use of Water in Lakes Mead and Mohave

As mentioned above, providing flood control for the Colorado River, irrigation and domestic uses, and the development of hydropower were the primary authorized purposes within the Boulder Canyon Project Act of 1928 that legislated construction of Hoover Dam (Bureau of Reclamation, 2005). Annual water deliveries from storage provided by Lake Mead helps to irrigate more than 2.5 million acres of land, with more than 80 percent of the allocations released through Hoover Dam utilized for agriculture within the States of Arizona and California. Hoover Dam's facilities feature 17 turbines, of which 1 is rated at 86,000 horsepower, 1 at 100,000 horsepower, and the remaining 15 at 178,000 horsepower each. The dam's maximum hydropower generation is more than 2 gigawatts, and annual output exceeds 4 billion kilowatt hours, which is delivered by the Western Area Power Administration within the States of California, Arizona, and Nevada (Bureau of Reclamation, 2005). The electricity generated from Hoover Dam in an average year is enough to meet the annual usage of nearly 1.4 million homes (Bureau of Reclamation, 2009).

Boating and water skiing are popular recreational activities at Lake Mead. Photograph by National Park Service.

Among Lake Mead's authorized primary purposes is operation to maintain flows to ensure efficient and timely delivery of Colorado River allocations for irrigation and domestic purposes to Arizona, Nevada, and California (Lower Basin States), as well as to meet treaty obligations to Mexico. These allocations include 300,000 acre-ft for Nevada, 2.8 million acre-ft (maf) for Arizona, 4.4 maf for California, and 1.5 maf for Mexico (Bureau of Reclamation, 2008). The prolonged drought of the 2000s has resulted in the Colorado River Basin States and the Bureau of Reclamation developing criteria for water allocations during specific low reservoir conditions (Bureau of Reclamation, 2007). These and other guidelines also have provided mechanisms for the Lower Basin States and Mexico to store currently unused allocations of water in Lake Mead for use in future years (Bureau of Reclamation, 2007). The potential for new water storage has highlighted some interagency concerns over degradation of this stored water by local stream inputs. These possible changes have renewed regional interest in maintaining the existing high water quality of Lake Mead.

Lake Mead plays a key role in the entire storage capacity and operational framework of the Colorado River (see Chapter 3). The lake has enough capacity (28.5 maf) to hold the entire flow of the Colorado River for 2 years of average annual flow. Lakes Mead and Powell together provide approximately 85 percent of the total storage capacity on the Colorado River, and currently are operated in close coordination to meet the annual delivery requirements of the river (Bureau of Reclamation, 2007). Lake Mohave is operated to provide steady flows to meet downstream requirements including treaty obligations to Mexico.

Annual visitation to LMNRA exceeds 8 million people. More than 60 percent of all visitors to the recreation area use some type of motorized watercraft; peak day use on the water between Lakes Mead and Mohave can exceed 5,000 boats (National Park Service, 2002). Lakes Mead and Mohave together provide in excess of 250,000 angler days annually (National Park Service, 2010). This visitation includes large numbers of residents of Nevada, Arizona, and California because LMNRA provides outstanding water-based recreational opportunities and amenities that contribute to improving the quality of life for the region. In general, recreational activities on Lakes Mead and Mohave include boating (both power boating and paddlecraft), swimming, fishing, scuba diving, picnicking, and shoreline camping (National Park Service, 2002). More than $45 million annually are directly generated from concession sales on the lakes, with an additional estimation of greater than $250 million annually added to the regional economy from recreation expenditures (Duffield and others, 2007).

Families visit Lake Mead for water recreation, including kayaking. Photograph by Jennell M. Miller, University of Nevada, Las Vegas.

## Lakes Mead and Mohave Characteristics and Tributary Sources

Lake Mead covers 157,420 acres (637.1 km$^2$) and extends 65 mi (104.6 km) from the inflowing Colorado River to Hoover Dam at full pool. The lake has a maximum water depth of 519 ft (158.2 m), an average depth of 183 ft (55.8 m), and holds more than 28 maf (greater than 35.5 billion m$^3$) of water at full capacity. Key characteristics of Lake Mead were recently updated by Holdren and Turner (2010) and are summarized in table 2-1.

From upstream to downstream, Lake Mead's four large, deep, but connected basins along the historical Colorado River channel are: Gregg, Temple, Virgin, and Boulder (fig. 2-1). These four basins are ecologically distinct from one another because the waters within them retain the properties of their sources (LaBounty and Burns, 2005). Four narrow canyons (Iceberg, Virgin, Boulder, and Black) and the nearly 33-mi (53.1-m) long Overton Arm, which extends south from the Virgin and Muddy Rivers to the Virgin Basin, are other important features of the lake. When full, it takes water an average of 2.6 years to travel through the lake.

Minor flooding in the Virgin and Muddy Rivers in April 2010 carries muddy water to Overton Arm. Photograph by Jorge Arufe, U.S. Geological Survey.

Lake Mohave covers approximately 30,000 acres (121.4 $km^2$) extending 67 mi (107.8 km) from Hoover Dam to Davis Dam. The lake has a maximum depth of 165 ft (50.3 m) and stores more than 1.8 maf (more than 2 billion $m^3$) of water at full capacity (table 2-1). Lake Mohave is long and narrow. There is only one large basin near the center of the lake, and it is 4 mi (6.4 km) across at its widest point (fig. 2-1). On average, it takes water about 60 days to travel through Lake Mohave when it is full. Davis Dam is operated as a regulation dam to hold the water released from Hoover Dam for smooth deliveries to meet downstream requirements in an efficient manner. As a result, the water level in Lake Mohave fluctuates between approximately elevation 630 and 645 ft (192.0 and 196.6 m) on an annual basis, and within predictable cycles.

The availability of water within the Colorado River system depends primarily upon the amount of annual snowmelt and rainfall received on the western slope of the Rocky Mountains in Colorado, which is the source of the Colorado River. Total inflows to Lake Mead averaged about 10.9 maf/yr (13.4 billion $m^3$/yr) between 1935 and 2001 (Ferrari, 2008). Flows decreased from 1999 through 2010 as the entire Colorado River Basin experienced drought conditions. More recent (1999–2010) Colorado River inflows average 8.23 maf/yr (10.1 billion $m^3$/yr) with additional inflow contributed by the lake's other tributaries. Inflows to Lake Mead are determined by releases from Glen Canyon Dam, as determined by annual operating plans and guidelines to meet operational requirements established through the framework of law, policy and guidelines collectively known as the "Law of the River." A smaller percentage of water comes from tributaries and washes along the river between Glen Canyon Dam and Lake Mead. In addition to inflow from the Colorado River mainstream, Lake Mead receives water from the Virgin and Muddy Rivers and from Las Vegas Wash (fig. 2-2). These three inputs combined, however, provide only 3 percent of the total input to Lake Mead (see U.S. Geological Survey National Water Information System web site at http://waterdata.usgs.gov/nwis). Only during periods of flooding do these tributaries contribute a larger proportion of the overall flow (up to 55,000 $ft^3/s$), and then only for short periods of time (generally hours to a few days). Diversions for irrigation upstream of Lake Mead limit flows in the Virgin and Muddy Rivers during the summer months. The annual inflow via Las Vegas Wash has increased over the past 30 years as a result of the rapid population growth in Las Vegas. Average flows in Las Vegas Wash have more than doubled during this period.

Expansion of the Las Vegas Metropolitan area occurred rapidly from 1970 to 2008. Photograph by Michael R. Rosen, U.S. Geological Survey.

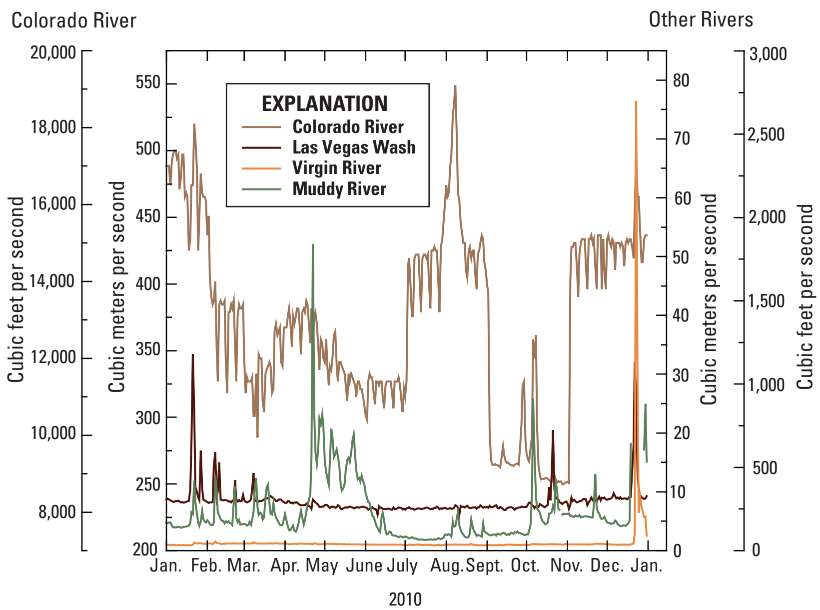



**Figure 2-2.** Discharge at the primary river gaging stations measuring discharge to Lake Mead for 2010. Left axis scales are for the Colorado River and right axis scales are for all other rivers.

Gregg Basin and Temple Basin are fed by the mainstream of the Colorado River. At current (2012) lake levels, the Colorado River enters Lake Mead at the northern end of the Gregg Basin, nearly 60 mi (96.6 km) upstream of Hoover Dam (fig. 2-1). The Virgin and Muddy Rivers flow into the Overton Arm, and then travel 25 mi (40.2 km) to merge with Colorado River water in the Virgin Basin. The combined flows from the upper end of Lake Mead enter the east end of Boulder Basin at the Narrows. Las Vegas Wash enters Las Vegas Bay at the west end of Lake Mead's Boulder Basin.

The average annual precipitation at Lake Mead, based on data from several weather stations around the lake, is only 5.74 in/yr (0.146 m/yr). Because of the large size of Lake Mead, direct precipitation on the lake surface would contribute 75,500 acre-ft/yr ($9.31 \times 10^7$ $m^3$/yr) at full pool, or slightly more than 6 in. (15.2 cm) of lake elevation. This is less than 1 percent of the total tributary inflow, but more than the average annual inflow from the Muddy River (Holdren and Turner 2010).

The Colorado River upstream of Lake Mead drains an area of 149,000 $mi^2$ (386,000.0 $km^2$) including parts of Colorado, Wyoming, New Mexico, Utah, Nevada, and Arizona. The Overton Arm collects the combined drainages of the Virgin and Muddy Rivers. These watersheds have a combined area of more than 12,030 $mi^2$ (31,157.6 $km^2$). Most of the land in the Colorado, Virgin, and Muddy River watersheds is either rangeland or forest, but the cities of St. George, Utah, and Mesquite, Nev., are undergoing rapid development that may affect both the quality of water in Lake Mead and the quantity of water delivered to the lake in the future.

The total drainage area for the Las Vegas Wash watershed is 2,193 $mi^2$ (5,679.8 $km^2$). Drainage in Las Vegas Wash includes non-point surface and groundwater discharges, non-point runoff from the Las Vegas metropolitan area, and treated wastewater from the cities of Las Vegas, Henderson, North Las Vegas, and Clark County municipal wastewater treatment facilities. The Las Vegas Wash watershed is predominantly non-developed scrub lands of the Mojave Desert, but the rapidly expanding urban Las Vegas metropolitan area covers nearly 450 $mi^2$ (1,165.5 $km^2$; 2010 U.S. Census Bureau data, http://www.census.gov).

Several basins within the Lake Mead watershed do not contribute runoff to the lake. These include 3,959 $mi^2$ (10,253.8 $km^2$) in the Great Divide basin in Wyoming and 697 $mi^2$ (1,805.2 $km^2$) on the Colorado Plateau in the Colorado River watershed, 3,780 $mi^2$ (9,790.1 $km^2$) in the White and Meadow Valley Wash subbasins of the Muddy River watershed, which is more than one-half of the total area of that watershed, and 607 $mi^2$ (1,572.1 $km^2$) in the Las Vegas Wash watershed.

Outflows from Lake Mead include water releases downstream through Hoover Dam, withdrawals for drinking water for southern Nevada, and evaporation. Nearly all water entering Lake Mohave comes through releases of Colorado River water through Hoover Dam.

## Geology below Lake Mead

Lake Mead lies within the Basin and Range Geologic Province of the Southwestern United States, and the shape of the lake is controlled by the complex terrain that characterizes this province (fig. 2-1). The result of this geology is that the lake is divided into five broad basins (Gregg Basin to the east; Temple Basin, Virgin Basin, and Overton Arm in the central part of the lake, and Boulder Basin to the west) separated by two narrow gorges where the lake cuts through mountain ranges (Virgin and Boulder Canyons).

Three different lake-floor substrates were identified on the basis of mapping completed prior to formation of the lake (Longwell, 1936) and geophysical data (Twichell and others, 2005): rock outcrops, alluvial deposits (material that has been eroded from the rocks by water and accumulated on hill slopes as sediments), and post-impoundment sediment deposits. The rock outcrops and alluvial deposits predate the lake, while the post-impoundment sediment has accumulated since completion of Hoover Dam. Areas of rock outcrop composed of Precambrian to Tertiary-age igneous, volcanic, and metamorphic rocks make up the flanks of the narrow gorges and Tertiary-age sandstones flank parts of Overton Arm, Virgin Basin, and Boulder Basin (Longwell, 1960). Alluvial deposits are Quaternary age (less than 1 million years old) (Longwell, 1960) and occupy large parts of the flanks of Overton Arm, Virgin Basin, and Boulder Basin (fig. 2-3). The post-impoundment sediment fills the axial (central) valley of the pre-impoundment Colorado River as well as the floors of tributary valleys.

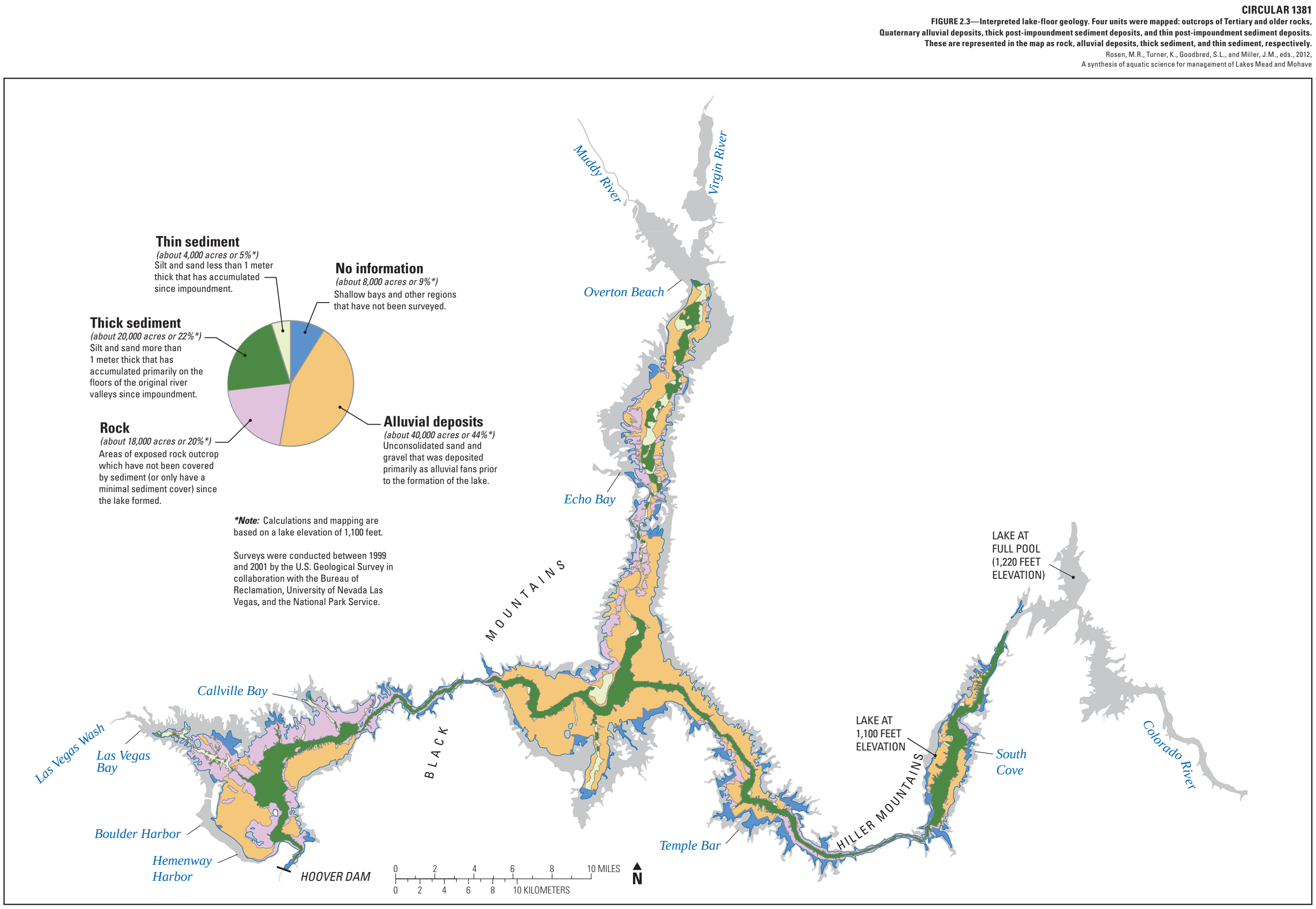



**Figure 2-3.** Interpreted lake-floor geology. Four units were mapped: outcrops of Tertiary and older rocks, Quaternary alluvial deposits, thick post-impoundment sediment deposits, and thin post-impoundment sediment deposits. These are represented in the map as rock, alluvial deposits, thick sediment, and thin sediment, respectively. An oversized version (11×17) of this figure is available for download at http://pubs.usgs.gov/circ/1381.

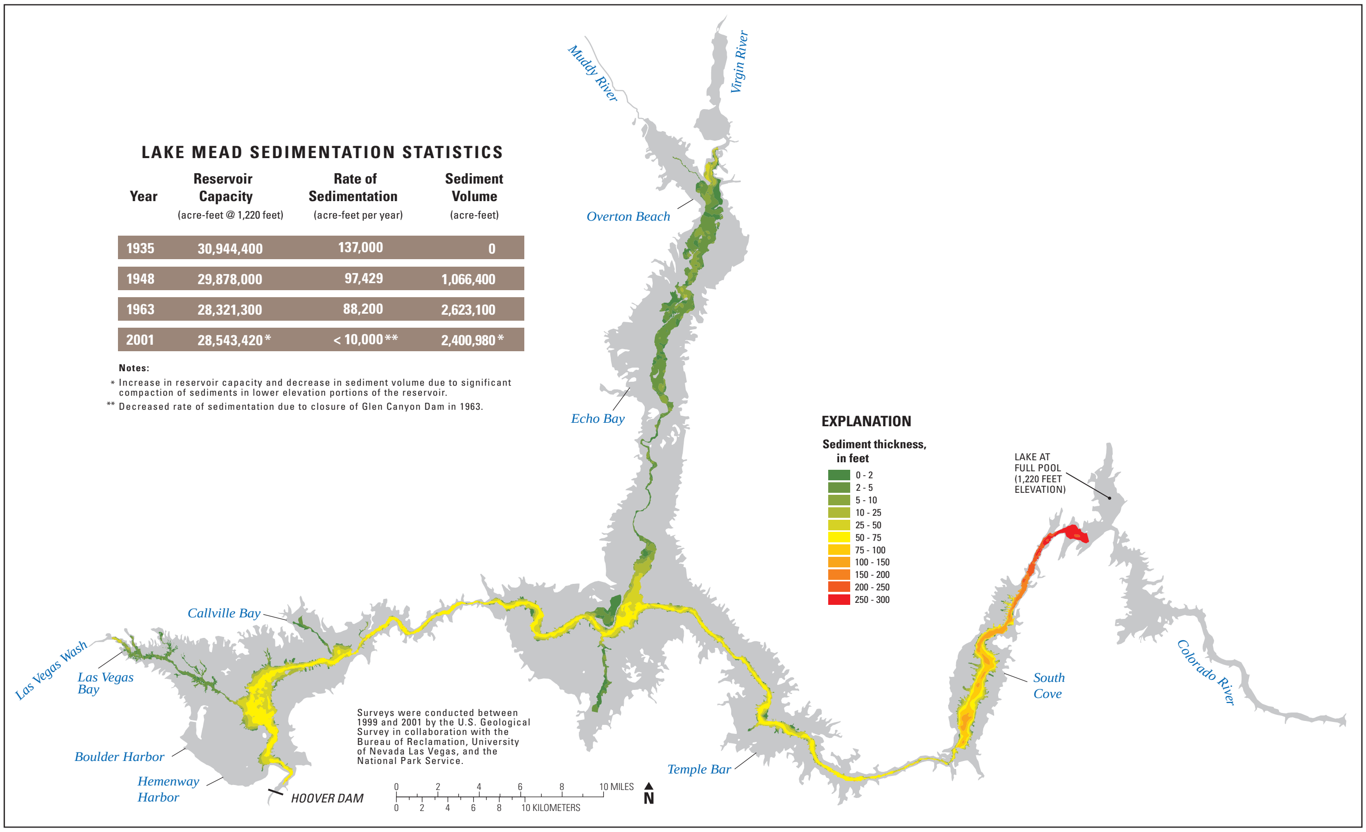
## Sediment Accumulation in Lake Mead

Sediment accumulation in Lake Mead has been extensively studied. The earliest studies preceded construction of the Hoover Dam and involved mapping the geology and topography of the region to be flooded by the reservoir (Longwell, 1936, 1960). Shortly after completion of the dam annual, **bathymetric** surveys were conducted along the pre-impoundment Colorado River channel to monitor sedimentation (Gould, 1960), cores were collected to assess the composition of the post-impoundment sediment (Gould, 1960) and suspended sediment concentrations in the Colorado River (Alexander and others, 1997) and Lake Mead (Gould, 1951; Howard, 1960) were measured to determine the volume of sediment brought to the lake and its distribution within the lake. Additional bathymetric surveys were completed in 1964 (prior to construction of the Glen Canyon Dam upriver of this reservoir; Lara and Sanders, 1970) and 2001 (Ferrari, 2008). A detailed geophysical survey of the entire lake, the results of which were used to map sediment distribution and thickness, was completed between 1999 and 2001 (Twichell and others 1999, 2003, 2005, 2009).

Sediment accumulation has been significant. Lara and Sanders (1970) reported that 1,425,900 acre-ft ($1.7588 \times 10^9$ $m^3$) of sediment accumulated in Lake Mead between 1935 and 1948–49. An additional 1,293,100 acre-ft ($1.5950 \times 10^9$ $m^3$) accumulated between 1948–49 and 1963–64, for a total of 2,716,900 acre-ft ($3.3512 \times 10^9$ $m^3$), 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). The Ferrari survey confirmed the interception of most sediment by Lake Powell and found the volume of Lake Mead actually increased by 219,150 acre-ft ($2.7032 \times 10^8$ $m^3$) between 1963–64 and 2001 (Ferrari, 2008). The increase was attributed to the reduction in sediment inflow and the consolidation (compaction) of previous sediment deposits.

Post-impoundment sediment extends the entire length of the lake from the mouths of the Colorado River and its tributaries to the Hoover Dam. This sediment is thickest along the original path of the Colorado River and thinner along the floors of the former Virgin River and Las Vegas Wash (fig. 2-4). At the eastern end of the lake, off the mouth of the Colorado River, these sediments are almost 279 ft (85.0 m) thick, thinning to about 82.0 ft (25.0 m) behind Hoover Dam. Sediment filling the floors of tributary valleys is mostly less than 3.3-ft (1.0-m) thick except in the deltas off the mouths of the tributary rivers, where sediment can reach thicknesses of 33 ft (10.0 m; Twichell and others, 2001, 2003).

CIRCULAR 1381
FIGURE 2.4—Sedimentation patterns in Lake Mead have contributed to declines in the capacity of the reservoir to hold water; however, with the completion of Glen Canyon Dam, the rate of sediment accumulation has slowed greatly
Rosen, M.R., Turner, K., Goodbred, S.L., and Miller, J.M., eds., 2012,
A synthesis of aquatic science for management of Lakes Mead and Mohave

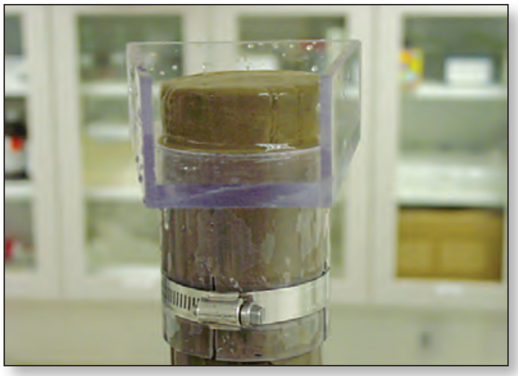



LAKE MEAD SEDIMENTATION STATISTICS

| Year | Reservoir Capacity (acre-feet @ 1,220 feet) | Rate of Sedimentation (acre-feet per year) | Sediment Volume (acre-feet) |
|---|---|---|---|
| 1935 | 30,944,400 | 137,000 | 0 |
| 1948 | 29,878,000 | 97,429 | 1,066,400 |
| 1963 | 28,321,300 | 88,200 | 2,623,100 |
| 2001 | 28,543,420 * | < 10,000 ** | 2,400,980 * |

Notes:
* Increase in reservoir capacity and decrease in sediment volume due to significant compaction of sediments in lower elevation portions of the reservoir.
** Decreased rate of sedimentation due to closure of Glen Canyon Dam in 1963.

**Figure 2-4.** Sedimentation patterns in Lake Mead have contributed to declines in the capacity of the reservoir to hold water; however, with the completion of Glen Canyon Dam, the rate of sediment accumulation has slowed greatly. An oversized version (11×17) of this figure is available for download at http://pubs.usgs.gov/circ/1381.



Clay at the top of a lake core from Las Vegas Bay. Photograph by Michael R. Rosen, U.S. Geological Survey.

A sandy delta at the mouth of the Colorado River advanced rapidly into the lake during the first 13 years after the dam was completed, slowed during the next 15 years, and after construction of the Glen Canyon Dam upstream in 1965 nearly stopped advancing (fig. 2-5). These surveys show that sediment also accumulated along the remainder of the profile at rates that decreased throughout the history of the lake (Smith and others, 1960; Ferrari, 2008). The regional geophysical mapping shows that post-impoundment sediments are found only along the floors of the deepest parts of the lake, namely, above the river valleys that drained the area prior to impoundment, which suggests that sediment has been distributed throughout the lake primarily by near-bottom flows. The early studies demonstrated that the Colorado River water with its heavy suspended sediment load, which was denser than the water mass in Lake Mead, sank upon entering the lake and flowed along the full length of the lake floor, following the deepest path available (Gould, 1951, 1960). As these flows, known as density flows or **turbidity** currents, traveled away from the river mouth across decreasing lake-floor slopes, they slowed and sediment settled out of suspension. Experiments indicate that the coarsest sediment in turbidity currents settles out at faster speeds (because larger grains require more turbulence to keep them in suspension) and the finer sediment travels farther because it takes longer to settle from suspension (Middleton and Southard, 1984). Cores from the floor of Lake Mead showed repeated sedimentary units (beds) of fine sand or coarse silt that grade upward to clay, which are typically the type of deposits that result from the passage of turbidity currents (Twichell and others, 2005).

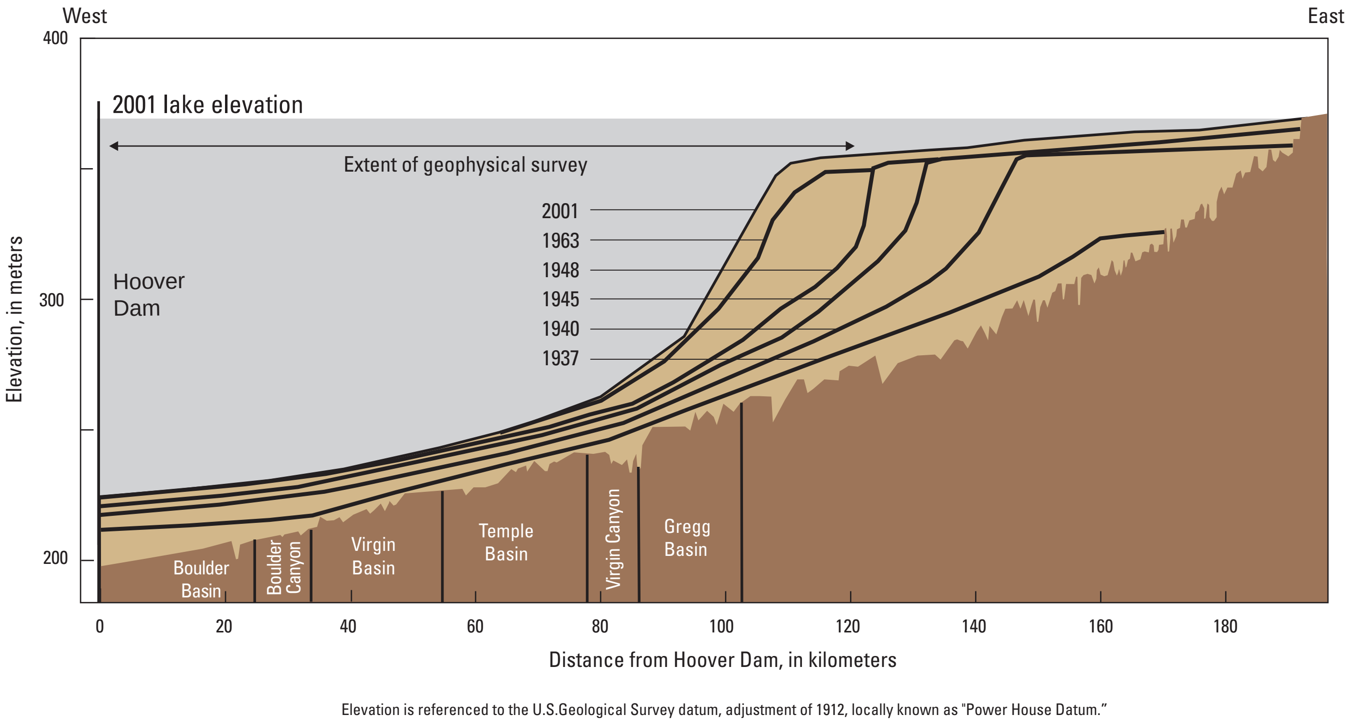



**Figure 2-5.** Four bathymetric profiles along the Colorado River channel through Lake Mead showing changes in sedimentation (modified from Ferrari, 2008).

Because of the well documented history of water discharge and suspended sediment loads of the Colorado River (Alexander and others, 1997), the rates at which turbidity currents travel the length of the lake (Gould, 1951), and the distribution and composition of sediments on the lake floor (Twichell and others, 2005), Lake Mead has proven to be a unique shallow-water natural laboratory for the study of turbidity currents, a process that most commonly is studied in more inaccessible, deep-sea settings (Bouma and Stone, 2000, and references therein).

## Geology below Lake Mohave

Lake Mohave was created with the completion of Davis Dam in 1950 and impoundment of the Colorado River below Hoover Dam. This region of the Colorado River Valley lies between the Black Mountains to the east and the Eldorado and Newberry Mountains to the west (fig. 2-6). Metamorphic and coarse-grained igneous rock makes up most of the exposed bedrock of these mountains. The northern section of the reservoir is constrained by the steep volcanic walls of Black Canyon. Below Black Canyon, Lake Mohave gradually widens with alluvial deposits bounding this section of the lake.

Farther south, Lake Mohave is constricted by a local protrusion of volcanic rock at Painted Canyon (Cross and others, 2005). The lake widens again to the south, where it lies within a wider, more gently sloping alluvial basin, reaching its greatest width in the central part of this basin. Lake Mohave is constricted once again still farther to the south with increasing slope of the alluvial basin and is bounded by the steep slopes of the Newberry Mountains to the west and **alluvium** to the east. Davis Dam, constructed within a narrow gorge cut into Precambrian igneous rock, marks the southern end of the lake.

## Sediment Accumulation in Lake Mohave

The floor of Lake Mohave is characterized by pre-impoundment features, including undulating sand deposits in the former river channel, rock outcrops along steep cliffs adjacent to the river channel, tree-lined floodplains adjacent to the river channel in the wider basins, and **alluvial fans** at the mouths of washes, which fringe most of the central part of the lake. In contrast to Lake Mead, remarkably little sediment has accumulated in Lake Mohave since its impoundment in 1950 (fig. 2-6).

Virtually all sediment transported by the Colorado River has been trapped in Lake Mead or in other upstream reservoirs, such as Lake Powell. The small amount of fine-grained sediment that has accumulated in Lake Mohave 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 at the mouths of washes that are 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. One notable debris flow at the mouth of Eldorado Canyon is the result of a large flash flood that moved through the wash in 1975.

**CIRCULAR 1381**

**FIGURE 2.6—Little sediment has accumulated in Lake Mohave due to upstream dams and reservoirs such as Lake Powell and Lake Mead. Post-impoundment lake muds cover only 1 percent of the lake floor.**

Rosen, M.R., Turner, K., Goodbred, S.L., and Miller, J.M., eds., 2012, A synthesis of aquatic science for management of Lakes Mead and Mohave

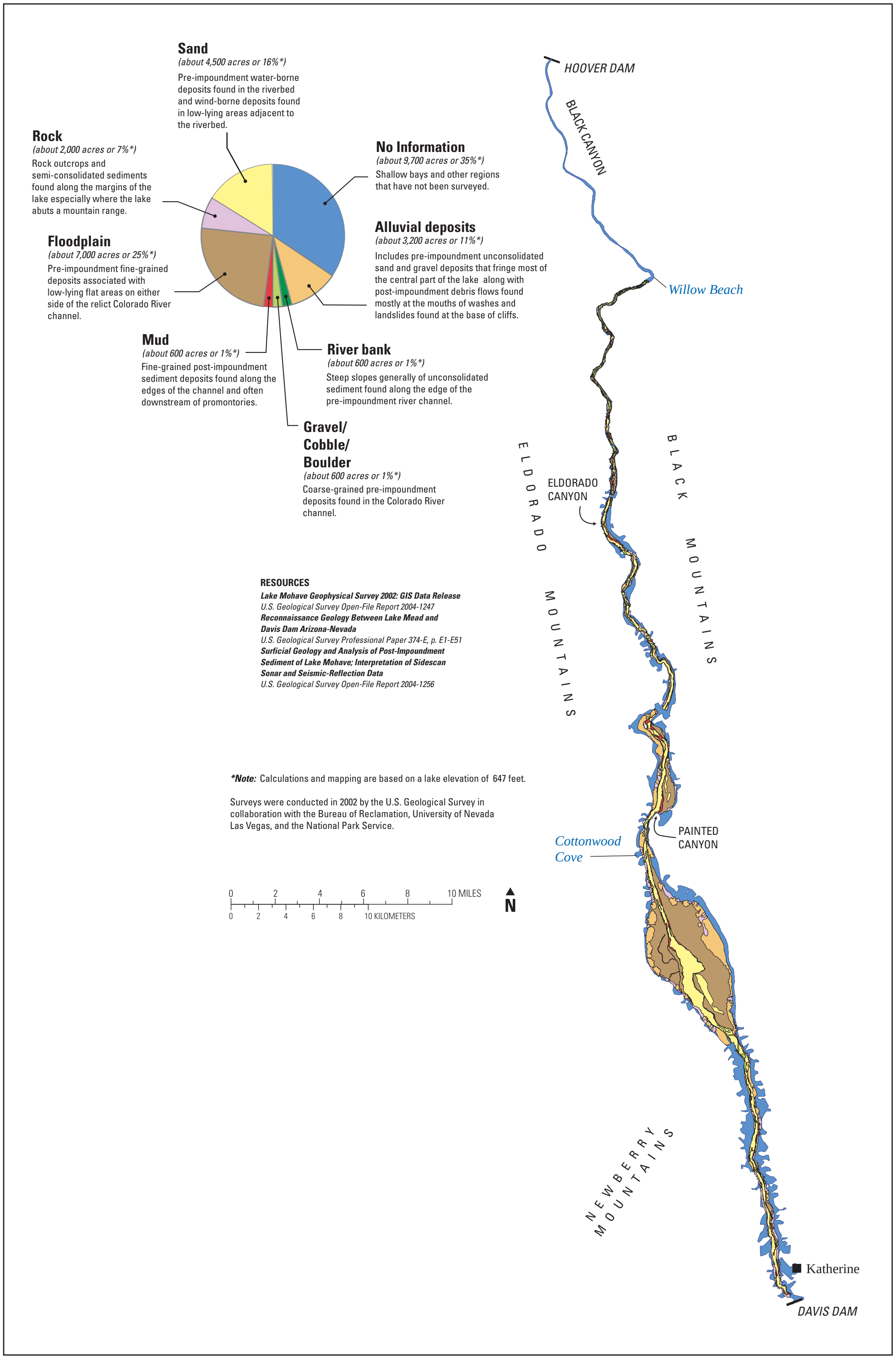



**Figure 2-6.** Little sediment has accumulated in Lake Mohave due to upstream dams and reservoirs such as Lake Powell and Lake Mead. Post-impoundment lake muds cover only 1 percent of the lake floor. An oversized version (11×17) of this figure is available for download at http://pubs.usgs.gov/circ/1381.

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Chapter 3

# Hydrology and Management of Lakes Mead and Mohave within the Colorado River Basin

By G. Chris Holdren[1], Todd Tietjen[2], Kent Turner[3], and Jennell M. Miller[4]

Rafting on Lake Mohave near Willow Beach. Photograph by Michael R. Rosen, U.S. Geological Survey.

## Colorado River Basin Hydrology and River Management

*The Colorado River Basin covers parts of seven States: Colorado, Wyoming, Utah, New Mexico, Nevada, Arizona, and California; at 1,450 mi (2,333.5 km) in length, the Colorado River is the seventh longest river in the United States (fig. 3-1). The Bureau of Reclamation has the responsibility for management of this system, in coordination with the seven basin States, within a complex framework of law, regulations, compact, treaty, and policies often referred to collectively as the "Law of the River." Lake Mead is a critical component of the overall Colorado River management, providing the capacity to store almost 2 years of the average runoff of the river.*

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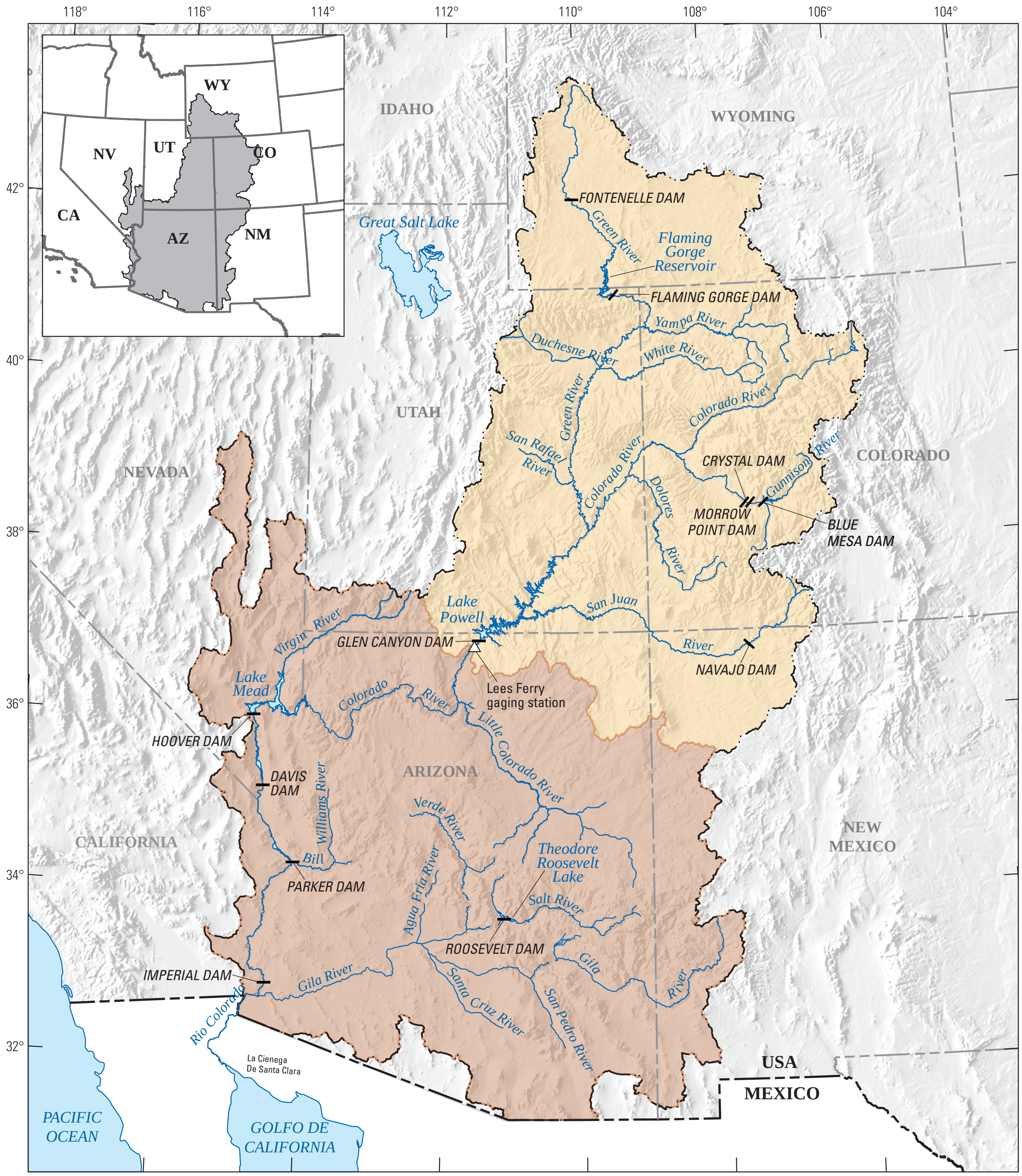



Base from National Park Service and U.S. Geological Survey digital data,1:675,000
Universal Transverse Mercator projection, Zone 11
North American Datum 1983



**Figure 3-1.** Colorado River Basin showing areas of the Upper and Lower Basins including Lakes Mead (upstream from) and Mohave (downstream from Hoover Dam). Lee Ferry is located at the boundary of the Upper and Lower Basins on the Colorado River, approximately 12 mi (19.3 km) southwest of Page, Arizona.

Through a series of compacts and treaty obligations, the water rights to the Colorado River have been apportioned or allocated to the seven basin States, along with a treaty obligation for water availability for Mexico. Within these legal requirements, in the United States the river is managed as two areas: the Upper Basin (Division) States of Colorado, New Mexico, Utah, and Wyoming; and the Lower Basin (Division) States of Arizona, California, and Nevada (fig. 3-1). The dividing line along the river for Upper and Lower Basin is set as Lee Ferry, Arizona, below Lake Powell.

The overall Colorado River allocations total 16.5 maf/yr. The overall allocation is set and managed as 7.5 maf to the Upper Basin States; 7.5 maf to the Lower Basin States; and 1.5 maf to Mexico. The Upper Basin is responsible for not depleting the flows of the Colorado River so all downstream allocations can be provided. Within the seven basin States and Mexico, annual consumptive use of the water ranges from 13 to 14.5 maf. Total system storage available within the more than 20 dams and reservoirs of the Colorado River Basin is 60 maf. Nearly 85 percent of this total available storage, or 50.2 maf, is stored in Lake Powell (24.3 maf) and Lake Mead (26.1 maf). Based on measurements of inflow into the Lake Powell region over the past 100 years, the approximate average annual "natural" inflow into the Colorado River within the Upper Basin has been 15 maf (fig. 3-2). Average annual inflow in the lower basin below Lake Powell has been approximately 1.3 maf. Because inflows depend on the amount of snowfall in the western Rocky Mountains and precipitation patterns for the side tributary inflows, the annual inflows are highly variable from year to year.

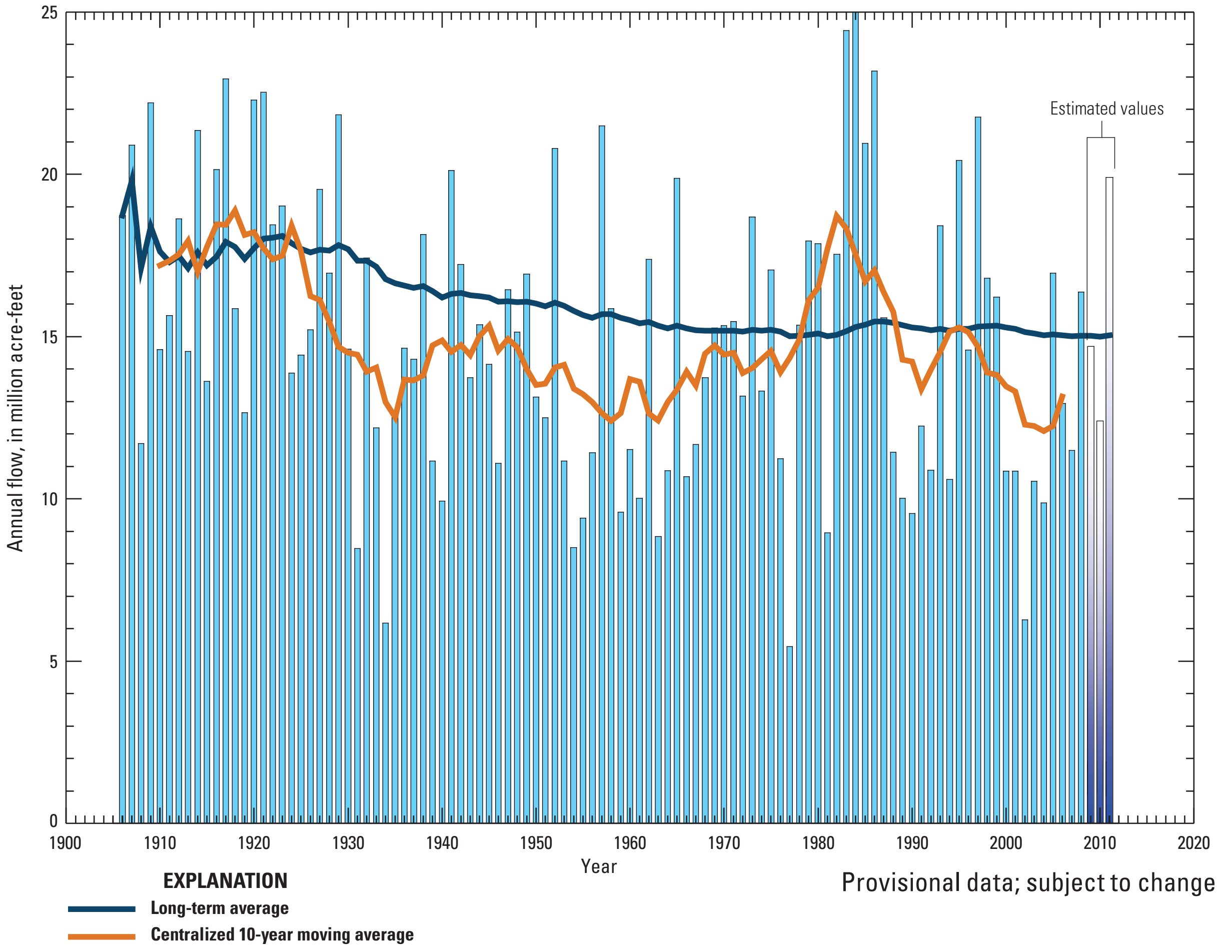



**Figure 3-2.** Colorado River computed natural flows at the U.S. Geological Survey gaging station at Lees Ferry, Arizona. Computed flows were provided by the Bureau of Reclamation. The term "natural" in this context refers to the absence of human development (for example, from depletion and regulation). "Natural Flow" is a recomputed streamflow that begins with the historical stream-gage record, then adds depletions and adds or subtracts impacts from reservoir regulation. The long-term average is each subsequent year being averaged to the previous years. The centralized 10-year moving average is the average of the 5 years before and 5 years after each point on the line.

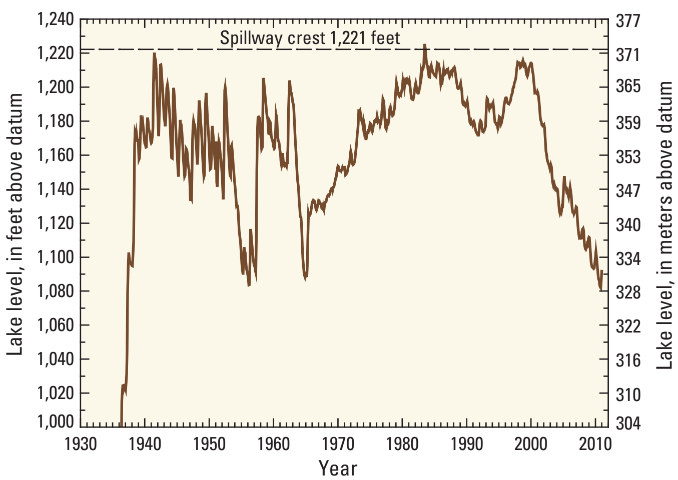
The long-term average natural flow in the Colorado River at Lees Ferry, Ariz., from 1906 to 2011 is 15.0 maf (fig. 3-2; flows for water years 2009–10 are estimated). The period from water year 2000 to 2010 was the driest 11-year period in the 100-year historical record for the Colorado River Basin (average annual flow of 12.1 maf), and the period from water years 1999 to 2010 has been the second driest 12-year period (12.5 maf) within that record.

Water-surface elevations in Lake Mead reflect the inflow-outflow regime as well as water use and demand; however, large differences in elevation are ultimately a reflection of drought years. Lake Mead began filling in early 1935, and filled to an elevation greater than 1,200 ft (365.8 m) above Power House Datum by mid-1941 (fig. 3-3). Between the 1940s and early 1960s, inflows into Lake Mead reflected the natural hydrologic variability of the Colorado River, and fluctuations in its elevation were approximately 19 ft (5.8 m). Construction of Glen Canyon Dam was completed in 1963, impounding Lake Powell upstream of Lake Mead. As Lake Powell initially filled, inflows to Lake Mead were reduced and its elevation declined more than 100 ft (30.5 m). After Lake Powell reached its minimum elevation for supplying power in 1964, both lakes then gradually began to fill at approximately the same rate during the spring runoff period of 1965.

Lake Mead's full pool elevation first reached in 1941 was not reached again until 1983. Seasonal fluctuations in the surface level of Lake Mead due to variations in inflows from the Colorado River were reduced by the buffering capacity of Lake Powell.

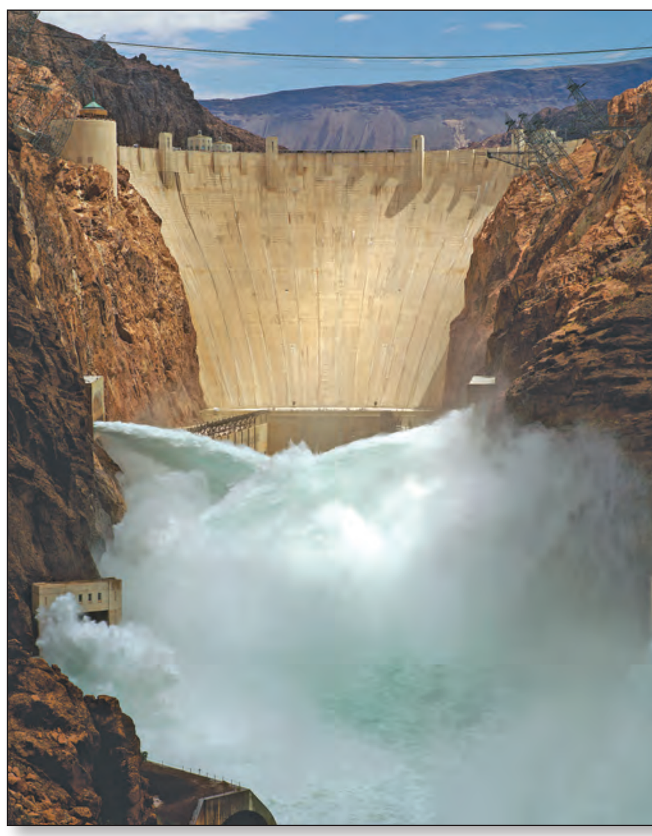
Lake Mead filled to full capacity (elevation greater than 1,221.4 ft [372.3 m]) in July 1983 and the spillway gates operated for the first time for flood-control purposes. The maximum-recorded elevation of 1,225.83 ft (373.63 m) was reached during this flood period. Lake Mead surface elevations declined through the late 1980s and increased again to higher than 1,215 ft (370.3 m) in 1999. Since that time, an extended drought has resulted in a decline in the elevation of Lake Mead by more than 130 ft (39.6 m). Historically, the elevation of the lake has declined this much only during the extreme drought of the 1950s, and during the filling of Lake Powell in the mid-1960s. In November 2010, the water level of Lake Mead reached just less than 1,082 ft (329.8 m), its lowest elevation since it was first filled in the late 1930s. Hydrologic conditions (for example, and in particular, the magnitude of the snowpack in the Colorado River Basin) improved in 2011, and the April–July 2011 inflow into Lake Powell was the highest inflow since 1984, the ninth highest inflow in the period of record from 1908 to 2011 (source: Colorado Basin River Forecast Center; http://www.cbrfc.noaa.gov).

Concern over the drought and water-level declines within Lake Mead and Lake Powell led the Bureau of Reclamation to coordinate river operations among the seven basin States in 2007, and to develop the Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Bureau of Reclamation,




Elevation is referenced to the U.S.Geological Survey datum, adjustment of 1912, locally known as "Power House Datum."

**Figure 3-3.** Lake Mead End-of-Month Elevations since completion of Hoover Dam, Bureau of Reclamation.



Jet flow gate testing at Hoover Dam, June 1998. Photograph by Bureau of Reclamation.

2007). These guidelines established criteria for the protection of certain critical water levels within Lake Mead and Lake Powell for water supply, benchmarks based on Lake Mead elevations when the availability of water would be low enough to require official determination of a water shortage in the lower basin, and specified reductions in annual water-use volumes to Lower Basin States during shortage years.

Most of Nevada's share of Colorado River water is withdrawn directly from Lake Mead by the Southern Nevada Water Authority (SNWA) through its intakes on the western side of Boulder Basin. These withdrawals meet requirements for Las Vegas Valley, but Nevada does have additional diversions downstream of Davis Dam. Annual withdrawals by SNWA to provide municipal water for Las Vegas Valley are currently about 450,000 acre-ft/yr ($5.5\times10^8$ $m^3$/yr), about 50 percent more than Nevada's 300,000 acre-ft/yr allocation of Colorado River water. SNWA is given **return flow** credits for water returned to Lake Mead via Las Vegas Wash, most of which is highly treated wastewater. The return flow credits help comprise the total Southern Nevada community use and are required to enable the additional withdrawals beyond its allocation.

Discharge from Hoover Dam occurs at elevations of 895 and 1,045 ft (272.8 and 318.5 m) above Power House Datum. Both outlets are in the **hypolimnion** (Chapter 4) at full pool but the upper outlet is near the bottom of the **epilimnion** at 2012 lake levels. The annual discharge can exceed 9.0 maf (see Lake Mead Water Budget).

## Lake Mead Water Budget

A water budget can describe the net balance of Lake Mead's water inputs, outflows, and losses over a given year. In practice, the water budget for Lake Mead is highly regulated and depends primarily upon releases from Lake Powell through Glen Canyon Dam and downstream releases through Hoover Dam. River operations are controlled by the Bureau of Reclamation to meet legal requirements and contractual demands for drinking, municipal, industrial, and irrigation water. The operational model prescribing inflows to Lake Mead and outflows to Lake Mohave and the lower Colorado River evaluates (1) releases from Lake Powell to the Colorado River; (2) downstream releases for the Central Arizona Project, Metropolitan Water District of Southern California, and other Lower Basin water contractors; (3) consumption by the Las Vegas metropolitan area through water deliveries from SNWA; (4) required deliveries under treaty with Mexico; (5) inflows from other tributaries such as the Virgin and Muddy Rivers and the Las Vegas Wash; (6) bank storage; and (7) evaporative losses.

The approximate annual minimum release from Lake Powell since the reservoir initially filled to capacity in 1980, referred to operationally as the "minimum objective release," is 8.23 maf. Additional tributary inflows below Lake Powell average approximately 0.7 maf, thus providing a total average operational inflow into Lake Mead of 9.0 maf (table 3-1). Approximate annual outflows to meet downstream requirements are approximately 9.6 maf. Evaporation rates in

**Table 3-1.** Lake Mead water budget.

[Data from Bureau of Reclamation. **Abbreviations:** maf, million acre-feet]

**Lake Mead Water Budget**

Given current average water demands over the past 10 years in the Lower Basin and Mexico, and a minimum objective release from Lake Powell (8.23 maf]), Lake Mead storage is reduced on average by about 1.2 maf[1] each year.

| | |
|---|---|
| **Approximate annual inflow into Lake Mead**<br>(8.23 maf release from Lake Powell plus average intervening flows between Lake Powell and Lake Mead) | **9.0 maf** |
| **Approximate annual outflow from Lake Mead**<br>(Lower Basin apportionments to States and Mexico Treaty allocation plus downstream regulation including side inflows, evapotranspiration, transmission losses, etc.) | **-9.6 maf** |
| **Approximate annual Lake Mead evaporation loss** | **-0.6 maf** |
| **Water balance** | [1]**-1.2 maf** |

[1]Equivalent of about 12 feet in elevation at Lake Mead.

the Mojave Desert around Lake Mead are among the highest in the United States (Farnsworth and Thompson, 1982; Westenburg and others, 2006). Thus at full pool, evaporative losses from the lake surface are estimated to be approximately 0.6 maf, almost 7 percent of the average annual inflow, and result in the removal of approximately 6 vertical ft (1.8 m) of water from the lake.

When the annual release volume from Lake Powell totals 8.23 maf, these values of inflow and outflow (including evaporation) indicate that the overall average yearly Lake Mead water budget operates at a 1.2 maf deficit, which is equal to approximately 12 ft (3.7 m) of lake elevation. This actuality means that in years of normal to slightly below normal snowpack in the headwaters of the Colorado River and standard operations, the water level in Lake Mead will decline by 12 ft (3.7 m) from the previous year's high water level. Significant increases in the water level of Lake Mead will require either several years of above average snowpack and precipitation within the watershed or lower consumptive use by Basin States. The overall water balance generally has been maintained since creation of Lake Mead through the overall storage capacity of the Colorado River system and the ability to store large volumes during wet years, and the fact that until recently, many Basin States were not using all of their water allocations. As climate models now predict longer periods of reduced snowpack within the Colorado River Basin, and as water demands and use approach full allocations, it is forecasted that the future will bring correspondingly longer periods of low water elevation and greater fluctuations in water levels than have been seen to date (Barnett and Pierce, 2009).

## Lake Mead Tributaries

All tributaries entering Lake Mead at times carry heavy sediment loads and have higher nutrient concentrations than the receiving waters of the lake. Other characteristics of the inflows, primarily temperature and dissolved solids, determine their impact on lake productivity and water quality (fig. 3-4). The **specific conductance** of water, or its ability to conduct electrical current (see Chapter 4), provides an estimate of the concentration of total dissolved solids present in water. Specific conductance, which differs among the Lake Mead tributaries (Holdren and Turner, 2010), is a traceable feature useful in tracking the path of one water source as it flows into another.

The distribution of dissolved solids, nutrients, and other chemicals of interest in Lake Mead is determined by vertical and horizontal mixing processes, which are heavily affected by stratification during the summer months and by wind and water currents in all seasons (Baker and others, 1977). Stratification is the process by which deep lakes separate into a warm surface layer and a colder, denser layer in deeper water. The river inflows will enter the lake's water column at the level at which their density, as determined by temperature and the concentrations of dissolved and suspended solids, is equal to the density of the receiving water (see Chapter 4 for a more detailed description of stratification). In Lake Mead, on an approximately every-other-year cycle, complete (top to bottom) mixing extends through late autumn, winter, early spring, and stratification extends from spring into autumn (LaBounty and Burns, 2005).

The Colorado River enters the eastern end of Lake Mead at the upper end of Gregg Basin at current (2011) lake levels. The river is colder and less salty than Lake Mead; because cold water is denser than warm water, the river water typically flows along the bottom of the lake, deep into the water column of Gregg Basin. This phenomenon limits nutrient availability and productivity in the upper levels of the lake (Paulson and Baker, 1983). The low conductivity water from the Colorado River that enters Lake Mead can often be detected all the way to Hoover Dam, more than 60 mi (96.6 km) downstream.

The Virgin and Muddy Rivers also are colder than Lake Mead, but unlike the Colorado River, they both have higher concentrations of total dissolved solids than Lake Mead. Both rivers enter Lake Mead at the northern end of the Overton Arm and also flow along the bottom of the lake. Unlike Gregg Basin, the upper end of the Overton Arm is relatively shallow and the river inflows typically mix with Lake Mead water. During periods of heavy storm runoff, the high conductivity signature of the Virgin and Muddy Rivers can be observed at significant distances downstream from the rivers' entry to the lake. Under these infrequent conditions, the high conductivity water can sometimes be traced all the way to Hoover Dam. Agricultural land uses along these rivers upstream of Lake Mead mitigate the impacts of the Virgin and Muddy Rivers on lake productivity, because during the summer months, almost the entire flow of both rivers is diverted for agriculture, thereby reducing nutrient inputs and algal productivity in the lake (Holdren and Turner, 2010).

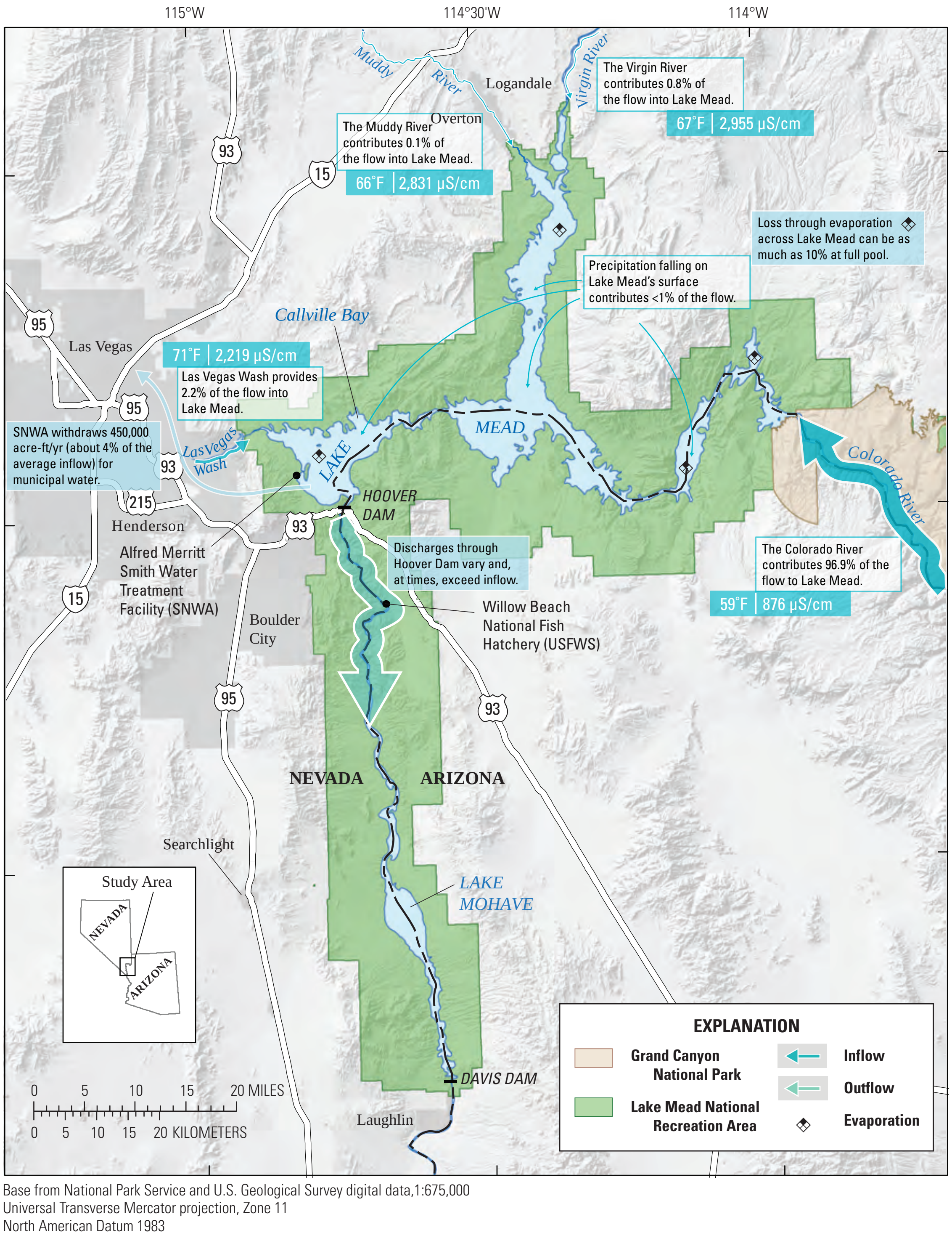



**Figure 3-4.** Relative contributions of inflows to Lake Mead and typical temperature and specific conductance values for these flows. Specific conductance (SC) is shown in microsiemens per centimeter (µS/cm). SNWA, Southern Nevada Water Authority; USFWS, U.S. Fish and Wildlife Service.

Las Vegas Wash drains the Las Vegas Valley and flows into Boulder Basin at the western end of Lake Mead. Las Vegas Wash is saltier than Lake Mead, but its temperature relative to the lake varies throughout the year. Las Vegas Wash typically enters Lake Mead as an underflow at the bottom of the lake in the winter; an interflow in the middle of the water column in the summer and autumn, when it flows along the top of the temperature contrast (**thermocline**) between warmer surface water and colder bottom water; and as an overflow at the water's surface in the spring. This flow regime can provide high nutrient concentrations to the lower part of the water column in the spring and summer and promote algal growth (LaBounty and Burns, 2005). As a result, Boulder Basin, and particularly Las Vegas Bay, is one area of the lake with high productivity.

Las Vegas Wash flowing toward Lake Mead. Photograph by Michael R. Rosen, U.S. Geological Survey.

## Lake Mead Operations

The Bureau of Reclamation operates Hoover Dam to provide flood control and to meet downstream demands as stated within the policies and guidelines comprising the "Law of the River." The Colorado River system operational requirements include the reservoir regulation of Lake Mohave and Lake Havasu (located downstream of Lake Mohave, outside LMNRA) to provide efficient deliveries of downstream users. Water is released from Lake Mead within standard operational guidelines to adapt to overall system gains and losses (for example, side inflows, evapotranspiration, and transmission losses) downstream of Hoover Dam.

Under the Colorado River Interim Guidelines (Bureau of Reclamation, 2007), water deliveries can be larger or smaller than under standard operational guidelines to adjust to surplus or shortage conditions based upon water availability and key reservoir levels within Lake Mead and Lake Powell. The Interim Guidelines provide a prescriptive methodology for determining the annual releases from Lake Powell and Lake Mead throughout the full range of reservoir operations, including periods of low reservoir levels (figs. 3-5 and 3-6).

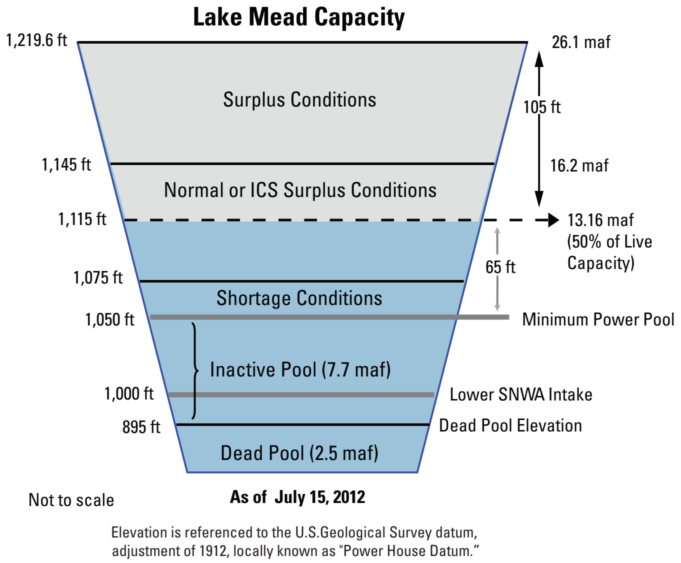



**Figure 3-5.** Bucket diagram depicting key elevation criteria under the 2007 Interim Guidelines (Bureau of Reclamation, 2007). Reservoir contents listed in the diagram refer to active storage above the dead pool elevation of 895 ft (272.7 m). Dead pool refers to lowest release capacity facilities within Hoover Dam, below which elevation additional releases are not possible. ICS, Intentionally Created Surplus; SNWA, Southern Nevada Water Authority.

## Lake Powell and Lake Mead Operational Diagrams and Current Conditions

**Lake Powell**

| Elevation (feet) | Operation According to the Interim Guidelines | Live Storage (maf)[1] |
|---|---|---|
| 3,700 | **Equalization Tier**<br>Equalize, avoid spills or release 8.23 maf | 24.3 |
| 3,636–3,666 (2008–2026) | **Upper Elevation Balancing Tier**[3]<br>Release 8.23 maf; If Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf | 15.5–19.3 (2008–2026) |
| 3,575 | **Mid-Elevation Release Tier**<br>Release 7.48 maf; If Lake Mead < 1,025 feet, release 8.23 maf | 9.5 |
| 3,525 | **Lower Elevation Balancing Tier**<br>Balance contents with a min/max release of 7.0 and 9.5 maf | 5.9 |
| 3,490 | | 4.0 |
| 3,370 | | 0 |

**Lake Mead**

| Elevation (feet) | Operation According to the Interim Guidelines | Live Storage (maf)[1] |
|---|---|---|
| 1,220 | **Flood Control Surplus or Quantified Surplus Condition**<br>Deliver > 7.5 maf | 25.9 |
| 1,200 (approx.)[2] | **Domestic Surplus or ICS Surplus Condition**<br>Deliver > 7.5 maf | 22.9 (approx.)[2] |
| 1,145 | **Normal or ICS Surplus Condition**<br>Deliver ≥ 7.5 maf | 15.9 |
| 1,105 | | 11.9 |
| 1,075 | **Shortage Condition**<br>Deliver 7.167[2] maf | 9.4 |
| 1,050 | **Shortage Condition**<br>Deliver 7.083[5] maf | 7.5 |
| 1,025 | **Shortage Condition**<br>Deliver 7.0[6] maf<br>Further measures may be undertaken[7] | 5.8 |
| 1,000 | | 4.3 |
| 895 | | 0 |

**Diagram not to scale**

[1] Acronym for million acre-feet.

[2] This elevation is shown as approximate as it is determined each year by considering several factors including Lake Powell and Lake Mead storage, projected Upper Basin and Lower Basin demands, and an assumed inflow.

[3] Subject to April adjustments which may result in a release according to the Equalization Tier.

[4] Of which 2.48 maf is apportioned to Arizona, 4.4 maf to California, and 0.287 maf to Nevada.

[5] Of which 2.40 maf is apportioned to Arizona, 4.4 maf to California, and 0.283 maf to Nevada.

[6] Of which 2.32 maf is apportioned to Arizona, 4.4 maf to California, and 0.280 maf to Nevada.

[7] Whenever Lake Mead is below elevation 1,025 feet, the Secretary of the Interior shall consider whether hydrologic conditions together with anticipated deliveries to the Lower Division States and Mexico is likely to cause the elevation at Lake Mead to fall below 1,000 feet. Such consideration, in consultation with the Basin States, may result in the undertaking of further measures, consistent with applicable Federal law.

**Figure 3-6.** Diagram of key criteria elevations for Lake Powell and Lake Mead under 2007 Interim Guidelines. ICS, Intentionally Created Surplus.

The Interim Guidelines recognize that low reservoir levels at Lake Mead have the potential to affect the following facilities and resources: power generation at Hoover Dam; pumping by SNWA at the drinking water intakes; boat launching, recreational facilities, and access within Lake Mead; water quality (for both Lake Mead and below Hoover Dam); and riparian and aquatic species in and near Lakes Mead and Mohave. Criteria were established to provide for flexibility of operations in times of potential water surplus and periods of water shortages, while protecting, to the extent possible, facilities and resources potentially affected at various water levels.

Use of Lake Mead water for its multiple purposes is constrained by several structural conditions. The top of Hoover Dam is at elevation 1,232 ft (375.5 m). The SNWA drinking water intakes for Las Vegas and Southern Nevada will operate down to lake levels of 1,000 ft (304.8 m). The minimum pool or elevation to support power generation within Hoover Dam is 1,050 ft (320.4 m). Within the operational criteria, an exclusive flood control pool is established between approximately 1,220 and 1,229 ft (371.7 and 374.6 m) elevation, meaning that space will be reserved to accommodate periods of high flow and upstream releases to provide additional flood protection within the system. This nearly 10-ft (3.0-m) zone contains approximately 1.5 million acre-ft (maf) of exclusive flood control space above elevation 1,220 ft (371.7 m). Lake Mead water elevations within this zone also are recognized as surplus conditions, meaning that additional water can be released to the Lower Basin States of California, Arizona, and Nevada, and Mexico.

Key operational criteria for both Lake Powell and Lake Mead were established within the 2007 Interim Guidelines (fig. 3-6). The diagram reflects the intent within the criteria to balance or equalize storage capacities within Lake Powell and Lake Mead within a framework of recognizing important water elevations on each lake that are related to its operations.

The operational guidelines for the reservoirs are driven by hydrology and projected reservoir conditions of Lake Powell and Lake Mead. The diagram presents various elevations on Lake Powell that trigger such equalization or balancing releases. In general, Lake Powell will release 8.23 maf or more of water downstream above elevation 3,575 ft (1,089.7 m), or 39 percent of its capacity. Between elevations 3,525 and 3,575 ft (1,074.4 and 1,089.7 m), Lake Powell will release 7.48 maf, unless Lake Mead's elevation is projected to be 1,025 ft (312.4 m) or below, in which case Lake Powell will release 8.23 maf. Below elevation 3,525 ft (1,074.4 m), or 24 percent of capacity, releases from Lake Powell are coordinated with the water level in Lake Mead and range between 7.0 and 9.5 maf.

For Lake Mead, the most significant elevation within the Interim Guidelines is 1,075 ft (327.7 m), or 34 percent of capacity. Lake Mead will generally release 7.5 maf annually for United States consumptive use above water-surface elevation 1,075 ft (327.5 m), and the Guidelines include mechanisms for the Lower Basin States to develop or store surplus water when the surface elevation is above 1,075 ft (327.5 m). At elevations 1,075 ft (327.5 m) or below, the shortage conditions are triggered, which provide that United States consumptive uses can decrease to 7.2 maf for Lake Mead elevations from 1,075 to 1,050 ft (327.7 to 320.0 m; between 34 and 27 percent of capacity); to 7.1 maf for elevations from 1,050 to 1,025 ft (320.0 to 312.4 m; between 27 and 21 percent of capacity); and 7.0 maf at lake elevations below 1,025 ft (312.4 m). Reductions in water deliveries to United States water users in the Lower Basin, such that depletions are less than 7.5 maf, affect the States of Nevada and Arizona until Lake Mead's surface declines to 1,025 ft (312.4 m). Below 1,025 ft (312.4 m), the Secretary of the Interior will consult the Basin States to determine the allocation of water. The coordinated operations of Lake Powell, Lake Mead, and the Lower Basin are much more complex than can be described here; detailed information is available in the document, "Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead" (Bureau of Reclamation, 2007).

## Lake Mohave Operations

Lake Mohave is operated as a regulation dam, or to hold releases from the Hoover Dam for efficient deliveries to meet downstream needs. As a result, Lake Mohave is operated within a consistent operational pattern that is tied to the predictable cycles of the downstream water needs. The surface elevation of the lake is not subject to wide variations, and typically is within a range of about 15 ft (4.6 m) or less (fig. 3-7). The annual maximum levels of approximately 645 ft (196.6 m) typically are reached in April or May and minimum levels of approximately 630 ft (192.0 m) are observed in September or October following summer releases for irrigation (fig. 3-8).

Lake Mohave is operated in support of the Lower Colorado River Multi-Species Conservation Program's implementation of the Razorback Sucker Replacement Program (see Chapter 5). To support razorback sucker (*Xyrauchen texanus*) populations and habitat, the lake's water level is held steady during the winter and spring months during the fish spawning season and raised to a higher level during the spring and summer months to maintain water quality in the backwater pools used for raising razorback suckers for return to the main lake system. The lake is drawn down in the autumn months to accommodate the harvesting of razorback suckers from lakeside rearing coves for their return to the lake.

The lake also is held higher during the spring and summer months to help meet higher downstream water demands during peak agricultural use. In addition, the lake is drawn down in the autumn months to enable it to capture runoff from autumn and winter precipitation events.

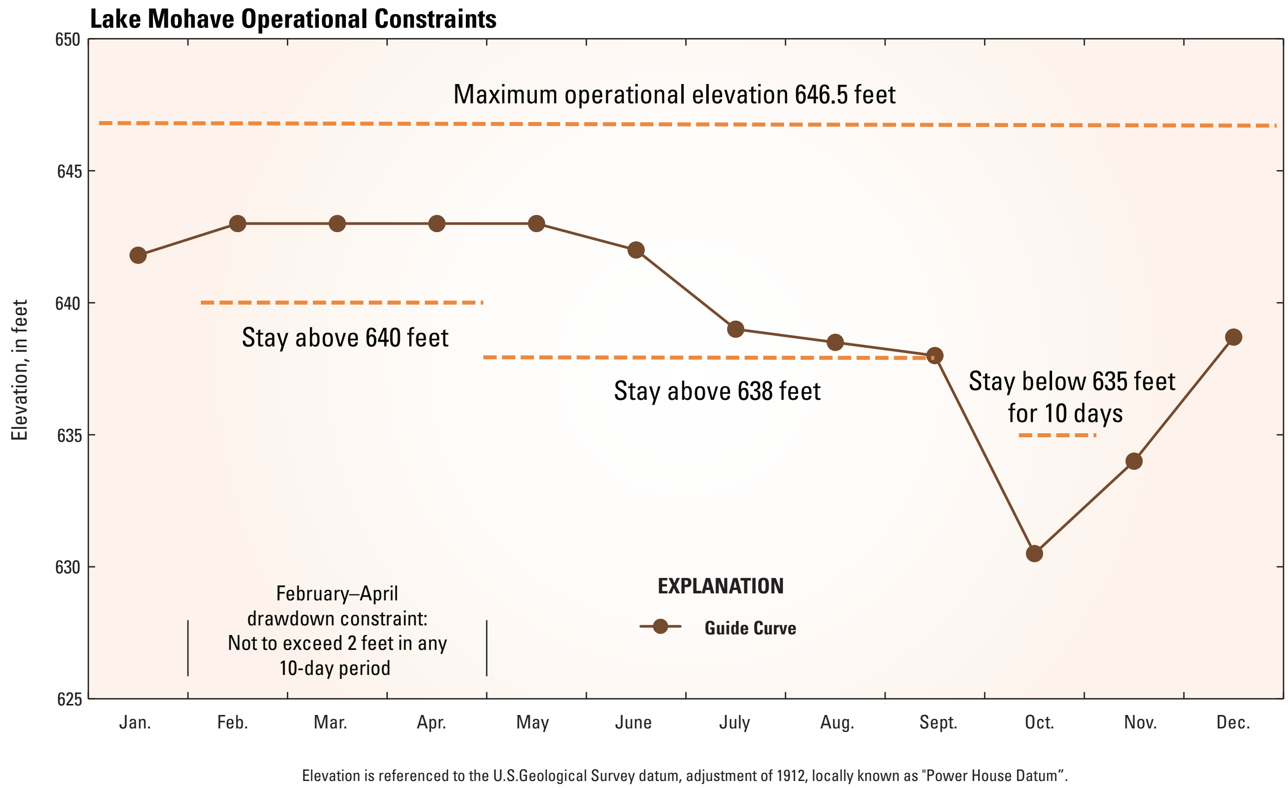



**Figure 3-7.** Lake Mohave Operational Constraints, Bureau of Reclamation.

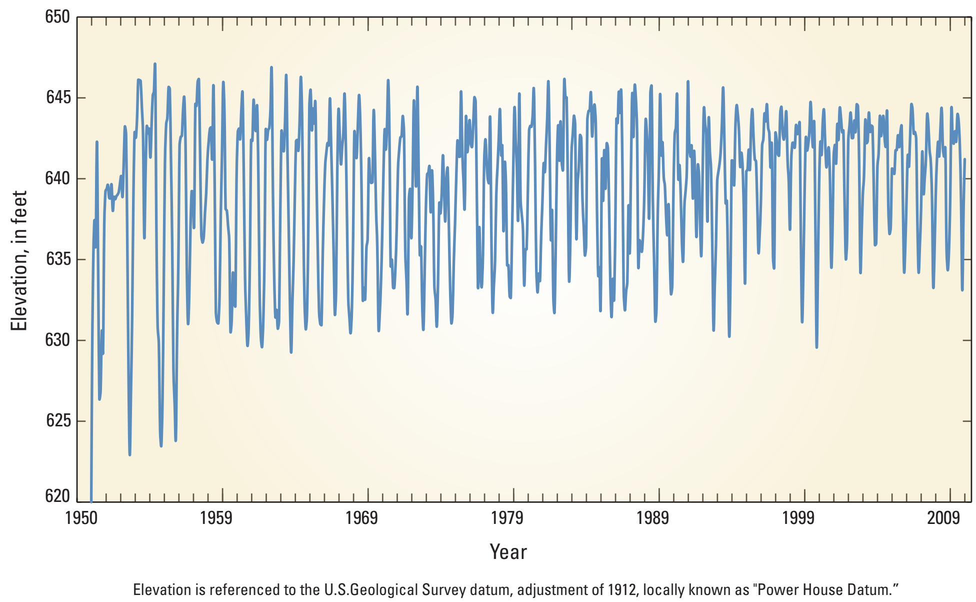



**Figure 3-8.** Lake Mohave average monthly surface elevations from January 1, 1950 to December 31, 2010.

## Chapter 3 References

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Chapter 4

# Lake Water Quality

By Todd Tietjen[1], G. Chris Holdren[2], Michael R. Rosen[3], Ronald J. Veley[3], Michael J. Moran[3], Brett Vanderford[1], Wai Hing Wong[4], and Douglas D. Drury[5]

Telephone Cove, Lake Mohave, on a busy day.  Photograph by National Park Service.

***Given the importance of the availability and quality of water in Lake Mead, it has become one of the most intensely sampled and studied bodies of water in the United States. As a result, data are available from sampling stations across the lake (fig. 4-1 and see U.S. Geological Survey Automated Water-Quality Platforms) to provide information on past and current (2012) water-quality conditions and on invasive species that influence—and are affected by—water quality. Water quality in Lakes Mead and Mohave generally exceeds standards set by the State of Nevada to protect water supplies for public uses: drinking water, aquatic ecosystem health, recreation, or agricultural irrigation. In comparison to other reservoirs studied by the U.S. Environmental Protection Agency (USEPA) for a national lake assessment (U.S. Environmental Protection Agency, 2010), Lake Mead is well within the highest or 'good' category for recreation and aquatic health (see U.S. Environmental Protection Agency National Lakes Assessment and Lake Mead for more details). While a small part of the lake, particularly Las Vegas Bay, is locally influenced by runoff from urbanized tributaries such as Las Vegas Wash, contaminant loading in the lake as a whole is low compared to other reservoirs in the nation, which are influenced by runoff from more heavily urbanized watersheds (Rosen and Van Metre, 2010).***

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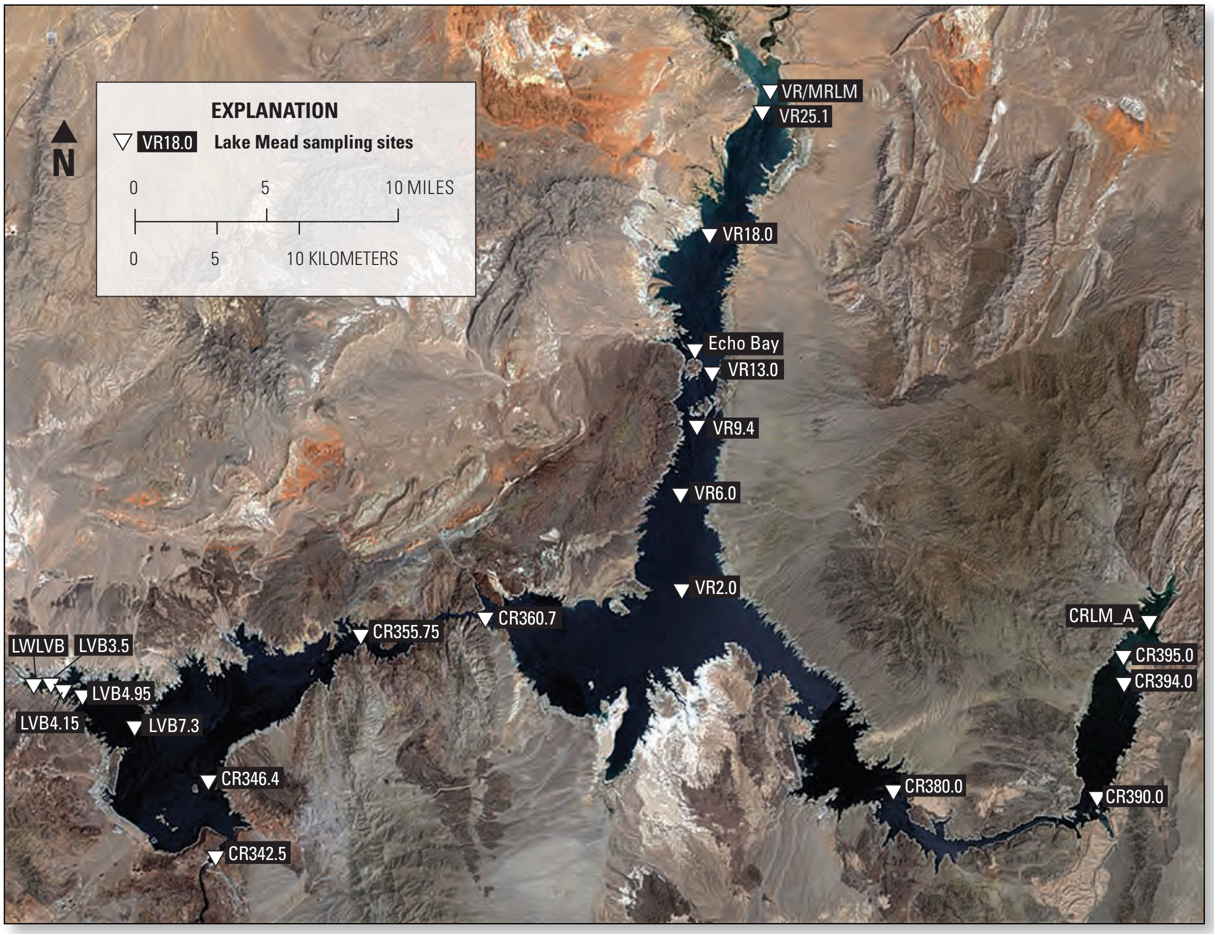



**Figure 4.1.** Map of Lake Mead showing primary sites for water-quality data collection. Sites are named for their locations along the main stem of the Colorado River (CR); along the flow of the Virgin River (VR); within Las Vegas Bay (LVB); or for their proximity to Las Vegas Wash inflow (LWLVB). Satellite imagery courtesy of NASA. Image processing provided by Julia Barsi, Landsat Project Science Office, NASA Goddard Space Flight Center. Data provided by the USGS EROS Data Center.

The quantity of Colorado River water entering Lakes Mead and Mohave greatly exceeds the smaller contributions of tributary inflow (Chapter 3), and the greatest volume of water entering Lake Mead is from a high-quality source. The Colorado River is fed by snowmelt from the western Rockies that drain through a largely rural part of the country, which minimizes the impact of human activities. Furthermore, most sediments settle from Colorado River water as it passes through Lake Powell before entering Lake Mead (Covay and Beck, 2001). Information on water quality is summarized in this chapter in terms of basic water-quality characteristics; nutrients and productivity; organic and inorganic chemicals and compounds in water; organic and inorganic chemicals and compounds in sediment; and effects of invasive species on water quality.

## U.S. Environmental Protection Agency National Lakes Assessment and Lake Mead

Lake Mead was included in the first U.S. Environmental Protection Agency (USEPA) *National Lakes Assessment* (U.S. Environmental Protection Agency, 2009, 2010), a baseline study of the condition of lakes in the United States during 2007. Using the USEPA report and additional information from more extensive Lake Mead sampling, Lake Mead water quality can be evaluated in relation to other lakes across the nation. For its report, the USEPA categorized lakes into regional clusters based on their locations within the previously defined EPA level-III ecoregions (U.S. Environmental Protection Agency, 2003), which placed Lake Mead in the Xeric ecoregion. Data were available to compare conditions in Lake Mead to those of other lakes in the Xeric ecoregion with respect to six parameters: concentrations of total nitrogen, total phosphorus, **chlorophyll** *a*, and dissolved oxygen; turbidity; and an aggregate measure of the lakes' suitability for recreation. USEPA used two separate evaluation schemes depending on the parameter of interest: (1) good/fair/poor relative to conditions found in reference lakes, or (2) undisturbed/impacted/highly disturbed compared to selected reference (least disturbed) lakes. For the parameters available for Lake Mead, total nitrogen, total phosphorus, chlorophyll *a*, and turbidity values were rated using the good/fair/poor scale; dissolved oxygen was rated using the undisturbed/impacted/highly disturbed scale. The aggregate measure of lake suitability for recreation takes into account three separate parameters: the concentration of chlorophyll *a*, the abundance of the algal toxin microcystin, and the abundance of cyanobacteria (blue-green algae). Each of these parameters was rated according to a scale of low/moderate/high risk according to their concentrations.

To capture conditions in different basins within Lake Mead, data were included from sampling sites in Boulder Basin, the Virgin Basin, and the upper Colorado River Arm (figs. 1-1 and 4-1). For the suitability-for-recreation parameters, the Southern Nevada Water Authority's drinking water intake system site was the only location where extensive microcystin measurements had been made. These data were compared to those at the lone Lake Mead location that was included in the *National Lake Assessment* (U.S. Environmental Protection Agency, 2009, 2010; fig. 4-2). For the comparison, values computed for each site are averages of values for all samples collected in 2010 (including those at all sample depths, where appropriate) except for the cyanobacterial abundance data. For cyanobacteria abundance, the average value was computed from samples collected in 2009, which was the last year for which a complete set of data of this type is available. Samples were collected approximately weekly in Boulder Basin and monthly in Virgin Basin and the Colorado River Arm.

Water quality in Lake Mead compared favorably to the parameters set forth in the USEPA *National Lake Assessment* and its Technical Appendix (U.S. Environmental Protection Agency, 2009, 2010). For the selected locations, Lake Mead scored in the highest categories for most of the individual parameters: 'good' for total phosphorus and chlorophyll *a* concentrations and 'reference/undisturbed' for dissolved oxygen. Total nitrogen values were in the 'good' range for the Virgin Basin and the upper Colorado Arm and at the low end of the 'fair' range for Boulder Basin. Boulder Basin values are elevated by nitrogen loading from Las Vegas Wash (LaBounty and Horn, 1997). Turbidity values for Boulder Basin were in the 'good' range while the Virgin Basin and upper Colorado River Arm samples were at the low end of the 'fair' range. Boulder Basin benefited from the long settling time of water entering from the most significant tributary inflows. The Colorado River inflow raised the turbidity in the upper Colorado River Arm, and turbidity values for the Virgin Basin were likely elevated by a combination of loading through Overton Arm, wind-driven resuspension of sediments, and the production of calcium carbonate particles in the water column. These high-quality scores, including those values in the 'fair' range, represent high water quality. They reflect the large volume of Colorado River water from the undisturbed upstream environment within Grand Canyon National Park traveling through the lake and the settling and sediment deposition that occurs within Lakes Mead and Powell. However, Lake Mead's scores would not have been as high if the selected sampling locations had been closer to the tributary inputs; samples from those locations would have been more indicative of water quality of the inflowing streams. As water from tributary inflow slows in the reservoir, most of the nutrients (nitrogen and phosphorus), sediments (turbidity), and algae (chlorophyll *a*) sink to the bottom. While this phenomenon can reduce the oxygen concentrations temporarily at the bottom of the water column, the overall impact is improved water quality throughout Lake Mead.

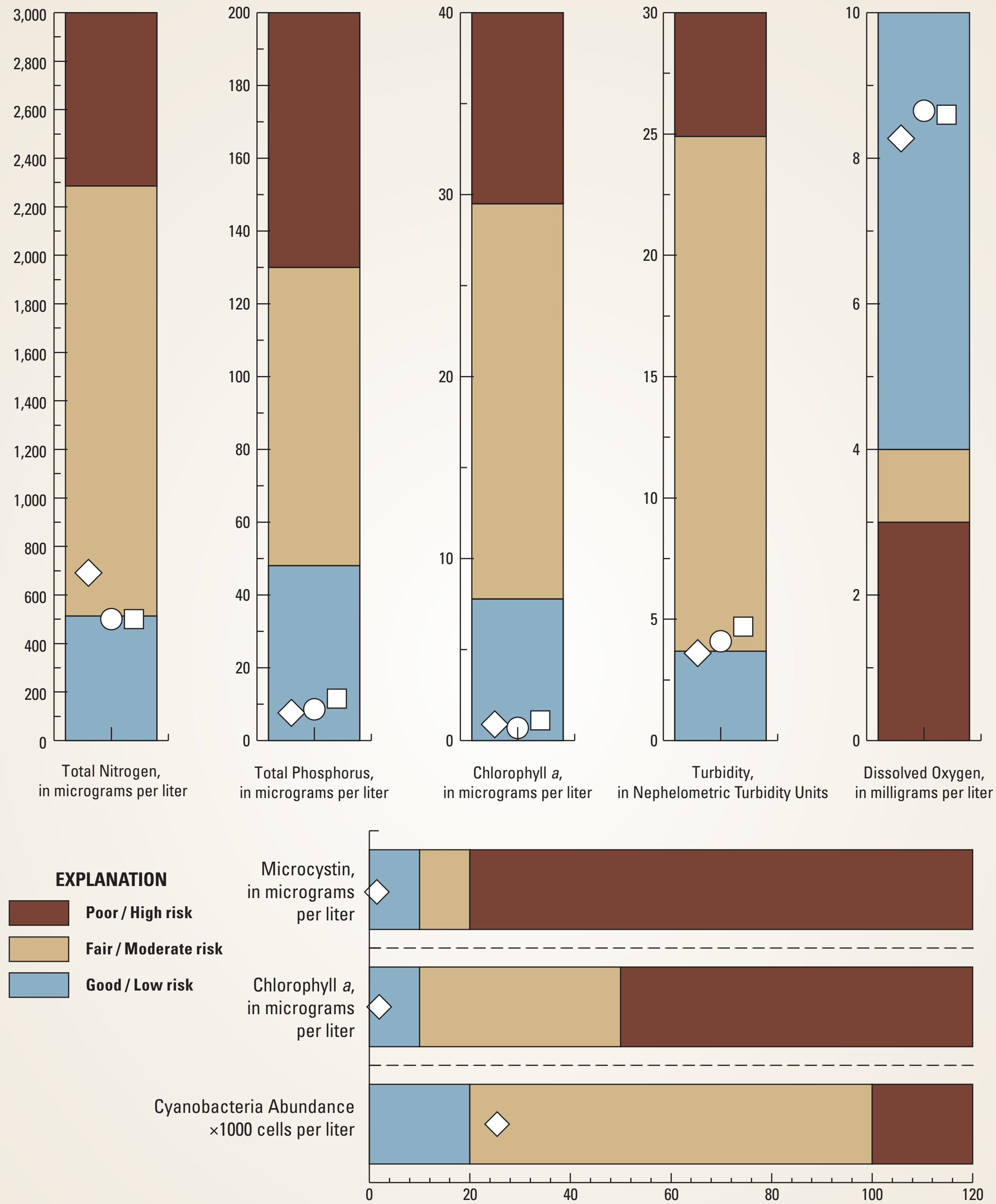



**Figure 4-2.** Lake Mead water-quality conditions compared to U.S. Environmental Protection Agency (2009, 2010) indicators. Boulder Basin (diamonds), the Virgin Basin (circles), and the upper Colorado River Arm (squares). Most areas sampled at Lake Mead resulted in a USEPA designation of "good" condition.

Three parameters constitute the USEPA's suitability-for-recreation assessment to result in classifications of 'low,' 'moderate,' or 'high' risk of exposure to algal toxin. Lake Mead water quality posed a low risk of exposure to algal toxins based on chlorophyll *a* and microcystin concentrations, and cyanobacterial abundance values were at the low end of the 'moderate' risk-of-exposure range. Interpretation of these results, however, is less straightforward than for the other water-quality parameters. Primarily, chlorophyll *a* concentrations are low in the open waters of the lake, so the sampling-location data underestimated algal cells where recreation is likely to occur. Secondly, although cyanobacterial abundance rated in the 'moderate' exposure to risk range, cyanobacteria actually present very little risk at Lake Mead for a variety of reasons. The Lake Mead environment favors extremely small cyanobacteria species, most of which are not the toxic, bloom-forming species (*Microcystis sp.*) that are detrimental to recreational uses of the lake. While *Microcystis sp.* and other nuisance cyanobacteria are found in Lake Mead, they simply do not represent a significant proportion of the overall population. Thus, the contribution of non-nuisance species, which is substantial, results in an aggregate cyanobacteria abundance value that overestimates risk. Overall, water quality in Lake Mead compared favorably to the findings in the USEPA National Lake Assessment and suggests that it is equal to or better than that in many other lakes in the Western United States.

## Basic Water-Quality Characteristics

### Physicochemical Description of Lake Mead

Information about the physicochemical characteristics of water in a lake, including temperature, dissolved oxygen, pH, and specific conductance are important to the understanding of the circulation of water in the lake. These data also can help in the evaluation of the level and timing of biological activity. Physicochemical data have been collected at Lake Mead for many years at many locations (for example, see LaBounty and Horn, 1997; LaBounty and Burns, 2005, 2007; Holdren and Turner, 2010) using standard manual methods. In more recent years, however, data collection at several locations has been automated (see U.S. Geological Survey Automated Water-Quality Platform) to obtain these data at a higher frequency for enhanced understanding of the lake and to provide information for numerical reservoir models.

## U.S. Geological Survey Automated Water-Quality Platforms

By Ronald J. Veley and Michael J. Moran

Between October 2004 and September 2009, the U.S. Geological Survey collected near-continuous water-quality physicochemical data at Lake Mead as part of a larger lake-wide monitoring study involving a variety of water resource agencies (Veley and Moran, 2012). One objective of this effort was to provide natural resource managers with basic water-quality data profiles from locations throughout the lake (fig. 4-3). Water-quality stations on Lake Mead were located at shallow-water sites in Las Vegas Bay and Overton Arm, and at deep-water sites in Boulder Basin (near Sentinel Island), Virgin Basin, and Temple Basin. The shallow-water sites were located in waters less than 66-ft (20.0-m) deep, while the deep-water sites were in waters deeper than 197 ft (60.0 m). At each station, an automatic-profiling system was used to collect near-continuous water-quality data. The systems used a water-quality sonde with sensors that measured water temperature, specific conductance, dissolved-oxygen concentration, pH, turbidity, and depth. The sonde starting collecting data near the top of the lake surface and continued until it nearly reached, but did not contact, the lake bottom. During the study, the sondes collected data every 6 hours beginning just after midnight of each day.

Shallow water automated water-quality data-collection platform in Las Vegas Bay. Photograph by Michael R. Rosen, U.S. Geological Survey.

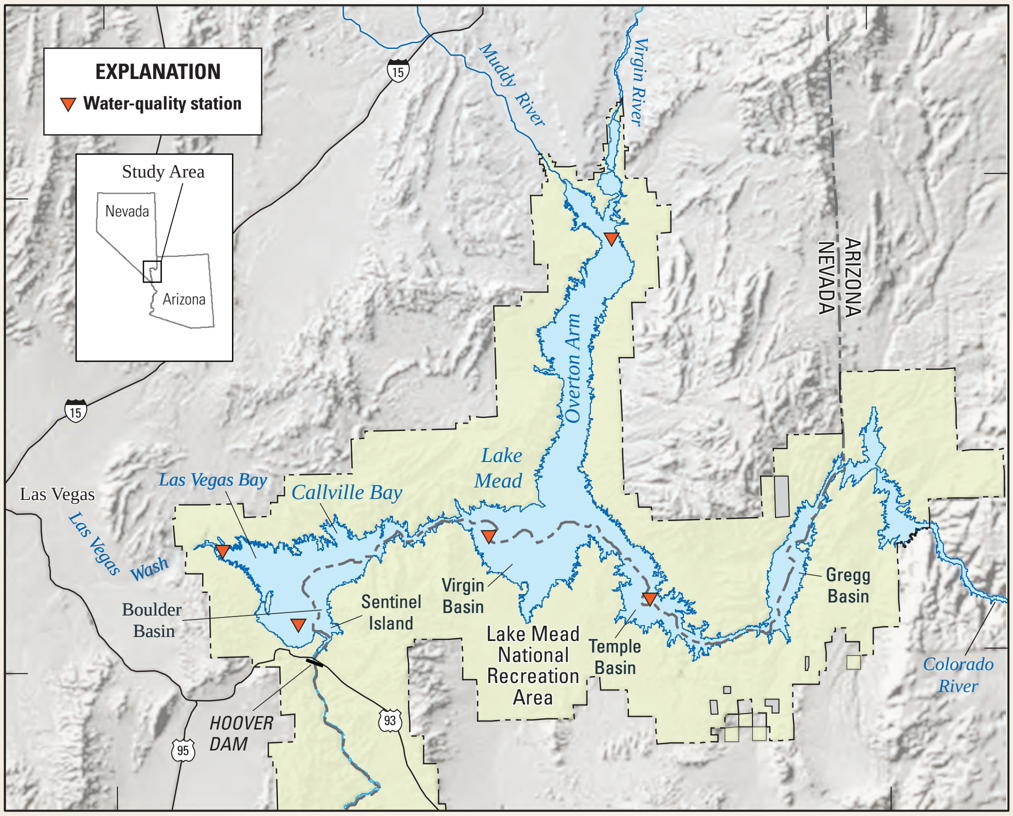



**Figure 4-3.** Locations of U.S. Geological Survey automated water-quality stations on Lake Mead, Nevada and Arizona.

## Temperature and Thermal Stratification

Water temperatures (fig. 4-4) in Lake Mead often follow the pattern that typifies warm monomictic lakes. Monomictic lakes are lakes that have a **thermal stratification** of the water column for most of the year and a single period of complete mixing. Occasionally, however, Lake Mead departs slightly from the warm monomictic pattern. On an average of 1 out of every 2 years, extensive but incomplete mixing occurs; the depth of the lake and complex interactions with the Colorado River are sufficient in these years.

Temperatures in Lake Mead's water column are usually 52–54°F (11–12°C) during the winter months (December–February). In years with complete mixing, water temperature is usually 54°F (12°C) throughout the water column. During years with incomplete mixing, temperature in the top one-half of the water column usually remains at 54°F (12°C) while the bottom of the water column cools to 52°F (11°C). Beginning in March, the lake's near-surface waters typically warm at different rates in two general areas: near inflowing tributaries and in the open waters that are distant from the shores and the influences of the tributaries (fig. 4-5). The tributaries are shallower than the lake and tend to warm faster than the lake's deeper open-water water areas. Therefore, the initial warming of the water column commonly is detected near the tributaries. Subsequently, as days get longer and air temperatures increase, the temperature of the open waters of the lake also begin to increase. In Lake Mead, stratification is usually first detected in late April or early May. During this period, stratification begins in the shallower bays and in the top 32.8 ft (10.0 m) of the water column in open-water areas. By the end of May, the surface waters warm to 64°F (18°C), and by early July the near-surface waters reach their maximum temperatures of 82–86°F (28–30°C).

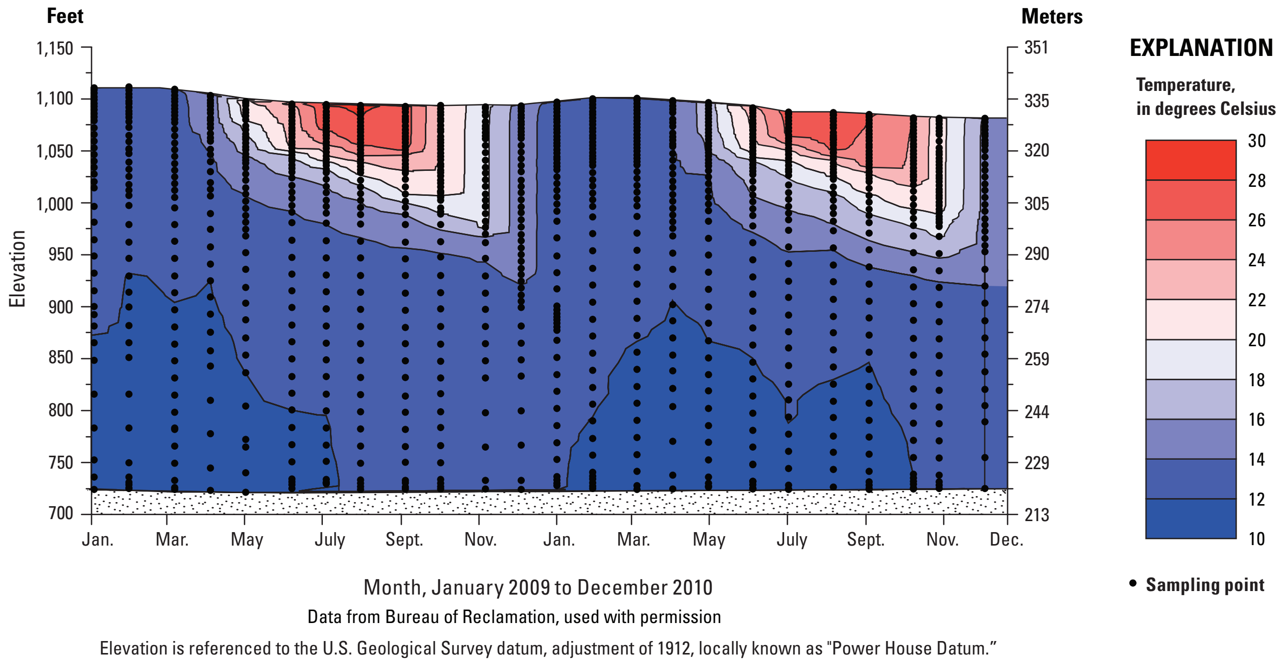



**Figure 4-4.** Water temperature profile for Lake Mead, at sampling site CR346 in Boulder Basin, January 2009–December 2010 (see fig. 4-1 for location map). Notice that the largest temperature differences between the lake surface and the lake bottom occur during the late summer and early autumn.

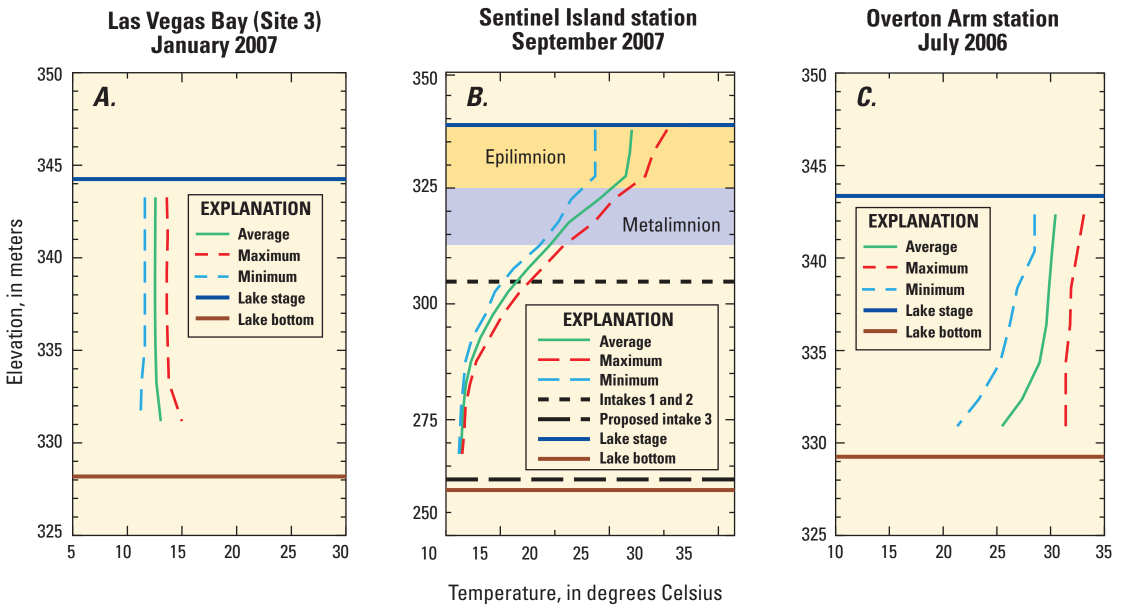



**Figure 4-5.** Automated temperature profiles and thermal stratification at Lake Mead. Automated temperature profiles for (*A*) USGS Las Vegas Bay (Site 3) station for January 2007; (*B*) USGS Sentinel Island station for September 2007; (*C*) USGS Overton Arm station for July 2006. In (*B*), potential inflow from Las Vegas Wash and the Colorado River are shown in the epilimnion and metalimnion, respectively. (From Veley and Moran, 2012. See U.S. Geological Survey Automated Water-Quality Platforms for location map.)

A mid-July profile through the Lake Mead water column would reveal temperatures greater than 77°F (25°C) in approximately the top 32.8 ft (10.0 m) of the water column, while between depths of 32.8 and 98.4 ft (10.0 and 30.0 m) temperatures would decrease to about 59°F (15°C; fig. 4-4). The **thermocline**, the region of the water column with the largest temperature change, typically is located between depths of 65.6 and 98.4 ft (20.0 and 30.0 m). Below depths of 98.4 ft (30.0 m), the temperature gradually decreases to 54°F (12°C) for the remainder of the water column. From mid-July through late autumn, the warm, near-surface waters move gradually deeper, reaching 114.8 ft (35.0 m) in August and 131.2 ft (40.0 m) in September. Water temperatures from the surface to a depth of about 65.6 ft (20.0 m) generally remain warmer than 77°F (25°C) through the middle of September, decreasing to approximately 68°F (20°C) in October and to 64°F (18°C) in November. Stratification of the water column typically ends in late November and early December as surface temperatures decrease to 61–64°F (16–18°C) and the total temperature difference in the water column decreases to 39–43°F (4–6°C). Finally, water typically cools again to 52–54°F (11–12°C) in December, with the actual timing dependent on air temperatures and the amount of wind-driven mixing that occurs.

The stratification of the water column into distinct horizontal layers of water at different temperatures can have important impacts on the ecology of a water body. The **epilimnion** (upper-most layer) has the greatest exposure to light and often has the most active phytoplankton population. A great abundance of **phytoplankton**, in turn, produces the most favorable conditions for zooplankton, which are a food source for some fish. The epilimnion also frequently has the highest concentrations of dissolved oxygen, which is a condition for survival for many higher organisms. Oxygen presence also influences the chemical environment: where sufficiently high concentrations of oxygen occur (such as in the epilimnion), nutrients and other chemicals can precipitate out of the water in forms unavailable to organisms. In the **hypolimnion** (lowest layer), oxygen concentrations typically are lower because the ***metalimnion*** (middle layer) can serve as a barrier between the upper and lower layers, limiting the transfer of oxygen from above. Any organic material decay in the hypolimnion occurs through a process that consumes oxygen, further reducing oxygen concentrations. In the hypolimnion, if oxygen concentrations are sufficiently low, nutrients and other chemicals can be released from precipitated forms back into solution, where they are bioavailable to aquatic organisms and have the greatest potential to influence the ecosystem.

## Dissolved Oxygen

Several gases, such as oxygen, nitrogen, and carbon dioxide, are dissolved in the water of streams and lakes. Dissolved oxygen (DO) is essential for aquatic life with the exception of certain types of bacteria, and therefore is important to monitor. The degree to which water is saturated with oxygen is determined by oxygen concentration, water temperature, and atmospheric pressure. Expressing oxygen concentrations in terms of percent saturation takes into account the ability of the water to hold oxygen. The warmer the water, the less oxygen it can hold. Within Lake Mead, DO concentrations generally are high enough (more than 50 percent saturation) to meet the requirements of aquatic organisms and support a thriving biological community.

Lake Mead's seasonal pattern of thermal stratification significantly influences DO conditions in the lake (fig. 4-6). During the autumn and winter mixing period, oxygen concentrations generally are 90 percent of saturation or higher as the water column is at equilibrium with the atmosphere. As the water column begins to stratify during the spring and summer, it can become supersaturated with oxygen at the surface during the day as algal photosynthetic oxygen production increases with warmer temperatures and nutrient inputs. This **supersaturation**, driven by nutrient loading to the surface waters, can persist through the early summer. In some years, the algae that produce areas of DO supersaturation accumulate in the metalimnion at the density barrier (thermocline) established during thermal stratification. When dead algal material collects and decomposes in this layer, oxygen is consumed, which can produce a metalimnetic oxygen minimum that can persist up to 3 or 4 months.

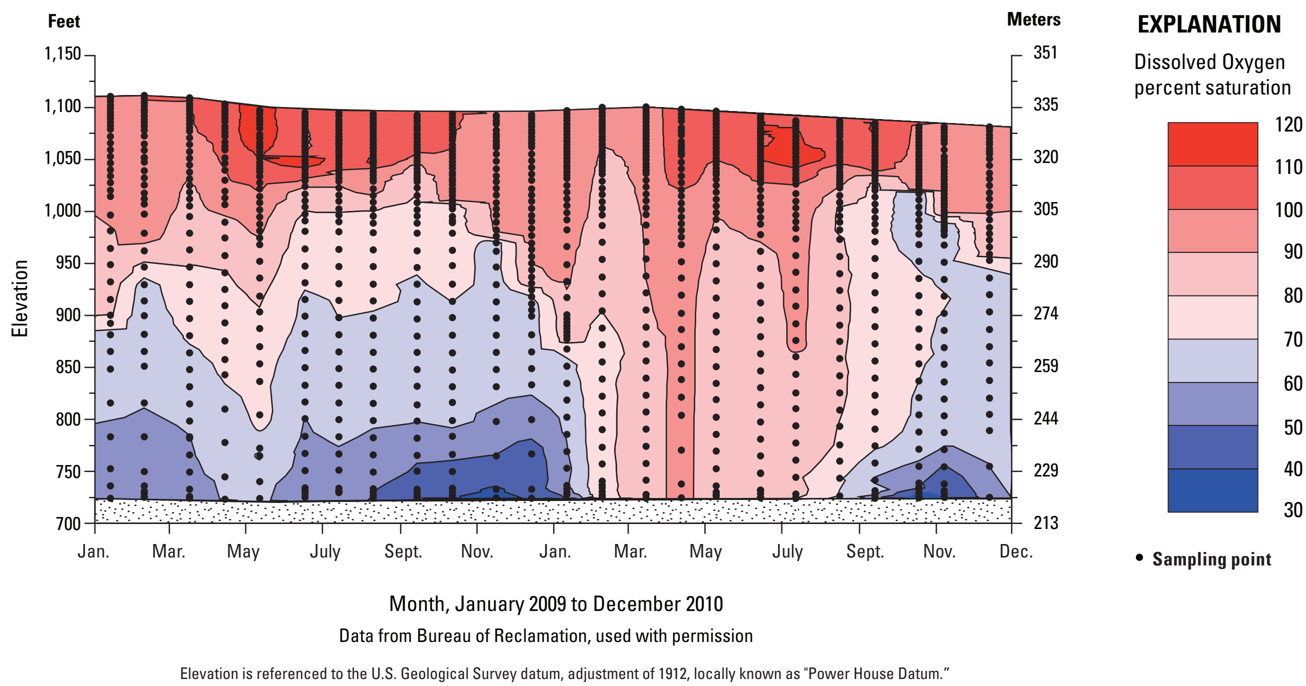



**Figure 4-6.** Dissolved oxygen (DO) profile for Lake Mead, at sampling site CR346.4 in Boulder Basin, January 2009–December 2010 (see fig. 4-1 for location map). Notice that the highest oxygen saturation percentages are near the surface of the lake.

Following peak algal production in spring, oxygen conditions in the water column are generally influenced by stratification. In the epilimnion, where surface water is exposed to atmospheric oxygen, DO saturation remains higher than 80 percent. In the hypolimnion, seasonal restriction from atmospheric oxygen results in a gradual decrease in DO saturation to approximately 50 percent by the end of the summer stratified period. In years when the water column mixes completely, oxygen is replenished throughout all thermal layers, whereas during years of incomplete mixing, oxygen at the bottom of the water column is usually replenished by underflowing Colorado River waters. The introduction of cold, dense Colorado River into the hypolimnion of Lake Mead during the autumn and winter can be important in maintaining oxygen concentrations greater than 4 mg/L until the next complete mixing of the water column.

DO concentrations decrease below critical levels only near the tributary inflows, and these low levels remain for only a matter of weeks. Near the confluence of the Las Vegas Wash and Lake Mead, oxygen dynamics are similar to those in other reservoirs with tributary inflow. In this area (Las Vegas Bay), the phytoplankton community increases algal biomass using nutrients contributed by Las Vegas Wash. When algal cells die, they begin to release nutrients as they settle through the water column and are deposited on the lake floor. On the lake floor, at the water-sediment interface, dead algae and other organic matter contributed by Las Vegas Wash inflow continue to decompose, decreasing oxygen in the vicinity. During autumn and winter, when mixing of the water column occurs, hypolimnetic waters depleted of oxygen mix with the upper layers. As a result, oxygen concentrations briefly decrease below 50 percent saturation in Las Vegas Bay near Las Vegas Wash. After this period, however, oxygen concentrations at greater depths are typically only slightly lower than those in the upper water column.

## pH

The physicochemical parameter pH is a measure of a solution's acidity (fig. 4-7). Acidic solutions have a pH less than 7 and basic solutions have a pH greater than 7; the pH of a neutral solution is around 7. Because the pH scale is logarithmic, there is a 10-fold difference in acidity between solutions that differ by 1-pH value. The pH of Lake Mead water generally is between 7.8 and 8.2, with slightly higher values in the near-surface waters and slightly lower values in the bottom part of the stratified water column (fig. 4-8). A carbonate buffering system—the equilibrium of carbon dioxide, water, and carbonic acid, bicarbonate, and carbonate ions—is responsible for maintaining this range in pH. The activity of phytoplankton can account for small, local differences in pH values in the lake.

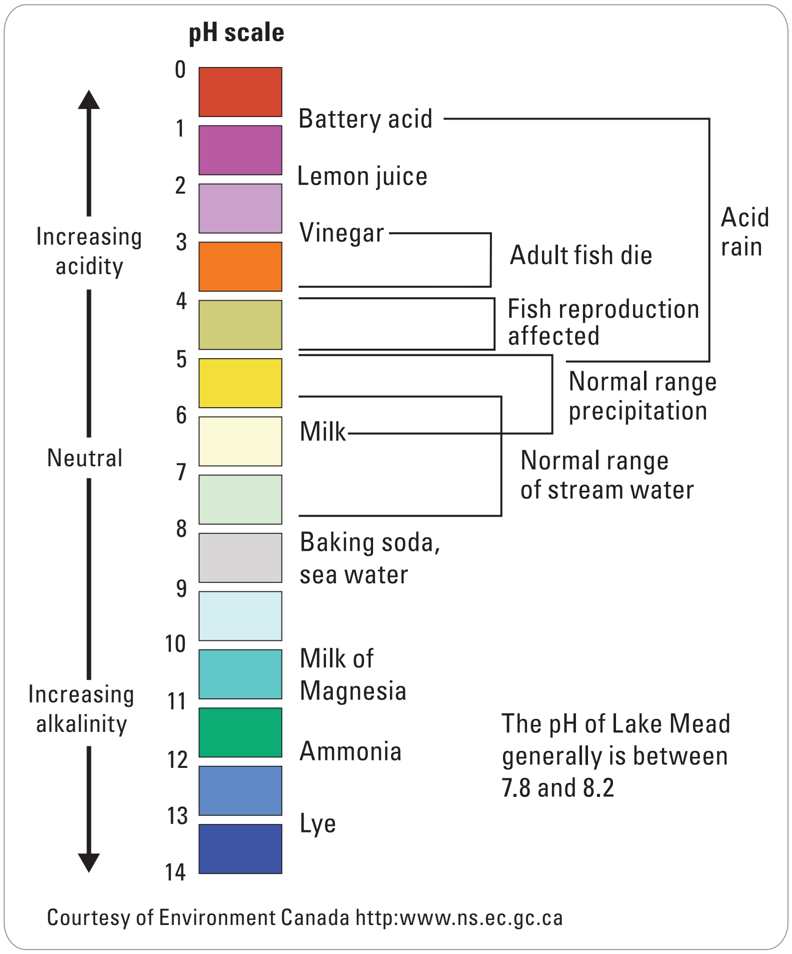



**Figure 4-7.** pH scale showing examples of liquids with different pH values.

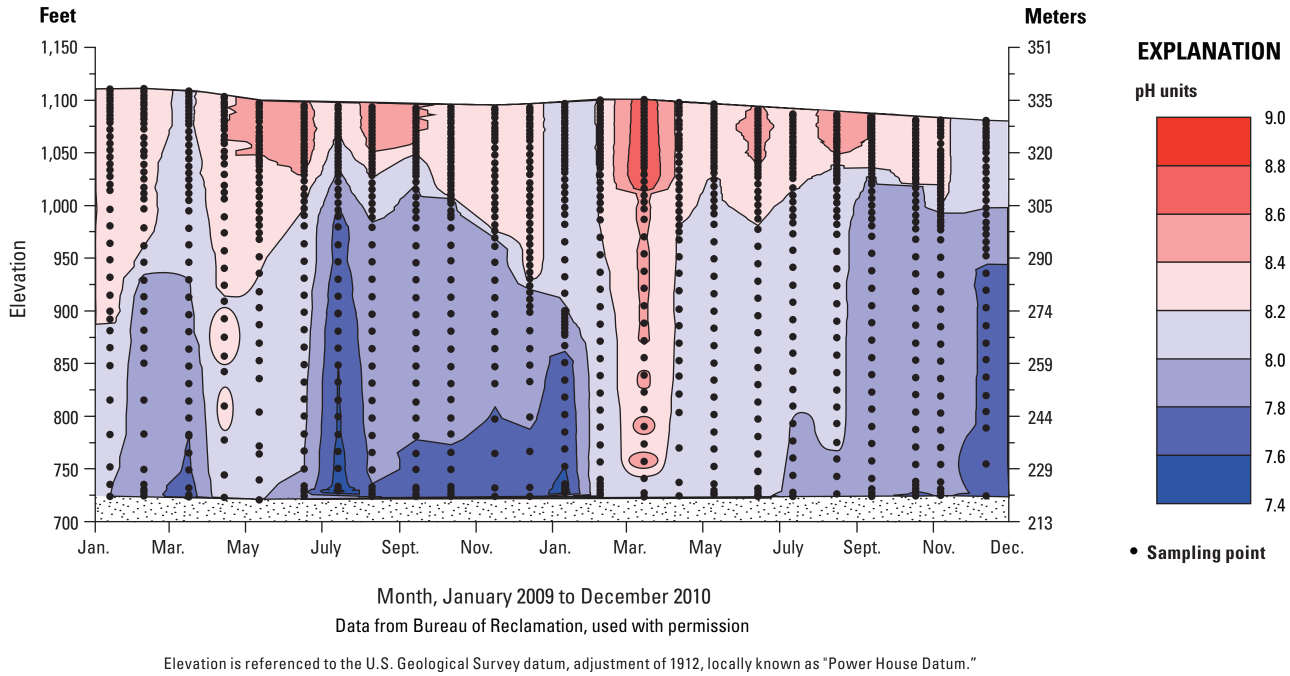



**Figure 4-8.** pH profile for Lake Mead, at sampling site CR346.4 in Boulder Basin, January 2009–December 2010 (see fig. 4-1 for location map). Notice that the highest pH measurements are near the surface of the lake.

During the spring and summer growing season, the pH of surface waters typically increases because free carbon dioxide ($CO_2$) is used by phytoplankton during **photosynthesis** and, as a result, there is less $CO_2$ and less carbonic acid (carbon dioxide and water) in the water. Later in the growing season, pH in the hypolimnion tends to decrease as acidifying $CO_2$ is produced by decomposition of organic matter in the sediment. Following the mixing of the water column in autumn and winter, pH throughout the water column shows little change until the following spring. However, the constant chemical equilibrium of the carbonate buffering system prevents large changes in pH and generally limits the importance of pH as a factor influencing water quality in Lake Mead regardless of phytoplankton (or other) inputs.

## Specific Conductance

Specific conductance (SC) is a measure of the ability of water to conduct electricity and it is proportional to the amount of dissolved chemicals in water. Distilled or deionized water has a SC of at least 1 microsiemens per centimeter (µS/cm) because it contains very small amounts of dissolved chemicals. By contrast, seawater, which contains a large amount of dissolved chemicals, has an SC of approximately 50,000 µS/cm. The specific conductance of the water in Lake Mead is controlled by a set of interrelated factors—the higher SC values of inflow from tributaries other than the Colorado River, the lower SC values of the Colorado River, and the evaporation of surface waters combined with water column stratification.

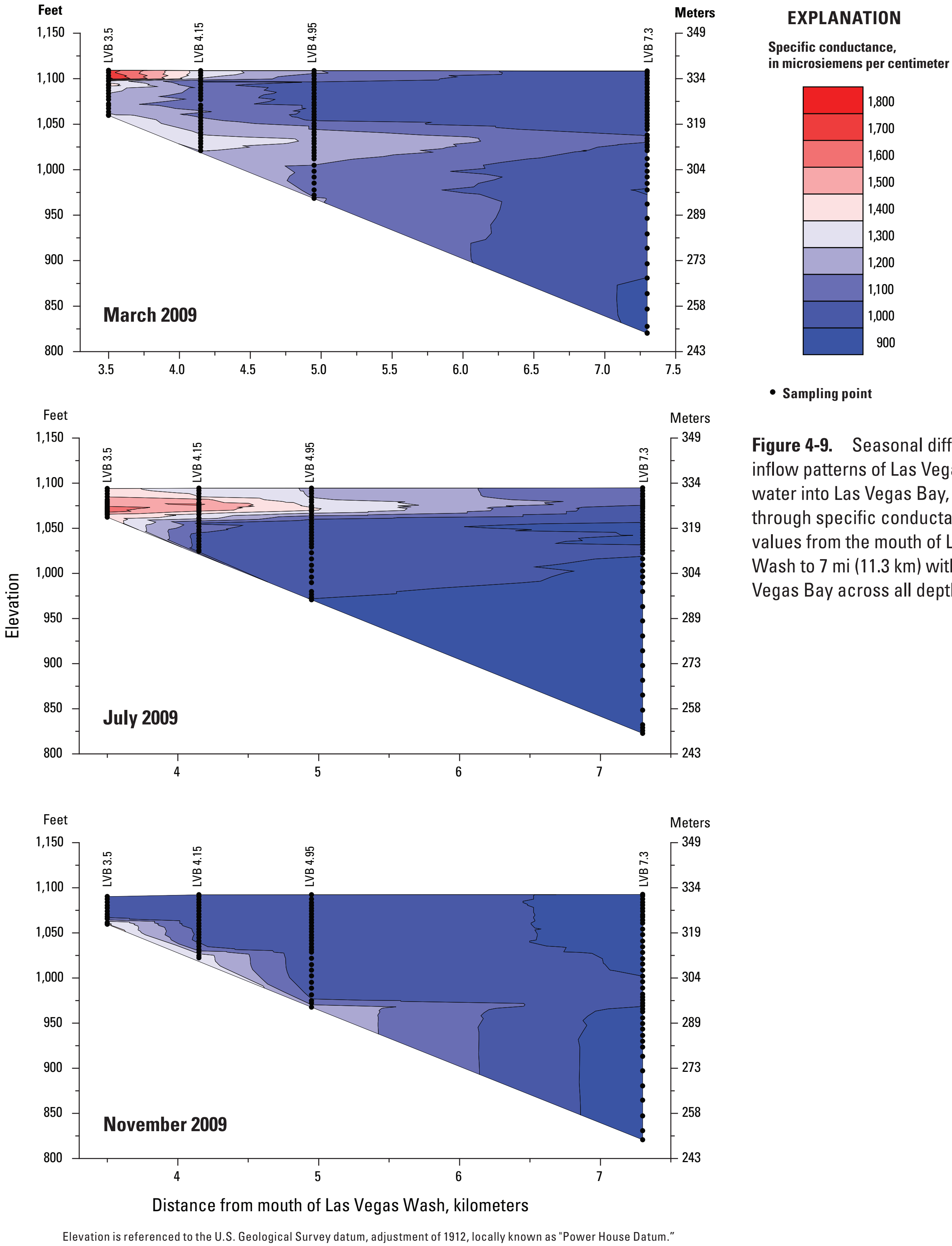



**Figure 4-9.** Seasonal differences in inflow patterns of Las Vegas Wash water into Las Vegas Bay, shown through specific conductance (SC) values from the mouth of Las Vegas Wash to 7 mi (11.3 km) within Las Vegas Bay across all depths.

Surface flow in Las Vegas Wash consists primarily of water released from wastewater-treatment facilities. The SC of this water generally is twice as high as that of the downgradient surface waters in Boulder Basin (LaBounty and Horn, 1997). When the temperatures of Las Vegas Wash and Lake Mead are equivalent (during early spring and early autumn), the difference in the SC values is the primary control on the position of the tributary inflow into the lake (fig. 4-9). Because of their similar densities, water in Las Vegas Wash travels as an interflow, or through an intermediate layer, within the lake. During these periods, this interflow from Las Vegas Wash may travel relatively far into Boulder Basin, but increased SC is most evident closest to the embayments where the interflow enters the lake. At other times of the year, however, temperature differences between Las Vegas Wash water and lake water can result in different inflow patterns (fig. 4-9):

1. During the late spring and summer, water in Las Vegas Wash has a higher SC than Lake Mead water but is warmer, and therefore less dense than water in the lake. As a result, the lower density water in the Las Vegas Wash typically flows across the surface of the lake, increasing SC in the upper layer of the lake.
2. During late autumn and winter, water in Las Vegas Wash has a higher SC and lower temperature than Lake Mead, and therefore is denser than water in the lake. Because of the higher density, water from Las Vegas Wash sinks and flows along the sediment/water interface, increasing SC in this layer.

Analysis of trends in water-quality parameters collected at the automated Lake Mead stations showed that SC values decreased from 2005 to 2009 at all stations except for Las Vegas Bay (see U.S. Geological Survey Automated Water-Quality Platforms; Veley and Moran, 2012). The upward trend in SC values at Las Vegas Bay (fig. 4-10) is thought to be a consequence of declining lake

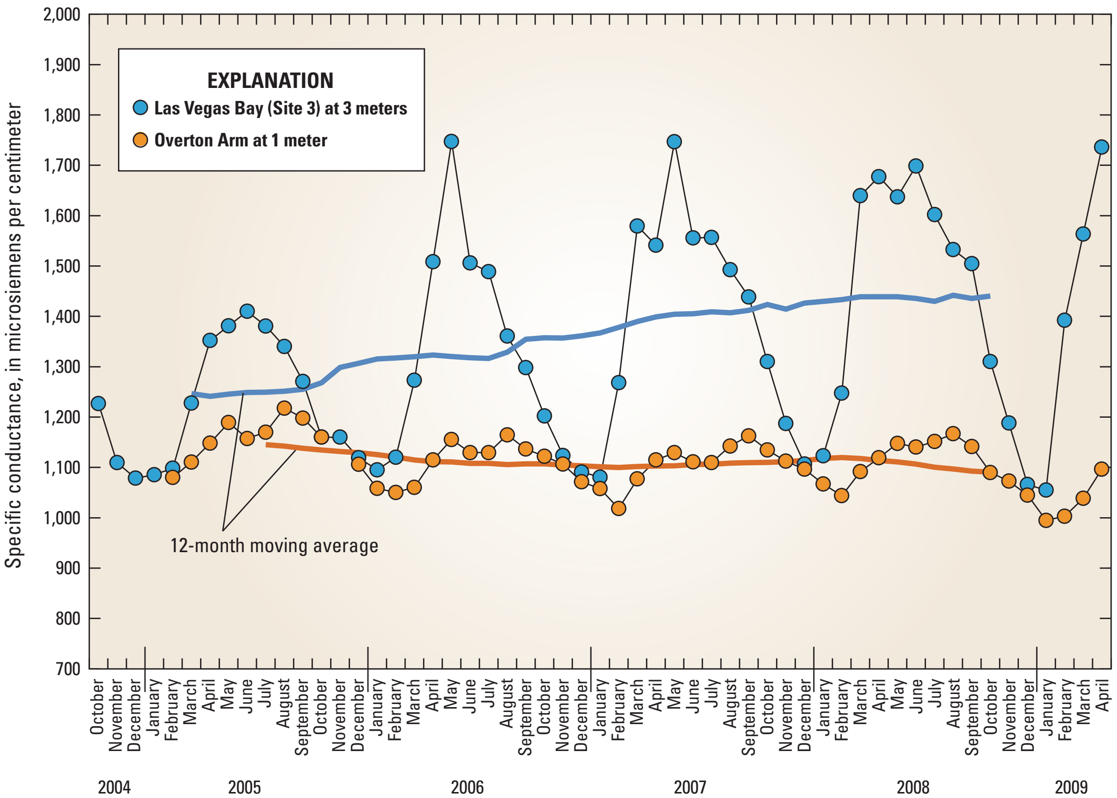



**Figure 4-10.** Monthly average values of specific conductance (SC) in Lake Mead from October 2004 to September 2009. SC averages from the U.S. Geological Survey's Las Vegas Bay and Overton Arm water-quality stations on Lake Mead at depths of 10 ft (3.0 m) and 3 ft (1.0 m), respectively (Veley and Moran, 2012).

levels during this period. As lake levels declined, a greater portion of inflow is contributed by Las Vegas Wash with higher SC. A similar upward trend in SC was not observed at the other shallow-water station in the Overton Arm, which receives water of lower SC levels from the Muddy and Virgin Rivers. The decreasing SC values at the deep-water stations are thought to be a result of waters with lower SC values entering the lake from the Colorado River.

Overall, the large volume of Colorado River water that enters Lake Mead influences SC more heavily than does inflow from the other tributaries. Between 1992 and 2005, SC in Boulder Basin cycled between relatively low to high in response to the volume of Colorado River water being released from Lake Powell (LaBounty and Burns, 2005). Years with higher lake-surface elevation correspond to lower SC values. Because the temperature of the Colorado River inflow is cooler (and therefore denser) than Lake Mead water, periods of extensive, long-term underflow brings low SC conditions to the bottom of the lake. This pattern continued from 2005 to 2010, showing an SC decrease also supported by the linkage to releases from Lake Powell that LaBounty and Burns (2005) reported. As Lake Powell releases water of lower SC into the Colorado River that flows into Lake Mead downstream, the average SC of Lake Mead's water column will similarly decrease.

Finally, seasonal stratification of the water column also produces conditions that increase SC locally through the process of evaporation (fig. 4-11). Once the water column becomes stratified, the surface waters continue to warm and are prevented from mixing with the remainder of the water column. As this water warms, evaporation rates increase and leave behind salts that accumulate as water is lost to the atmosphere.

## Secchi Depth

The clarity or transparency of natural waters varies widely and can be measured in several different ways. A simple and inexpensive tool that has been used to measure water clarity for more than 100 years is the 8-in. (20.0-cm) black and white Secchi disk (Wernand, 2010). A Secchi measurement is the average of the depths at which the disk visually disappears upon repeatedly lowering it into the water and reappears upon raising it. Secchi data collected

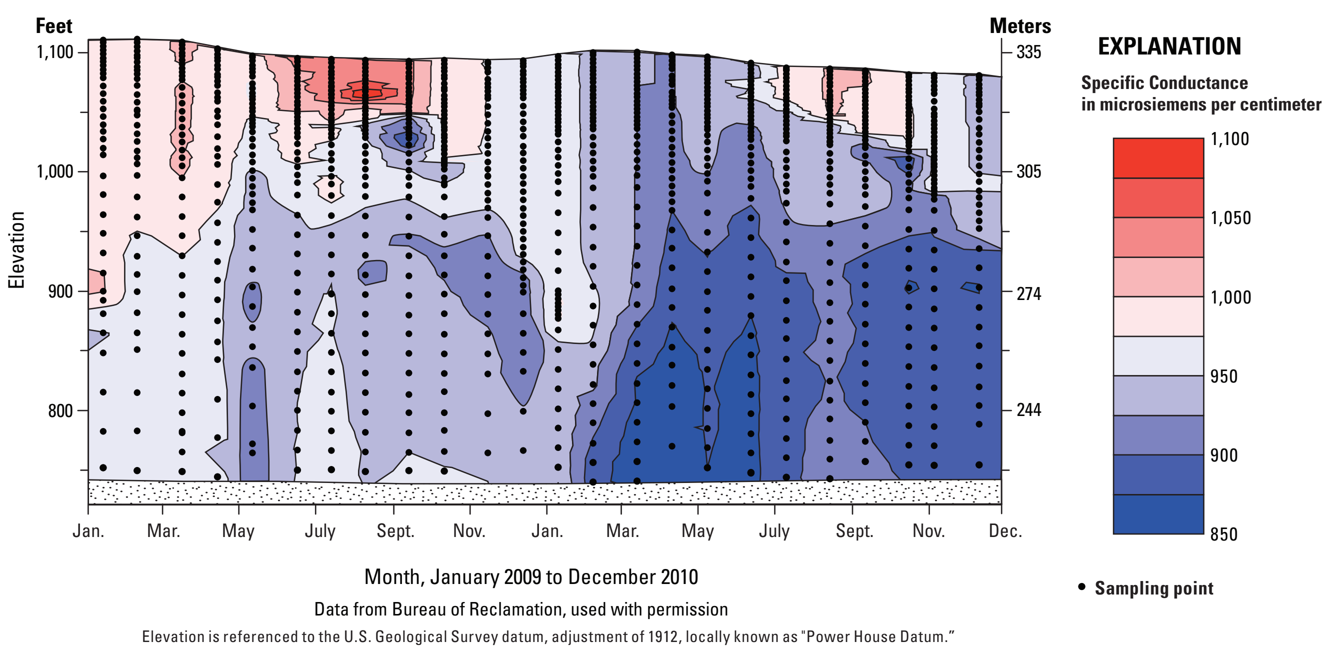



**Figure 4-11.** Specific conductance (SC) profile for Lake Mead, at sampling site CR346.4 in Boulder Basin, January 2009–December 2010 (see fig. 4-1 for location map). Higher values occur near the air-water interface during summer when the lake is stratified and evaporation removes water and concentrates dissolved salts near the surface of the lake.

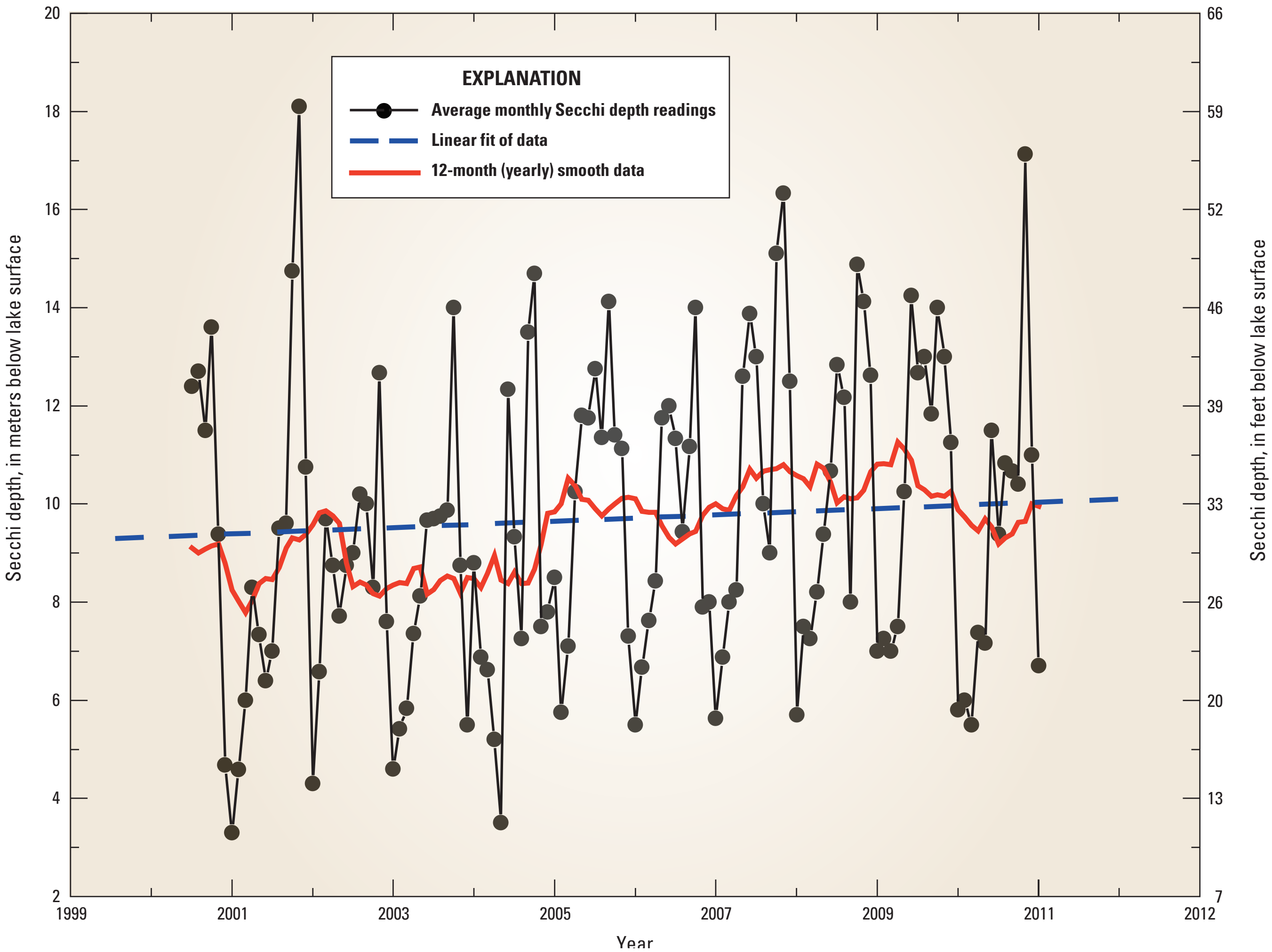
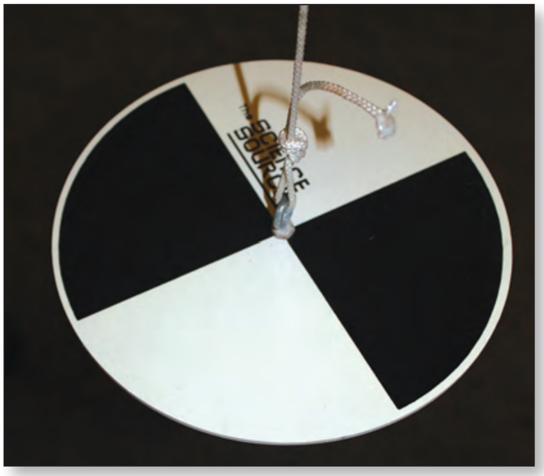



**Figure 4-12.** Average monthly Secchi depth for Boulder Basin, Lake Mead, 2000–2009. The overall trend shows increases in water clarity over the past decade. Values greater than 3 ft (1.0 m) indicate very clear water.

over time can reflect changes in the concentration of suspended sediments or algal abundance but do not quantify the amount of particles present. Nonetheless, water clarity is an important property of water. For Lake Mead, water clarity in open waters generally has been increasing over the past decade (fig. 4-12; LaBounty, 2008). Closer to the tributaries, however, water clarity generally is lower due to higher algal production and biomass and sediment load (turbidity) contained in tributary inflow.

The values presented for both Secchi depth (fig. 4-12) and chlorophyll *a* concentrations, discussed later in the chapter, reflect changes in water quality in recent years. The measurements are consistent with an improvement from high water quality values to extremely high water quality values.



A Secchi disk used for measuring water clarity in lakes. Photograph by Michael R. Rosen, U.S. Geological Survey.

## Nutrients and Productivity

### Phosphorus

Phosphorus is an essential nutrient used by all organisms for the basic processes of life. Its natural source is the weathering and leaching of phosphate-rich geological formations. Phosphorus concentrations in the open waters of Lake Mead are low, falling in the lower quartile of the "good" range in the USEPA National Lakes Assessment. However, phosphorus is used extensively in fertilizer and other chemicals, and is a component of wastewater, so it can be found at higher concentrations near human activity. Past evaluations of nutrients in Lake Mead have focused on phosphorus as the primary limiting algal nutrient from tributary inflow. A recent nutrient-budget study (Flow Science Inc., 2011) determined that while further refinements are needed to accurately describe tributary contributions of phosphorus to the lake, conclusions can be made. Most of the phosphorus entering the lake, an estimated 34,400 lb/d (15,600 kg/d), is bound to sediment particles in the inflow of the Colorado River. Approximately 32,000 lbs (14,900 kg) of this phosphorus quickly settles to the lake bottom, so that most of the nutrient is unavailable for use by algae in downgradient areas of lake. A different form of phosphorus, dissolved phosphorus, enters the lake primarily through the Colorado River and Las Vegas Wash at loads of 280 lb/d (127.0 kg/d) and 134 lb/d (60.8 kg/d), respectively. Las Vegas Wash receives highly treated wastewater effluent from Las Vegas Valley and is the primary source of dissolved phosphorus during dry-weather conditions (fig. 4-13*A*). Even though the dissolved phosphorus loads are approximately 100 times smaller than the total phosphorus load, dissolved phosphorus is more readily available and more rapidly used by algae. In comparison to the Colorado River and Las Vegas Wash, the combined contributions of phosphorus to Lake Mead by the Muddy and Virgin Rivers are approximately 220 lb/d (99.7 kg/d) of total phosphorus and 31 lb/d (14.0 kg/d) of dissolved phosphorus.

Advanced wastewater treatment beginning in 1994 reduced total and dissolved phosphorus inputs into Boulder Basin via Las Vegas Wash. However, as the Las Vegas Valley population grew throughout the 1990s and early 2000s, phosphorus concentrations increased in wastewater. Wastewater facilities enhanced treatment for phosphorus removal in 2002 and 2005 (LaBounty and Burns, 2007), and successfully reduced phosphorus input. By 2009, total phosphorus concentrations in Las Vegas Bay and Boulder Basin typically were less than 10 µg/L (fig. 4-13*A*) and dissolved reactive phosphorus concentrations typically were less than 2 µg/L. Total phosphorus load was reduced by as much as 98 percent from the concentrations of the 1970s and 1980s.

### Nitrogen

All organisms require the nutrient nitrogen to live and grow; it is a building block of cellular proteins. In Lake Mead, total concentrations of nitrogen have remained stable from 1999 to 2010 at approximately 1,000 µg/L; with most of the nitrogen in the form of dissolved nitrite plus nitrate. Although wastewater contributes significant levels of nitrogen to Lake Mead's Boulder Basin and Las Vegas Bay (fig. 4-13*B*), Colorado River water also showed moderately high average total nitrogen concentrations (516 µg/L) between 2001 and 2009 (Holdren and Turner, 2010).

### Organic Matter

Organic matter is important in all aquatic systems, storing and providing carbon as a source of energy and affecting many features of a water body's ecology. New biomass is produced from available carbon. A measurement of total organic carbon (TOC) includes many components, including visible particles from decaying organisms and dissolved molecules of carbon-containing compounds. For many lakes and reservoirs, most of the organic matter present is not produced within the system but from land-derived sources (for example, leaves and tree litter) entering from the watershed

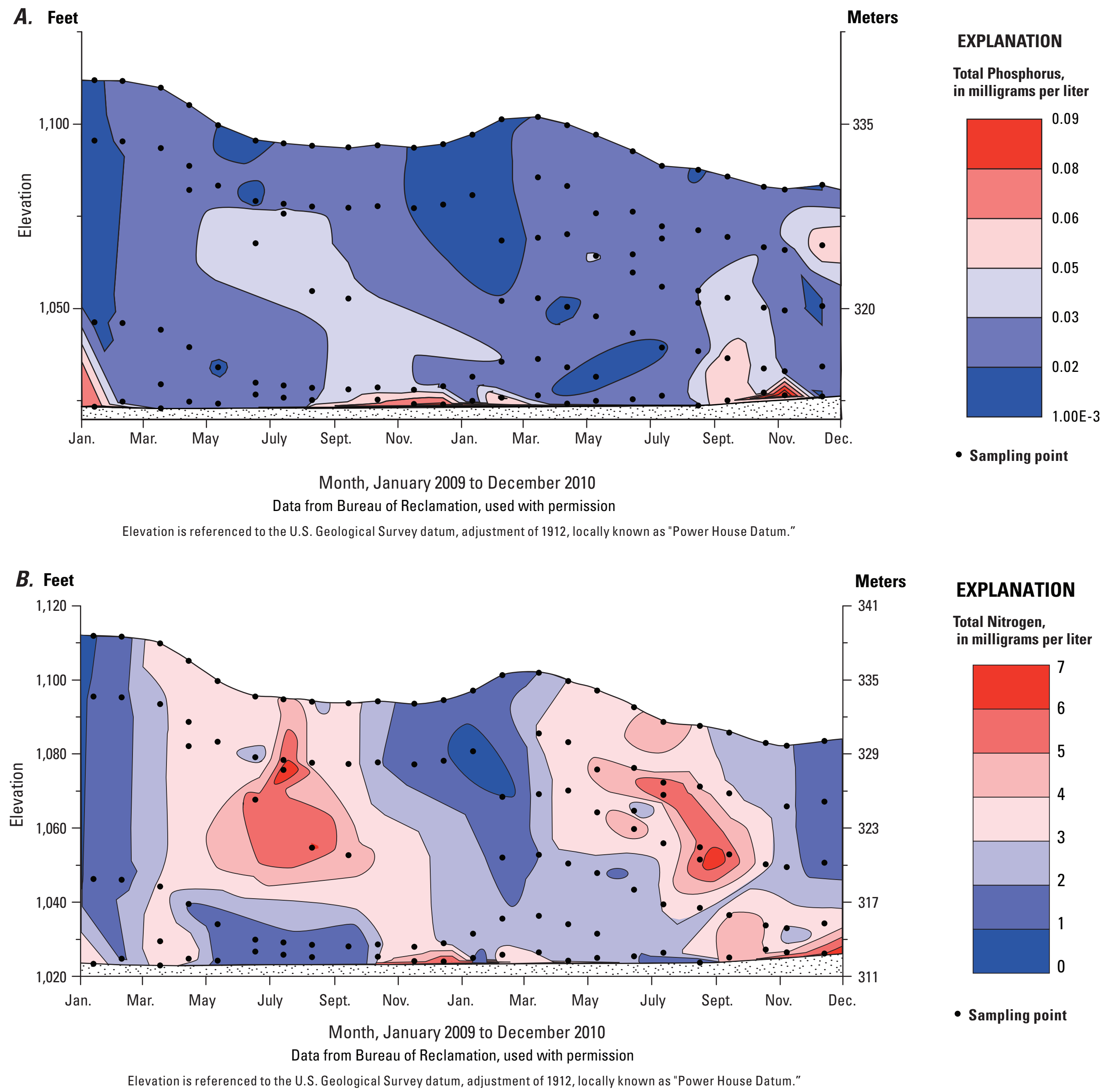



**Figure 4-13.** Changes in the concentrations of total phosphorus (*A*) and total nitrogen (*B*) in the water column of Lake Mead near Las Vegas Wash in Las Vegas Bay, January 2009–December 2010.

or inflowing rivers (Bade and others, 2007, and references therein). Lake Mead represents an unusual case in that it is large and its tributary inputs are few (that is, three or four locations depending on water level). Dominating inflow to Lake Mead is the Colorado River, which travels through the arid landscape of the Grand Canyon with minimal organic matter inputs; approximately 300 mi (482.8 km) of upstream watershed is protected from industry and development within Grand Canyon National Park. Moreover, sediments settle and are deposited behind Glen Canyon Dam at Lake Powell, effectively removing associated organic matter from the water above the Grand Canyon. As a result, TOC concentrations in Lake Mead have never been high following the closing of Glen Canyon Dam, and varying for example from approximately 3 mg/L in 2000 to about 4 mg/L in 2004 (Roefer and others, 2005).

## Productivity

In aquatic ecosystems, primary productivity is the growth of new biomass by primary producers (phytoplankton; Chapter 5), which form the base of the food web. Through the process of photosynthesis, phytoplankton convert dissolved inorganic carbon in the water into organic compounds. In Lake Mead, productivity is a complex process due to the influences of inflowing tributaries and the characteristics of the somewhat confined larger basins that are relatively far away from tributary inflow. In the large, deep basins of Lake Mead, productivity is generally quite low (**oligotrophic**) and has been decreasing during recent years. Nearer to inflowing rivers, productivity, in general, increases to **mesotrophic** levels due to the introduction of two components: nutrients (nitrogen and phosphorus) and organic matter. Nutrients stimulate the production of algal growth. Areas of relatively greater primary production generally have higher populations of invertebrates, which provide food for the fishery and other food-web components. However, too much primary production (**eutrophic**) decreases water quality (evidenced by lower clarity, wide ranges in DO and pH) and, therefore, degrades conditions for fish and other wildlife.

Productivity of Boulder Basin has been evaluated using the Burns Trophic Level Index (TLI; LaBounty and Burns, 2005). This index does not provide a quantitative measure of productivity, but simply attempts to classify trends towards improving or degrading water quality based on the **trophic** state of lakes (Burns and others, 1999). To this end, TLI combines information on nutrients (nitrogen and phosphorus), algal biomass (chlorophyll *a*), and water clarity (Secchi depth), standard water-quality parameters that also are described in this chapter. For TLI calculations in Lake Mead, however, the nitrogen component was not included; although nitrogen concentrations generally are high, it is the low concentrations of phosphorus that control primary production in this system (Paulson and Baker, 1983; LaBounty and Horn, 1997; Du, 2002; LaBounty and Burns, 2005; LaBounty, 2008; Holdren and Turner, 2010). As with other indicators of water quality, the Boulder Basin's TLI scores reflect efforts in wastewater treatment enhancement during the past decade. The lower the TLI value, the higher the water quality. Basin-wide, the evaluation (fig. 4-14) showed that TLI scores have improved during the past decade, with the 2001–2004 period categorized as mesotrophic (TLI value is between 3 and 4) and the 2004–2008 period categorized as oligotrophic (TLI value is between 2 and 3). TLI indices computed for sampling locations near Las Vegas Wash inflow have reflected an eutrophic status at some times of the year, but this level of productivity declines rapidly as the inflow is diluted by Boulder Basin.

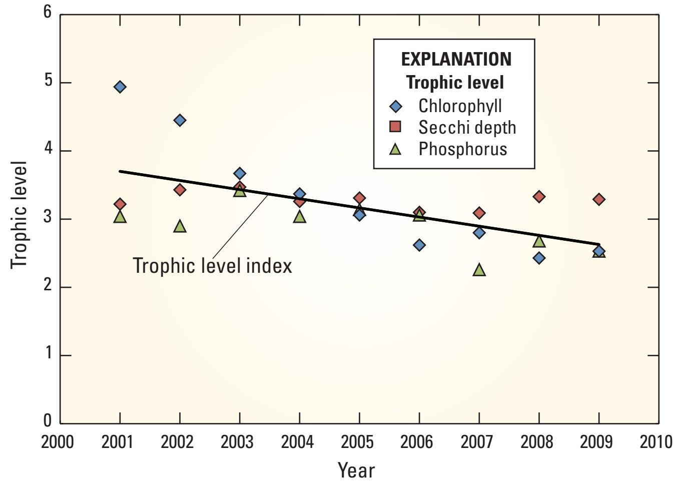



**Figure 4-14.** Burns Trophic Level Index (TLI) averaged scores for Lake Mead, 2000–2010, from three locations within Boulder Basin, including sampling sites LVB6.7 and CR346.4 (see fig. 4-1 for location map). The TLI score is calculated using the annual chlorophyll Trophic Level value; annual Secchi Trophic Level value; and annual total phosphorus Trophic Level value. The TLI trend has been downward from 2000 to 2010, indicating that water quality is improving.

## Chlorophyll *a*

Chlorophyll *a*, one of the pigments involved in photosynthesis, is an indicator of water quality and is frequently used as a measure of algal biomass. Concentrations of chlorophyll *a* are usually the highest near a reservoir's tributaries, which contribute nutrients. In Boulder Basin and Las Vegas Bay, elevated chlorophyll *a* concentrations near tributary inflows are particularly enhanced by the supply of phosphorus from Las Vegas Wash. A major algal bloom occurred in 2001 (see Nutrients and Algae in the Las Vegas Bay and Boulder Basin of Lake Mead and Chapter 6), with peak chlorophyll *a* concentrations greater than 1,000 µg/L in Boulder Basin (fig. 4-15). The bloom consisted primarily of the green algal species *Pyramiclamys disecta*, which is not known to produce or release toxins or any other compounds that affect drinking water taste or odor.

The 2001 algal bloom in Lake Mead has been attributed to the effects of a combination of factors: lowered lake levels, exposed tributary delta areas, spring rains, nutrient loading, the position of inflows in the water column, and construction activities (LaBounty and Burns, 2005). The ultimate driving factor, however, appears to have been the increased phosphorus concentrations at the surface of the water column during the spring warming of the lake, which allowed the algal species to sustain a high level of productivity.

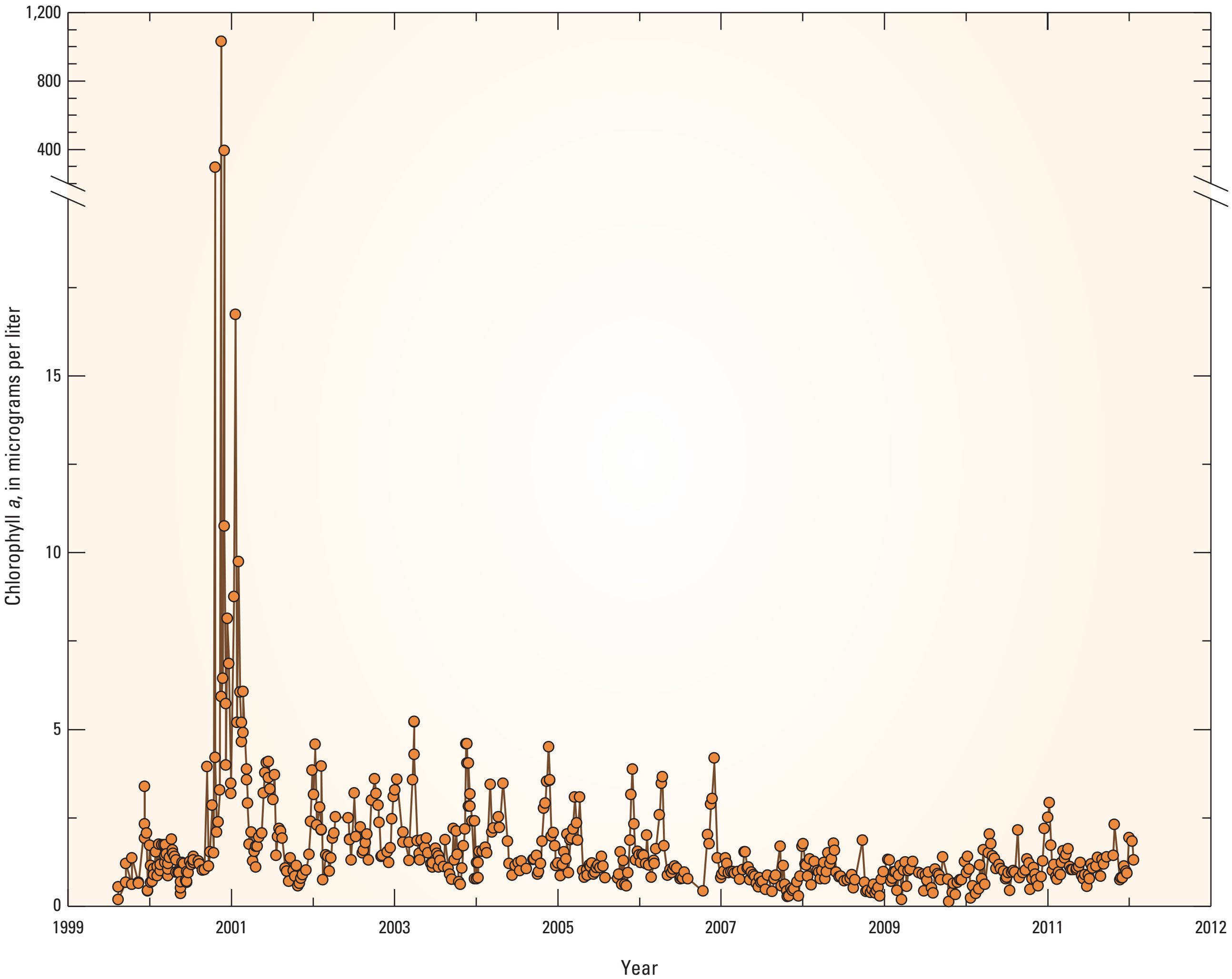



**Figure 4-15.** Chlorophyll *a* concentrations in Lake Mead's Boulder Basin since 2000, measured at sampling site CR346.4 (see fig. 4-1 for location map). Note the spike in values in 2001 during the green algal bloom. Note the break in chlorophyll *a* values on the y-axis.

Since 2001, improvements in wastewater treatment have resulted in significant reductions in phosphorus concentrations in Las Vegas Bay and Boulder Basin (LaBounty and Burns, 2007). Simultaneously, chlorophyll *a* concentrations have decreased in these areas. Following the 2001 bloom, peak concentrations of chlorophyll *a* in Las Vegas Bay typically have been less than 30 µg/L and, in Boulder Basin, less than 5 µg/L in most years. However, continued lowering of lake-surface elevations during drought conditions from 2000 to 2011 resulted in the extension of Las Vegas Wash waters farther into Las Vegas Bay than would have been expected at higher lake levels. This condition resulted in an apparent shift of elevated chlorophyll *a* concentrations farther into Las Vegas Bay, although their position relative to the Las Vegas Wash-Las Vegas Bay interface remained fairly constant.

## Nutrients and Algae in Las Vegas Bay and Boulder Basin of Lake Mead

By Wai Hing Wong and Douglas D. Drury

Within Lake Mead, the water within Las Vegas Bay has the highest concentration of nutrients. Both nitrogen and phosphorus are discharged in wastewater effluent from the Las Vegas metropolitan area by Clark County Water Reclamation District (CCWRD), and the Cities of Henderson, Las Vegas, and North Las Vegas. As a result, among all basins of Lake Mead, Las Vegas Bay has the highest production of algae (LaBounty and Burns, 2005).

In Las Vegas Bay and Boulder Basin, other human-caused and natural changes also may contribute to chlorophyll concentrations. However, neither the severe drought that began in 2000 (Holdren and Turner, 2010) nor the 2007 quagga mussel (*Dreissena rostriformis bugensis*) invasion (Wong and others, in press) have had the impact that can be attributed to the anthropogenic nutrient loading into Las Vegas Wash from inflows of wastewater and occasional stormwater. Because of low phosphorus concentrations, lower daily mass loadings of phosphorus, and daily wastewater flows being discharged, wastewater can be described as a persistent contributor of the phosphorus needed to support algal growth. Because storms are intermittent events and stormwater has higher phosphorus concentrations and higher daily mass loadings, stormwater can be considered to be an acute contributor to algal growth.

### Chlorophyll *a*

Chlorophyll *a* water-quality standards for Las Vegas Bay were established in 1988. The wastewater dischargers have been collecting chlorophyll *a* data in Las Vegas Bay for more than 20 years (Clark County Water Reclamation District and others, 2012a, 2012b).

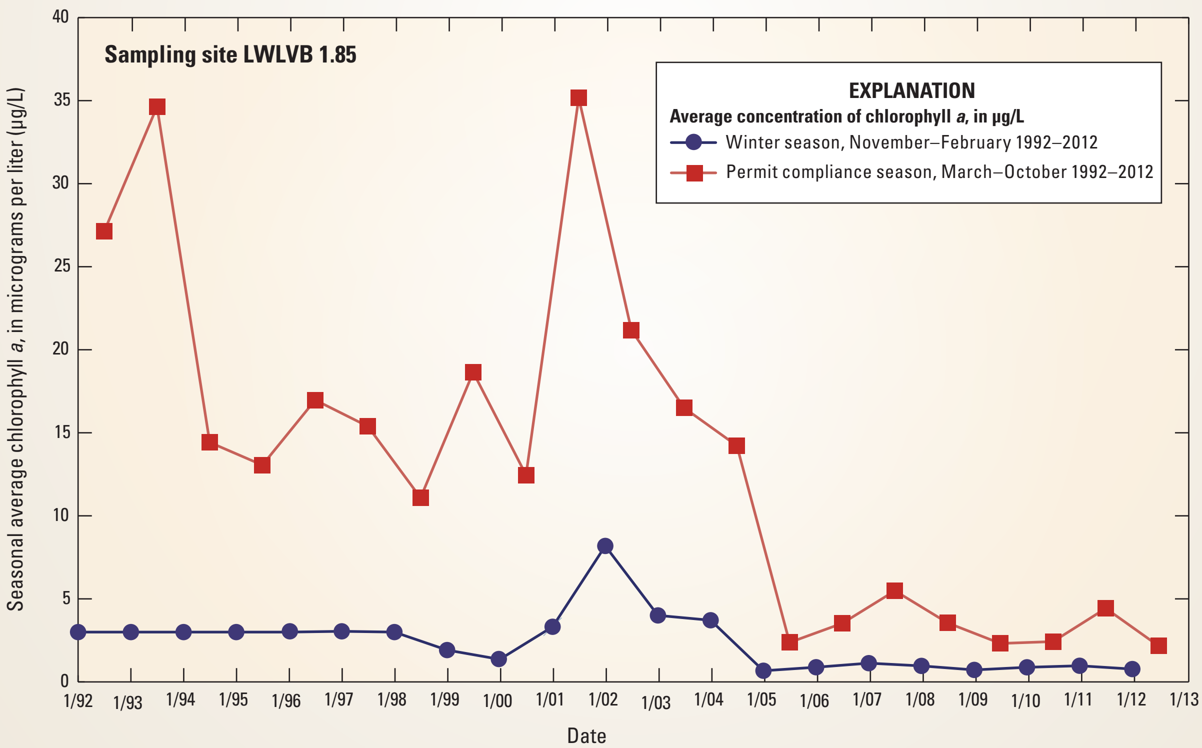



**Figure 4-16.** Seasonal averages of chlorophyll *a* concentrations in Lake Mead. Sampling site LWLVB 1.85 is 1.85 mi (3.0 km) from the Las Vegas Bay/Las Vegas Wash interface (see fig. 4-1 for location map). Both the winter season (November–February) and the permit compliance season (March–October) average chlorophyll *a* concentrations are shown.

Chlorophyll *a* concentrations greater than 300 µg/L have been observed numerous times over the years in individual samples. The highest chlorophyll *a* concentration in any sample collected after the 2005 treatment plant optimizations was 26 µg/L in August 2007; the average chlorophyll *a* concentrations in Las Vegas Bay have been decreasing in recent years (fig. 4-16).

## Phosphorus

In 1978, the load of total phosphorus being discharged by the City of Las Vegas and CCWRD's treatment plants was estimated to be greater than 2,800 lb/d (1,270.0 kg/d). The minimum monthly phosphorus discharged over the last 50+ years was 130 lb/d (59.0 kg/d) in December 1981, just after the City of Las Vegas and CCWRD started up their advanced phosphorus-removal wastewater-treatment plants. In March 1994, a Total Maximum Daily Load (TMDL) of 334 lb/d (151.5 kg/d) of total phosphorus was established for Lake Mead. The wastewater dischargers have been calculating monthly average data for total phosphorus loads from the effluent of the wastewater treatment plants for more than 20 years (Clark County Water Reclamation District and others, 2012b; fig. 4-17). The phosphorus contribution from wastewater effluent has been steadily decreasing even though population has been increasing over this time.

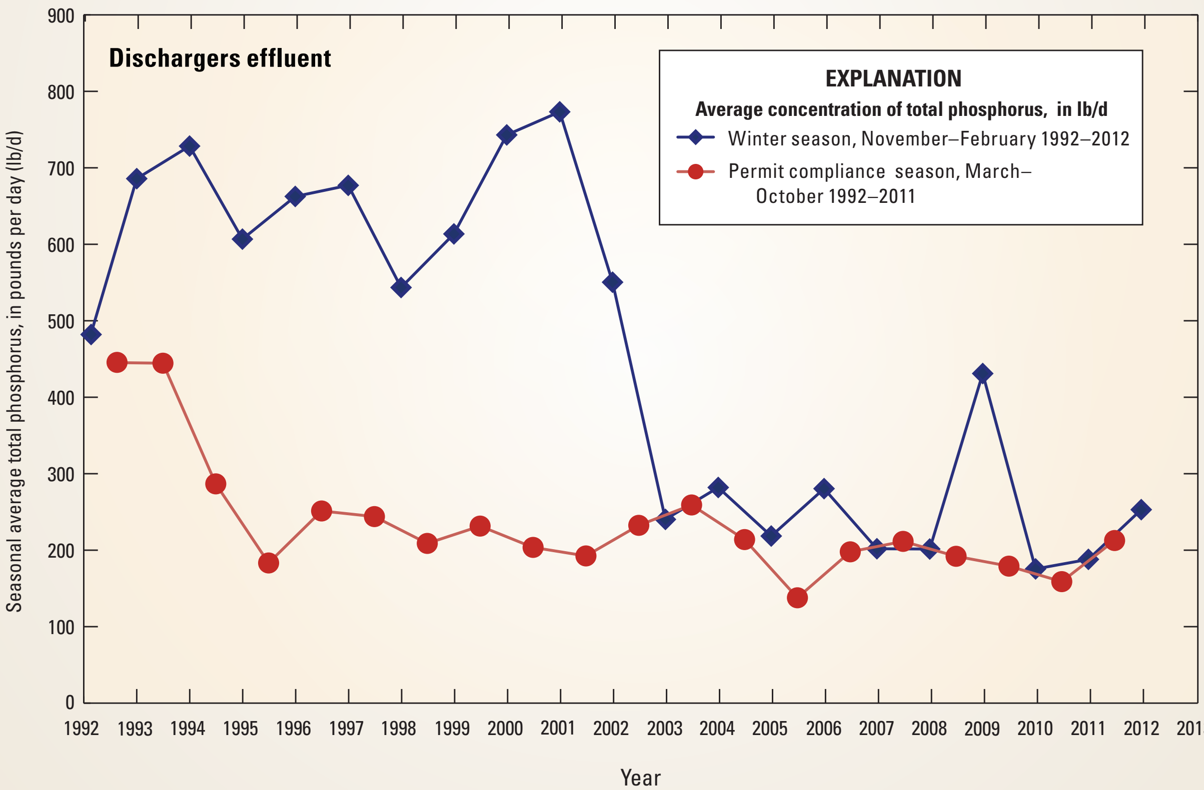



**Figure 4-17.** Average total phosphorus load in effluent discharged by wastewater treatment facilities at Lake Mead. Both the winter season (November–February) and the permit-compliance season (March–October) monthly phosphorus mass loading are plotted.

## Algal Bloom of 2001

In 2001, a large green algae bloom occurred across the entire Boulder Basin. Chlorophyll *a* concentrations in excess of 300 µg/L were measured in individual samples. The 2001 algal bloom primarily was due to a large load of phosphorus that entered the surface of Boulder Basin and remained in the **euphotic zone** (LaBounty and Burns, 2005). Algal blooms also were apparent downstream in Lake Havasu and as far as a reservoir in San Diego County, Calif. and in canals of the Metropolitan Water District of Southern California. A Lake Mead-focused Algae Task Force was formed and is ongoing; members of the task force include managers and scientists from the City of Henderson, City of Las Vegas, City of North Las Vegas, CCWRD, National Park Service, Nevada Department of Wildlife, Nevada Division of Environmental Protection, Southern Nevada Water Authority, and the University of Nevada, Las Vegas.

## Wastewater Discharge Actions

Following the 2001 algal bloom, the dischargers voluntarily agreed to remove phosphorus year round. The City of Henderson and CCWRD were able to implement year-round phosphorus removal by November 2001. The City of Las Vegas achieved year-round phosphorus removal in November 2002. By 2005, the dischargers had optimized their treatment plants to remove even more phosphorus. The decreased phosphorus loadings from the dischargers after 2001 are readily apparent in figure 4-17. No significant algal blooms have occurred since 2001.

Chlorophyll *a* concentrations were reduced in Las Vegas Bay after the dischargers reduced their phosphorus loadings in 2001 (fig. 4-16). For example, the amount of phosphorus discharged to Las Vegas Wash before 2002 was about 400 lb/d (181.4 kg/d); this amount was reduced to about 200 lb/d (90.7 kg/d) after 2005. Accordingly, the annual chlorophyll *a* concentration at the Las Vegas Bay monitoring station LWLVB 1.85 has been reduced from 14 to 2.4 µg/L since 2005 (fig. 4-18). The lowest average annual phosphorus load discharged to Las Vegas Wash was about 170 lb/d (77.1 kg/d) in 2010. The wastewater treatment efforts have significantly improved the water quality in the Boulder Basin of Lake Mead.

The concentrations of phosphorus in effluent from wastewater-treatment facilities increased during the winter season in 2005–2006 and 2008–2009 (fig. 4-17). These increases were due to the shutdown of nutrient removal processes at the City of Las Vegas for construction to ensure more reliable wintertime (and otherwise) phosphorus removal in the future. Phosphorus loading also increased starting in summer 2011 to early 2012, when the City of North Las Vegas wastewater-treatment plant came on line in June 2011. The North Las Vegas plant experienced start-up difficulties that lasted until March 2012. Clearly, achieving low phosphorus concentrations remains a challenge for the wastewater dischargers.

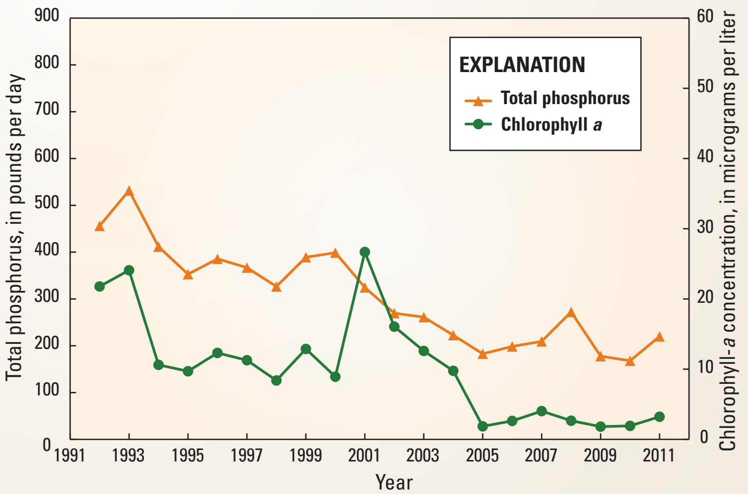



**Figure 4-18.** Annual discharge of total phosphorus from Las Vegas Wash to Las Vegas Bay and chlorophyll *a* concentration near Las Vegas Wash from 1992 to 2011.

## Organic and Inorganic Chemicals and Compounds in Water

By Michael R. Rosen

### Organic Compounds in the Lake Mead Water Column Sampled by Passive Samplers

Traditional (grab) sampling for analysis of organic compounds in water provides a snapshot of the compounds detectable at a given moment in time. However, most organic compounds are present at such low concentrations that they are not detected in samples collected by traditional sampling techniques, and analytical results do not represent the concentrations that aquatic organisms accumulate over time within their tissues. Semipermeable membrane devices (SPMDs) and polar organic chemical integrative samplers (POCIS) capture organic chemicals at low concentrations over a period of time (Alvarez and others, 2004; Huckins and others, 2006). SPMDs are designed to collect organic compounds passively. The types of compounds that SPMDs collect have low solubility in water (hydrophobic) and are likely to attach to particles, sediment, and fat (lipids). In this way, an SPMD serves as a synthetic fish that is used to estimate the amount of chemicals that can accumulate in actual fish tissues over a period of time. Hydrophobic compounds sampled by SPMDs include organochlorine pesticides (dichlorodiphenyltrichloroethane, DDT; hexachlorocyclohexane, HCH; and their breakdown products), polychlorinated biphenyls (PCBs), and certain volatile organic compounds (VOCs). POCIS detect organic compounds that are likely to remain dissolved in water (hydrophilic) and that could be present in the blood stream or organs of animals. Hydrophilic compounds sampled by POCIS include pharmaceuticals, personal care products, and certain pesticides.

Deployment of SPMD and POCIS containers in Las Vegas Bay for vertical organic contaminant profiling. Photograph by Michael R. Rosen, U.S. Geological Survey.

SPMD samplers have been deployed in Las Vegas Wash and Lake Mead at various times since 1995 (Bevans and others, 1996; Covay and Leiker, 1998; Goodbred and others, 2007; Leiker and others, 2009; Rosen and others, 2010), and POCIS samplers since 2006 (Rosen and others, 2010). Compounds detected at low concentrations by these samplers include organochlorine pesticides (DDT and its breakdown products), personal care products (for example, triclosan, an antibacterial agent used in many soaps), tonalide and galaxolide (fragrances), caffeine, PCBs, and VOCs (Goodbred and others, 2007; Rosen and others, 2010). The highest concentrations of most organic compounds have been detected in Las Vegas Wash and Las Vegas Bay, but compounds also have been detected in SPMD and POCIS samplers as far out in Boulder Basin as Sentinel Island (fig. 4-19). Organic compounds in these waters come primarily from Las Vegas Wash tributary inflow, a mixture of urban runoff, shallow groundwater flow, and treated wastewater discharge.

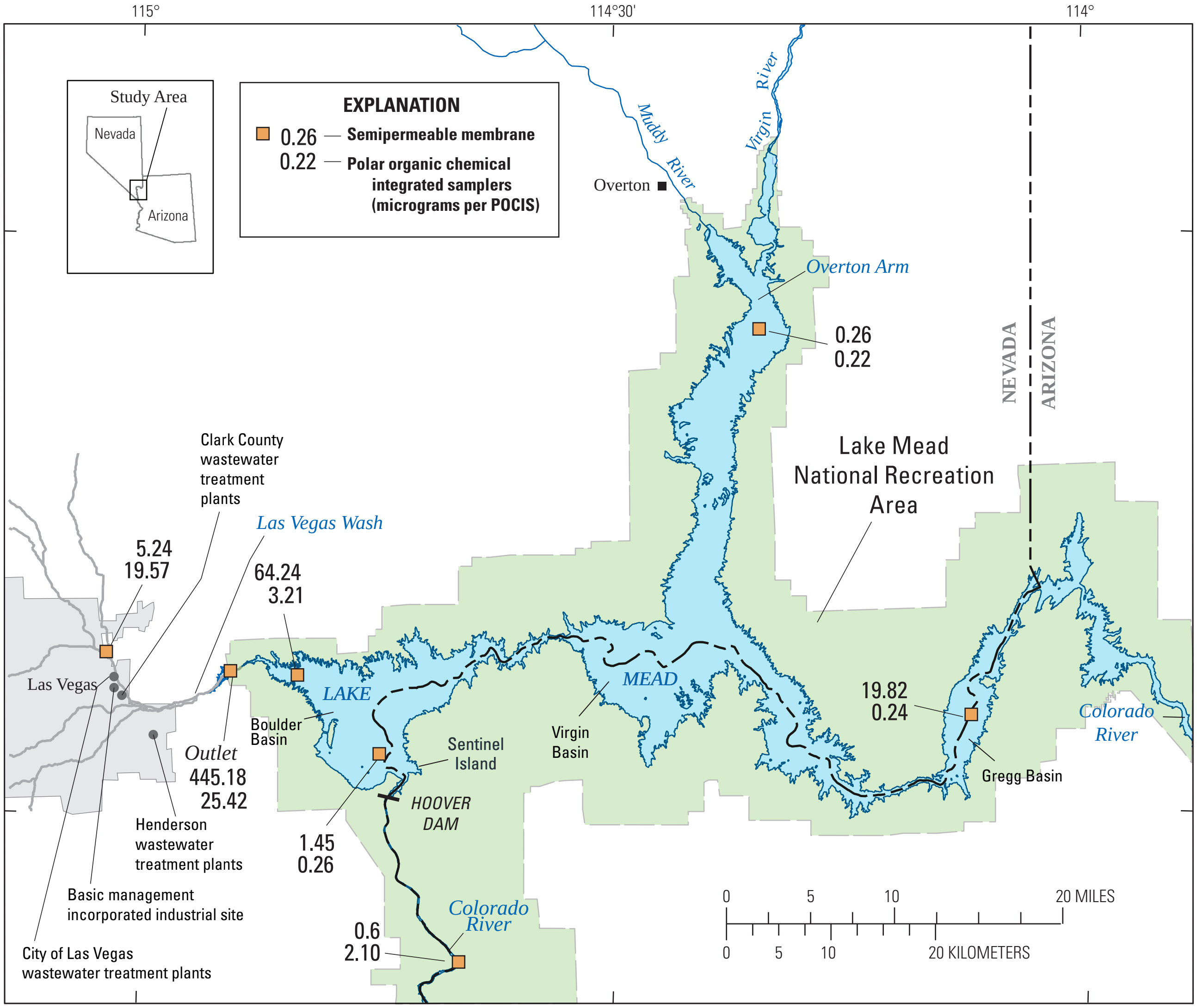



**Figure 4-19.** Distribution of the total concentration of organic compounds in Lake Mead sampled by semipermeable membrane devices (SPMDs; top value) and polar organic chemical integrative samplers (POCIS; bottom value). SPMD concentrations are shown in nanograms per liter (ng/L); POCIS concentrations are in micrograms (µg) per POCIS sampler. The estimated concentration of 50 µg per POCIS for *tris* (2-butoxyethyl) phosphate was not included in the total for the Las Vegas Valley Drive (LVVD) site. Boulder Basin (BB); Las Vegas Bay (LVB); Overton Arm (OA); Willow Beach (WB). Modified from Rosen and others (2010).

The organochlorine pesticide DDT has been banned in the United States since 1972. In southern Nevada, DDT was manufactured at a plant near Las Vegas Wash and, after the plant closed in the early 1970s, the disposal methods used for this product led to its transport into Las Vegas Wash by stormwater runoff (http://ndep.nv.gov/bmi/index.htm). As a result, DDT has been routinely detected in Las Vegas Wash and Las Vegas Bay, although its concentrations, based on sediment analyses, have been decreasing primarily due to post-production clean-up efforts (see section, "Organic and Inorganic Chemicals and Compounds in Sediment"). The breakdown products of DDT do not completely degrade, however, and may persist in the environment for many years.

In Las Vegas Bay, sets of **passive samplers** have been deployed in a vertical series to determine whether chemicals in Las Vegas Wash water enter Lake Mead near the surface or near the bottom of the lake. In March 2006, the resulting vertical chemical profile (fig. 4-20*A*) showed that water with higher concentrations of organic compounds from Las Vegas Wash entered along the bottom of the lake as underflow (Rosen and others, 2010). Entry of the Las Vegas Wash plume as underflow positions it to more directly affect bottom-feeding fish and bottom-dwelling organisms. Other chemicals, such as volatile organic compounds (VOCs) that are byproducts of gasoline combustion, were more highly concentrated near the surface of the lake (fig. 4-20*B*). This finding suggests that the source of VOCs occurred at the lake surface (a consequence of motorized boat traffic) rather than in Las Vegas Wash.

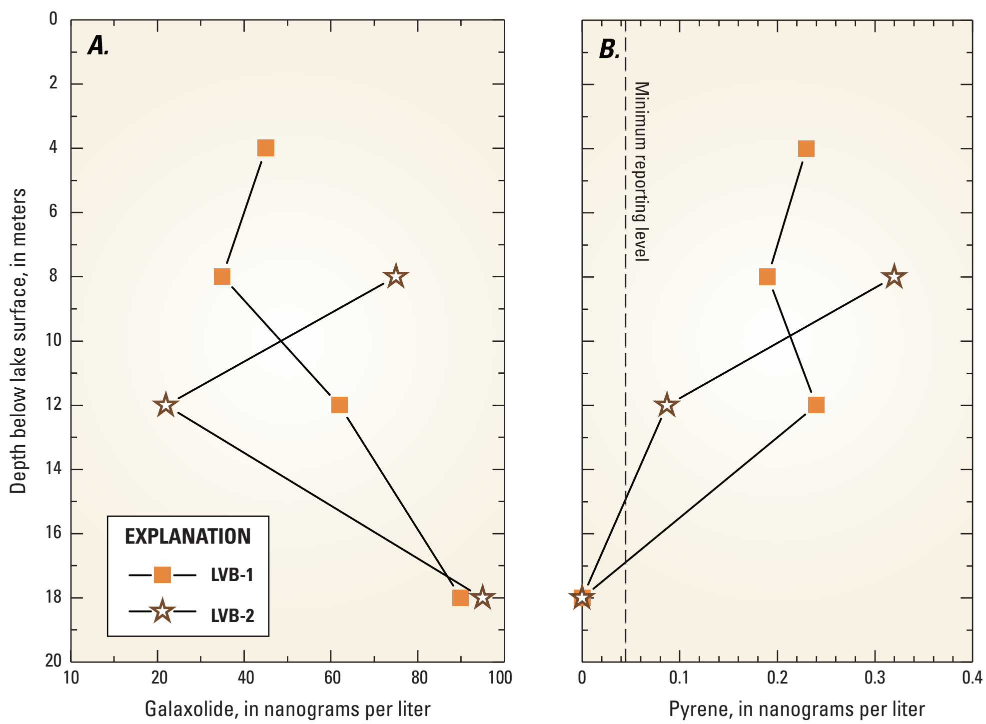



**Figure 4-20.** Galaxolide (*A*), a fragrance found in many personal care products, is present at elevated concentrations at the bottom of a vertical profile obtained in Las Vegas Bay, indicating that the source of organic compounds is Las Vegas Wash water entering the lake as underflow at this time of year. Pyrene (*B*), formed from the incomplete burning of gasoline, shows higher concentrations at the top of the profile, indicating that the source of volatile organic compounds is at the surface of the lake.

## Volatile Organic Compounds Related to Boating

From 2004 through 2006, SMPDs were used to collect samples to investigate the distribution of gasoline-derived VOCs in Lakes Mead and Mohave (Lico and Johnson, 2007). Most of these compounds are toxic to varying degrees. Because of this toxicity, they also are a potential source of environmental pollution and pose a health hazard. VOCs known as BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) and PAH compounds (polycyclic aromatic hydrocarbon compounds), which are produced during combustion of gasoline, were detected at every site sampled. During this period, the concentrations of BTEX and PAH compounds increased as the boating season progressed and decreased to less-than-detectable levels during the winter, when few boats were on the water. Moreover, concentrations of boat-related organic compounds were highest at sampling points near marinas or popular launching areas. These findings indicate that motorized watercraft are the major source of BTEX and PAH organic compounds to the lakes. The gasoline additive methyl *tert*-butyl ether (MTBE) also was detected during the 2004 sampling, but concentrations decreased to less than the detection level during the latter part of the study, most likely due to the removal of MTBE from gasoline purchased in California.

Studies by Lico and Johnson (2007) at Lakes Mead and Mohave, and by Lico (2004) at Lake Tahoe (Calif. and Nev.), showed that two-stroke gasoline engines can release up to 40 percent of their fuel into water bodies and are a major source of gasoline-derived organic compounds. In response to these and other studies, the National Park Service is phasing out the use of two-stroke engines that do not use direct injection within LMNRA by 2013 (http://www.nps.gov/lake/parkmgmt/twostroke.htm).

## Inorganic Compounds in Water

Inorganic chemicals and compounds are substances that do not contain carbon-hydrogen bonds as a fundamental component of their molecule. Inorganics occur naturally in the environment or can be manufactured. Many are soluble in water and have the potential to trigger health concerns if the USEPA standard is exceeded. Because of this, they are potential drinking water contaminants. This subsection focuses on inorganic perchlorate, selenium, and metals.

### Perchlorate

Derived from inorganic salts, perchlorate ($ClO_4$) is a naturally occurring and manufactured oxidizer that has been used (primarily as ammonium perchlorate) as a component in fireworks and solid rocket fuel. Perchlorate has been produced in Las Vegas Valley since the early 1950s at industrial plants near and upgradient of Las Vegas Wash. Leakage and transport of perchlorate to Las Vegas Wash through shallow aquifers has occurred from two manufacturing plants that were operated until the late 1990s (Urbansky, 1998; Boralessa, 2001; Sellars and others, 2007), and efforts to remove the perchlorate from groundwater and surface water have been underway for many years. Because exposure to perchlorate may create adverse health effects by disrupting the ability of the thyroid gland to produce **hormones** needed for normal growth and development (see Chapter 6), the USEPA recently (2011) determined that perchlorate meets the criteria for regulation under the Safe Drinking Water Act. Formal regulation of perchlorate by USEPA initiates a process to develop and establish a national primary drinking water regulation, which is a legally enforceable standard that applies to public drinking water supplies (U.S. Environmental Protection Agency, 2011).

Perchlorate concentrations in Lake Mead generally have been stable since 2005 with values of 0–3 µg/L for open water areas, where they are influenced by seasonal stratification of the water column. As a result, perchlorate tends to be concentrated within the uppermost layers of the epilimnion, reaching values of approximately 3 µg/L, whereas concentrations in the deep layers of the hypolimnion remain lower. When the water column mixes during the winter and autumn, perchlorate concentrations equalize throughout the water column at 0–3 µg/L. In Las Vegas Wash, at sites nearest Las Vegas Bay, however, perchlorate concentrations historically have been higher than in the remainder of the lake, decreasing from approximately 300 µg/L in 2003 to nearly 90 µg/L in 2007 (Ryan, 2008).

### Selenium

Selenium is a naturally occurring metalloid that is found globally in organic-rich marine sedimentary shale, including many geologic formations in the Western United States and commonly in southern Nevada. At low concentrations, selenium is an essential element for the health of animals (including humans) and some plants; at elevated concentrations, however, it is toxic and the threshold between providing a benefit and toxicity is narrow (Brown and Shrift, 1982; National Research Council, 2005). Furthermore, in the aquatic environment, selenium has the potential to **bioaccumulate** in zooplankton and **benthic** invertebrates, **biomagnifying** as it reaches top-level predators (Presser and Luoma, 2010, and references therein; Chapter 6). In so doing, selenium has been found to negatively affect the reproductive health of aquatic biota and to cause deformities in birds (Seiler and others, 2003). Hamilton and others (2002) summarized the risks posed by selenium in the broader Colorado River Basin to the endangered razorback sucker (*Xyrauchen texanus*), reporting that selenium in sediment, water, and biota may adversely affect reproduction of this species.

Low selenium concentrations in Lake Mead itself resulted in a focus on concentrations and loading of the element in Las Vegas Wash. Monitoring selenium concentrations in Las Vegas Wash is important because soils in upgradient areas in Las Vegas Valley are known to contain selenium concentrations, which may leach into the shallow groundwater that enters the Wash and flows into Lake Mead (Zhou and others, 2004). Typical concentrations of selenium in the upper Las Vegas Wash exceed the USEPA criterion for protection of wildlife of 5.0 µg/L; however, the increased water volumes provided by the wastewater reclamation plants along Las Vegas Wash dilute these concentrations. Ryan and Zhou (2010) reported average selenium concentrations in the lower Las Vegas Wash area near the historical confluence with Lake Mead at Las Vegas Bay to be 3.3 µg/L, which results in an annual loading to the reservoir of 1,890 lbs (857.3 kg) of selenium. These values were in general agreement with those reported by Zhou and others (2004) when average selenium concentrations near the Las Vegas Wash confluence with the lake were 2.85 µg/L and the reported annual load was 1,426 lbs (646.8 kg) of selenium.

## Metals

Because elevated levels of metals can cause serious health problems, acceptable concentrations of metals in drinking water are strictly limited by State and Federal law. Sampling for metals in the water of Lake Mead has been limited, with the greatest emphasis being associated with sites within Las Vegas Wash (table 4-1) and the location of the drinking water intakes of the Southern Nevada Water Authority (SNWA) (table 4-2).

Water quality test results for the Southern Nevada Water System (2010; table 4-1) are taken from SNWA 2010 Water Quality Report. This report is required by the Safe Drinking Water Act and provides water customers with water-quality information about their drinking water. The report, which is updated each year, compares water test results to drinking-water standards and, in the 2010 Water Quality Report, all values were well below the Maximum Contaminant Level established by USEPA.

**Table 4-1.** Concentrations of metals in water in Las Vegas Wash.

[Average (2003–07) metal concentrations in Las Vegas Wash (LW0.8) near the interface with Lake Mead compared to U.S. Environmental Protection Agency (USEPA) maximum contaminant levels for drinking water. Source for USEPA maximum contaminant level is http://water.epa.gov/drink/contaminants/index.cfm. **Abbreviations:** µg/L, micrograms per liter]

| Metal | Concentration (µg/L) | USEPA maximum contaminant level (µg/L) |
|---|---|---|
| Aluminum[1] | 304 | 50–200 |
| Arsenic | 9.0 | 10 |
| Barium | 63 | 2,000 |
| Chromium | 1.2 | 100 |
| Copper | 4.5 | 1,300 |
| Iron[1] | 310 | 300 |
| Manganese[1] | 52 | 50 |
| Lead | 0.92 | 15 |
| Nickel | 8.7 | None |
| Selenium | 3.3 | 50 |
| Zinc[1] | 36 | 5,000 |

[1]Secondary standard.

**Table 4-2.** Concentrations of metals in water at the Southern Nevada Water Authority's drinking-water intakes in Lake Mead.

[Average 2009 metal concentrations from the Southern Nevada Water Authority's Water Quality Report for entry point (Lake Mead drinking water intakes) monitoring compared to U.S. Environmental Protection Agency (USEPA) maximum contaminant levels for drinking water. Source for USEPA maximum contaminant level, in micrograms per liter, is http://water.epa.gov/drink/contaminants/index.cfm. **Abbreviations:** µg/L, micrograms per liter]

| Metal | Concentration (µg/L) | USEPA maximum contaminant level (µg/L) |
|---|---|---|
| Arsenic | 1.7 | 10 |
| Barium | 100 | 2,000 |
| Selenium | 2.0 | 50 |
| Uranium | 4.6 | 30 |

Las Vegas Wash data were collected for the Las Vegas Wash Coordination Committee to support their efforts to monitor and improve water-quality conditions in the Wash. As mentioned previously, the water in Las Vegas Wash is a mixture of urban runoff, shallow groundwater discharge, stormwater, and reclaimed wastewater effluent. It is expected that the concentrations of metals in Lake Mead would be significantly lower following dilution of Las Vegas Wash water with the much larger volume of lake water. In Las Vegas Wash, the average concentrations for metals generally were below the USEPA's Criteria Maximum Concentration, Criterion Continuous Concentration, or Criteria Recommendation for Priority Pollutants for the protection of aquatic organisms (for details, see http://water.epa.gov/scitech/swguidance/standards/current/index.cfm).

Historically, the risk of impact to Lake Mead by metals was considered to be low due to their generally low concentrations in Las Vegas Wash, the only significant tributary subject to urban and industrial influences. However, future investigations of concentrations in sediment entering the lake would be warranted to establish and expand baseline conditions to better evaluate future conditions.

## Contaminants of Emerging Concern

By Michael R. Rosen and Brett Vanderford

Human-related sources of contamination that can affect the quality of water resources and aquatic ecosystems also are monitored and studied. Contaminants of emerging concern (CECs) include pharmaceuticals, personal care products, plasticizers, and other compounds disposed of into the environment by households and industries. Although these compounds commonly are removed by conventional wastewater-treatment processes to levels below detection, CECs typically are not completely removed prior to effluent discharge. Several studies have documented low levels of CECs in Lake Mead, typically in the nanograms per liter (part-per-trillion) range (Chapter 6; Daughton and Ternes, 1999; Osemwengie and Gerstenberger, 2004; Goodbred and others, 2007; Leiker and others, 2009; Benotti and others, 2010; Rosen and others, 2010). Sparse data exist on the long-term bioaccumulation of CECs in Lake Mead and other reservoirs throughout the world and, as a result, the potential ecosystem and human health effects of these compounds at low concentration remain largely unknown.

Studies on the fate and transport of CECs at Lake Mead began in 1996 when Bevans and others (1996) published the first report of the occurrence of endocrine disruption in common carp (*Cyprinus carpio*). Carp collected from Las Vegas Wash, the primary source of CECs from treated wastewater discharge, and Las Vegas Bay were found to have significantly different levels of plasma steroid hormone and vitellogenin compared to carp collected from a reference site upstream in Callville Bay (fig. 1-1); however, the cause of the endocrine disruption was unknown. Subsequent work used toxicity identification and evaluation methodology to screen Lake Mead for estrogenic compounds. Snyder and others (2001) provided a link between endocrine disruption and natural and synthetic hormones present in Las Vegas Wash, and their work along with other research, served as an impetus for studies to better understand possible impacts of CECs on aquatic organisms, such as the endangered razorback sucker, in Lake Mead.

## Organic and Inorganic Chemicals and Compounds in Sediment

By Michael R. Rosen

Sediment-core analyses provide information about how chemical inputs to a lake have changed with time. In 1998, multiple sediment cores were collected from several Lake Mead locations (Las Vegas Bay, Boulder and Virgin Basins, and Overton Arm) to determine spatial differences in chemical inputs and temporal changes in selected constituents starting from the completion of the Hoover Dam in the mid-1930s (Covay and Beck, 2001; Rosen and Van Metre, 2010). Results of this study were then compared to those of similar studies for other lakes in the United States that also are influenced by urban watersheds; these comparisons indicate that concentrations of inorganic and organic chemicals are relatively low in Lake Mead. Chemical concentrations vary among basins, however, and even within each basin no single value can be assumed to typify conditions within the lake (Rosen and Van Metre, 2010). For example, concentrations of DDE (a breakdown product of DDT) were higher in Las Vegas Bay cores, particularly in the 1980s, when DDT was produced at a facility located along Las Vegas Wash, but concentrations decreased after cleanup efforts were implemented (fig. 4-21). Mercury also was present in sediment cores from Lake Mead; mercury concentrations were twice as high in the Virgin Basin core as in the Las Vegas Bay cores (but these are still relatively low concentrations compared to those in other urban lakes). Relative to other Lake Mead basins tested, Overton Arm cores had the lowest concentrations of most chemicals, except organic carbon.

In the Las Vegas Bay core, concentrations of the organic compound tetrachlorodibenzo-p-dioxin (TCDD) have steadily increased since the completion of Hoover Dam and appear to correlate with population growth in Clark County, which includes the Las Vegas metropolitan area (fig. 4-22). The cause of this steady increase in TCDD has not been determined; however, Rosen and Van Metre (2010) attributed the increase to the effects of increased urbanization and an increase in the area of impervious surfaces that may have allowed more TCDD to flow into Las Vegas Wash. TCDD is produced by different types of waste-burning incinerators, including backyard burn-barrels, and is very toxic; however, waste incineration by methods other than burn-barrels has declined in the United States since the 1980s. TCDD also may be a breakdown product of triclosan, an antibacterial agent used in deodorants, toothpastes, and other personal-care products (Buth and others, 2009), and therefore a likely cause for increased concentrations of TCDD over time consistent with increased use of triclosan-containing products by a growing population.

Collecting a sediment core from Las Vegas Bay. Photograph by Michael R. Rosen, U.S. Geological Survey.

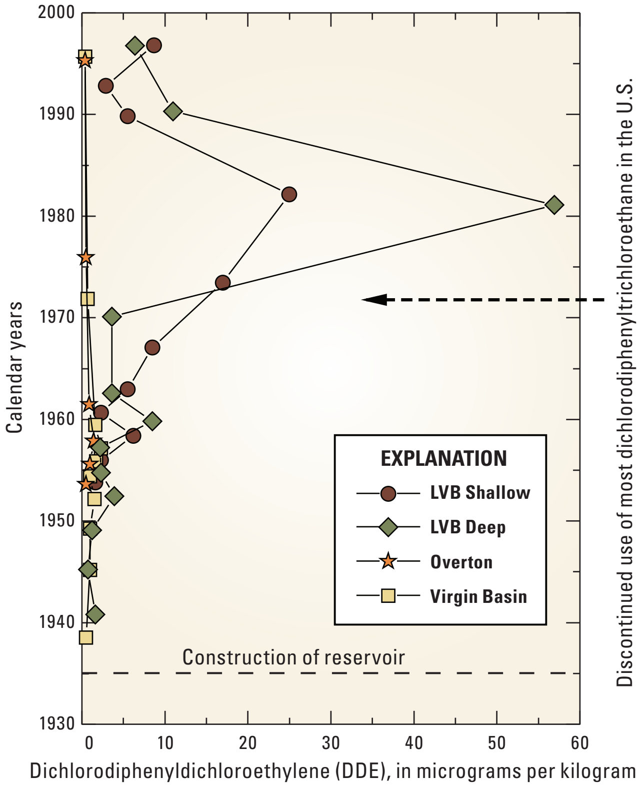



**Figure 4-21.** Concentrations of DDE (a breakdown product of DDT) in sediment cores from Lake Mead's Las Vegas Bay (LVB), Virgin Basin, and Overton Arm. DDE was not detected in Virgin Basin and Overton Arm cores indicating Las Vegas Wash was the source. Concentrations peaked in the early 1980s when DDT was entering the Wash from waste ponds near the Wash, but after cleanup of the site began, concentrations decreased. Modified from Rosen and Van Metre (2010).

Elements such as manganese and lead in sediment cores also showed differing spatial and temporal changes in concentrations across Lake Mead. Manganese and lead concentrations were higher in Las Vegas Bay than in other portions of Boulder Basin, the Overton Arm, and Virgin Basin, particularly during the 1960s and early 1970s, but for different reasons. Manganese concentrations were high due to erosion of waste sediment from a manganese mine near Las Vegas Wash. The mine closed in the 1960s, but erosion of the sediments occurred until the 1980s when sediment-control structures were constructed to reduced sediment erosion into Las Vegas Wash (Rosen and Van Metre, 2010).

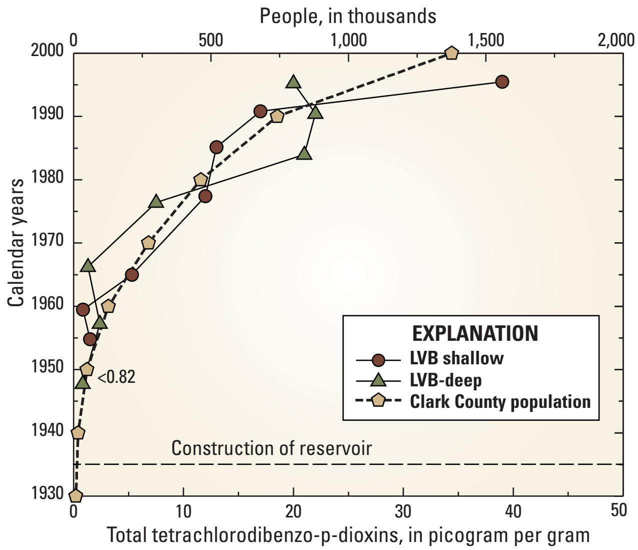



**Figure 4-22.** Concentrations of total tetrachlorodibenzo-p-dioxin (TCDD) in sediments of Las Vegas Bay (LVB), Lake Mead. TCDD concentrations in Las Vegas Bay sediments appear to correlate with population growth in Clark County. Concentrations of TCDD in a core taken in Virgin Basin sediments were less than the detection limit for the length of the core.

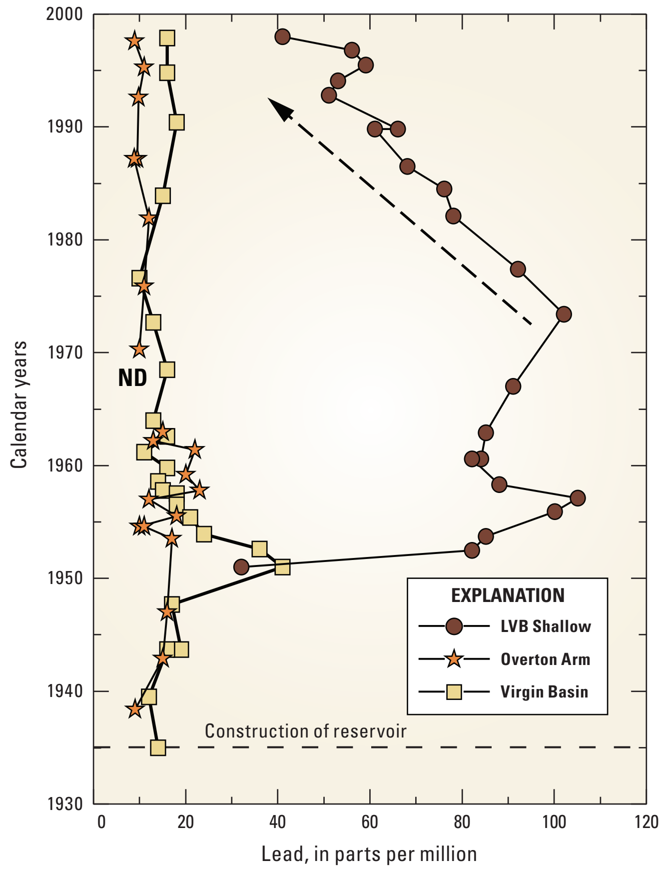



**Figure 4-23.** Lead concentrations in sediment cores from Las Vegas Bay (LVB), Lake Mead. Lead concentrations were elevated when lead was used as an additive in gasoline. Concentrations decreased after the use of lead in gasoline was phased out beginning in 1973. Virgin Basin and Overton Arm cores do not show this increase because urban areas were too far away. ND = no data.

Lead concentrations were elevated in Las Vegas Bay due to the addition of lead to gasoline up until 1973; after this time, the addition of lead was phased out of gasoline until its use was banned in 1996 (http://www.epa.gov/history/topics/lead/02.htm). Sediment cores show high concentrations of lead only in Las Vegas Bay sediments because motorized traffic is sparse in areas outside of the Las Vegas Bay area and near tributaries to other basins in Lake Mead. Peak lead concentrations in Las Vegas Bay sediments correlates with the greatest use of lead additives in gasoline (fig. 4-23), which has decreased since the 1970s. Many other trace elements showed decreasing concentrations in the Virgin Basin core after the 1960s. This may have been a consequence of sediment being trapped behind Glen Canyon Dam at Lake Powell (Rosen and Van Metre, 2010), which began filling in 1963. New sediment cores were taken in Las Vegas Bay in 2007 to assess whether increases or decreases in some compounds are occurring and whether new compounds can be detected in the cores. In addition, the cores are being analyzed to see if concentrations of those compounds are lower in the outer part of the bay than in the area closest to Las Vegas Wash.

## Effects of Invasive Species on Water Quality

Invasive species can have significant effects on water quality; and changes in water quality caused by invasive species can encourage the growth of other undesirable species (Hecky and others, 2004). One example of this relationship involves quagga mussels (Chapter 6), an invasive species that is now thriving in Lake Mead. Large numbers of quagga mussels in a lake can rapidly consume an extraordinary amount of algal cells in the water column while releasing nitrogen and phosphorus back to the water as waste. Under the right conditions, the remaining algae could use these nutrients to create an unsightly algal bloom that can cause taste and odor problems. Quagga mussels potentially can enhance the level of microcystin toxin in a lake because they do not consume many cyanobacteria, leaving this group to proliferate. Under the right conditions and in other water bodies, dreissenid mussels appear to have enhanced the growth of cyanobacteria and their toxin producers (Knoll and others, 2008). These problems have not occurred in Lake Mead, and are not expected, but have occurred elsewhere (Hecky and others, 2004) and therefore the possibility cannot be eliminated.

Quagga mussels also represent a future potential threat to DO concentrations. If Lake Mead's quagga mussel population increases, oxygen demand at the bottom of the lake also will increase; in time, oxygen deficiencies could become more common in deep, poorly mixed locations. (In shallow regions of the lake where active mixing infuses oxygen, such depletions would not present a significant problem.) Areas of low oxygen caused by quagga mussels could compound the quagga mussel problem. At sufficiently low DO concentrations, quagga mussels and other organisms will die, and bacterial decomposition of dead individuals would further reduce oxygen concentrations. Once lake-floor sediments are covered by oxygen-free (anoxic) water, phosphorus stored in sediment can be released back to the water column (Böstrom and others, 1982; Nürnberg, 1988). Following seasonal mixing, this newly available phosphorus source could then stimulate algal production, reinforcing the entire cycle. At the time this report was published (2012), the quagga mussel population was not large enough in Lake Mead to affect the ecosystem so broadly.

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# Chapter 5

# Wildlife and Biological Resources

By Sudeep Chandra[1], Scott R. Abella[2], Brandon A. Albrecht[3], Joseph G. Barnes[2], E. Cayenne Engel[2], Steven L. Goodbred[4], Paul B. Holden[3], Ron B. Kegerries[3], Jef R. Jaeger[2], Erik Orsak[5], Michael R. Rosen[4], Jon Sjöberg[6], and Wai Hing Wong[2]

Lake Mohave near Willow Beach. Photography by Michael R. Rosen, U.S. Geological Survey.

***The creation of Lakes Mead and Mohave drastically changed habitats originally found along their region of the historical Colorado River. While still continuing to provide habitat conditions that support a rich diversity of species within the water, along shorelines, and in adjacent drainage areas, the reservoirs contain organisms that are both native and non-native to the Colorado River drainage (fig. 5-1). The diversity of species within these lakes continues to change with time due to changing habitat conditions, the invasion of non-native species, and extirpations of native species. From the bottom of the food web to the top predators, all organisms within the ecosystem are interconnected in food webs or food-chain networks. As non-native invasive species continue to be introduced into the lakes, alterations to the food web, species competition, and species predation likely will continue to change the ecosystem and populations of native organisms. Following an overview of the food web, this chapter summarizes information on aquatic and aquatic-dependent wildlife at Lakes Mead and Mohave and their relationships within the food web from members of lower trophic levels to the highest: phytoplankton, invertebrates, including zooplankton, and macroinvertebrates; fishes; and birds. The following sections describe the biological diversity, limiting factors, and ecological functions of these groups in Lake Mead, and to a lesser extent, in Lake Mohave.***

[1] University of Nevada, Reno
[2] University of Nevada, Las Vegas
[3] BIO-WEST, Inc.
[4] U.S. Geological Survey
[5] U.S. Fish and Wildlife Service
[6] Nevada Department of Wildlife

## Overview of the Food Web

By Sudeep Chandra

Understanding a lake's food web—or how each member gets its energy in the form of food—is an important aspect of ecological research. This knowledge can help clarify population dynamics and how nutrients are recycled (and contaminants accumulate) within an ecosystem. The term "food-web coupling" describes energy or food movement from one habitat, such as open water, to another, such as lake bottom, which occurs frequently in freshwater systems where nutrient fluxes are common. Many species live and interact within the Lake Mead system (fig. 5-1). Aquatic **macrophytes** and algae, which produce food from the sun's energy, are at the base of the Lake Mead food web. Algae can be found in two habitats—at the bottom of the lake (benthic zone) and in open water. Plants and algae living in the benthic environment support invertebrates, amphibians, and bottom-feeding fishes, such as common carp (*Cyprinus carpio*) and the endangered razorback sucker (*Xyrauchen texanus*). Some benthic-supported organisms (for example, crayfish or razorback sucker) are omnivorous; they eat a variety of smaller benthic invertebrates in addition to plants and benthic algae. In the open water, phytoplankton support a variety of microorganisms, including bacteria, protists, and tiny invertebrate animals known as zooplankton. Zooplankton are crucial in supplying nutrients to juvenile and smaller fish species. Lake Mead's bass fishery, in turn, is largely supported by small fish species, such as shad (*Dorosoma sp.*) and bluegill (*Lepomis macrochirus*). Omnivorous aquatic birds such as ducks eat aquatic plants and invertebrates. Grebes feed on both fish and large benthic invertebrates, and piscivorous predatory birds such as bald eagle (*Haliaeetus leucocephalus*) eat shad, bass, and carp.

Within the food web, the strength of relationships can increase or decrease over time depending on the nutrients delivered to the lake as well as changes in the population structure of community members. The introduction of invasive species such as quagga mussel (*Dreissena rostriformis bugensis*), which feed on plankton and concentrate nutrients in the benthic environment, can drastically alter the connections and coupling across lake habitats, resulting in unpredictable disruptions to the food web and lake fishery.

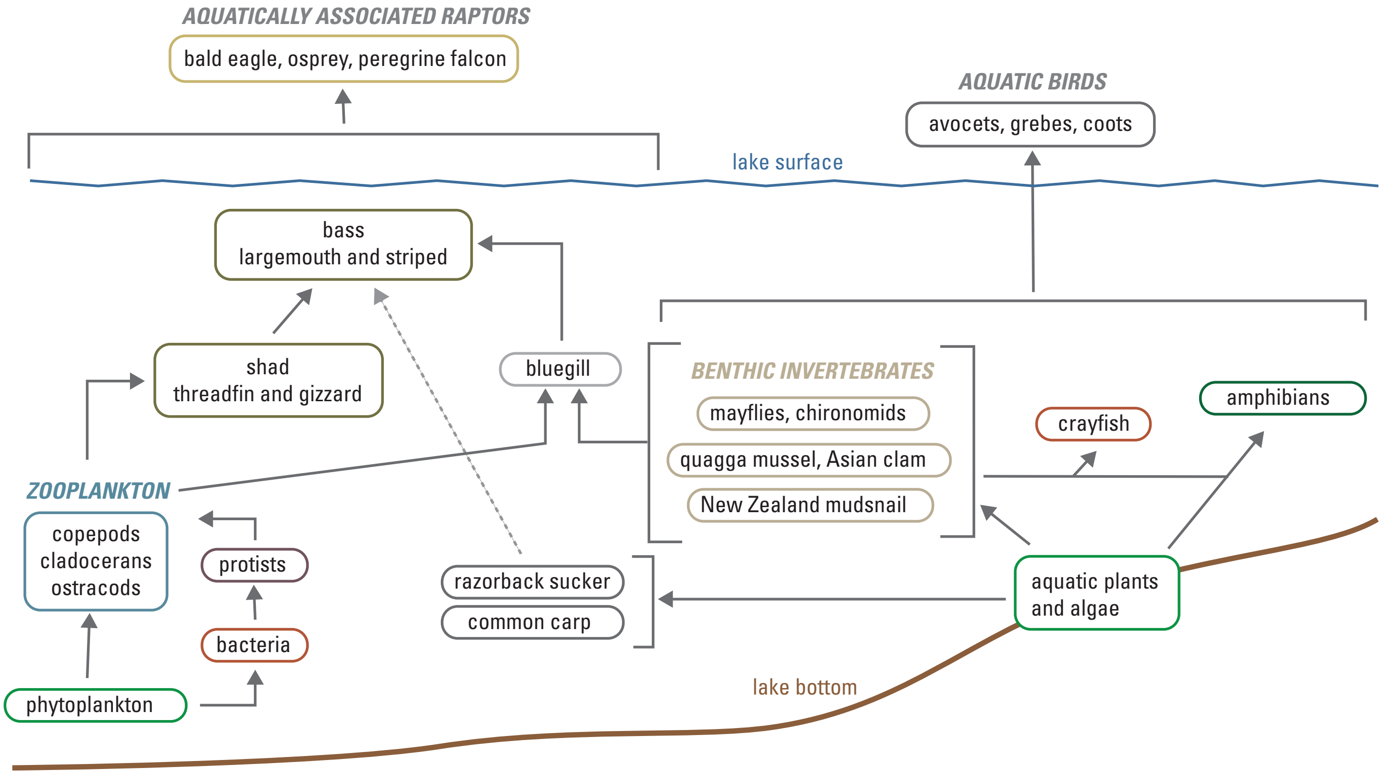



**Figure 5-1.** Conceptual illustration of the Lake Mead food web.

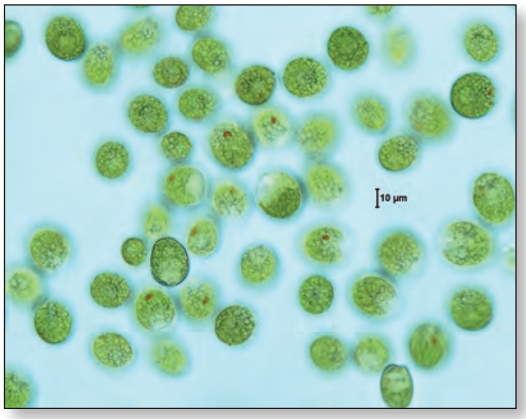
## Algae

By Wai Hing Wong and Michael R. Rosen

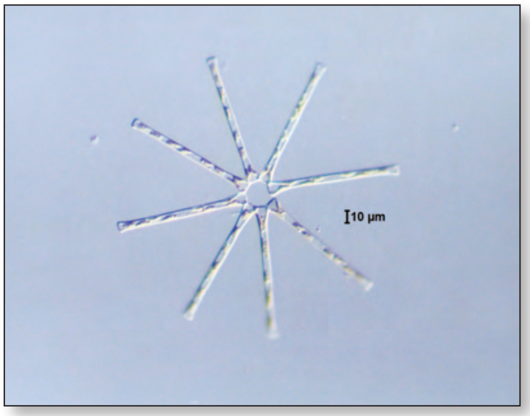
Algae are microscopic plants that form the base of the aquatic food web. Free-floating algae in the water column known as phytoplankton are an important source of food (energy) for zooplankton (microscopic, invertebrate animals that float in the water), some fish, and aquatic birds in the Lake Mead ecosystem. Similar to plants on land, most algae utilize the sun's energy to grow through a process called photosynthesis. Phytoplankton can be categorized into different groups such as green algae, cyanobacteria that also are known as blue-green algae, diatoms, golden-brown algae, and dinoflagellates.

The population of phytoplankton in a lake is controlled by many environmental and chemical factors. Besides light and carbon dioxide used during photosynthesis, phytoplankton also require nutrients such as nitrogen and phosphorus to grow. Because nitrogen and phosphorus must be present at a certain ratio (the Redfield ratio; Redfield, 1934) for optimal algae growth, if either or both of these nutrients are absent or in low supply, algal growth will be limited. Cold winter temperatures also can inhibit algal growth. Reductions in algae populations can limit zooplankton growth and, in turn, reduce subsequent food availability for fish. A "phosphorus-limited" lake is one in which little phosphorus but abundant nitrogen are present in the water. Lake Mead generally is phosphorus-limited (Paulson and Baker, 1983; LaBounty and Horn, 1997; Du, 2002; LaBounty and Burns, 2005; LaBounty, 2008; and Holdren and Turner, 2010). Thus, when excess phosphorus is transported to the lake from the Colorado River or other tributaries, becomes concentrated in an area through the excretions of organisms, or is added to the lake from wastewater (effluent), algae can grow rapidly. With enough nutrients and light, algae can grow quickly within a short period of time, resulting in a bloom that changes the color of a lake from blue to the bright green of photosynthesizing algae.

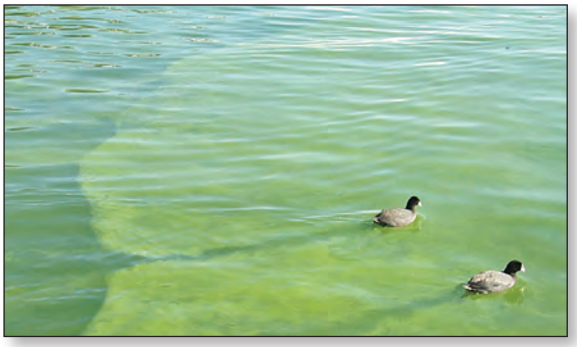
In 2001, conditions at Lake Mead's Boulder Basin resulted in a large algal bloom (LaBounty and Burns, 2005; Chapter 4) of green algae (*Pyramichlamys dissecta*). The bloom started in March and persisted through September; it was visible throughout Boulder Basin, with concentrations of algae (measured as chlorophyll *a*) peaking at less than 200 mg/m$^3$ in the middle and outer basins (LaBounty and Burns, 2005). The bloom formed a surface scum and unsightly conditions that affected recreation, visual enjoyment of the lake, and reduced light penetration into the lake. When algae die, microbes decompose them in a process that consumes dissolved oxygen; a large algal die-off following a bloom, therefore, can result in large increases in decomposing microbes and a further reduction of dissolved oxygen content of the water. The resulting low oxygen levels can kill invertebrate and fish species; however, the 2001 Lake Mead algal bloom did not cause fish kills. Nonetheless, in response to this significant algal bloom, the wastewater-treatment facilities that discharge into Las Vegas Wash enhanced their phosphorus removal, thereby greatly reducing its concentrations in the lake and the potential for a repeat bloom on the scale of the 2001 event (see Chapter 4 for information about the relationship between nutrients and algal productivity).




Photomicrograph of green algae (*Pyramichlamys sp.*); 640x magnification. Photograph by Ann St. Amand, Ph.D., PhycoTech, Inc.

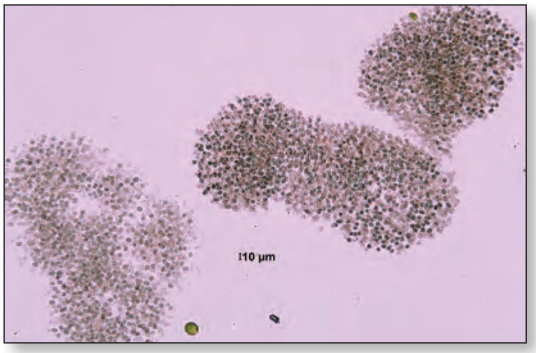



Photomicrograph of a diatom (*Asterionella formosa*); 400x magnification. Photograph by Ann St. Amand, Ph.D., PhycoTech, Inc.



Coots (*Fulica americana*) swimming through a green algal bloom in Boulder Basin in March 2001. Photograph by National Park Service.

Smaller algal blooms also have occurred in marinas and bays of Lakes Mead and Mohave depending on nutrient and temperature conditions in those environments. A brief bloom of small blue-green algae (cyanobacteria) occurred in the middle of Las Vegas Bay in 2003 (LaBounty and Burns, 2005). Of all areas in Lake Mead, Las Vegas Bay has the highest potential for algal growth due to the supply of nutrients from wastewater outflow and stormwater runoff from the Las Vegas metropolitan area into Las Vegas Wash and Lake Mead. Across Boulder Basin, populations of different algal groups generally peak throughout the warmer months of the year: green algae in May, diatoms in June, golden-brown algae in July, dinoflagellates in August, and blue-green algae from October to November (LaBounty and Burns, 2005). Among the thousands of algal species present in lakes worldwide, most are harmless and typically beneficial at moderate concentrations; some species, such as cyanobacteria, however, can create harmful toxins given the right conditions.




Photomicrograph of blue-green algae (*Microcystis aeruginosa*); 200x magnification. Photograph by Ann St. Amand, Ph.D., PhycoTech, Inc.

## Invertebrates

By Wai Hing Wong and Sudeep Chandra

### Zooplankton

Zooplankton are a broad group of mostly microscopic, invertebrate, aquatic animals. They are mostly free-floating and free-swimming but also live in the bottom sediments. Different types of zooplankton vary in size—microzooplankton are less than 200 µm, mesozooplankton are between 200 and 2,000 µm, and others can be larger than 0.8 in. (20 mm). Zooplankton feed on phytoplankton and other zooplankton, and, in turn, are consumed by other invertebrates, birds, and fish. Zooplankton are the main food of threadfin shad, which are the key source of food for game fish in Lakes Mead and Mohave, such as largemouth bass (*Micropterus salmoides*) and striped bass (*Morone saxatilis*). Thus, monitoring zooplankton abundance is critical to the sportfishery on both lakes (LaBounty and Burns, 2005).


Photomicrograph of *Daphnia pulex,* a zooplankton of the order Cladocera. 35x magnification; 500-micrometer scale bar. Photograph by Ted Rosati and John Beaver, BSA Environmental Services.

Free-swimming zooplankton community types can be classified by the lake location in which they reside, commonly littoral (near shore) and limnetic (open water) zones. Littoral zooplankton live only in shallow water near the shoreline among weeds and other vegetated habitats. Limnetic zooplankton live predominantly in open water but also can be present in the littoral zone. Because the density of aquatic vegetation is one of the major influences on the diversity and abundance of littoral zooplankton, a lake, such as Lake Mead, that generally lacks abundant aquatic vegetation is dominated by limnetic zooplankton. Littoral species rarely exceeded 2 percent of the monthly total zooplankton densities collected in Lake Mead in 1984–1985 regardless of location, and littoral zooplankton species diversity was low (Sollberger and Paulson, 1992). Limnetic zooplankton abundance can be controlled by wind mixing, light, pH levels, dissolved oxygen, water temperature, and other environmental factors, but in Lake Mead, zooplankton abundance and species composition appear to be largely controlled by fish abundance and predation (Sollberger and Paulson, 1992). Vertical movement of zooplankton can change over the course of the day, with some species coming up to surface waters at night to feed and moving back down to deeper water during daylight hours.

Overall, a diverse zooplankton community exists in Lake Mead, with 27 limnetic and15 littoral species present in surveys conducted in 1984–1985 (Sollberger and Paulson, 1992). The major types of zooplankton observed in Lake Mead are copepods, cladocerans, ostracods, and rotifers (fig. 5-2). Similar species were found in 1996–1997 collections (Mueller and Horn, 1999). Although species diversity appears to be greater in the later survey, the later study surveyed a greater portion of the lake than did the first survey. In zooplankton surveys made from 2000 to 2004, more than 70 species were identified in Boulder Basin alone (LaBounty and Burns, 2005) indicating that species diversity in Lake Mead is rich. Zooplankton abundance increased from 2000 to 2004 in Boulder Basin, with a large spike in population in 2003. Increases such as these lead to increases in the abundance of sportfish available. However, when populations of zooplankton-eating fish exceed the zooplankton supply, zooplankton abundance can crash. Such a crash, which is part of a natural cycle in Lake Mead, occurred at the end of 2003 (LaBounty and Burns, 2005).

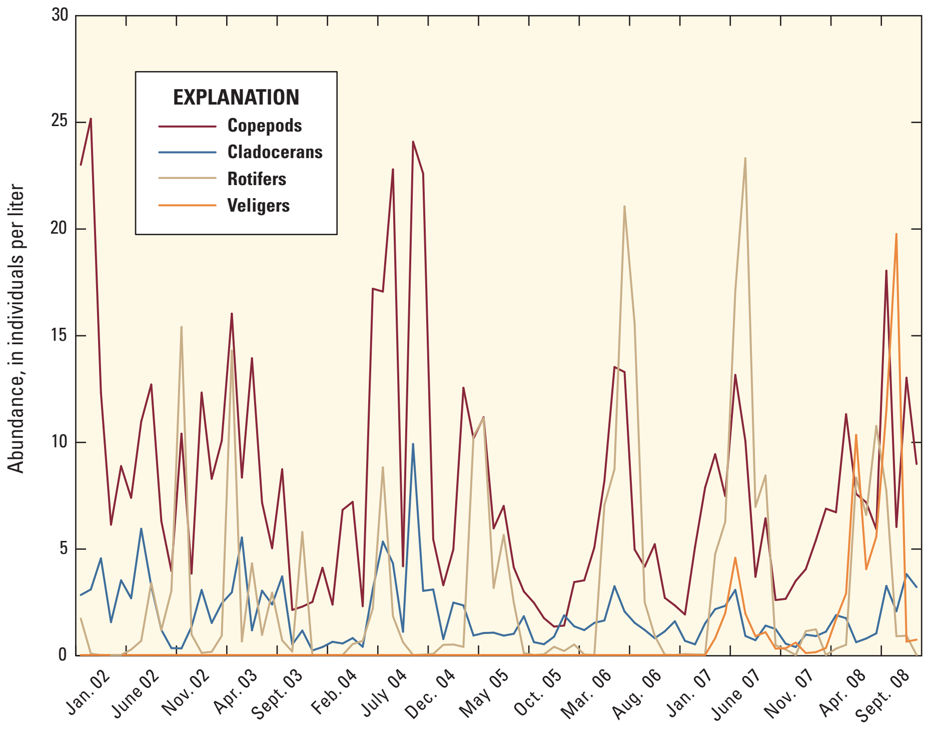



**Figure 5-2.** Abundance of major zooplankton groups in Lake Mead from 2002 to 2009 (modified from Wong and others, 2010). Different groups are important in different years and at different times of the year.

Some organisms have lifecycles that include a temporary **planktonic** phase. Since 2007, free-swimming veligers (larval quagga mussels) have been part of the Lake Mead and Mohave zooplankton community (Beaver and others, 2010; Wong and others, 2010). While studies from other areas infested by quagga mussels have shown that this species, in general, has the potential to substantially alter the zooplankton composition, Lake Mead monitoring to date shows that neither the abundance of different zooplankton taxa nor their seasonal patterns have changed significantly since quagga mussels have been established in the lake (Beaver and others, 2010; Wong and others, 2010).

## Macroinvertebrates

Many different types of invertebrate species live in the benthic (lake bottom) or open water environment of Lake Mead. The benthic invertebrate community of the lake consists of approximately 90 species belonging to 10 phyla: Annelida, Arthropoda, Bryozoa, Cnidaria, Entoprocta, Mollusca, Nemotoda, Nemertea, Platyhelminthes, and Porifera (Melancon, 1977; Peck and others, 1987). The numbers and densities of invertebrates can change with depth, depending on the type of organism (Peck and others, 1987). Generally, invertebrate densities are higher in deltas receiving inflows from the Colorado River, Virgin River, Muddy River, and Las Vegas Wash than they are in downstream locations. The abundance of benthic organisms also changes by season depending on the food supply, temperature, and predation by fishes. For example, the density of the Asian clam (*Corbicula fluminea*) often abruptly declines from April to July (Peck and others, 1987), possibly due to predation of the young-of-the-year, which predominate in Asian clam populations following the summer spawning season.

Photomicrograph of a polychaete, a class of invertebrate worm found in Lake Mead in the phylum Annelida. Approximate length: 15 mm. Photograph by Annie Caires, University of Nevada, Reno.

Photomicrograph of an oligochaete, a class of invertebrate worm found in Lake Mead in the phylum Annelida. Approximate length: 20 mm. Photograph by Luke Tiano, University of Nevada, Reno.

Photomicrograph of an ostracod, a class of invertebrate crustacean found in Lake Mead in the phylum Arthropoda. Approximate length: 1–2 mm. Photograph by Luke Tiano, University of Nevada, Reno.

Many native invertebrate species are **endemic** to the unique tributary streams and spring environments at Lakes Mead and Mohave, and there is concern that non-native species will feed on or compete with these native species. The red swamp crayfish (*Procambarus clarkii*) is of particular concern—a non-native large-bodied invertebrate that now lives in the lakes, principally in the pockets of cattails and emergent vegetation surrounding the edges of the lakes or in Las Vegas Wash and other tributaries that flow into Lake Mead. Red swamp crayfish eat plants, other invertebrates, small fish, and dead fish of any size (Leavitt and others, 1989). While few studies on the ecology of the crayfish have been done in Lake Mead, there is concern about its invasive spread upriver and into neighboring springs where native fishes, amphibians, and benthic invertebrates reside. Although novel trophic interactions can develop in which both black bass and striped bass select crayfish as a food source where they co-exist, fish predation is often unable to eradicate the species.

Although there have been changes in the benthic invertebrate community of Lake Mead over the last 30 years (Wittmann and others, 2010), it is unclear whether these changes are due to declining lake levels, decreases in algal levels, or the introduction of non-native invertebrate species. Since the 1980s, the benthic community has been a mixture of native and non-native species; comparing data from 1986 and 2008, abundances of *Corbicula* and chironomids generally have decreased, Oligochaeta densities have not changed significantly, and other taxa have increased in average density (Umek and others, 2010; Wittmann and others, 2010; fig. 5-3). The most dramatic changes were related to two new non-native species, the quagga mussel (Chapter 6), which were first found in Lake Mead in 2007, and the New Zealand

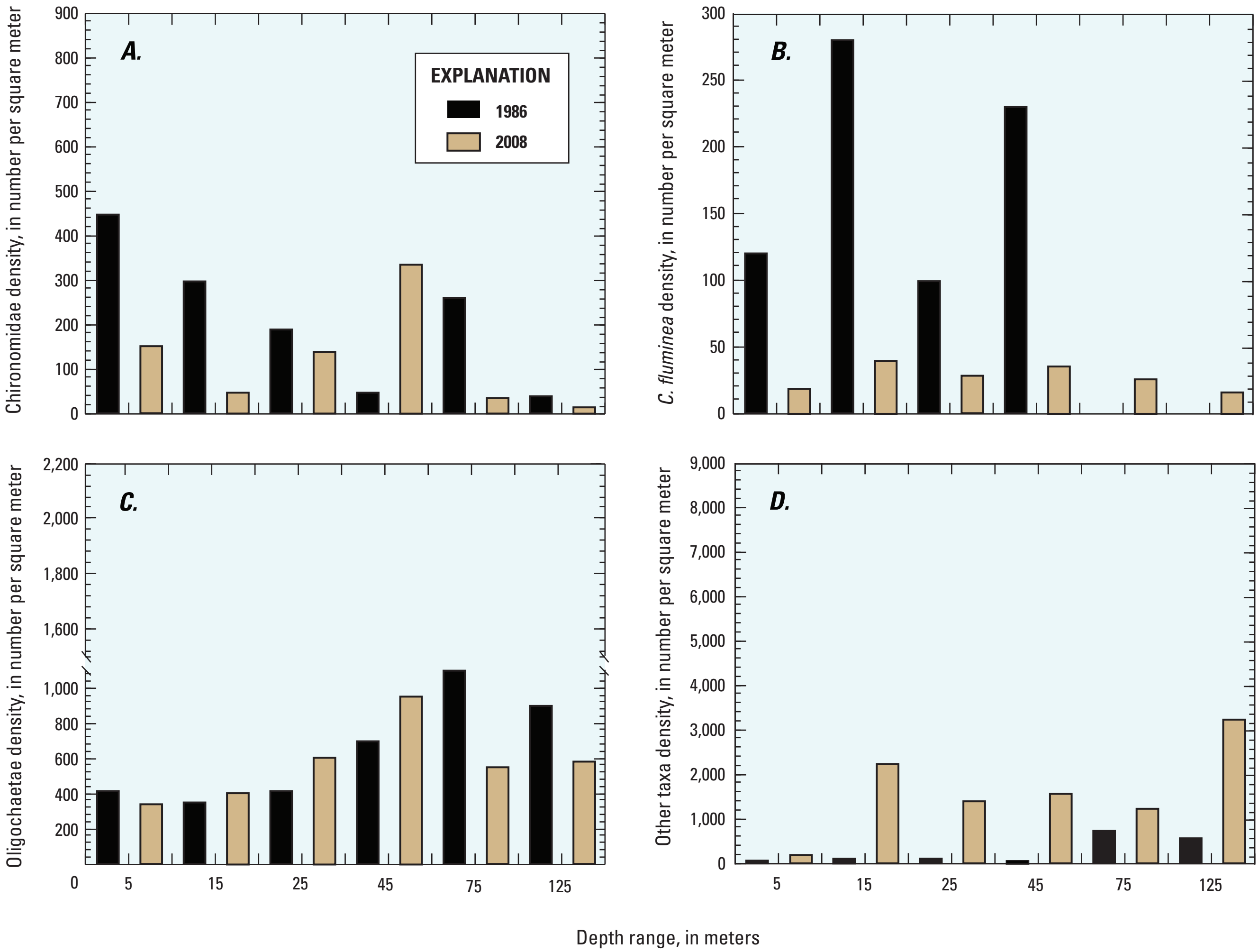



**Figure 5-3.** Changes in overall abundances of Lake Mead macroinvertebrates between 1986 and 2008. Temporal comparison of animal densities by depth distribution on the bottom of the lake for (*A*) Chironomidae, (*B*) Corbicula, (*C*) Oligochaetae, and (*D*) other taxa. (Modified from Wittmann and others, 2010).

mud snail (*Potamopyrgus antipodarum*), which arrived shortly after in 2008 (LaBounty and Roefer, 2007; Davis and Moeltner, 2010; Wong and Gerstenberger, 2011). Two years after quagga mussels were found in Boulder Basin, they had spread throughout the lake (Wittmann and others, 2010; Wong and others, 2011). Currently, this mussel, which has colonized rocks and hard surfaces, dominates the benthic community covering it with their shells and also establishing populations in soft sediments at depths greater than 328 ft (100.0 m; Wittmann and others, 2010; Wong and others, 2011).

### Invertebrates as a Food Source and Invertebrate Feeding Strategies

Whether in benthic or open-water habitat, invertebrates play an important role in the ecosystems of Lakes Mead and Mohave. Both benthic invertebrates and zooplankton are major food sources for fish in these ecosystems. Analyses of fish-stomach contents have shown that largemouth bass, bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), and channel catfish (*Ictalurus punctatus*) rely to some degree on benthic invertebrates either seasonally or year round (Deacon and others, 1972). In contrast, threadfin shad (*Dorosoma petenense*) feed primarily on open-water cladocerans or copepods (Loomis and others, 2011). Moreover, diets of particular fishes also can differ in the various basins around the lake (Umek and others, 2010). In Las Vegas Bay and Overton Arm, 80–92 percent of the diet of fish includes benthic resources. The diet of top predatory fishes, such as striped bass and largemouth bass, includes primarily the intermediate consumers, such as threadfin shad, bluegill, and green sunfish in differing amounts depending on their availability in each basin. For example, predatory fish from Overton Arm likely use primarily threadfin shad for food and energy while those from Las Vegas Bay incorporate greater numbers of available invertebrates and other fishes into their diets, and utilize shad only when available (Umek and others, 2010). Additionally, the diets of benthic invertebrates and zooplankton play an important functional role in the lake ecosystem. Nematodes, a benthic invertebrate that lives in the lake-floor sediment, for example, can be parasitic, feeding on other invertebrates, plants, or fishes depending on the species and life stage. *Daphnia*, a type of cladoceran zooplankton, eats algae by filtering phytoplankton particles into its mouth.

## Fishes

By Sudeep Chandra, Jon Sjöberg, Steven L. Goodbred, and Erik Orsak

Lakes Mead and Mohave are home to at least 15 different fish species (fig. 5-4; table 5-1). In addition to the 15 species, a hybrid between common carp and goldfish (*Carassius auratus*) has been documented in the Overton Arm of Lake Mead (Goodbred and others, 2013). Although many of these fishes were introduced and are not native to the Colorado River drainage, native fishes endemic to this region still persist in small numbers. Introduced sportfish species support an important recreational fishery, and many of these introduced species are important food resources for aquatic birds. The lake's top predators, black bass and striped bass, have received considerable attention because they are an important economic resource for the region (Martin and others, 1982). Some non-native fish species, such as channel catfish and carp, were likely present in the Colorado River prior to the creation of Lake Mead, but largemouth bass were introduced into the reservoir shortly after its completion in 1935, and threadfin shad were introduced 19 years later as a forage species to provide increased food resources for the game fish (Allan and Roden, 1978).

**Figure 5-4.** Selected native and non-native fish species that occur in Lakes Mead and Mohave. See table 5-1 for complete list. Illustrations by Joseph R. Tomelleri.

**Razorback sucker (*Xyrauchen texanus*) (Native)**

Endemic to Colorado River Basin. Federally listed as endangered. Maximum size 36 in. (0.9 m), 13 lbs (5.9 kg), with a hardened cartilaginous dorsal ridge behind head and large fleshy mouth. Historically found in middle and lower elevation rivers, tributaries, and flood-plain habitats. Presently found in small numbers in rivers and reservoirs. Warm water species that reproduces and grows best at 54–64°F (12–18°C). Matures at 1–3 years of age and lives to 44 years. Young feed on zooplankton (cladocerans, copepods, and rotifers), juveniles consume algae and bottom ooze, and adults eat immature mayflies (Baetidae), stoneflies (Plecoptera, Protonemoura), and midges (Chironomidae), and algae and detritus (U.S. Fish and Wildlife Service, 1998). Two separate populations found in Lake Mead National Recreation Area: one in Lake Mohave and one in Lake Mead. Recently found spawning at the Colorado River inflow area to Lake Mead (Albrecht and others, 2010a, 2010b). The Lake Mead population appears to be the only one to reproduce successfully in the lower Colorado River Basin.

**Common carp (*Cyprinus carpio*) (Non-native)**

Introduced into warm rivers, streams, ponds, and reservoirs of the Colorado River Basin. Maximum size 48 in. (1.2 m), 100 lbs (45.4 kg), with large scales, mouth barbells, and serrated dorsal spine. Matures at 2–4 years of age and lives to 20 years. Native to Asia. Imported to United States in mid to late 1800s and stocked into lower Colorado River in the late 19th century (Mueller, 2005). Found throughout Lake Mead National Recreation Area and are especially abundant in marinas. Spawns May to June at 64–86°F (18–30°C) with optimum of 73°F (23°C). Eats variety of foods, including algae, seeds, and other plant matter and invertebrates. Efficient at finding and vacuuming small fish and eggs from substrate. Recently found to hybridize with goldfish in Overton Arm of Lake Mead (Goodbred and others, 2013).

**Flannelmouth sucker (*Catostomus latipinnis*) (Native)**

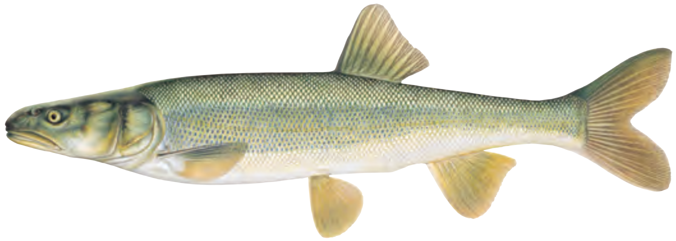
Indigenous to Colorado River Basin. Maximum size 30 in. (0.8 m), 4 lbs (1.8 kg), with prominent fleshy mouth. Occurs in most middle and lower elevation rivers and large tributaries. Warm-water species that reproduces at 48–64°F (9–18°C; Weiss and others, 1998). Matures at 3–4 years of age and lives to 20 years. Eats primarily bottom vegetation, benthic invertebrates, algae, organic detritus, and seeds. Although common in the Grand Canyon upstream, it is found only rarely in Lake Mead and not found in Lake Mohave.

**Bonytail chub (*Gila elegans*) (Native)**

Endemic to Colorado River Basin. Federally listed as endangered. Maximum size 24 in. (0.6 m) with fine scales a streamlined body, and very narrow caudal peduncle. Generally prefer backwaters with rocky or muddy bottoms and flowing pools, although they have been reported in swiftly moving water and feeds on surface. Spawning has been observed during May where eggs are laid randomly over the bottom, and no parental care occurs. Young bonytail chubs typically eat aquatic plants, while adults feed mostly on small fish, algae, plant debris, and terrestrial insects. In Lake Mead National Recreation Area, only a few adult individuals remain in Lake Mohave, although larger numbers of stocked bonytail chub survive in locations downstream (U.S. Fish and Wildlife Service, 2002a).

**Figure 5-4.**—Continued.

**Colorado pikeminnow (*Ptychocheilus lucius*) (Native)**
Endemic to Colorado River Basin. Federally listed as endangered. Maximum size historically up to 6-ft (1.8 m) long and weighing more than 100 lbs (45.4 kg) although fish found now only grow up to 24 in. (0.6 m) and between 4 and 9 lbs (1.8 and 4.1 kg). It has an elongated body, a cone-shaped and somewhat flattened head forming nearly a quarter of the body length. Their usual habitat is the backwaters of the turbulent and turbid streams in the Colorado River system. Young pikeminnows eat cladocerans, copepods, and chironomid larvae, then shift to insects at around 4 in. (10.2 cm), gradually eating more fish as they mature. Once they achieve a length of about 1 ft (30.5 cm), they feed almost entirely upon fish. Natural populations survive only in the Upper Basin and are not currently found in Lake Mead National Recreation Area (U.S. Fish and Wildlife Service, 2002b).

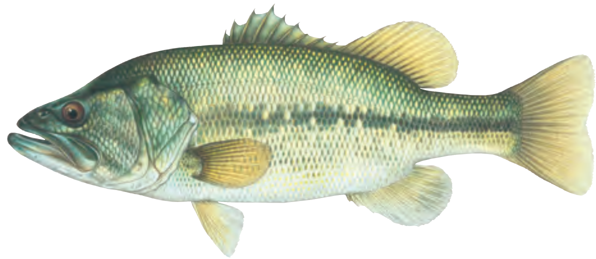


**Bluegill (*Lepomis macrochirus*) (Non-native)**
Originally found only east of the Rocky Mountains but now widely distributed throughout North America from transplanting and stocking as a popular sportfish. Maximum size up to 16 in. (40.6 cm) and rarely weighs more than 4 lbs (1.8 kg). They are characterized by a deep, flattened, laterally compressed body with a terminal mouth, and ctenoid scales. They can be found in shallow waters in lakes and in slow-moving areas of streams; they prefer water with many aquatic plants and debris for protection and feeding. Spawning starts in May when the male builds a nest and peaks at water temperatures of 67–80°F (19–27°C). Young bluegill diet consists of rotifers and water fleas. The adult diet consists of aquatic insect larvae (mayflies, caddisflies, dragonflies), but also can include crayfish, leeches, snails, and other small fish. They are located in shallow bays and coves with aquatic plants and cover throughout Lake Mead National Recreation Area.

**Channel catfish (*Ictalurus punctatus*) (Non-native)**
Native to central drainages in southern Canada, the United States, and northern Mexico. Maximum size up to 50 in. (1.3 m) and weighs more than 50 lbs (22.7 kg). Has long barbels around the mouth used to locate food, a deeply forked tail, spines on dorsal and pectoral fins and unlike most fish has no scales. They inhabit lakes and larger rivers that have clean bottoms of sand and gravel. During spawning, eggs are deposited in a nest below undercut banks or under logs or stones and guarded by the male for some time after eggs hatch. Has a varied diet including fish, insects, and crustaceans. Like most catfish, they chiefly feed at night. Channel catfish were stocked into the Colorado River in the areas of Lakes Mead and Mohave as early as 1895 and were common before establishment of the reservoirs.

**Figure 5-4.**—Continued.

**Largemouth bass (*Micropterus salmoides*) (Non-native)**



Originally distributed from southeastern Canada through the Great Lakes, and south in the Mississippi Valley to Mexico and Florida, and up the Atlantic coast as far north as Maryland. Maximum size to almost 30 in. (0.8 m) and more than 20 lbs (9.1 kg). Lives an average of 16 years. They are a heavy body fish where the lower jaw extends beyond the upper jaw, and have both a spiny and soft ray dorsal fin. Preferred habitat is shallow water less than 20 ft (6.1 m) with aquatic vegetation and other cover. Spawning starts at 62–65°F (17–18°C) after the male makes a nest within 8 ft (2.4 m) of shore in shallow water. Adhesive eggs are attached to the nest after being fertilized by male. The nest is guarded by the male until shortly after the eggs have hatched. Juvenile fish consume mostly small baitfish, amphipods, small shrimp, and insects. Adults consume smaller fish (bluegill), snails, crayfish, frogs, snakes, salamanders, however very large fish will eat bats, small water birds, mammals, and baby alligators. Stocked in Lake Mead in 1935 where a very productive sportfishery has been established. They also are present in Lake Mohave.

**Striped bass (*Morone saxatalis*) (Non-native)**

Native to the Atlantic coast of North America from the St. Lawrence River into the Gulf of Mexico to approximately Louisiana. They are normally anadromous fish that migrate between fresh and salt water although fish are stocked in large lakes that prevent access to the ocean. Maximum size is more than 6 ft (1.8 m) in length and 125 lbs (56.7 kg). Matures at 2–3 years and lives up to 30 years. It is a deep body fish with a long head, pointed snout, projecting lower jaw, and a spiny and soft ray dorsal fin. In large landlocked lakes, they are highly pelagic preferring deeper water in autumn and winter then coming to the surface in spring and summer to find schools of forage fish. They consume fish and a variety of invertebrates. Stocked in Lake Mead in 1969 to establish a sportfishery. As spawning does not occur in all landlocked lakes, fish were stocked to maintain populations. However, in 1973, reproduction was documented in Lake Mead so further stocking was not continued (Wilde and Paulson, 1989) and striped bass are now the most abundant sportfish in both Lake Mead and Lake Mohave.

**Threadfin shad (*Dorosoma petenense*) (Non-native)**

Found along the Gulf Coast from Florida to Texas and northward into the Mississippi valley to Tennessee and southern Arkansas and Oklahoma. Maximum length a little more than 8 in. (20.3 cm) but most are much smaller. Short lived species, normally less than 3 years. They are pelagic in large lakes and reservoirs forming large schools to feed. It has a typical herring body with an elongated dorsal ray, silvery color, large eye, and large deciduous scales. Can mature in less than 1 year. Spawns at water temperatures above 60 F (16 C) over plants and other objects or under logs and brush. The young and adults feed on a variety of planktonic organisms and organic debris. Stocked in Lake Mead and Lake Mohave in 1954 to provide forage for sportfish, threadfin shad have been the primary forage species supporting the striped bass fishery.

**Table 5-1.** List of fishes found in Lakes Mead and Mohave and their scientific and common names.

[Native fishes to the Colorado River Watershed are listed, along with the first establishment date of non-native species, if known]

| Family name, scientific name | Common name | Native? (first establishment date of non-native fish, if known) | Lake Mead | Lake Mohave |
|---|---|---|---|---|
| **Clupeidae** | | | | |
| *Dorosoma petenense* | Threadfin shad | No–1954 | ✓ | |
| *Dorosoma cepedianum* | Gizzard shad | No–2007 | ✓ | |
| **Salmonidae** | | | | |
| *Oncorhynchus mykiss* | Rainbow trout | No–1969 | ✓ | ✓ |
| **Catostomidae** | | | | |
| *Catostomus latipinnis* | Flannelmouth sucker | Yes | ✓ | |
| *Xyrauchen texanus* | Razorback sucker | Yes | ✓ | ✓ |
| **Cyprinidae** | | | | |
| *Cyprinus carpio* | Common carp | No | ✓ | ✓ |
| *Gila elegans* | Bonytail chub | Yes | | ✓ |
| **Ictaluridae** | | | | |
| *Ictalurus punctatus* | Channel catfish | No | ✓ | ✓ |
| **Serranidae** | | | | |
| *Morone saxatilis* | Striped bass | No–1969 | ✓ | ✓ |
| **Centrarchidae** | | | | |
| *Micropterus dolomieu* | Smallmouth bass | No | ✓ | ✓ |
| *Micropterus salmoides* | Largemouth bass | No–1935 | ✓ | ✓ |
| *Lepomis cyanellus* | Green sunfish | No | ✓ | ✓ |
| *Lepomis macrochirus* | Bluegill | No | ✓ | ✓ |
| *Pomoxis nigromaculatus* | Black crappie | No | ✓ | |
| **Cichlidae** | | | | |
| *Oreochromis aureus* | Blue tilapia | No | ✓ | |

Largemouth bass have been a focus of anglers since the inception of the Lake Mead sportfishery. Beginning in the early 1940s, largemouth bass were reported as being thin and in poor condition. This condition continued into the 1950s, when it was determined that a new forage species for largemouth bass was needed, resulting in the introduction of threadfin shad in 1954. Although initial results indicated improved conditions, some largemouth bass populations, particularly those in ***littoral*** zones of lake, did not have access to the large ***pelagic*** schools of threadfin shad. The completion of Glen Canyon Dam in the 1960s and subsequent reduction in sediment and nutrient loads and changes to reservoir storage patterns led to significant decreases in threadfin shad (fig. 5-5) and the largemouth bass fishery. Post-dam phosphorus loads—a key **limiting nutrient** needed for algal growth and food-web production—were reduced by more than 90 percent in the upper basins of Lake Mead (Morgensen and Padilla, 1982; Evans and Paulson, 1983). Reduced upper basin sediment and nutrient loads, along with improved wastewater-treatment methodologies to remove nutrients from water discharge into Las Vegas Wash, caused a reoligotrophication of the lake, a condition of reduced productivity and increased clarity (Peck and others, 1987; Ney, 1996). Moreover, a change in reservoir storage patterns at this time appears to have enabled successful largemouth bass spawning in the spring and early summer months.

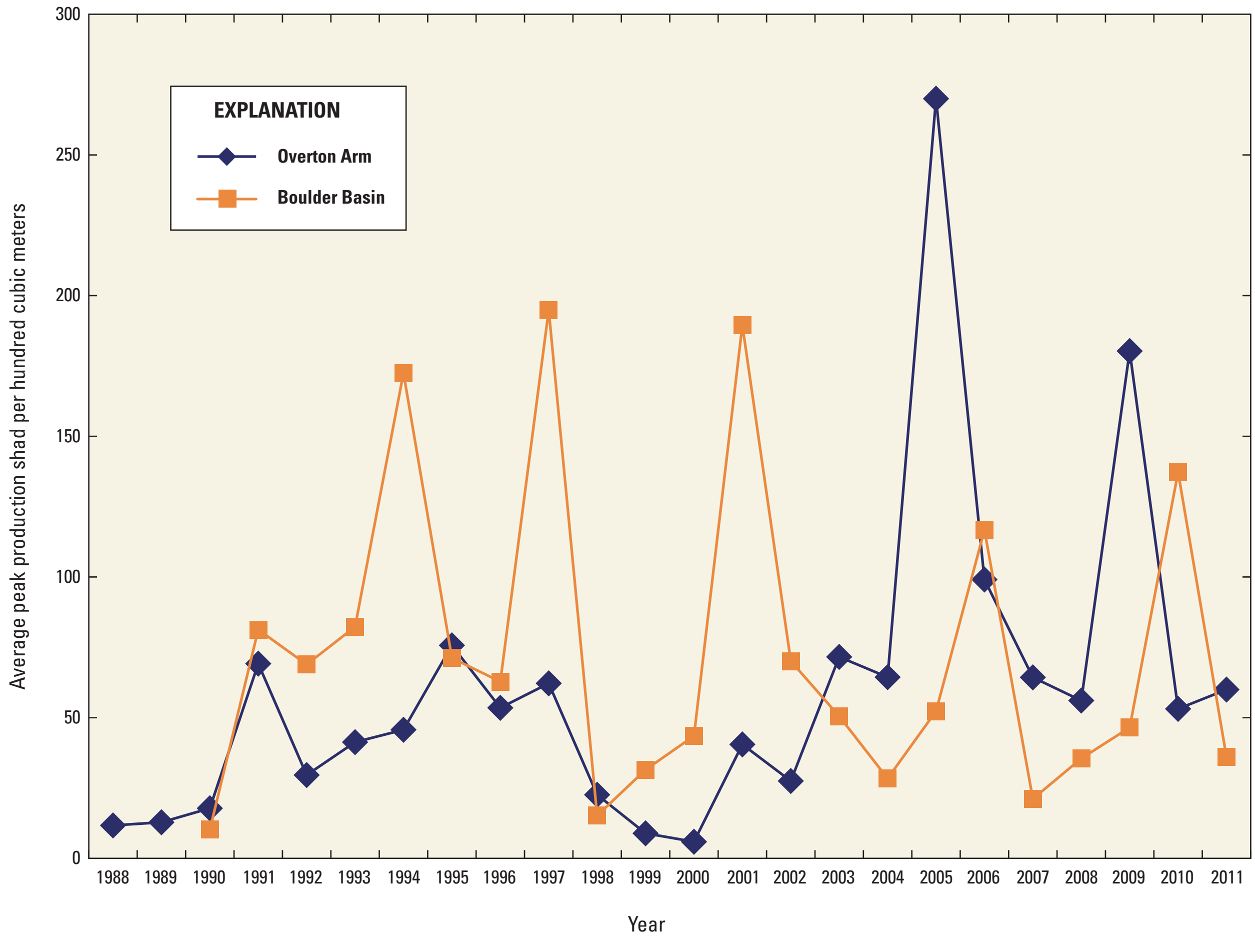



**Figure 5-5.** Lake Mead shad peak production densities (Nevada Department of Wildlife, 2011a, 2011b).

In an attempt to create a more sustainable sport fishery at Lake Mead, a cool-water sportfish, striped bass, and several cold-water salmonid species, such as rainbow trout (*Onchorhynchus mykiss*) and brown trout (*Salmo trutta*), and silver salmon (*Oncorhynchus kisutch*), were introduced in 1969. Although it was initially presumed that striped bass would not be able to reproduce in Lake Mead, within 10 years, striped bass dominated the fishery and had significantly reduced the pelagic biomass of threadfin shad. Due to decreased availability of threadfin shad, fish condition was reduced in some largemouth bass and striped bass populations (figs. 5-6 and 5-7). Moreover, evidence indicated that striped bass were negatively affecting the recently introduced salmonid fishery and contributing to the severe decline of the long established black crappie (*Pomoxis nigromaculatus*) fishery. By 1983, trout stocking was discontinued due to poor long-term returns and other demands on production capability in fish hatcheries. Although rainbow trout stocking was begun again in the 1990s, the dominance of the fishery by abundant striped bass has limited the survival and persistence of stocked trout. As a result, the trout fishery at Lake Mead has been managed more recently as a winter-period fishery for shore anglers, with no survival of trout to larger sizes documented in recent years.

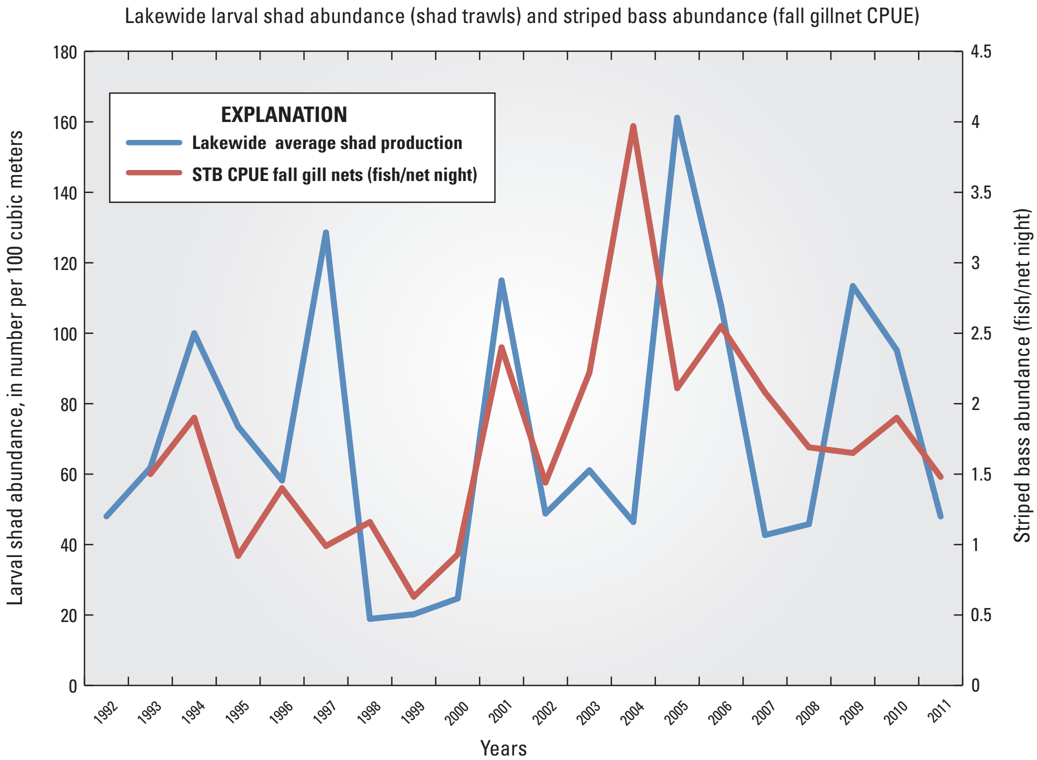



**Figure 5-6.** Comparison of larval threadfin shad density (peak spawning period, lakewide average) and striped bass (STB) abundance (autumn CPUE), Lake Mead 1992–2011 (NDOW data). CPUE=catch per unit effort.


**Figure 5-7.** Fish condition. (*A*) striped bass in poor condition; (*B*) striped bass (*Morone saxatilis*) in good condition. Photograph by Nevada Department of Wildlife.

During the 2000s, a more stable and predictable balance developed between striped bass and threadfin shad populations, possibly due to more constant nutrient loads from the Virgin and Muddy Rivers and Las Vegas Wash. There appears to be a typical cycle of 3–4 years duration within which striped bass numbers and, to a lesser extent, condition factors, decline rapidly following large-scale depletion of the threadfin shad forage base, followed by a rapid rebuilding of striped bass numbers after the quick recovery of the prey (Nevada Department of Wildlife, 2011a). Additionally, there is an annual cycle of condition factors in striped bass related to seasonal thermal separation from the prey base; large striped bass are unable to enter warmer surface waters where shad are abundant. The current management strategy for striped bass is an attempt to manipulate the structure of the lake-wide population by encouraging anglers to harvest the large number of available fish in the smaller size ranges through increased possession limits. Increased harvest of 12–15 in. (30–38 mm), primarily 1- and 2-year-old fish, would decrease the impact on young-of-the-year shad, thus making more of the current shad production available to larger striped bass when they can feed upon them in late summer and early autumn. Ideally, this should result in improved condition factors in larger fish. Currently, abundant, young cohorts of striped bass in Lake Mead are under-utilized because of many years of declining angler use, but allowing increased take of small striped bass should increase total harvest, and increase the interest in fishing and angler use on the lake.

In contrast to striped bass, reduced numbers of largemouth bass in Lake Mead that were reported during the 2000s are likely due to changes in habitat from lower reservoir water levels. Lower water levels reduce the number of shallow coves, which have aquatic vegetation and cover that are preferred spawning habitat for largemouth bass. Smallmouth bass (*Micropterus dolomieu*), introduced from an unknown source and first observed in Lake Mead in 1999, have expanded bass fishing opportunities considerably in Lake Mead and now make up more than 40 percent of the annual black bass (largemouth and smallmouth) catch. Smallmouth bass have somewhat different habitat preferences for spawning than do largemouth bass, and their success and available habitat also might be related to lower reservoir elevations during this period, which provided more rocky, well washed shorelines.

Young threadfin shad abundance can vary considerably over a 2–3-year cycle, because of changes in predation as sportfish abundance varies (Nevada Department of Wildlife, 2011a, 2011b), and because of differences in nutrient inputs to the lake. Although Las Vegas Bay in the Boulder Basin typically is the most productive area of the reservoir for shad production because of constant and abundant nutrient inputs from Las Vegas Wash, changes in lake inputs, such as flood flows from the Virgin and Muddy Rivers, can increase shad abundance in Overton Arm to equal or exceed that of Boulder Basin in some years. In 1987, a 4-year program was conducted to evaluate large-scale fertilization as a potential management tool for enhancing forage and game fish populations (Vaux and others, 1995). From 1987 to 1989, six treatments of liquid ammonium polyphosphate between 5,000 and 20,000 gal were applied to a 10,000-ha area in northern Overton Arm. Monitoring suggested both **forage fish** and zooplankton were positively correlated with increases in chlorophyll but no significant improvements were demonstrated in the fisheries.

Gizzard shad (*Dorosoma cepedianum*), a species native to the Mississippi River system that were first observed in Lake Mead in 2007, further complicates the dynamics of the Lake Mead fishery. Gizzard shad, thought to have come from an illegal introduction in the upper Colorado River watershed, rapidly dominated the pelagic forage base for sportfish, and by 2010 comprised more than 40 percent of the catch in lakewide sportfish surveys (Nevada Department of Wildlife, 2011a). Although abundant young gizzard shad have so far been a benefit to sportfish species through increased forage availability, particularly for striped bass, gizzard shad grow to a much larger adult size than threadfin shad and can become too large for most striped bass to consume. For this reason, the long-term effect of the gizzard shad introduction on the sport fishery is still unknown (Nevada Department of Wildlife, 2011a).

Although similar in many respects to Lake Mead, the Lake Mohave sport fishery does exhibit some distinct differences. Because Lake Mohave is operated primarily to regulate water released from Hoover Dam for downstream water users, rather than for flood control and long-term water storage, it is much more stable and typically fluctuates only several meters in elevation during the year and from year to year. Because of this, the reservoir does not have the ability to develop shoreline vegetation during low storage conditions that would then be flooded by high water, limiting the availability of cover for some fish species. Unlike Lake Mead, Lake Mohave lacks an abundant prey species, such as threadfin shad. The reservoir is relatively shallow and narrow, lacking the extensive protected coves typical of Lake Mead, and its upper 32 mi (51.5 km) are within the river-like Black Canyon reach influenced at its upper end by cooler water discharge from Hoover Dam.

Although some sportfish including channel catfish and smallmouth bass likely inhabited this reach of the Colorado River before the closure of Davis Dam in 1950, Lake Mohave was primarily managed as a fishery for rainbow trout for many years with the introduction of both trout and threadfin shad after the reservoir's creation. Influenced by cool-water inflows from Lake Mead, the Black Canyon area in particular was renowned as a trophy-quality trout fishery, with largemouth bass contributing a major component of the fishery in warmer, downstream reaches (Allan and Roden, 1978). This situation all changed in 1983, when surface-water discharge from Lake Mead through the Hoover Dam spillways was thought to have introduced striped bass eggs and young fish into the reservoir. Striped bass rapidly became the dominant sportfish in the reservoir, and although rainbow trout remain a majority of the angler catch in upper Black Canyon, the trout fishery now consists almost entirely of small, recently stocked fish (Nevada Department of Wildlife, 2011b). Most of the striped bass harvest is smaller 1–2 lb fish, but the reservoir also is known for its trophy striper fishing, producing the State record striped bass at 63 lbs (28.6 kg) in 2001, although large striped bass more than 20 lbs (9.1 kg) are increasingly rare. One additional effect of the striped bass introduction has been the virtual elimination of threadfin shad as a food resource, with records of that species in Lake Mohave virtually absent since the late 1980s. Largemouth bass remain an important component of the fishery, primarily in downstream reaches below Black Canyon.

## Species of Special Concern

By Erik Orsak

With the completion of Hoover Dam in 1932 and Davis Dam in 1950, and the subsequent formation of Lakes Mead and Mohave, the Colorado River was forever altered from a free-flowing, seasonally warm, and connected river into two large reservoirs containing relatively still, cold, and isolated aquatic systems. Although these reservoirs provide riparian and aquatic habitats that are now home to a diverse community of wildlife (including migratory birds, introduced sportfish, and reptiles), native fishes of the Colorado River have been negatively affected by this change. Native species are now found in low numbers warranting special protective status, and in some cases are listed as endangered under the Federal Endangered Species Act of 1973.

Of the four large-bodied endemic fish that were once common in the lower Colorado River, Lakes Mead and Mohave are home to small populations of just two native fish belonging to the sucker family, the federally endangered razorback sucker and the flannelmouth sucker (*Catostomus latipinnis*; Mueller and Marsh, 2002). Two other native fish from the minnow family were once common in the Colorado River system: the Colorado pikeminnow (*Ptychocheilus lucius*), which is believed extirpated from the river's lower basin, and the bonytail chub (*Gila elegans*) remains only as a few adult individuals in Lake Mohave, although larger numbers of stocked bonytail chub survive in locations downstream (U.S. Fish and Wildlife Service, 2002a, 2002b). These native fishes once numbered in the tens of thousands and evolved in a very large range of flows that were characteristic of the free-flowing Colorado River before the dams were built and the reservoirs formed. The pre-dam Colorado River discharged large volumes of water from spring snowmelt and runoff or from summer monsoon thunderstorms. At other times of the year, the river's discharge could be greatly reduced by lack of precipitation, especially during prolonged drought periods. In particular, the razorback sucker has life history characteristics well adapted to the ever-changing hydrologic conditions of the historical river, including a life span believed to exceed 50 years, and the capability to produce tens of thousands of eggs annually (Hamman, 1985; McCarthy and Minckley, 1987; Minckley and Marsh, 2009). However, the populations of all these native fishes have steadily declined over the last one-half of the 20th century despite conservation efforts. Predation by non-native fish and loss of suitable habitats are believed to be the primary causes for the population declines in the lower Colorado River Basin (Minckley, 1983; Minckley and others, 1991).

Lake Mead contains one of the few populations of the razorback sucker in the Colorado River Basin, where consistent natural **recruitment** from larval fish to adulthood has been documented. Adults of this fish are known to spawn in at least four locations within present-day Lake Mead: the inner Las Vegas Bay on the western end of Boulder Basin, two areas of Overton Arm, and the inflow area of Gregg Basin where the Colorado River enters Lake Mead from the Grand Canyon. The reasons why razorback suckers can successfully survive to adulthood in Lake Mead, unlike other Colorado River reservoirs, is still unclear and the subject of ongoing research. The adult population in Lake Mead remains small, however, likely consisting of fewer than 800 fish (Kegerries and others, 2009a; Albrecht and others, 2010c).

Adult razorback suckers also are present throughout much of Lake Mohave, where they use shallow gravel benches along coves in the middle and upper parts of the reservoir for spawning in February through April each year, as evidenced by the presence of thousands of young larval fish. Unlike in Lake Mead, successful spawning in Lake Mohave has not resulted in natural recruitment, and survival of wild fish to adulthood has not been documented in this lake for many years. As recently as the 1980s, Lake Mohave was thought to have a population of 50,000 or more adult razorback suckers, but those fish have been lost to old age. Despite an aggressive campaign by State and Federal biologists to capture larval razorback suckers in Lake Mohave and grow them in rearing ponds to sizes sufficient to avoid non-native predators, such as bass, the population has declined to less than 2,500 adults (Schooley and Marsh, 2007; Kesner and others, 2008).

The flannelmouth sucker primarily is a fish that exists in flowing waters, and although common in the Grand Canyon upstream, it is found only rarely in most of Lake Mead. Recent monitoring in 2009–2010, however, resulted in the capture of 52 flannelmouth in the Colorado River inflow area, and 5 flannelmouth were captured in the vicinity of the Virgin and Muddy River inflow areas (Albrecht and others, 2010a, 2010b, 2010c). Historically, flannelmouth suckers were uncommon in the area of Lake Mohave and downstream reaches of the lower Colorado River (Minckley, 1973), although a population does persist in the river below Lake Mohave (Best and Lantow, 2010).

In both Lakes Mead and Mohave, natural reproduction rates are not sufficient to meet goals established by the U.S. Fish and Wildlife Service for recovery of the native species without continued active management by conservation agencies. For many years, the Bureau of Reclamation has coordinated interagency monitoring, research, and conservation programs for the razorback sucker on Lakes Mead and Mohave, following guidelines outlined in the Lower Colorado River Multi-Species Conservation Program (Bureau of Reclamation, 2011). These programs are implemented primarily through two interagency groups: the Native Fish Work Group for Lake Mohave and the Interagency Lake Mead Work Group. Within these groups, the Federal Government leads efforts on developing recovery plans that provide a road map with detailed, site-specific, management actions for private, Federal, and State cooperation in conserving listed species and their ecosystems. Specific areas of focus include recovery and conservation activities for the razorback sucker in both reservoirs including research, monitoring to track the status of populations, and the stocking of large fish grown from wild-caught larvae to maintain adult populations and preserve the genetic integrity of the remaining small wild populations. However, State agencies actively manage endangered species in the lakes. In addition, State agencies manage both native and non-native game species, including popular recreational fish like striped bass, which are top predators in the reservoir's food web and are known to consume razorback suckers. In fact, razorback suckers in Lakes Mead and Mohave are prone to predation by non-native species due to increases in the number of predator species and clarity of water since their original evolution in the turbid waters of the Colorado River that provided some cover and protection from predation (Mueller and Marsh, 2002). For these reasons, managing the reservoirs and fisheries for both non-native sportfish and native fish is one of many challenges facing natural resource agencies responsible for managing and mitigating competing interests for aquatic resources.

## Understanding the Ecology of Rare and Sensitive Native Fishes

By Paul B. Holden, Brandon A. Albrecht, Ron B. Kegerries, and Erik Orsak

To better understand the ecology of endangered razorback suckers in Lake Mead, scientists have deployed sonic transmitters in fish to study their movement (fig. 5-8). Data from the transmitters indicate that razorback suckers occur in the areas of Las Vegas Bay, Echo Bay, and the inflows of the Muddy, Virgin, and Colorado Rivers, locations that have relatively high turbidity and vegetation that are essential to survival of young fish. Population estimates indicate that a total of 700–1,000 wild razorback suckers live in Lake Mead based on the 60–80 fish caught among all Lake Mead locations sampled each year (Shattuck and others, 2011). However, growth rates for razorback suckers in these areas of Lake Mead are substantially higher than other populations of razorback sucker in the Colorado River Basin, indicating that Lake Mead has a younger

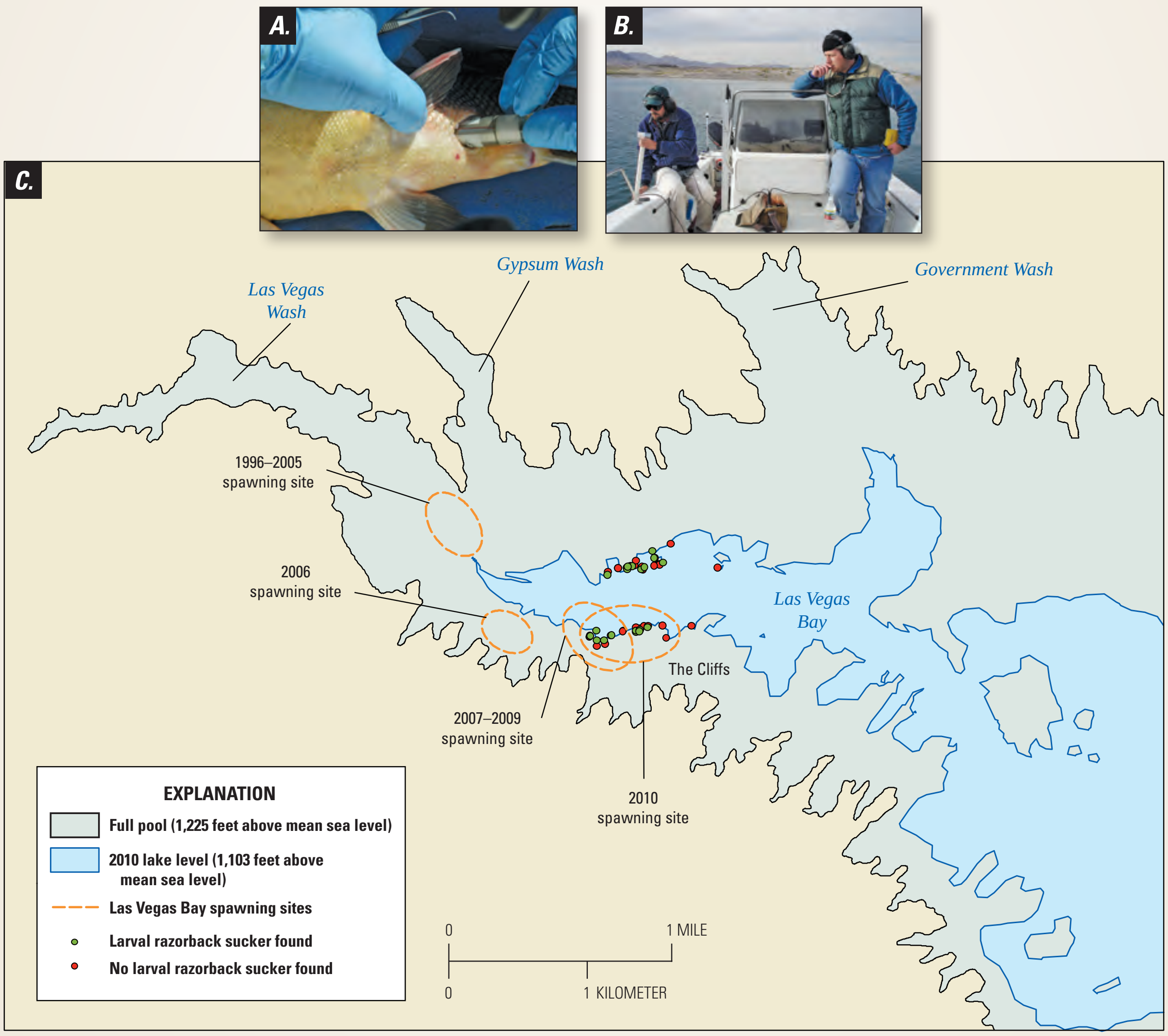



**Figure 5-8.** How native fish are studied at Lake Mead National Recreation Area. (*A*) First, a razorback sucker is implanted with a sonic transmitter. (*B*) Scientists then listen for the signal from the transmitter with a hydrophone to help locate spawning areas (*C*) that might change from year to year. Images courtesy of BIO-WEST, Inc., used with permission.

population, because growth rates slow substantially in older fish (Kegerries and others, 2009b). In fact, Lake Mead is the only large reservoir in which recruitment of naturally spawned fish into breeding adults has been documented in recent years. To learn about recruitment of razorback suckers, it was necessary for scientists to determine the age of a fish at the time of capture. However, the most common technique for determining the age of fish could not be used in this study. In the common technique, the fish is killed and a bone, called an otolith, is removed from the inner ear. The otolith is then sliced and examined microscopically to count growth rings similarly to the way trees are aged. To avoid harming endangered fish, scientists developed the technique of removing a portion of a fin and counting the rings on the fin spine to determine the fish's age. Using this method, recruitment data can be compared to a number of different environmental conditions that could affect fish populations. For example, recruitment at Lake Mead appears to be influenced by changing lake levels, with pulses of young fish occurring at both high, and more recently, at low water levels (Shattuck and others, 2011). Because Lake Mead has the highest known recruitment levels of wild razorback suckers, it also may have the largest populations in existence today; however, present day populations represent only a small fraction of historical numbers, estimated to have once been in the millions throughout the Colorado River before Hoover Dam was constructed. Although these native fish appear to be reproducing in Lake Mead, a number of environmental conditions should be monitored that have the potential to adversely affect fish health and survival, including habitat loss from lake level changes, alterations to food resources from invasive species such as quagga mussels, and contaminant loading to the lake from Las Vegas Wash and other tributaries influenced by human activities.

## Amphibians

By Jef R. Jaeger and Jon Sjöberg

In general, the fluctuating shorelines of Lakes Mead and Mohave are not ideal habitats for most amphibians, but frogs and toads do occur along the lakes and in tributary springs and streams. Along the lake shorelines, the Woodhouse's toad (*Bufo* [*Anazyrus*] *woodhousii*) can often be observed, particularly in wetlands and wet sandy areas near major inflows. This common toad is widespread across the Southwest and can grow to be rather large and plump, with the main body (snout to vent) reaching lengths of 4.5 in. (114 mm). In the region of Lake Mead, Woodhouse's toad appears to have hybridized with and displaced a similar species, the Arizona toad (*B.* [*A.*] *microscaphus*; Bradford and others, 2005). Another toad, the Great Plains toad (*B.* [*A.*] *cognatus*) no longer occurs in the region following the loss of its historical habitats along the river due to the formations of Lakes Mead and Mohave (Bradford and others, 2005).

Tributary inflow areas along the lakes also are occupied by a non-native species, the American bullfrog (*Rana* [*Lithobates*] *catesbeiana*). This frog is predominantly aquatic and prefers more **lentic** (slack water) habitats. Adults are easily recognized by their very large sizes, with body lengths commonly greater than 6 in. (152 mm), and their distinctive, low pitched, rumbling drone or bellow. Bullfrogs are known predators of native frogs and toads, and are considered a threat to the conservation of some species.

Woodhouse's toad (*Bufo* [*Anazyrus*] *woodhousii*). Photograph by National Park Service.

The red-spotted toad (*B.* [*A.*] *punctatus*) is a small native species broadly distributed throughout the region, where it generally occurs in springs and streams within rocky canyons (Bradford and others, 2003). During the spring, the often *very* red-spotted males fill the night air with their trilling calls, and are quite common along the warm springs within Black Canyon along Lake Mohave.

Although not found on the shorelines of Lakes Mead and Mohave, a Pacific treefrog or chorus frog (in the genus *Pseudacris*) occurs in tributary areas. The treefrog found in LMNRA appears to be a variant of a more southern species, the Baja California treefrog (*Pseudacris hypochondriaca*; Recuero and others, 2006). This small, variable colored frog once occurred locally along the historical Colorado River prior to the formation of the reservoirs (Banta, 1961), and it is still common along the floodplain of the Muddy (Bradford and others, 2005) and Virgin Rivers. The canyon treefrog (*Hyla arenicolor*) also has a wide distribution, with its northwestern limit on the eastern edge of the Lake Mead area. This mainly gray-colored treefrog is abundant within the western Grand Canyon, where it can often be found around pools in rocky springs and streams.

Red-spotted toad (*Bufo* [*A.*] *punctatus*). Photograph by Gary Nafis, used with permission.

LMNRA also is home to a regional endemic species, the relict leopard frog (*R.* [*L.*] *onca*). Once occurring along the historical Colorado River in the areas now covered by Lakes Mead and Mohave, and in the basins of the Virgin and Muddy Rivers as far as southern Utah, natural populations of this frog are now limited to a few spring and stream habitats in Black Canyon and in the region of Overton Arm of Lake Mead (Jaeger and others, 2001; Bradford and others, 2004). Although the relict leopard frog was once thought to be extinct, it has persisted despite losses of suitable habitat and isolation of populations. As a result, the relict leopard frog is the subject of a multi-agency conservation effort (Relict Leopard Frog Conservation Team, 2005), which, so far, has been successful at establishing additional populations within the region and maintaining a few remaining wild populations.

A small adult relict leopard frog (*Rana* [*L.*] *onca*). Photograph by Jef R. Jaeger, University of Nevada, Las Vegas.

## Riparian Vegetation

By Scott R. Abella and E. Cayenne Engel

Studies of historical photographs and non-impounded portions of the contemporary Colorado River and its tributaries indicate that pre-Hoover Dam vegetation along the Colorado River varied spatially according to factors such as geomorphology and temporally owing to flooding regimes (Webb, 1996). The geomorphic setting of the river—such as whether the river was passing through a steep canyon, intersected tributaries or alluvial fans, or contained flatter areas along the river bed—influenced the growing environment for plants and seed deposition (Bowers and others, 1997). Floods periodically scoured soil and vegetation from some locations and deposited sediment and seed in others. Historical photographs suggest that not all, or even most, of the river corridor was heavily vegetated with riparian vegetation because of the scouring action of the water and the desert climate (fig. 5-9). Historical riparian vegetation is not as well documented along the present-day Lake Mead corridor as it was farther northeast along the Grand Canyon (Webb, 1996), but is believed to have included:

- riparian forests containing species such as honey mesquite (*Prosopis glandulosa*), screwbean mesquite (*Prosopis pubescens*), and Goodding's willow (*Salix gooddingii*) in protected canyon areas, flatter bottomlands, and tributaries including the Las Vegas Wash;
- moist and drier marshes with shrubby or herbaceous wetland species such as rushes (*Juncus* species);
- various transitional communities to the uplands; and
- vegetation such as creosote bush (*Larrea tridentata*) typifying upland communities growing to the river.

**Figure 5-9.** A view of Black Canyon looking downstream in 1871 (left) and 2009 (right), illustrating changes to riparian habitat that occurred along the river after the completion of Hoover Dam and subsequent changes to natural surface-water discharge. The summer water discharge from Hoover Dam submerges the sandy and rocky bar visible at a lower river stage in the foreground of the 1871 photograph. The rock to which the boat is tied in 1871 can be seen in both photographs. Left photograph by Timothy O'Sullivan/Library of Congress (September 23, 1871). Right photograph by Gary A. Reese, Logan Simpson Design (August 17, 2009).

Current vegetation along Lake Mead also is a function of factors like geomorphology and the coarseness of the soil along the shoreline, and declining lake levels (fig. 5-10). A variety of plant communities occupy the shoreline, with references such as the U.S. Natural Resources Conservation Service PLANTS Database (*http://plants.usda.gov*) providing photographs and general information on the species mentioned here. Riparian forest communities typified by Goodding's willow occur in locales like the confluence of the Muddy River with Lake Mead, southeast of Overton (Busch and Smith, 1995); mesquite and catclaw acacia (*Acacia greggii*) in steep shoreline areas and flatter areas like washes entering the lake; Fremont cottonwood (*Populus fremontii*) along Las Vegas Wash entering Lake Mead (Stave, 2001); marshy areas with species including common reed (*Phragmites australis*) or rushes (Patten and others, 2008); arrowweed (*Pluchea sericea*), big saltbush (*Atriplex lentiformis*), or other species comprising moist shrubby communities (Busch and Smith, 1995); upland vegetation like creosote bush (Larrea tridentata) present down to near-shoreline areas; and monocultures of the exotic tree saltcedar (*Tamarix ramosissima*) and related species (Walker and others, 2006).

The riparian communities that currently exist around Lake Mead are young; their development coincides with the completion of the Hoover Dam in 1935 and the subsequent flooding of the river corridor to full capacity within 5 years. Therefore, the existing Colorado River vegetation was submerged without time to adapt or "move up" the hillsides with the rapidly increasing water depth as the lake filled. While existing riparian vegetation was quickly submerged, there were seed sources for riparian vegetation in the extensive network of springs along the river


**Figure 5-10.** Examples of riparian vegetation around Lake Mead: (*A*) native vegetation along a shoreline near Grand Wash, Lake Mead, consisting primarily of sedges, cattails, and willows; (*B*), a rocky shoreline along Stewarts Point, Lake Mead, where rough terrain in part hinders plant establishment aside from patchy individuals of the exotic species saltcedar; (*C*) saltcedar forms dense thickets at the confluence of the Virgin River with Lake Mead; and (*D*) Boulder Beach, containing primarily bare soil and monocultures of saltcedar. Photographs (*C*) and (*D*) both represent locations where native riparian vegetation could be established through management activities. Photographs by: (*A*) Carrie Norman, LMNRA, 2008; (*B*) E. Cayenne Engel, University of Nevada, Las Vegas, 2010; (*C*) and (*D*) Joseph G. Barnes, University of Nevada, Las Vegas, 2009 and 2010, respectively.

corridor. These springs harbored the cattails, rushes, sedges, arrowweeds, willows, and mesquites (among other species) that provided seed sources to the newly established shoreline. However, like most plant successions (progressions of plant communities through time) in the stressful environment of the Mojave Desert (Abella, 2010), plant colonization along the shoreline is relatively slow and dependent on seed availability and suitable habitat. Riparian vegetation becomes established most prolifically along gentle slopes leading to the shoreline, and most of the shoreline along the former river corridor is steep and unsuitable for riparian plant establishment. Additionally, it takes time for the viable seeds to travel down the washes from their host sites at the larger springs and for suitable germination conditions to coincide with seed availability. While some riparian communities have developed and prosper around the shoreline, most of the vegetation along the water's edge consists of species characteristic of dry uplands.

Change continues to be the rule rather than the exception in current Lake Mead shoreline vegetation. As reported for areas in the Grand Canyon where marshes have increased in number and extent along the regulated river reach that is less subject to scouring floods (Stevens and others, 1995), riparian vegetation could have increased along Lake Mead above historical amounts in some areas, while decreasing in others. The current extended period of decreased lake levels and corresponding increase in land area along Lake Mead's shoreline is alarming from a reservoir-water-storage perspective, but enlarges the area available for plant colonization. From 1998 to 2010, the elevation of the lake declined from near its full-pool elevation of 1,220 ft (371.9 m) to a low of 1,083 ft (330.1 m) in 2010 (Holdren and Turner, 2010). This drawdown exposed more than 25,000 ha of formerly submerged land. While this new land is available for plant colonization, plant establishment is complicated by increasing distance to water and by fluctuating water levels that can inundate establishing plants.

A great deal of uncertainty surrounds plant colonization and succession along the newly exposed shoreline. Succession generally is slower in deserts compared to that in moister regions, with newly exposed surfaces (such as the shoreline) sometimes requiring centuries to millennia to resemble old desert communities (Abella, 2010). Additionally, soil properties such as pH can be altered from those of typical desert soils through invasion of the non-native tree saltcedar (Walker and others, 2006). It seems likely that dynamic zones of vegetation will form based on distance from the fluctuating shoreline.

Invasion by non-native species is changing the look and function of landscapes across the world, including along the Lake Mead shoreline. For example, saltcedar has invaded riparian areas throughout Western North America (Busch and Smith, 1995). The species establishes prolifically and forms dense thickets that alter the landscape around it and may prevent establishment of native species within areas that could be suitable native species habitat. While saltcedar is the most prolific invasive species around the Lake Mead shoreline, several other problematic species include (but are not limited to) crimson fountaingrass (*Pennisetum setaceum*) and Sahara mustard (*Brassica tourneforti*). Left unmanaged, these species also may limit establishment of native riparian species that could function as productive wildlife habitat and provide other ecosystem services such as stabilizing soils and providing shade for recreation along the lake.

Vegetation management along the Lake Mead shoreline by the National Park Service has been ongoing and is planned for the future. Since the early 2000s, surveys for non-native plants have been made along the shoreline, commonly by boat, to detect infestations early enough to forestall invasions both along the shoreline and in surrounding drainages and uplands (Abella and others, 2009). While the scale of invasion by saltcedar is daunting, the National Park Service has effectively treated some saltcedar monocultures by cutting (burning also can be effective) followed by immediate herbicide application to the stump. Removing saltcedar has increased native plant cover in the Mojave Desert, although colonization by native plants often is slow (Harms and Hiebert, 2006). A saltcedar biological control agent, the tamarisk leaf beetle (*Diorhabda carinulata*), was approved for release in 2001 and has been moving south along the Colorado River. As of 2010, the beetle had reached the lower Virgin River north of Lake Mead, defoliating saltcedar (Tamarisk Coalition, Grand Junction, Colo., http://www.tamariskcoalition.org). On shoreline areas where little vegetation has colonized or where saltcedar is dying, techniques such as planting native riparian vegetation or treating soils to facilitate plant colonization could be attempted to hasten plant succession (Harms and Hiebert, 2006). From a vegetation standpoint, the newly exposed shoreline affords opportunities for increasing the extent of both riparian and upland vegetation.

## Riparian Vegetation Management

Many challenges exist to maintaining habitat quality along the Lake Mead shoreline, but several measures and management actions can limit degradation and improve habitat.

### Invasion and Persistence of Non-Native Species

Non-native plant species can out-compete native species and alter soil properties. These plants can be managed by surveying for new infestations and treating invaders (for example, through hand pulling or herbicide) and establishing native vegetation to occupy sites (Abella and others, 2009).

### Unvegetated Shoreline Soils

Unvegetated soils are subject to erosion and provide minimal habitat value. Revegetation by planting greenhouse-grown seedlings or seeding native species can provide plant cover on exposed soil (Abella and Newton, 2009).

### Lack of Propagules for Native Plants

A lack of seeds in the seed bank or absence of dispersal from nearby sites can slow plant colonization of the shoreline (Abella, 2010). Seeding, planting greenhouse-grown seedlings, or transplanting individual plants can help hasten plant establishment (fig. 5-11).

### Other Issues

Many other issues affect management of the shoreline. For example, an important objective of the National Park Service is to protect existing stands of riparian vegetation, such as mesquite woodlands from unauthorized cutting and unnatural fire through law enforcement, education, and other measures.

**Figure 5-11.** Students and staff with the Environmental Science Program (University of Nevada, Las Vegas) planting greenhouse-grown seedlings of native **perennial plants**. The project was designed to help evaluate factors that limit plant establishment along newly exposed shoreline of Lake Mead. The wire cages are designed to protect the plants from being eaten by animals. The inset photograph (bottom right) shows a mature desert marigold (*Baileya multiradiata*). Main photograph by Sylvia Tran (November 2011); inset photograph by Scott R. Abella (April 2012), University of Nevada, Las Vegas.

## Littoral Vegetation

By E. Cayenne Engel and Scott R. Abella

In lake ecosystems, the littoral zone may be defined by site and management needs. Some working definitions of a lake littoral zone include: (a) the portion of a lake less than a certain depth, (b) the region that extends from the shoreline to the depth where sufficient light for plant growth reaches the substrate (known as the compensation level—the depth at which light intensity supports sufficient photosynthesis to compensate for respiratory energy losses; Lampert and Sommer, [1997]), or simply (c) the shallow shoreline region occupied by rooted vegetation (Brewer, 1994).

In some lakes, including many areas of Lake Mead, littoral zones typically are narrow horizontally because of steep shorelines, as opposed to lakes with gently sloping shorelines that commonly contain broader littoral zones. In the case of Lake Mead, there generally are relatively narrow regions where the lake shoreline is shallow enough to sustain littoral vegetation. The scarcity of littoral vegetation is common among dam-created reservoirs owing to the shoreline structure, water turbidity, and fluctuating levels. Only in reservoirs with clear water and stable levels do well-developed macrophytic communities (aquatic plants growing in or near water) generally develop (Kimmel and others, 1990). Lake Mead's fluctuating water levels leave little opportunity for plant species that require submersion in water for their subsistence. Additionally, within Lake Mead, the compensation depth varies drastically from approximately 6–36 ft (1.8–11.0 m), depending on the time of year and phytoplankton activity in a given area (Acki, 1975).

Many of the same anthropogenic changes and limitations that affect riparian plant colonization (see Riparian Vegetation Management) of Lake Mead also influence littoral communities. Water levels in the Colorado River Valley rose quickly (within 5 years to maximum depth after damming), not allowing time for the naturally established littoral vegetation to adapt, completely submerging the existing plant communities. Therefore, any littoral vegetation currently established is essentially a form of primary succession along the lake edge, with these species largely becoming established in places they have not occupied in recent history. The exceptions are species that may be present along well-developed springs that emanate from hillsides and flow to the lake's edge, with plants around the springs serving as seed sources.

Cove surveys by scuba divers within Las Vegas Bay—more than 50 years since the Hoover Dam was completed—indicated that most near-shore areas were devoid of aquatic vegetation in winter and exhibited only patchy vegetation in summer and autumn, although never deeper than 16.4 ft (5.0 m; Jennifer Haley, written commun., in Sollberger, 1987). In areas of Lake Mead that do support vegetation, littoral vegetation can consist of grasses (*Phragmites australis*), rushes (*Juncus* species), sedges (*Eleocharis rostellata*, *Scirpus americana*), cattails (*Typha domingensis*), **forbs** such as yerba mansa (*Anemopsis californica*) and water pimpernel (*Samolus parviflorus*), and aquatic species like sago pondweed (*Potomogeton pectinatus*) that may be able to disperse from springs to the lakeshore via washes. However, the distances between springs and the shoreline are commonly great [averaging more than 2 mi (3.2 km) in LMNRA and increasing as lake levels decline], which might create challenges to seed dispersal. Other challenges to development of littoral vegetation in Lake Mead might include increasing susceptibility to changes in lake chemistry with the introduction of human-made products, toxic algae, and **eutrophication** (Lieberman, 1995; LaBounty and Burns, 2005).

Documentation of littoral vegetation along the Lake Mead shoreline is limited. Uncertainly exists regarding potential threats to native littoral vegetation communities. Possible threats include exotic plants, changes in water quality including toxic algae blooms, and the invasive quagga mussel (Chapter 6). Potential management actions to enhance or maintain native habitat of the littoral zone include:

- Attempting to establish native vegetation that serves as habitat for wildlife of key management concern (for example, relict leopard frog [Bradford and others, 2004] along with native fish and sportfish species). Vegetation structure is known to be important for a variety of nest-building fish, like largemouth bass, providing the substrate within which or on which eggs are laid and protecting eggs from wave action and erosion (Kimmel and others, 1990).

- Preventing establishment of invasive colonizers such as the exotic species fountaingrass (*Pennisetum setaceum*) that was detected during weed surveys along the Lake Mead shoreline (Abella and others, 2009). These species may outcompete native species and clog waterways and coves that are otherwise useful for human recreation.

Southern cattail (*Typha domingensis*), an example of a common, native species that inhabits the littoral zone around Lake Mead. Photograph by Mitchell Urban, National Park Service.

## Invasive Plant Species

### Exotic Plant Species within and near the Littoral Zone of Lake Mead

Many exotic plant species inhabit the littoral zone of Lake Mead. Below are three key examples.

1. **Eurasian watermilfoil** (*Myriophyllum spicatum*)

Eurasian watermilfoil is a submerged plant that adversely impacts aquatic ecosystems by forming dense canopies over the surface of a lake that are capable of shading out native vegetation and degrading habitat for fish and other wildlife. Dense Eurasian watermilfoil mats alter water quality by raising pH, decreasing oxygen, increasing temperature, and increasing phosphorus and nitrogen loadings (Smith and Barko, 1990; Madsen and others, 1991).

2. **Giant reed** (*Arundo donax*)

Giant reed is a grass that can grow taller than 20 ft (6.1 m) in height and become established via floating root and stem fragments. The species provides poor wildlife habitat, and, once established, often forms pure stands that outcompete native vegetation (Bell, 1997).

Spraying herbicide on invasive fountaingrass (*Pennisetum setaceum*) near the Lake Mead shoreline during exotic plant surveying and management activities conducted by the 'Weed Sentry' program of the University of Nevada, Las Vegas in collaboration with the National Park Service (Abella and others, 2009). Photograph by Carrie Norman, National Park Service.

3. **Fountaingrass** *(Pennisetum setaceum)*

Fountain grass may establish in areas that are not waterlogged, but this densely clumping and readily propagating grass can outcompete other species, clog shorelines, and limit establishment of native species (Cronk and Fuller, 1995).

## Aquatic Birds

By Joseph G. Barnes and Jef R. Jaeger

The nature of the lower Colorado River, and the aquatic bird species the river supports, has changed dramatically since the creation of dams and associated impoundments (Rosenberg and others, 1991). The reservoirs of Lakes Mead and Mohave have altered more than 200 mi (322.0 km) of river. These manmade ecosystems have been further modified by intentional and unintentional introductions of non-native fish, other aquatic organisms, and plants, which have undoubtedly altered food resources for many aquatic birds. Lakes Mead and Mohave are situated in a low elevation trough along the eastern edge of the Mojave Desert, where summer temperatures are extreme, but winters tend to be relatively mild, with freezing temperatures uncommon (see Chapter 2). As a result, these lakes are now important stopover habitat and wintering grounds for many aquatic birds migrating along the Pacific and Intermountain Flyways (Brown and others, 2000).

American avocets (*Recurvirostra americana*) in breeding plumage on Lake Mead. Photograph by Joseph G. Barnes, University of Nevada, Las Vegas.

White-faced ibis (*Plegadis chihi*) over Lake Mead. Photograph by Joseph G. Barnes, University of Nevada, Las Vegas.

Information on aquatic birds summarized in this section is based on an inventory and monitoring project conducted at Lakes Mead and Mohave from spring of 2004 through summer 2009 (Barnes and Jaeger, 2011). Several bays, coves, and other sites known to attract aquatic birds were monitored during monthly surveys. Occasional surveys were conducted at other sites, and incidental observations of rare or unusual species or of large congregations of aquatic birds during migrations were recorded.

The sites systematically monitored on the two lakes are quite different. Sediment and nutrient inflows greatly influence the survey sites on Lake Mead, particularly the nutrient-rich, shallow bay at the confluence of the Virgin and Muddy Rivers and the outflow from Las Vegas Wash, where treated effluent from the Las Vegas metropolitan area enters Las Vegas Bay (see Chapters 3 and 4 for more details). The Grand Wash Impoundment also was monitored—a currently isolated segment of Lake Mead near the entry point of the Colorado River. The Grand Wash Impoundment receives only occasional pulses of floodwaters coming down the Wash, but an algal bloom was observed in late 2008, indicative of high levels of nutrients. In contrast, the more open bays monitored on Lake Mohave (Arizona and Nevada Bays) receive little nutrient inflows from surrounding lands, whereas Black Canyon receives cold, clear water emerging from the base of Hoover Dam. To further complicate site comparisons, the nature and scope of the shallow water sites on Lake Mead varied greatly over the course of the study as the lake level declined and fluctuated, while the level of Lake Mohave was kept within a tighter range with a more predictable seasonal pattern (see Chapter 2 for more detailed information on changing lake levels and dam operations along the river).

The inventory documented 92 species of aquatic birds, excluding the ruddy shelduck (*Tadorna ferruginea*), which likely escaped from regional captivity. Additionally, four other species strongly associated with Lakes Mead and Mohave were identified: the belted kingfisher (*Megaceryle alcyon*), bald eagle (*Haliaeetus leucocephalus*), and osprey (*Pandion haliaetus*), which rely on aquatic prey, and the peregrine falcon (*Falco peregrinus*), which on these lakes feeds extensively on aquatic birds (appendix A). In terms of observed species richness (the number of different species), the diversity of aquatic birds was higher on Lake Mead than on Lake Mohave. At Lake Mead, 89 species were observed, of which 34 were unique to the lake. In contrast, at Lake Mohave, 59 species were observed, of which only 4 were unique to the lake. Three of the four unique species were represented by no more than two individuals. Many species of shorebirds were documented only on Lake Mead, reflecting the ephemeral mudflats and open beaches that formed in areas along this lake at times when the lake level declined (fig. 5-12). Other species unique to Lake Mead included several marsh birds and herbivorous waterfowl seen in marshy habitats formed at the mouths of the major tributary inflows.

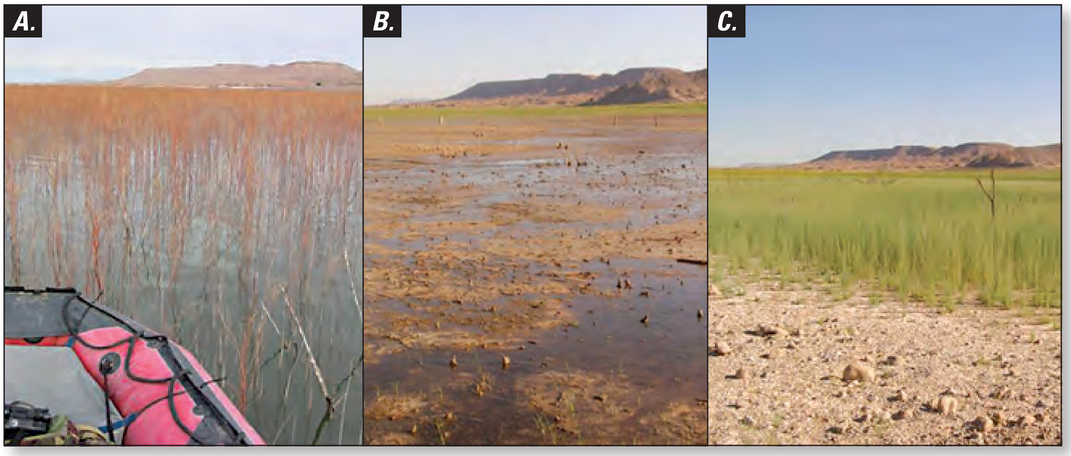



**Figure 5-12.** Photographs looking north from the western side of the Muddy River basin, near the river outflow into Lake Mead, showing changing conditions over time resulting from fluctuations in the water level of Lake Mead. Photographs were taken during (A) January 2005, (B) June 2007, and (C) July 2007. Photographs by Joseph G. Barnes, University of Nevada, Las Vegas.

Although many of the same aquatic bird species occur at both lakes, species evenness (which accounts for the relative abundance among species) of aquatic birds was higher at sites around Lake Mead than at Lake Mohave. Overall, the American coot (*Fulica americana*), a migratory herbivore, is the most abundant species regularly observed on both lakes, occurring in great numbers during winter months. On Lake Mohave, this species alone accounted for more than 77 percent of the birds observed during monthly surveys. On Lake Mead, however, several other species representing several **feeding guilds** (Paszkowski and Tonn, 2006) also are quite abundant (fig. 5-13), particularly the diving carnivores, Clark's and western grebes (*Aechmophorus clarkii* and *A. occidentalis*).

Abundances on either lake, however, can be greatly affected by short-term congregations of certain other species, such as the eared grebe (*Podiceps nigricollis*), American white pelican (*Pelecanus erythrorhynchos*), snow goose (*Chen caerulescens*), and ring-billed/California gulls (*Larus delawarensis* and *L. californicus*; these two species are difficult to distinguish under field conditions). For example, during spring migration, eared grebes often form the largest such congregations, with one raft on Lake Mead in April 2007 estimated at more than 16,000 birds. Overall seasonal abundance of aquatic birds on these lakes generally reflects relatively predictable patterns associated with winter residency or migratory stopovers in spring and autumn (fig. 5-14). Abundances of wintering birds typically peak from November through January, with the pattern driven to a great extent by the presence of the American Coot. Not all individuals of wintering species, however, remain on these lakes, and many individuals appear to stop only briefly during migration. Stopovers by migrating species are somewhat less well defined, but abundances of many migrants peak in March and April and again in September and October. During the hot summer months, the abundance of aquatic birds is quite low, with only a subset of species remaining on these lakes.

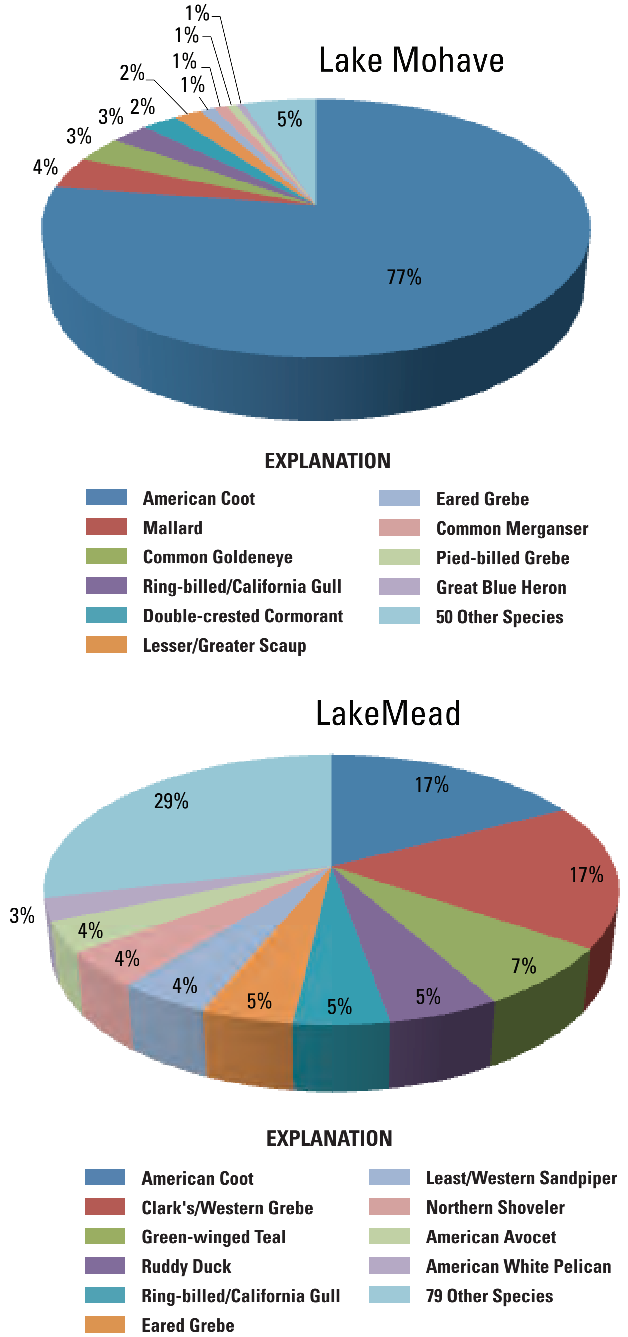



**Figure 5-13.** Percentages of the 10 most common species or species-groups of aquatic birds on each lake derived from observations at sites monitored monthly from March 2004 through August 2009 on Lakes Mead and Mohave. The identified species-pairs are difficult to distinguish in the field and were often recorded into these combined categories.

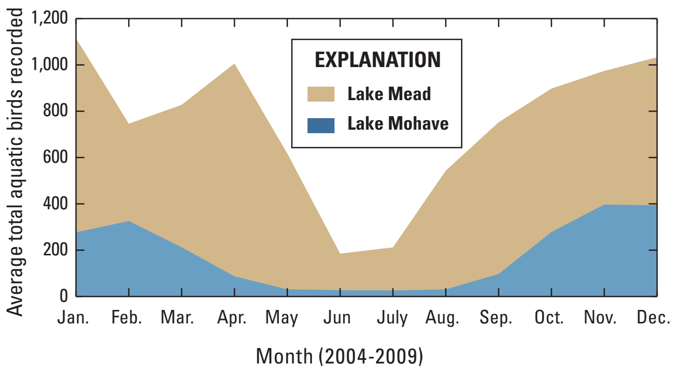



**Figure 5-14.** Monthly averages of total aquatic birds (on y-axis; see appendix A for species list) recorded per survey at sites monitored monthly on Lakes Mead and Mohave from March 2004 through August 2009.

Changes in the surface-water level of Lake Mead significantly alter the availability and composition of habitats for aquatic birds. Unlike most areas around the lake, the river mouths on Lake Mead and many of the coves and bays are shallow and have gradual slopes. For these sites, shifts in lake level expose or inundate large areas, some of which are covered by sediments. In recent years, the fluctuations in lake level tended to create temporary mudflats and open beaches that generally favored shorebirds (for example, sandpipers, plovers), of which many are species of conservation concern. For example, successful breeding by snowy plovers (*Charadrius nivosus*) was documented at Lake Mead in 2007 and 2008, undoubtedly resulting from declines in surface-water level at that time, which uncovered large areas of favorable habitat. The Pacific Coast population of snowy plover is federally listed as Threatened, and its nearest previously known breeding colonies are more than 300 mi (482.8 km) away from the breeding sites at Lake Mead.

Snowy plover (*Charadrius nivosus*). Photograph by Joseph G. Barnes, University of Nevada, Las Vegas.

Mudflats on the lake are particularly ephemeral, and during extended periods of lake-surface-level declines, vegetation, such as non-native salt cedar, quickly encroaches on exposed sediments, rendering these areas increasingly unsuitable for shorebirds. The shallow topography of the shoreline in areas where mudflats occur, however, allows for quick inundation when waters rise. In recent years, variation in lake level has at times inundated large areas of emergent vegetation creating shallow-water conditions (fig. 5-12) advantageous to many types of waterfowl, particularly herbivores like the green-winged teal (*Anas crecca*).

For aquatic birds, some aspects of migration strategies may vary, but many species rely on foraging opportunities along flyways to maintain energy reserves. Consequently, migratory pathways generally follow seasonally reliable resources (Shuford and others, 2002; Skagen, 2006). At Lake Mead, the highly variable nature of shoreline and shallow-water habitats is a result of unstable resource conditions from year to year. However, the impact of large changes in available resources on migrating or wintering bird populations at Lake Mead has not been studied. Because Lakes Mead and Mohave are part of a complex of several reservoirs extending from Lake Powell southward along the lower Colorado River into its delta at the Gulf of California in Mexico, any comprehensive assessment would require understanding resource availability and use along the entire river system. Moreover, a resource assessment for the river system below Lake Mead should include potential future climate effects on snowfall patterns, water availability, and associated changes in habitat and food resources for aquatic birds.

In addition to potential impacts from climate, aquatic bird species at Lakes Mead and Mohave also will be affected by anthropogenic-induced change, particularly from non-native invasive species and contaminants contained in tributary inflow. For example, quagga mussels (*Dreissena bugensis*; Chapter 6) have recently invaded both lakes. Quagga mussels may have substantial impacts on aquatic bird species, particularly those that feed on invertebrates. On the lower Great Lakes and elsewhere, omnivorous diving ducks have altered migration patterns in response to quagga mussel and related zebra mussel invasions (Wormington and Leach, 1992; Petrie and Schummer, 2002). During the last year of monitoring on Lake Mohave, increases in two omnivorous diving ducks known to feed on quagga mussels were observed, the common goldeneye (*Bucephala clangula*) and lesser scaup (*Aythya affinis*). Moreover, starting in 2008, white-winged scoters (*Melanitta fusca*), another omnivorous diving duck, also began showing up regularly on this lake.

Studies have indicated that contaminants in water may bioaccumulate in quagga and zebra mussels (Mills and others, 1993; Link, 2010; Mueting and Gerstenberger, 2010). Birds that feed on these mussels may gain weight and have an acceptable looking body condition, but contaminant loads have been hypothesized to reduce survival and reproductive success (Austin and others, 2000). What impact quagga mussels will have on aquatic birds at Lakes Mead and Mohave is not clear. In general, contaminant levels in water and sediments vary across these lakes (see Chapter 4), and potential future increases in wastewater effluent from Las Vegas Wash into Las Vegas Bay and Lake Mead may present an accumulating impact regardless of the pathway into food chains. Since changes in endocrine and reproductive health of fish in these areas have been documented (Bevans and others, 1996; Patiño and others, 2003), there is a concern for exposure to both Clark's and western grebes, migratory birds that feed on fish within or near Las Vegas Bay. However, higher food-chain, non-migratory species, such as peregrine falcons that remain on Lakes Mead and Mohave for longer periods, are of greater concern.

## Aquatically Associated Raptors

By Joseph G. Barnes and Jef R. Jaeger

Osprey, bald eagles, and peregrine falcons occur at Lakes Mead and Mohave, where they prey primarily on aquatically associated species. Osprey feed almost exclusively on fish, while bald eagles are more opportunistic foragers, relying on fish, but also preying on aquatic birds, small mammals, and scavenging carrion. Bald eagles have been observed on numerous occasions preying on aquatic birds, primarily waterfowl, which may be an important portion of their diet while on these lakes.

Observations of osprey and bald eagles during monthly aquatic bird monitoring show that both species can be found on the lakes throughout the year (Barnes and Jaeger, 2011). However, peak occurrence for osprey was in September and October, which is consistent with autumn migration as osprey pass through the region heading towards winter grounds farther south (Martell and others, 2001). In contrast, bald eagles appear to winter regionally, occurring in large numbers starting in November or early December and departing by late February or early March. Annual winter counts in early January by survey crews covering both lakes in a single day indicate increasing numbers of bald eagles in recent years, with 163 counted in 2011, more than 60 percent of which were subadults (Fletcher and Jaeger, 2011). The migration patterns of bald eagles using Lakes Mead and Mohave have not been studied, but limited tracking information from elsewhere indicate that some birds wintering in California pass through Lakes Mead and Mohave areas during migration. Juvenile birds migrating from a breeding population farther south in Arizona also may use these lakes.

Bald eagle (*Haliaeetus leucocephalus*) and common raven (*Corvus corax*) on the shoreline of Lake Mead. Photograph by Joseph M. Hutcheson.

Peregrine falcons are bird-eating specialists less tightly associated with water, but along Lakes Mead and Mohave peregrines have been documented to prey on 29 species of aquatic birds, accounting for 37 percent of their diet by item and 77 percent of diet by mass (Barnes, 2011). Peregrines are year-round residents at these lakes and their numbers have grown since a breeding pair was documented on Lake Mead in 1985. By 2010, 33 nesting territories were occupied within LMNRA (Barnes, 2011), with the majority of these located near lakeshores and densities highest along steep-walled canyons overlooking lake waters.

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Chapter 6

# Threats and Stressors to the Health of the Ecosystems of Lakes Mead and Mohave

By Michael R. Rosen[1], Steven L. Goodbred[1], Wai Hing Wong[2], Reynaldo Patiño[1,3], Kent Turner[4], Craig J. Palmer[2], and Peggy Roefer[5]

Lake Mead at sunrise. Photograph by Michael R. Rosen, U.S. Geological Survey.

***Ecosystem impacts from visitor activities or natural environmental change are important concerns in all units of the National Park system. Possible impacts to aquatic ecosystems at Lake Mead National Recreation Area (LMNRA) are of particular concern because of the designation of Lakes Mead and Mohave as critical habitat for the federally listed endangered razorback sucker*** (Xyrauchen texanus)***, the significance of the sport fishery, and the regional importance of its habitats to more than 90 documented species of waterbirds. Potential threats to shoreline habitats are of concern not only for their ecosystem values but also for maintaining the recreational setting. Many areas adjacent to the shorelines of Lakes Mead and Mohave are designated wilderness areas.***

***For purposes of this document, stressors are any chemical, biological, or physical agent that has a detrimental effect on aquatic ecosystems at the organism, population, or community level. Human-made stressors at Lakes Mead and Mohave include direct effects of recreation on the lakes, like boating and fishing, as well as indirect effects of activities away from the lakes, such as growing population and increasing urbanization. Common natural environmental stressors include extended changes in climate (precipitation or temperature), or the erosion, transport, and loading of chemical constituents in rocks and sediments to aquatic environments. Human activity also can exacerbate natural stressors in a variety of ways.***

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[3] Texas Tech University
[4] National Park Service
[5] Southern Nevada Water Authority

Past studies suggested that inorganic and organic chemicals are major environmental stressors at LMRNA (for example, Bevans and others, 1996; Hamilton and others, 2002; Goodbred and others, 2007). Sources of these chemicals include inputs from the urbanized tributary Las Vegas Wash, transport of naturally occurring selenium from rocks and soil in Las Vegas Valley to Lake Mead (Hamilton and others, 2002; Cizdziel and Zhou, 2005), or organic compounds from fuels and oils used in recreational watercraft on Lakes Mead and Mohave (Lico and Johnson, 2007). Other past or potential stressors on the aquatic ecosystem include algal blooms, invasive species [such as quagga mussels (*Dreissena rostriformis bugensis*), New Zealand mudsnails (*Potamopyrgus antipodarum*), and Asian clams (*Corbicula fluminea*)], pathogens, viruses, and parasites, effects of population growth, and changes in climate. Most information on effects of stressors and the health of aquatic ecosystems at LMNRA comes from fish studies completed during the 1990s and 2000s; information is sparse on the effects of stressors on other levels of the food web.

## Inorganic Chemicals

Inorganic chemicals (those without biologically produced carbon in them) that enter LMNRA come from both human and natural sources (Rosen and Van Metre, 2010). Mercury and perchlorate are the focus of this subsection as the two main inorganic chemicals of concern at LMNRA (see Chapter 4). Nearly 87 percent of mercury present in the environment today is due to human activities (U.S. Environmental Protection Agency, 2001b), including mining and mineral extraction. In the last century, the environmental burdens of mercury have increased dramatically due to extensive use of coal fired electrical power plants worldwide (Shimshack and others, 2007). Perchlorate was manufactured in Henderson, Nev., at the BMI Complex as a component of rocket fuel from 1945 to 1998. Although possible, natural contamination of water bodies by both mercury and perchlorate typically is of less concern.

Coal-fired power plants can release mercury into the air, which then can fall into water bodies as inorganic mercury that is soluble in water. However, in or near sediments or shallow wetland areas, bacteria convert the inorganic mercury to the organic, more toxic methyl mercury, which is less soluble and tends to concentrate in organic matter and biota. Mercury concentrations in sediment in LMNRA are relatively low compared to those in other lakes nationally as well as in other lakes in Nevada. However, mercury concentrations in sediment and fish are not uniformly distributed throughout Lakes Mead and Mohave (Kramer, 2009; Rosen and Van Metre, 2010), indicating different loadings and sources.

Sampling at Lake Mead. Photograph by Michael R. Rosen, U.S. Geological Survey.

Mercury is of concern because it biomagnifies (fig. 6-1) up the ***food web***; that is, animals at the top of the food web will have higher concentrations of mercury than algae or invertebrates lower in the food web. Biomagnification occurs because animals and plants, once exposed, have very little ability to eliminate mercury. As a result, animals that eat more, are bigger, and live longer will have higher mercury concentrations. For example, the recently (2007) discovered quagga mussels at LMNRA have the ability to filter large quantities of water and, through that process, bioaccumulate significant concentrations of mercury (Mueting and Gerstenberger, 2010). As quagga mussels accumulate mercury from the water column, other biota, such as fish and diving ducks that consume the mussels, also would accumulate mercury and continue the biomagnification process up the food web to concentrations high enough to cause health effects in top predators (Hogan and others, 2007). Mercury concentrations in quagga mussels soon after they became established at Lakes Mead and Mohave averaged 0.031 µg/g dry weight (DW) and 0.43 µg/g DW, respectively (Mueting and Gerstenberger, 2010). These concentrations are well below mercury concentrations in quagga mussels in Lakes Erie and Ontario but comparable to concentrations in these mussels in the Niagara River, which flows northward from Lake Erie to Lake Ontario.

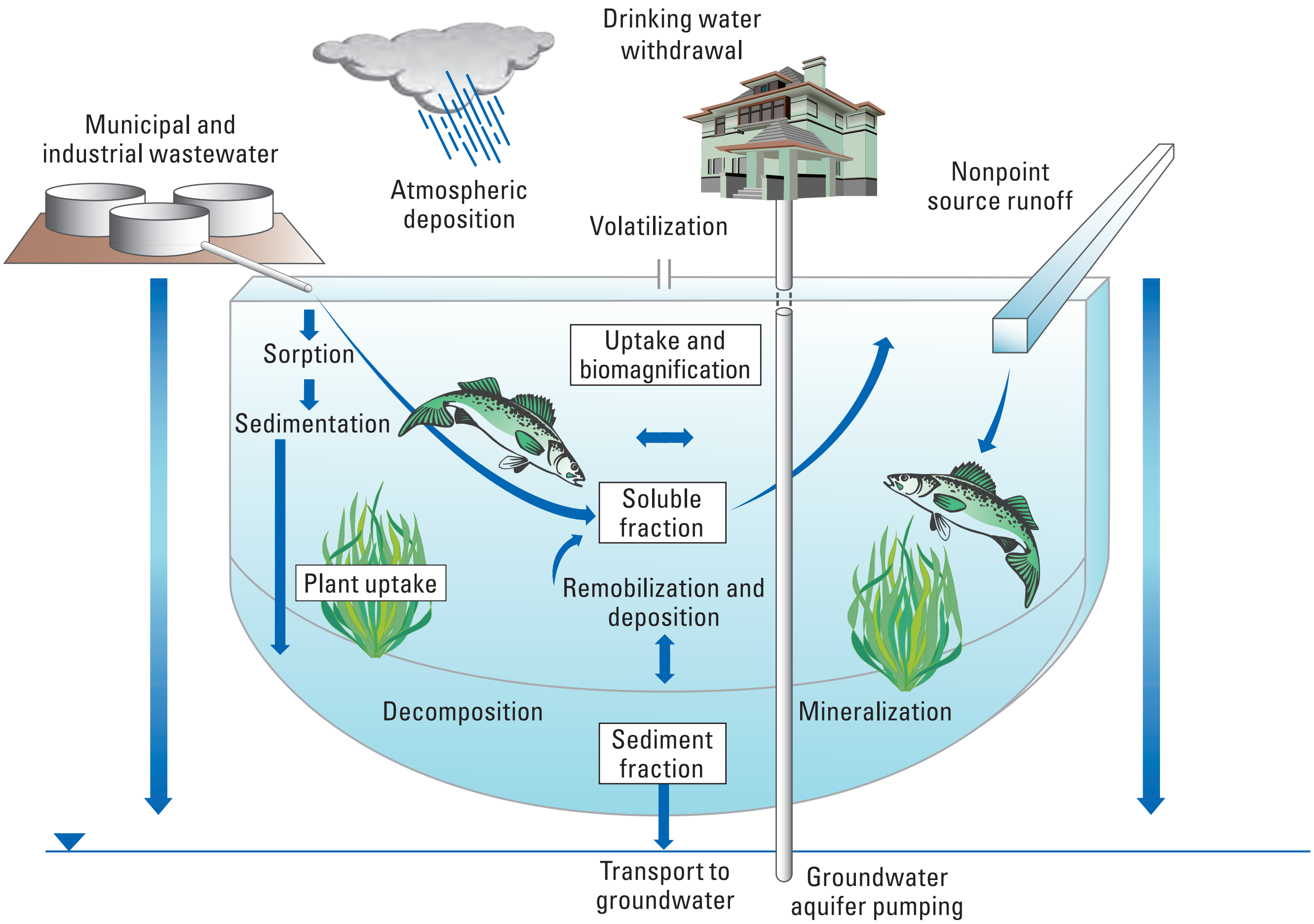



**Figure 6-1.** Sources and pathways of organic compounds in water and aquatic ecosystems. Household organic compounds disposed down drains are transported to municipal and wastewater-treatment plants (point sources) that can then be discharged into aquatic ecosystems if they are not completely removed during the treatment process. Other compounds may enter the ecosystem from the land surface (non-point sources) in a watershed, such as the spraying of pesticides on agricultural fields or golf courses. Removal of organic compounds from water in an aquatic ecosystem can occur from pumping for irrigation or water supplies, being attached to and buried in sediment, taken up by aquatic organisms, or microbial degradation.

Higher on the food web, mercury concentrations in sportfish studied by Cizdziel and others (2002, 2003), Kramer (2009), and Kramer and Gerstenberger (2010) varied by species and location. For example, mercury concentrations in muscle samples of blue tilapia (*Oreochromis aurea*) were less than the detection limit of the analytical method (0.01 µg/g), but mercury concentrations were highest in striped bass (*Morone saxatilis*) of all fish species—an average concentration of 0.15 µg/g (Cizdziel and others, 2002, 2003). The low mercury concentrations in blue tilapia are likely a consequence of their position lower on the food web than striped bass and their vegetarian diet, whereas striped bass are predators that eat higher on the food web, live longer, and accumulate more mercury from the smaller fish they eat.

In a more recent study of 221 fish samples collected in 2007 and 2008 at Lake Mead, the mean concentrations of mercury detected were less than the U.S. Environmental Protection Agency's tissue residue criterion of 0.3 µg methylmercury per gram wet weight (ww) fish tissue (Kramer and Gerstenberger, 2010). This tissue residue value represents the concentration of methylmercury in freshwater and estuarine fish and shellfish that should not be exceeded to protect consumers in the general population (U.S. Environmental Protection Agency, 2001a). Results of the study included 10 samples (less than 5 percent) with concentrations that exceeded U.S. Environmental Protection Agency (USEPA) tissue residue criterion (Kramer and Gerstenberger, 2010). However, in spite of these generally low methylmercury values in Lake Mead fish, the State of Nevada has issued statewide fish consumption advisories (table 6-1) to protect public health related to this widespread contaminant for the majority of large water bodies in the State. The advisories include those for several of the common sportfish species in Lakes Mead and Mohave (fig. 5-1, table 5-1; http://ndow.org/fish/health/#southern).

**Table 6-1.** Nevada Department of Wildlife Fish Consumption Advisory, based on methylmercury.

[An adult meal size is considered 8 ounces of fish meat, about the size of two decks of cards. Children should eat smaller, age-appropriate amounts]

| Location | Fish species | Maximum number of meals per month |
|---|---|---|
| | Lake Mead | |
| Boulder Basin | Common carp | 8 |
| | Channel catfish | 12 |
| | Largemouth bass | 16 |
| | Striped bass | 4 |
| | Tilapia | Unrestricted, >16 |
| Colorado River Inflow Arm | Channel catfish | 8 |
| | Largemouth bass | 16 |
| | Striped bass | 4 |
| | Tilapia | Unrestricted, >16 |
| Overton Arm | Channel catfish | 4 |
| | Largemouth bass | 4 |
| | Smallmouth bass | 4 |
| | Striped bass | 4 |
| | Lake Mohave | |
| | Common carp | 12 |
| | Channel catfish | 8 |
| | Largemouth bass | 4 |
| | Striped bass | 4 |

Perchlorate has been used to treat thyroid disorders in humans for almost 50 years, but in the environment, the salt can be harmful to an animal's endocrine system (Kendall and Smith, 2006). Few research findings on the effects of perchlorate on fish health in Lake Mead have been published, but a study by Snyder and others (2002) indicated that there might be some effects on thyroid hormones in male carp in Las Vegas Bay. Further evidence of the possible effects of perchlorate on fish health was demonstrated in a controlled experiment completed on goldfish (*Carassius auratus*) (Crouch, 2003), which are in the same family as common carp (*Cyprinus carpio*). In this experiment, male and female goldfish were exposed to perchlorate under laboratory conditions. Results of the experiment indicated increased thyroid activity (hyperthyroidism) in female goldfish at perchlorate concentrations of 1.2 mg/L, and increased thyroid activity in male goldfish at significantly higher concentrations of 31 mg/L. However, the concentrations used in this laboratory experiment were higher than most concentrations measured in Las Vegas Wash, and many times higher than concentrations measured in Las Vegas Bay (see Chapter 4). Although perchlorate concentrations in Las Vegas Wash, the main source of perchlorate to Lake Mead, were higher in the past, cleanup and bioremediation since 1997 has effectively lowered concentrations by 90 percent. Current concentrations of perchlorate in Lake Mead range from 0.06 mg/L at the Las Vegas Wash inflow to Lake Mead, to 0.002 mg/L 11 mi (17.7 km) south of Hoover Dam (see Chapter 4).

The fate and transport of metals to LMNRA also are of concern, whether from natural sources (erosion of weathered rock) or from past and present human uses of metals in industry (see Chapter 4). Many metals are essential for life at low concentrations but become toxic at elevated concentrations. Although elements such as selenium, copper, iron, chromium, and zinc are essential **micronutrients** for fish and invertebrates, other elements, such as arsenic, cadmium, mercury, and lead are not considered essential for life functions but are known to be toxic even at low concentrations when ingested over a long period. Moreover, inorganic chemicals such as cadmium may act as endocrine disrupting compounds at low concentrations. Arsenic, cadmium, mercury, and lead have been detected in common carp from Gregg Basin (near the inflow of the Colorado River to Lake Mead) and at Willow Beach on the Colorado River downstream of Hoover Dam (Hinck and others, 2006). Concentrations of these non-essential trace elements in fish from both locations were less than the toxicity benchmarks for reproduction, growth, and survival (Arsenic, 5.4 µg/g; Cadmium, 0.12µg/g; mercury, 4.47µg/g; lead, 0.4µg/g; Jarvinen and Ankley, 1999). Another study (Patiño and others, 2012) in which 63 elements were analyzed in samples of common carp from Las Vegas Wash and Bay, Overton Arm, and Willow Beach, found a negative association between fish health and reproductive condition, and levels of certain trace metals (silver, arsenic, barium, mercury, iron, selenium, and zinc). Fish from Las Vegas Wash generally had the highest metal concentrations and the lowest fish health and reproductive biomarkers of the four sites studied. Las Vegas Bay had the next lowest fish health followed by Willow Beach. Overton Arm, which was used as a reference site, had the best fish health and lowest metal concentrations in fish compared to Las Vegas Wash, Las Vegas Bay, and Willow Beach.

Treatment facility for bioremediation of perchlorate in Henderson, Nevada. Photograph provided by Nevada Division of Environmental Protection, Bureau of Corrective Actions, Special Projects Branch.

Selenium is an essential trace element, and small amounts are required to meet dietary needs, but at elevated concentrations can cause adverse health effects in fish and birds, ranging from reduced embryo viability and egg hatchability in mild cases, to embryo deformities in severe cases (Seiler and others, 2003). Selenium concentrations in fish from Gregg Basin and Willow Beach (Hinck and others, 2006) exceeded the 1.0 µg/g wet weight (ww) that is commonly recommended to prevent toxicity (Hamilton, 2004). Humans typically are not at risk from such levels of selenium, but wildlife may experience adverse health effects at fairly low levels due to biomagnification within the food chain. Even if selenium concentrations in water are only slightly elevated, organisms at the bottom of the food chain, such as plankton, can consume and concentrate selenium in their diet. Through the bioaccumulation process, top predators at LMNRA, such as bald eagles or striped bass, tend to be exposed to higher selenium levels in their diet and may be at greater risk for selenium poisoning (Seiler and others, 2003).

USEPA is currently revising the criterion for the concentration of selenium in water that is considered safe for aquatic life, also known as the water-quality standard for selenium; the existing standard is a concentration of 5 µg/L. There is some debate about historical selenium levels in the Southwest prior to human settlement in the 1800s, but most experts believe natural background levels would have averaged 1 µg/L or less in the Colorado River Basin (Seiler and others, 2003). As the Western United States was settled and human activities, such as farming and mining increased, selenium concentrations throughout the Colorado River and LMNRA became elevated above background, with an average concentration from approximately 2 to 4 µg/L (Seiler and others, 2003). The large urban areas of Las Vegas, with residential lawns, landscaping, and golf courses that require routine watering, contribute selenium to LMNRA in the form of irrigation runoff.

Irrigation of a golf course in the Las Vegas Valley. Photograph by Jennell M. Miller, University of Nevada, Las Vegas.

With a population of 1.8 million residents in 2012, the watering of lawns throughout the Las Vegas Valley serves to mobilize selenium from soil at an accelerated rate far exceeding concentrations that would otherwise be removed by natural rainfall. Leached selenium from the soil is mobilized in the shallow groundwater system, ultimately draining to Las Vegas Wash and Lake Mead. Stormwater channels typically flow year-round in Las Vegas Valley with irrigation-landscape source water that can contain selenium at concentrations of three to five times the USEPA standard, averaging between 15 and 25 µg/L (Shanahan and Zhou, 2011). When urban flows in stormwater channels reach Las Vegas Wash, selenium concentrations are diluted by the higher volume treated discharge from wastewater facilities along the Wash. For example, selenium concentrations for the mainstem Wash below the Clark County Wastewater Reclamation Facility typically are less than USEPA standards, averaging between 3 and 4 µg/L (Ryan and Zhou, 2010).

Although selenium concentrations (average 2–4 µg/L) exceeded background levels throughout the Colorado River, including Lake Mead, this concentration is still less than the current USEPA water-quality standard of 5 µg/L. Some species of migratory birds found along selenium-rich tributaries flowing to Lake Mead may experience lower reproductive success, but the lower selenium concentrations in LMNRA are unlikely to pose significant risk to most aquatic life (Hamilton, 2004). However, some species, such as the endangered razorback sucker, may be particularly sensitive to selenium or particularly vulnerable due to their rare or imperiled status. A study of razorback suckers in the Upper Colorado River basin by Hamilton and others (2002) indicated that selenium concentrations greater than 4.6 µg/g in razorback sucker food sources can adversely affect their reproductive success. The effect of selenium on reproduction of razorback suckers in LMNRA, where highest selenium concentrations in Lake Mohave fish was 1.70 µg/g and in Lake Mead was 2.19 µg/g (Hinck and others, 2006), is unknown and is an area of current research. The health effects of chronic, long-term exposures to relatively low concentrations of selenium, however, are particularly difficult to detect, even for scientists who regularly monitor wildlife health. Understanding the effects of long-term exposure to selenium can be challenging because (1) selenium toxicity in wildlife is often difficult to detect in early life stages (for example, larval fish or newly hatched birds), the most vulnerable segment of the population, because effects, including mortality and deformities, require very intensive monitoring studies; and (2) it is difficult to separate the effects of low-level selenium toxicity from the other environmental stressors that may cause similar health effects, such as low weight gain or a general failure of young to thrive.

## Radionuclides from Aboveground Nuclear Testing

Above ground nuclear tests were performed at the Nevada National Security Site (formerly the Nevada Test Site) and other locations in Nevada and the United States in the 1950s and 1960s, resulting in the distribution of very low levels of radioactive material (radionuclides) throughout the Northern Hemisphere (fig. 6-2). Radionuclides are isotopes of elements that have an unstable nucleus and emit either gamma rays and (or) subatomic particles. Some radionuclides decay quickly (within seconds or minutes) and some decay over periods of years or even millions of years. Because of these differences in decay rates, radionuclides formed by nuclear testing, or naturally formed by the sun, may still be found in small amounts in the environment even though above ground testing was banned in 1963.

Research has shown that many radionuclides, particularly $^{137}$Cs, deposited in soils in the arid Southwest typically are tightly bound to clays and silts (Foster and Haksonson, 1985). Analyses of $^{137}$Cs have been used to date sediment in studies around the world because of its wide distribution, known rate of decay (losing half of its radioactivity about every 30 years), and known time of deposit from above ground testing (see Rosen and Van Metre, 2010). Moreover, because Lake Mead is relatively close [less than 100 mi (160.9 km)]) to the Nevada National Security Site, $^{137}$Cs concentrations from individual nuclear tests appear as discrete peaks in some sediment cores obtained from the bed of Lake Mead (see fig. 6-3). A 1995 study by Rudin and others (1997) sampled sediment from the lower mile of Las Vegas Wash for radionuclides. They found $^{137}$Cs and other radionuclides that come from atmospheric bomb testing at low levels, and additional testing and monitoring for radionuclides by the Southern Nevada Water Authority have confirmed that drinking water for the Las Vegas metropolitan area typically contains concentrations of radionuclides below maximum contaminant levels developed by the U.S. Environmental Protection Agency.

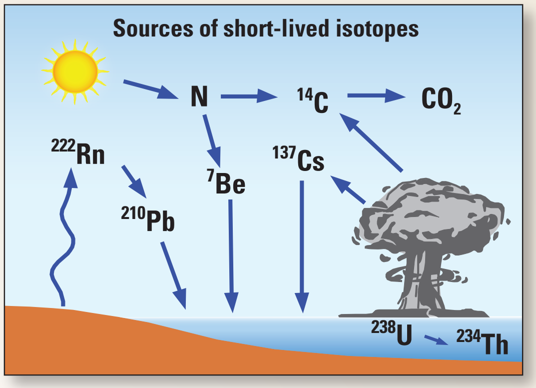



**Figure 6-2.** Illustration of different radionuclides (isotopes) formed naturally or from atmospheric testing. $^{7}$Be = beryllium-7; $^{14}$C = carbon-14; $CO_2$ = carbon dioxide; $^{137}$Cs = cesium-137; N = nitrogen; $^{210}$Pb = lead-210; $^{222}$Rn = radon-222; $^{234}$Th = thorium-234; $^{238}$U = uranium-238.

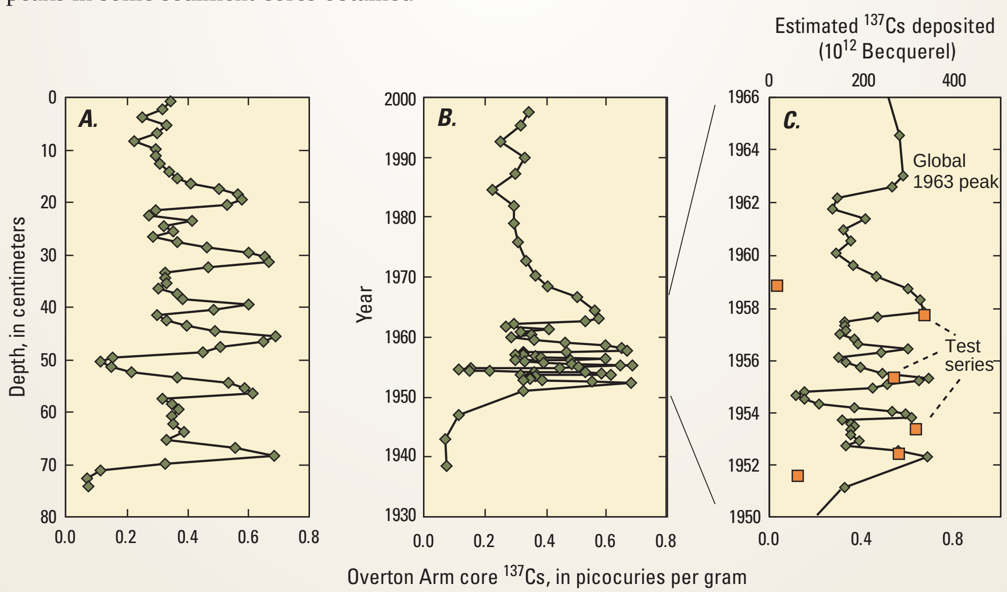


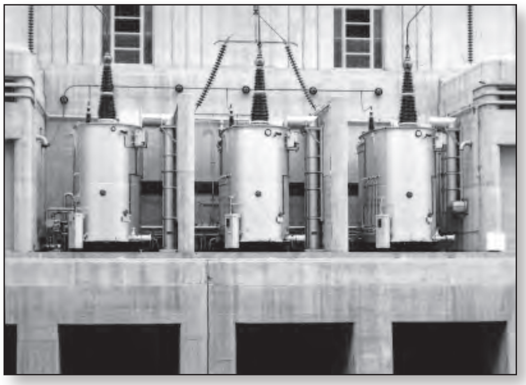

**Figure 6-3.** Concentrations of cesium-137 ($^{137}$Cs) in an Overton Arm sediment core. $^{137}$Cs plotted versus depth (*A*) and date (*B*) in the sediment, and (*C*) for 1950–1966 shown with estimated $^{137}$Cs deposition for the continental USA from individual nuclear weapons test at the Nevada National Security Site. These plots show the sediment records individual pulses of $^{137}$Cs from tests that deposited high concentrations of $^{137}$Cs. Modified from Rosen and Van Metre (2010).

## Organic Compounds

Organic compounds contain carbon (C), and many of these chemicals in the environment are derived from human activity (fig. 6-1), although some occur naturally, such as polycyclic aromatic hydrocarbons (PAHs) deposited from forest fires. Many organic chemicals used in agriculture are designed to be toxic to a variety of pests and weeds; some of these [such as dichlorodiphenyltrichloroethane (DDT)], along with some industrial chemicals (such as polychlorinated biphenyls, or PCBs), have been banned in the United States. Other organic chemicals are used in the home as personal care products, such as medicine, fragrances, and antibacterial soaps. Because many personal care products cannot yet be totally removed by municipal wastewater treatment, these products can be transported to streams and lakes.

Detecting organic chemicals in the environment commonly is difficult because of the specialized instruments needed and because of the vast number of these chemicals present in the environment. Typically, organic chemicals occur at low concentrations, and instruments are needed to detect these chemicals at concentrations of about 1 ng/L, which is equivalent to about the volume of 1 drop from an eyedropper in an Olympic-sized swimming pool. Even when organic chemicals are detected, it may be difficult to distinguish a specific organic compound from the thousands of compounds that currently exist.

In spite of these difficulties, organic chemicals have been detected and identified in many streams within the United States and around the world. For example, a national survey documented the presence of low levels of organic compounds from treated wastewater effluent in 139 targeted streams across the United States, including the Las Vegas Wash (Kolpin and others, 2002). One or more chemicals were detected in samples from 80 percent of the streams sampled, and 82 of 95 chemicals analyzed were detected at least once. Mixtures of these chemicals were common; 50 percent of the streams had 7 or more, and 34 percent had 10 or more compounds detected. Generally, these organic compounds were detected at very low concentrations (in most cases, less than 1 µg/L). Although streams were selected for this study on the basis of their susceptibility to contamination from wastewater sources (downstream of intense urbanization or livestock production), the study shows that organic compounds are common in aquatic environments.



Hoover Dam transformer bank, Units A1 and A2, showing A-phase transformer with the new heat exchange unit installed. Photograph by Bureau of Reclamation.

At Lake Mead, many organic compounds in the water come from human activities on the lake, such as motorized watercraft use, and from the tributary inflow of Las Vegas Wash. These compounds, especially water-soluble organic compounds, also can be transported downstream to Lake Mohave. In addition, present and past activities from the building and operation of Hoover Dam probably contribute some organic compounds to Lake Mohave, such as PCBs that were historically used in electric transformers. The operation and fueling of watercraft within LMNRA can introduce other organic compounds into the water, either directly as spills of unburned fuel, or indirectly as PAHs in engine exhaust (Lico and Johnson, 2007). Some of these compounds are toxic to aquatic biota, are carcinogens, or are thought to be endocrine disruptors. Even though a group of these chemicals present in gasoline (BTEX) can occur at high concentrations during peak periods of watercraft use in LNMRA (Chapter 4; Lico and Johnson, 2007), they typically do not persist in water because they are volatile, move from water to air easily, and also can be degraded by bacteria. This is illustrated by low or less-than-detection levels of BTEX compounds during the non-boating season in all samples collected during March 2006. In spite of the fact that BTEX compounds have some toxicity and are present at high concentrations in LMNRA at certain times of the year, samples collected in Callville Bay at Lake Mead and at two locations on Lake Mohave in 2004–2006 during peak watercraft use had low concentrations of the chemicals compared to controls (Lico and Johnson, 2007).

The sources of other manmade organic chemicals in LMNRA, including small areas of agricultural fields, golf courses, landscaped areas, industry, and wastewater, are derived primarily from Las Vegas Wash. The chemicals from these sources are very diverse and have a wide range of properties, including environmental persistence in water and sediment, toxicity, and unknown fate and transport in LMNRA. Las Vegas Wash is the main drainageway for natural and urban discharge from Las Vegas valley, as well as for treated wastewater effluent. Additionally, areas adjacent to and upgradient of the Wash have historically been used for production of organic chemicals including pesticides, such as DDT, and endosulfan, as well as industrial chemicals like PCBs and dioxins. There are 483 chemicals either known or suspected to be associated with the BMI Complex (fig. 6-4) in Henderson, Nev. (Sahu, 2006). As a result, concentrations of some legacy compounds (compounds that are not currently used), such as DDT and PCBs, were elevated enough in the 1980s to be considered potential threats to the health of downgradient aquatic ecosystems in Lake Mead. Although the concentrations of both compounds in water at Lake Mead have decreased since environmental regulations banned their use in the 1970s (DDT, 1972; PCBs, 1979) DDT concentrations in Lake Mead were not lowered as quickly due to erosion of contaminated sediment in Las Vegas Wash below the facilities where DDT was produced (Chapter 4; Rosen and Van Metre, 2010). Better containment of waste piles since 1980 have helped to reduce DDT and its breakdown products in lake sediments, but these compounds are still detected in fish and water in Las Vegas Bay (Bevans and others, 1996; Goodbred and others, 2007; Rosen and others, 2010). In spite of source reductions, some organic compounds are found in Las Vegas Wash in concentrations that are of concern for fish and wildlife (Advanced Concepts and Technologies International, 2011).

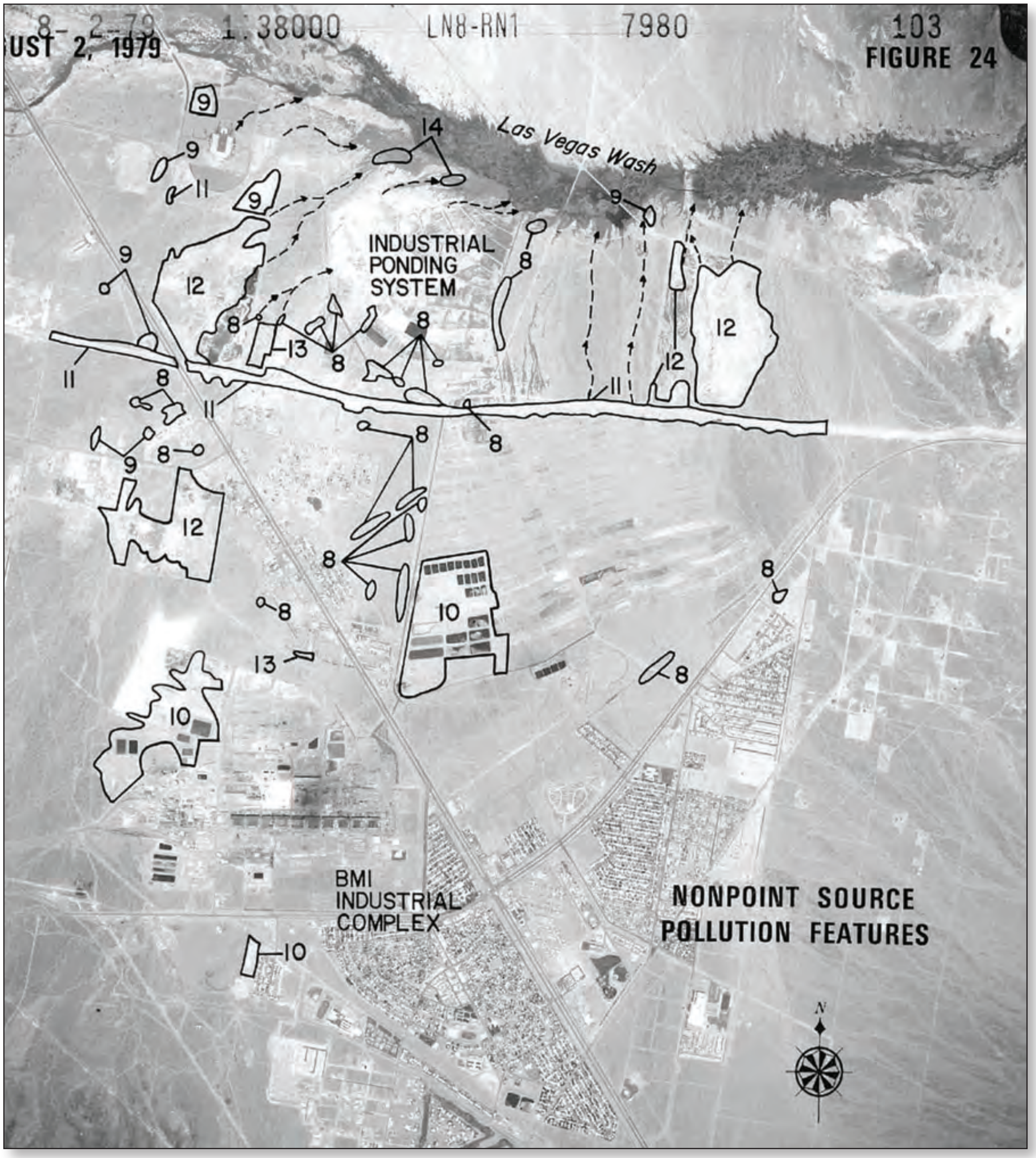



**Figure 6-4.** Historical aerial photograph of BMI Complex, Henderson, Nevada (1979). Source: Nevada Division of Environmental Protection web site, http://ndep.nv.gov/bmi/photos/1979.htm.

The transport of organic chemicals from Las Vegas Wash into Las Vegas Bay and farther downstream in Lake Mead depends on the physical and chemical properties of these compounds, and on lake hydrology. Physical and chemical properties, for example, are important factors in determining the degree to which an organic compound will persist in the environment and, consequently, the exposure time of aquatic organisms to a particular compound. Some organic chemicals degrade quickly in the environment (minutes, hours) whereas others, such as DDT, degrade much more slowly and may persist for decades. Lake hydrology also influences how organic chemicals are distributed within the lake; for example, in Las Vegas Bay, organic compounds may be transported near the bottom of the lake or "float" near the surface depending on temperature and density differences of water in Las Vegas Wash and Las Vegas Bay, and on stratification of the water column (LaBounty and Burns, 2005). Changes in water density and depths of chemical transport from Las Vegas Wash to Las Vegas Bay follow a seasonal pattern (Chapter 4) that effects the distribution of organic chemicals and the exposure of aquatic organisms to these chemicals.

More than 100 organic compounds have been detected in various media within LMNRA, such as water, sediment, and fish (Bevans and others, 1996; Covay and Beck, 2001; Snyder and others, 2001; Boyd and Furlong, 2002; Osemwengie and Gerstenberger, 2004; Hinck and others, 2006; Goodbred and others, 2007; Lico and Johnson, 2007; Marr, 2007; Rosen and others, 2010; Alvarez and others, 2012). In 1995, organic compounds detected in water from Las Vegas Bay and Wash and Callville Bay included organochlorine compounds, PAHs, and phthalates (Bevans and others, 1996). More organochlorine compounds were detected in water from Las Vegas Wash and at higher concentrations compared to Las Vegas Bay. The lowest concentrations and number of detections were observed at Callville Bay. Organochlorine compounds found included hexachlorobenzene, dimethyl tetrachloroterephthalate (DCPA), several components of chlordane, degradation products of DDT, and PCBs. Dioxins also were detected in water at higher concentrations in Las Vegas Wash compared to Las Vegas Bay with the lowest concentrations in Callville Bay (Bevans and others, 1996). In a more recent study, Alvarez and others (2012) detected 41 organic contaminants in water from Las Vegas Bay, including PAHs, pesticides, Polybrominated diphenyl ethers (PDBEs), and PCBs, and concluded that the source of some of these compounds was flux from the lake bottom sediment. In 1998, Covay and Beck (2001) analyzed sediment samples from four sites in Lake Mead. In Las Vegas Bay, they detected 48 organic contaminants in the inner bay, and 57 in the outer bay; they also detected 31 contaminants in Virgin Basin and 26 in Overton Arm. They detected PAHs, PCBs, organochlorine pesticides, and dioxins and furans; concentrations of the latter two groups were higher in Las Vegas Bay than in Overton Arm and Virgin Basin, suggesting that Las Vegas Wash was one source of these compounds. Alvarez and others (2012) detected 21 compounds in Las Vegas Bay sediment, including PAHs, PCBs, a PDBE, and organochlorine pesticides.

The highest concentrations of organic chemicals detected in fish sampled from May 1999 to May 2000 occurred in Las Vegas Bay, the area of Lake Mead that receives tributary inflow of treated wastewater and urban runoff from Las Vegas Wash (fig. 6-5); six times lower concentrations were detected in Overton Arm. This pattern of detections of hydrophobic organic contaminants in fish from Lake Mead was similar to patterns observed in sediment (see Chapter 4).

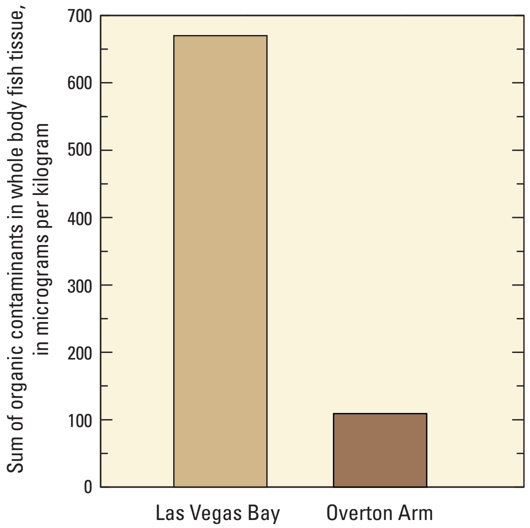



**Figure 6-5.** Comparison of the total mass of organic chemicals in fish in Las Vegas Bay and Overton Arm. Inputs from Las Vegas Wash contribute to the higher mass of organic chemicals for Las Vegas Bay fish (modified from Goodbred and others, 2007).

The number of organic contaminants detected in fish also was greater in Las Vegas Bay (33) than in Overton Arm (20); many of these contaminants are known or suspected endocrine disrupting compounds (Goodbred and others, 2007). In addition, the average concentrations of PCBs in seven fish sampled from Las Vegas Bay were greater than 0.156 mg/kg; all concentrations were greater than the 0.11mg/kg wet weight (ww) value calculated by New York State to protect piscivorous wildlife (Newell and others, 1987). In May 1999, fish PCB concentrations of 0.026 µg/kg in Overton Arm were well below this value. An earlier study of organic compounds in Lake Mead fish by Bevans and others (1996) showed the highest number of detected oganochlorine compounds in Las Vegas Wash (18) compared to 17 in Las Vegas Bay and only 9 in Callville Bay. The highest concentrations of all detected organochlorines were detected in fish from either Las Vegas Bay or Las Vegas Wash. The data from Bevans and others (1996) showed that concentrations exceeded the 0.11 mg/kg value in 100 percent of the fish (6) from Las Vegas Wash and in 66 percent of the fish (4) from Las Vegas Bay, but in none of the fish (6) from Callville Bay. An organic contaminant study in fish from Lake Mohave (Marr, 2007) showed the presence of DDT metabolites, PDBEs, PCBs, chlordane, DCPA, HCB, and octachlorostyrene. All concentrations of PCBs in fish tissue were below the 0.11 mg/kg value although there also were PCBs detected in plasma of both razorback suckers and common carp at levels up to 4 ng/mL.

The latest study (Intertox, 2008) in LMNRA showed that PCBs and chlordane collected in 2005 were detected only in fish from Las Vegas Wash and Las Vegas Bay and not at a reference site, Pahranagat National Wildlife Refuge, which is about 90 mi (144.8 km) north of Las Vegas. Twenty-five percent (8 of 33) of the fish in Las Vegas Wash/Valley and Las Vegas Bay had a PCB concentration that exceeded the 0.11 mg/kg wet weight criterion to protect piscivorous wildlife. DDT breakdown product concentrations were highest in fish from Las Vegas Bay and lowest in fish from Pahranagat National Wildlife Refuge. The results of all these studies of organochlorine contaminants in fish from LMNRA suggest that the most significant threat is from PCBs, which are continuing to decrease over time but still might be of concern for piscivorous wildlife like bald eagles, which are at the top of the food chain.

Within the past couple of decades, a group of organic chemicals that previously were not considered an environmental concern have been detected in streams and lakes around the world, including LMNRA. These chemicals are collectively known as emerging contaminants, and many of them are part of a larger group of organic and inorganic chemicals often referred to as endocrine disrupting compounds (EDCs) because of potential effects from these chemicals on the endocrine system of fish and aquatic animals (see "Endocrine System"). Endocrine disruptors include legacy compounds such as DDT and PCBs, emerging contaminants, as well as metals like cadmium.

## Endocrine System

### What is the endocrine system?

The endocrine system is composed of glands and tissues such as the hypothalamus, pituitary, thyroid, adrenal, thymus, pancreas, ovaries, and testes. These glands and tissues produce and release hormones into the bloodstream that travel to different parts of the body to control development, growth, reproduction, and behavior. In some animal species, hormones also determine whether individuals become male or female during their early development.

### What is an endocrine disruptor?

An endocrine disruptor is a natural or synthetic chemical that, when ingested by an organism, mimics, modifies, or blocks the actions of hormones and disrupts normal physiology (fig. 6-6).

Endocrine disruption occurs through alterations in the production or metabolism of hormones, the delivery of hormones in the bloodstream, or through direct actions on the tissues regulated by hormones. Synthetic chemicals known to cause endocrine disruption include diethylstilbestrol (DES), ethinylestradiol, dioxins, PCBs, DDT/DDE, perchlorate, flame retardants, and some heavy metals. A great deal of attention has been placed on endocrine disruptors with estrogenic (feminizing) activity. The strongest evidence of endocrine disruption in fish from field studies suggest that exposure to steroidal estrogens (including estradiol, estrone, and ethinylestradiol) is the major cause of that disruption, with alkylphenols (breakdown products of chemicals found in detergents and plastics) contributing occasionally (Sumpter and Johnson, 2005).

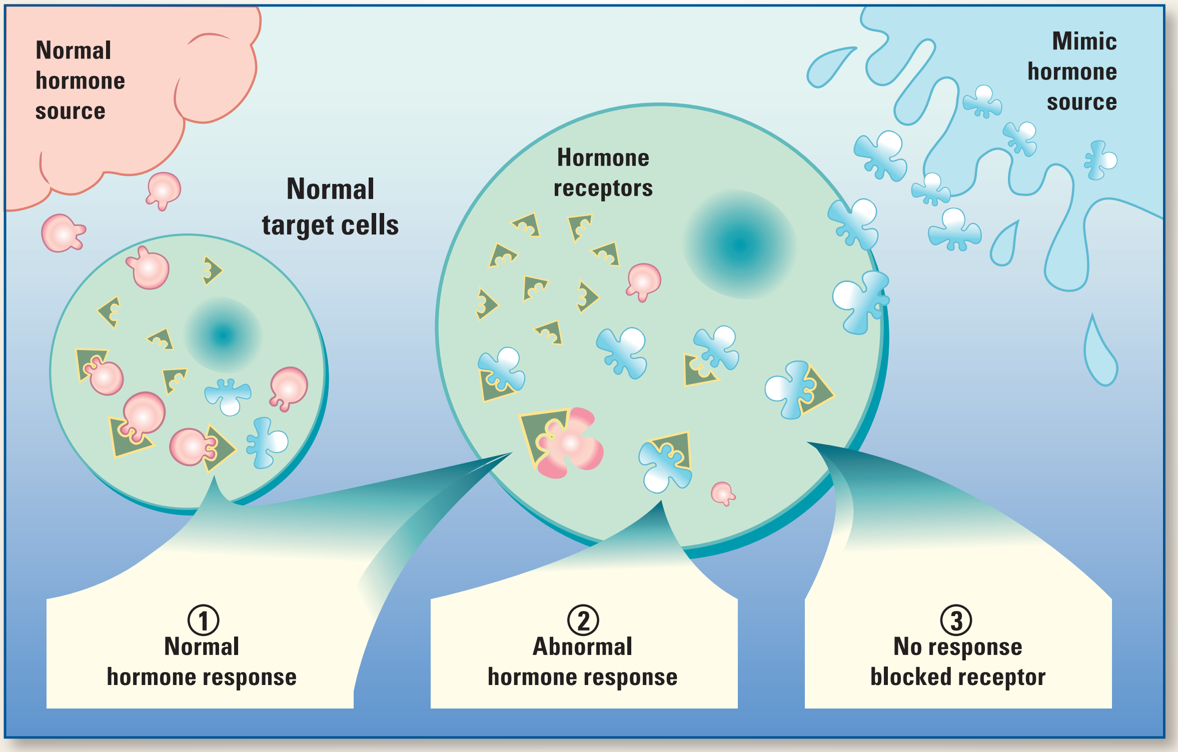



**Figure 6-6.** Endocrine disrupting compounds mimic the response of normal cells and can (1) mimic normal responses and minimally affect the organism, (2) create abnormal responses by the organism's endocrine system, which affect the organism, or (3) block the response of the receptor, which also can be detrimental to the organism.

## Why is knowledge of endocrine disruption important?

At concentrations observed in the environment, many synthetic chemicals cause endocrine disruption in laboratory animals. Some field studies also have implicated endocrine disruption as a factor contributing to the impaired health of fish and wildlife populations. A national study of 139 streams that were considered susceptible to contamination from intense urbanization or livestock production identified 33 streams that contained hormone-based endocrine disruptors and 46 streams that contained pharmaceutically based disruptors (Kolpin and others, 2002). For further information on endocrine disruption, see Tulane University's web site: http://e.hormone.tulane.edu/learning/endocrine-disrupting-chemicals.html. Other useful web sites are those of the National Institute of Environmental Health Sciences (http://www.niehs.nih.gov/health/topics/agents/endocrine/index.cfm) and U.S. Environmental Protection Authority (http://www.epa.gov/endo.)

The first evidence of altered endocrine systems in LMNRA was male common carp in Las Vegas Wash and Las Vegas Bay that were found to have reduced male hormone levels and the presence of a female egg yolk precursor, compared to male fish from a reference site (Bevans and others, 1996). Subsequently, water sampled from Las Vegas Wash and Bay contained detectable levels of **estrogenicity** due to the presence of a natural female hormone (estradiol) and the artificial female hormone used in birth control (ethinyl estradiol; Snyder and others, 1999). These findings suggested that exposure to estrogenic compounds in Lake Mead might explain, at least partially, the '**feminization**' of male carp. In addition, an ecological risk assessment (Linder and Little, 2009) indicated that estradiol at a concentration of 0.1 ng/L or greater in LMNRA posed a risk to more sensitive aquatic life. Although estrogenic compounds were present at some locations in LMNRA, and were suspected endocrine disruptors, a number of other organic chemicals also were present that may have been endocrine disruptors and involved in altering the endocrine systems of aquatic organisms and associated fish health.

More recent information from environmental studies at LMNRA suggest that EDCs likely include a relatively broad group of organic chemicals, including emerging compounds, such as triclosan, a commonly used antimicrobial (Leiker and others, 2009), several types of fragrances like galaxolide (Osemwengie and Gerstenberger, 2004; Rosen and others, 2010), and pharmaceuticals (Boyd and Furlong, 2002; Benotti and others, 2010). Several environmental studies have documented altered health and endocrine effects in some aquatic biota at Lakes Mead and Mohave, including reduced testicular growth in male carp from Las Vegas Bay (Bevans and others, 1996; Patiño and others, 2003; Goodbred and others, 2007), and a number of abnormalities in male carp at Willow Beach on Lake Mohave, such as lesions, liver and kidney abnormalities, **intersexed** ovaries (fig. 6-7), and testicular abnormalities (Hinck and others, 2007; Patiño and others, 2009).

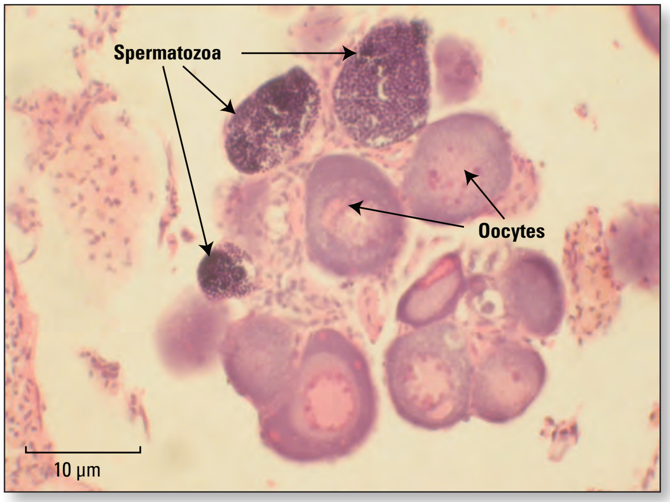



**Figure 6-7.** Intersexed ovary from a female common carp (*Cyprinus carpio*), Willow Beach (Hinck and others, 2007).

Although intersex fish have been documented at Willow Beach, a recent study by Patiño and others (2011) found no intersex common carp in Lake Mead in Las Vegas Bay, nor in Overton Arm or Las Vegas Wash. The occurrence of intersex fish in other areas of LMNRA is uncertain because many of the earlier endocrine and reproductive studies at Lake Mead did not sample gonadal tissue, a requirement to assess intersex. In addition, other species like largemouth bass (*Micropterus salmoides*) (Hinck and others, 2009), which are sensitive to developing gonadal intersex characteristics, have not been thoroughly assessed yet in LMNRA. Another issue to consider in future monitoring of endocrine and reproductive health using common carp as a model is to ensure no hybrids of common carp and goldfish are included in the analysis. Hybrids look similar (fig. 6-8) and they are more susceptible to gonadal tumors and have different endocrine profiles that could bias the results (Goodbred and others, 2013).

In addition to documenting intersex gonads, assessing sperm quality and the presence of vitellogenin (precursor of egg yolk normally found in female fish) are other ways to measure endocrine and reproductive effects of organic contaminants on male fish. Many organic compounds from wastewater are EDCs because they bind to estrogen receptors (Nishihara and others, 2000). Evidence to date has suggested that exposure to potent steroidal estrogens are the primary cause of endocrine disruption in fish, particularly the feminization of males (Sumpter and Johnson, 2005). Feminization can occur after exposure to estrogenic or anti-estrogenic compounds, causing alterations in sex steroid hormone profiles, sperm quality, and secondary sex characteristics (Kime, 1998). Complicating the interpretation of biomarkers from field studies is the fact that fish are exposed to multiple EDCs simultaneously with other chemicals that might interact, resulting in unknown synergisms (combined effects) or antagonisms (canceling effects) and modes of action (Ropero and others, 2006). Because synthetic sex steroid hormones, like ethinyl estradiol (EE2) (the active ingredient in oral contraceptives), can be present at extremely low concentrations (ng/L) (Ying and others, 2002), novel and sensitive methods are being developed to detect such environmental estrogenic compounds (Snyder and others, 1999, 2001). **Xenobiotic** pollutants, including EDCs, may disrupt reproductive endocrine function by interacting with the hypothalamus-pituitary-gonadal axis, as well as between the endocrine and immune systems (Arcand-Hoy and Benson, 1998). Pollutants can affect gamete (egg or sperm) development indirectly via disturbance of the natural hormonal environment, but if such pollutants have hormonal activity themselves, they also can directly affect the local hormonal environment in which the gamete develops (Kime and Nash, 1999). Some environmental contaminants can be toxic to the gamete itself. Sperm quality is the measure of the ability of sperm to successfully fertilize an egg (Rurangwa and others, 2004). The quality of sperm is a major contributing factor to successful production of fish larvae (Kime, 1998) and can be affected by endocrine disruption (Kime and Nash, 1999). The combination of multiple assays on sperm is a better predictor of male fertility than any individual test (Jenkins, 2000).

In 1999, environmental studies in LMNRA began using multiple assays of sperm quality to assess endocrine and reproductive health of fish.

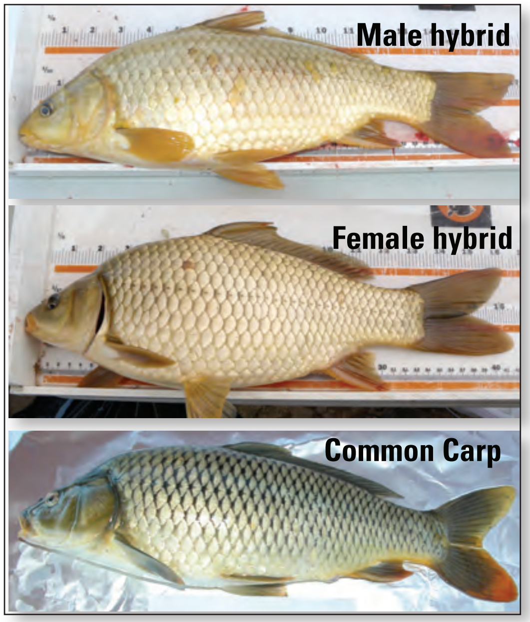



**Figure 6-8.** Hybrid common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) (top two fish), and common carp (bottom fish) from Overton Arm in Lake Mead. Note differences in shape and color.

Tests included sperm counts, viability, motility, and stage of maturation. In Lake Mead, results suggest that sperm quality generally is low at sites with high concentrations of organic chemicals, such as Las Vegas Bay (fig. 6-9; Goodbred and others, 2007; Jenkins and others, 2009). Over a year of sampling bimonthly from May 1999–May 2000, sperm counts, motility, and percent mature sperm were lower in male common carp from Las Vegas Bay than those factors in fish from Overton Arm (Goodbred and others, 2007). In Lake Mohave, Jenkins and Goodbred (2005) found sperm viability reduced by 18 percent compared to fish from areas farther downstream in the Colorado River (fig. 6-10). Lower sperm quality effectively reduces the ability of male fish to fertilize eggs. Ratios of 1,500 sperm per egg are needed to ensure good fertilization rates in the catfish (*Clarias batrachus*) (Rurangwa and others, 1998). It has been suggested that male fish in the wild closely control the sperm/egg ratio to achieve the minimum for full fertilization (Warner, 1997). If this same ratio is maintained by using milt from a fish that has 18 percent reduced sperm viability, the resulting ratio of 1,230 viable sperm per egg in fish from Lake Mohave would likely result in a reduced fertilization rate (Jenkins and Goodbred, 2005). This type of effect could be greater in Lake Mead, where reduced mean sperm counts at Las Vegas Bay and Wash are at least 30 percent lower than Overton Arm (fig. 6-9).

A summary of selected organic chemicals detected in LMNRA is presented in table 6-2. Results of studies in LMNRA indicate that the endocrine system and reproduction in aquatic biota have been altered by some of these chemicals, particularly at Las Vegas Bay and Willow Beach (Bevans and others, 1996; Patiño and others, 2003; Jenkins and Goodbred, 2005; Hinck and others, 2006; Goodbred and others, 2007; Patiño and others, 2009). Legacy compounds like DDE have accumulated through the food chain to high concentrations in bird eggs near Las Vegas Wash and might be causing some effects like eggshell thinning. PCBs also are present at fairly high concentration at both Las Vegas Bay and Willow Beach and may be affecting reproduction and health in aquatic biota. However, many manmade organic compounds detected in LMNRA are present at very low concentrations and have little or no effect on aquatic biota. For example, caffeine has been detected in Lake Mead at higher concentrations in samples collected in August than in March, reflecting higher recreational use in the summer (Boyd and Furlong, 2002), but effects identified in fish are minimal (Brinley, 1934). The highest concentrations of BTEX compounds detected in LMNRA also showed almost negligible toxicity to fish (Lico and Johnson, 2007).

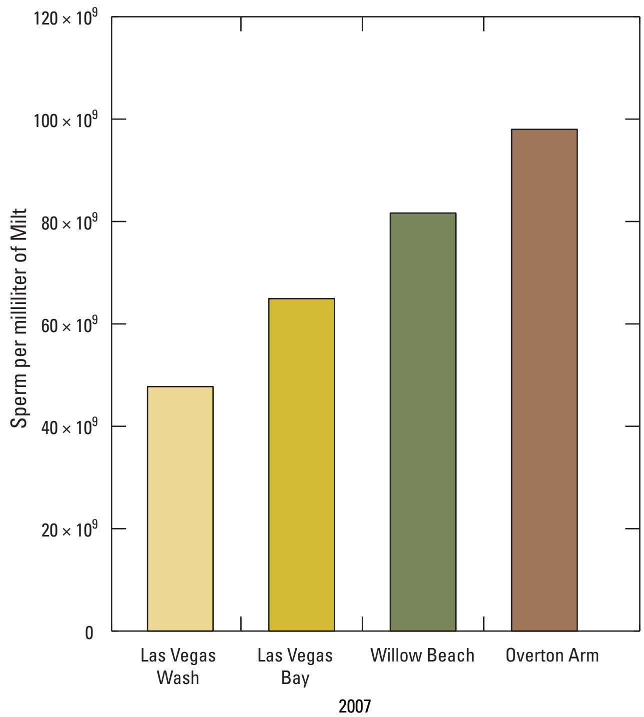



**Figure 6-9.** Sperm counts from male common carp (*Cyprinus carpio*) in LMNRA show the reference site Overton Arm has the highest counts and is statistically different. From Jenkins and others (2009).

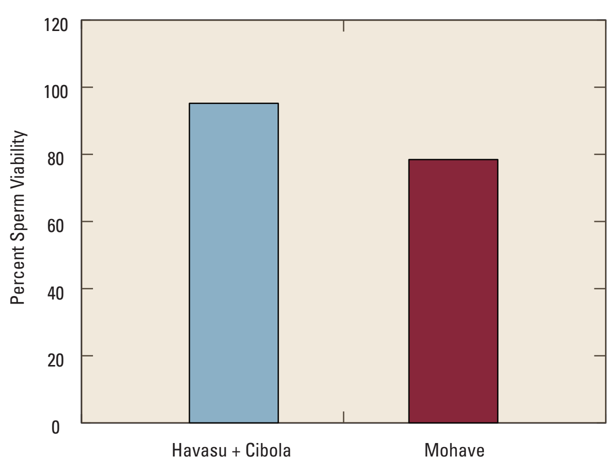



**Figure 6-10.** Mean sperm viability from male common carp collected from downstream sites (Lake Havasu and Cibola National Wildlife Refuge) were statistically higher than those from the upstream site (Lake Mohave). From Jenkins and Goodbred (2005).

**Table 6-2.** Selected organic compounds found in Lake Mead National Recreation Area.

[**Abbreviations:** WWTP, Wastewater treatment plant effluent; LVW, Las Vegas Wash; LV-H, Surface and subsurface inflow to Las Vegas Wash from Las Vegas and Henderson areas; HDT, transformers from Hoover Dam; NA, not analyzed]

| Chemicals | Use | Potential effects | Sources | Maximum concentrations (parts per billion) | |
|---|---|---|---|---|---|
| | | | | Lake Mead | Lake Mohave |
| Legacy compounds | | | | | |
| BTEX | Components of gasoline | Toxicity, cancer | Marinas, boats | [1]10.8 (in water) | [1]23.5 (in water) |
| DDE (breakdown product of DDT) | Mosquito control | Eggshell thinning in birds | LVW, LV-H-pesticide | [2]6,920 (in bird egg) | [3]110 (in fish) |
| PAHs | By-product of burning fossil fuel, found in oil, coal, and tar | Cancer, genetic mutations | LV-H - boat engines | [4]290 (in sediment) | [1]288 (in sediment) |
| PBDEs | Flame retardants | Endocrine disruption | WWTP - clothing, old computers | [5]834 (in fish) | [6]32 (in fish) |
| PCBs (banned in 1979) | Coolant and insulating fluid | Neurotoxicity, endocrine disruption | LVW, HDT - old electric transformers | [5]1,390 (in fish) | [3]1,600 (in fish) |
| Emerging compounds | | | | | |
| Caffeine | Stimulant | Increased heart rate and blood pressure | WWTP-coffee, tea, energy drinks | [7]0.138 (in water) | NA |
| Ethinyl estradiol | Oral contraception | Feminization of male fish | WWTP, LVW - birth control pills | [8]0.0004 (in water) | NA |
| Galaxolide | Fragrance | Weakly estrogenic | WWTP-LVW - perfumes, soaps | [5]2,876 (in fish) | NA |
| Triclosan (including break-down products) | Antimicrobial | Alternations in thyroid hormones | WWTP-LVW - toothpaste, handsoaps | [5]19,105 (in fish) | NA |

[1]Lico and Johnson, 2007.

[2]Advanced Concepts and Technologies International, 2010.

[3]Hinck and others, 2006.

[4]Bevans and others, 1996.

[5]Goodbred and others, 2007.

[6]Marr, 2007.

[7]Boyd and Furlong, 2002.

[8]Snyder and others, 1999.

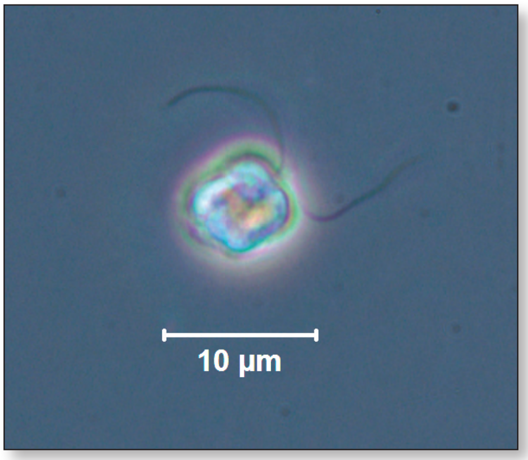
The emerging compounds that are either not currently regulated in wastewater discharges or that do not have water-quality standards pose the most interesting challenge. Even though present at extremely low concentrations (table 6-2), compounds like ethinyl estradiol are very potent endocrine disputing compounds in fish and should be monitored in LMNRA to assess potential effects on aquatic biota. Other emerging compounds, like the fragrance galaxolide, are actually bioaccumulating in fish through the food chain and/or water to quite high levels and, although galaxolide is not nearly as estrogenic as ethinyl estradiol, it could still cause adverse endocrine and reproductive effects (Schnell and others, 2009). The compound with the highest concentration in fish of any organic chemical detected in LMNRA was methyl triclosan—a degradation product of the antimicrobial triclosan (table 6-2), which disrupts thyroid hormones (Leiker and others, 2009). Thyroid hormones in common carp from Lake Mohave were lower than those in fish from other sites in the lower Colorado and could indicate effects of organic contaminants, but cooler water temperatures also might be a factor (Marr, 2007). A recent study in Lake Mead that analyzed thyroid hormones in fish is currently being completed and will provide some insight if this is an issue, especially because concentrations of triclosan can be high in fish (Goodbred and others, 2007).

Organic chemicals detected in LNMRA have a wide diversity of sources and properties and are present in water, sediment, and aquatic biota at varying concentrations. However, one factor that may potentially increase the effects of organic chemicals is the extended drought in southern Nevada that has caused lower lake-surface levels in Lake Mead, resulting in a decrease in dilution of contaminants within the lake (Benotti and others, 2010). This effect may be a greater problem downstream of major sources of organic chemicals, such as Las Vegas Bay. As a result, alterations to endocrine systems, reproduction, and fish health in LMNRA might become more significant in the future if drought conditions are sustained, causing possible increases in organic chemical concentrations. If the drought continues much longer, monitoring of selected manmade organic chemicals to document any changes in concentrations seems warranted.

## Algal Blooms

An increase in abundance of algae is one of the most common, readily visible effects of nutrient loading into aquatic ecosystems (Reckhow and Chapra, 1983; Carpenter and others, 1998) that can be a stressor on the system. With the exception of inner Las Vegas Bay, which is considered nutrient rich (or eutrophic at certain times of the year) due to its relatively high content of nutrients from wastewater, most regions of Lake Mead have normal levels of nutrients (mildly mesotrophic to oligotrophic; Chapter 4). The typical mesotrophic-to-oligotrophic conditions in the lake generally support fairly clear lake conditions rather than high levels of algal growth (primary productivity; Lieberman, 1995; LaBounty and Horn, 1997). A major algal bloom in Boulder Basin in 2001 (LaBounty and Burns, 2005; Chapter 4), however, indicated that Lake Mead has the potential to support very high algae growth when certain conditions are met. Although algae are essential to food-web function, an algal bloom can be a stressor primarily because of decreased dissolved oxygen (DO) levels that can result. When algae die and sink to the lake bottom, bacteria feed on the dead algae, using oxygen in the process. This activity can decrease concentrations of DO in the water column, especially in the hypolimnion, when the lake is stratified. In some circumstances, DO can be depleted in bottom waters, creating a condition known as hypoxia, which has occurred across relatively large aquatic ecosystems, such as parts of the Gulf of Mexico below the Mississippi River (Dale and others, 2010). Certain species of algae also can stress aquatic ecosystems by producing toxins that can be harmful during large blooms (Landsberg, 2002). In LMNRA, some blue-green algae (cyanobacteria) exist that have the potential to produce cyanotoxins. In other lakes, mussels, such as quagga mussels, have caused cyanobacterial blooms following colonization (Higgins and Van Zanden, 2010, and references therein). Cyanotoxins can be highly toxic to animals and have caused mortalities around the world (Stewart and others, 2008). Although it is unlikely that cyanobacterial toxins could cause significant effects in LMNRA (Chapter 4), continued research and monitoring of algae toxins and cyanobacteria populations would be prudent if quagga mussel populations continue to increase in Lakes Mead and Mohave.

Golden alga (*Prymnesium parvum*) is a small organism tolerant of a wide range of salinity and temperature environments and produces toxins capable of killing gilled aquatic organisms like fish (Edvardsen and Imai, 2006; Southard and others, 2010). The first recorded incidence of a golden algal bloom in inland waters of the United States was in 1985 in the Pecos River, Texas (James and de la Cruz, 1989). Since then, golden algae have been linked to killing millions of fish of different species in Texas, but records of blooms also have been found in many other States, including Arizona and Nevada (Sager and others, 2008; Southard and others, 2010). In Lake Mead, samples from Boulder Basin indicated the presence of low densities of golden alga cells as early as 2001 (LaBounty and Burns, 2005). A unique aspect of golden algal blooms in inland (typically brackish) waters is that they tend to occur when water temperatures are seasonally low (Sager and others, 2008).



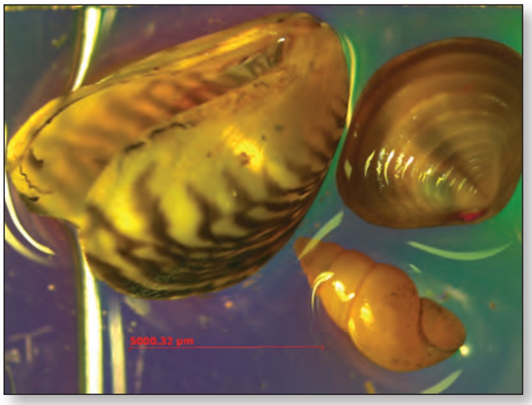

Photomicrograph of golden algae (*Prymnesium parvum*); 1250x magnification. Photograph by Ann St. Amand, Ph.D., PhycoTech, Inc.

However, for the first time in Nevada, a toxic golden alga bloom was reported in Lake Las Vegas in the winter of 2010 (Weber and Janik, 2010). This event raised concern about the potential for toxic blooms to spread into LMNRA and become yet another stressor to aquatic biota. Unfortunately, the environmental factors responsible for golden algal blooms or how and when they produce toxins are not fully understood (Edvardsen and Imai, 2006; Sager and others, 2008), and as a result, it may be difficult to manage blooms if they do occur or to try to prevent them from spreading to LMNRA.

## Invasive Species

By Wai Hing Wong

Invasive species are any non-native species whose introduction creates or is likely to cause environmental or economic harm, or harm to human health. For example, invasive species often cause damage to the native ecosystem or increase industrial costs, such as maintaining cooling water intakes at power plants (see details below; Charles and Dukes, 2007). The rapid introduction of most invasive species is caused by human activities, whether intentional or unintentional, such as recreational boating, cargo shipping, and aquaculture (Nentwig, 2007). Quagga mussels, Asian clams, and New Zealand mudsnails are three major aquatic invasive species found in Lake Mead. These species all belong to the Mollusca phylum of invertebrate animals that include both freshwater and marine mussels, clams, oysters, and snails. Among these, quagga mussels are the most destructive because they attach in vast numbers to hard surfaces (biofouling), such as drinking-water intakes (fig. 6-11). The other effect of quagga mussels is an alteration of the food chain and ecosystem by collectively filtering huge amounts of water and removing large amounts of plankton for food, which then becomes unavailable for other aquatic biota like larval fish.



Photograph of quagga mussel (*Dreissena rostriformis bugensis*) (top left), Asian clam (*Corbicula fluminea*) (top right), and New Zealand mudsnail (*Potamopyrgus antipodarum*) (bottom center) collected from Lake Mead, Nevada-Arizona. Photograph by Scott Rainville, University of Nevada, Las Vegas.

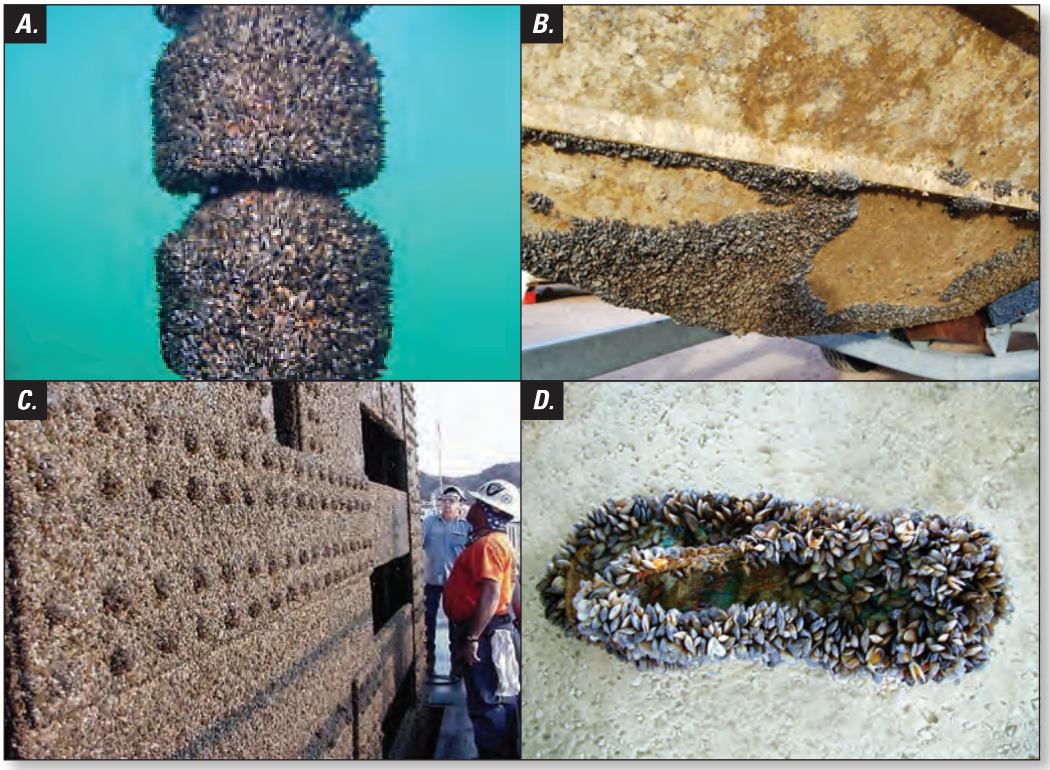


**Figure 6-11.** Examples of quagga mussel fouling at Lake Mead, Nevada-Arizona. (*A*) Water intake; (*B*) boat hull exterior; (*C*) dam gate; and (*D*) a portion of a sandal (Wong and others, 2011). Photographs by: (*A*) and (*B*) Bryan Moore, National Park Service; (*C*) Dave Arend, Bureau of Reclamation; and (*D*) by Wai Hing Wong, University of Nevada, Las Vegas.

The quagga mussel and another related dreissenid species, such as the zebra mussel (*Dreissena polymorpha pallas*), are native to Europe and were accidentally introduced into the Laurentian Great Lakes in North America during the 1980s (Nalepa and Schloesser, 1993). Currently, quagga mussels have been detected in only about 50 lakes outside of the Great Lakes (U.S. Geological Survey, 2012). Quagga mussels were first detected in the Boulder Basin of Lake Mead (Nevada and Arizona, USA) in January 2007. The discovery of quagga mussels was of considerable interest because it was the first confirmed introduction of a dreissenid species in the Western United States (LaBounty and Roefer, 2007; Stokstad, 2007). Since 2002, LMNRA has had policies in place for inspecting large boats arriving from east of the Rocky Mountains via transport company haul permits. From 2003 to 2007, 6 of the 54 inspected boats entering LMNRA had invasive mussels on their hulls and were quarantined and cleaned prior to launch (Hickey, 2010). Most scientists studying the issue believe that quagga mussels were introduced into Lake Mead by recreational boats from the Great Lakes region, because adult quagga mussels are resistant to drying out for long periods (multiple days) and can tightly close their shell when out of water.

The number of young plankton-like quagga mussels (which can float or swim and are called veligers) increased five times in Boulder Basin of Lake Mead, from 0.9 individuals/L in 2007 to 4.5 individuals/L in 2008. In contrast, the numbers of adult quagga mussels counted from 2007 to 2009 increased more than 14 times (624 to 8,925 individuals/$m^2$) in rocky areas, and increased more than 41 times (80 to 3,350 individuals/$m^2$) in sandy and muddy areas (Loomis and others, 2011; Wong and others, in press). Generally, there are more quagga mussels on hard substrates than in soft sediments (Wittmann and others, 2010; Loomis and others, 2011). The presence and spread of the invasive quagga mussel at LMNRA may be influencing lake clarity and food-chain dynamics. From 2007 to 2009, water clarity has increased significantly (13 percent) in Boulder Basin of Lake Mead (Chapter 3). The increase in lake clarity was due primarily to a decline in algae evidenced by declining measurements of chlorophyll (45 percent), a pigment used in algae for photosynthesis (Wong and others, 2011). However, it is unclear how much of the change in lake clarity can be attributed to quagga mussels, as new processing systems for wastewater-treatment plants along Las Vegas Wash has significantly reduced the amounts of phosphorus entering Lake Mead. Because phosphorus is the limiting nutrient for algae growth in Lake Mead, any reductions of phosphorus also reduce algae growth, decreasing chlorophyll and improving water clarity. It is interesting that even with a significant increase in the number of quagga mussels, no detectable changes in composition and abundances to the lower levels of the food chain at Lake Mead have been documented (Beaver and others, 2010; Wong and others, 2010). Moreover, for higher levels of the food chain, no detectable differences in threadfin shad abundance is apparent; however, for gizzard shad, an invasive species first found in Lake Mead in 2007, abundances are increasing (Loomis and others, 2011).

The presence of quagga mussels in Lake Mead may cause a number of potential ecosystems changes (fig. 6-12; Wong and others, in press). For example, quagga mussels filter plankton and nutrients from the middle of the water column and deposit their fecal pellets on the bottom of the lake, shifting energy from the pelagic (swimming) community to the benthic (bottom) community. Because of this shift in energy, fish, such as common carp, that feed on the bottom will benefit, while species, such as threadfin shad, that eat algae and zooplankton will be negatively affected. Quagga mussels also will reduce suspended solids in the water column, providing a general increase in water clarity (Wong and others, 2003; Binding and others, 2007; Wong and others, 2011); as a result, shallow areas in Lake Mead may have improved habitat for both rooted aquatic plants and benthic algae. Additionally, the large population of quagga mussels currently (2012) in the lake may cause an increase in dissolved inorganic phosphorus and nitrogen (Wong and others, 2011). With substantial populations of mussels on the bottom of Lake Mead, the concentration of dissolved oxygen in the hypolimnion (Chapter 4) can be significantly reduced, especially during times of stratification (Caraco and others, 2006).

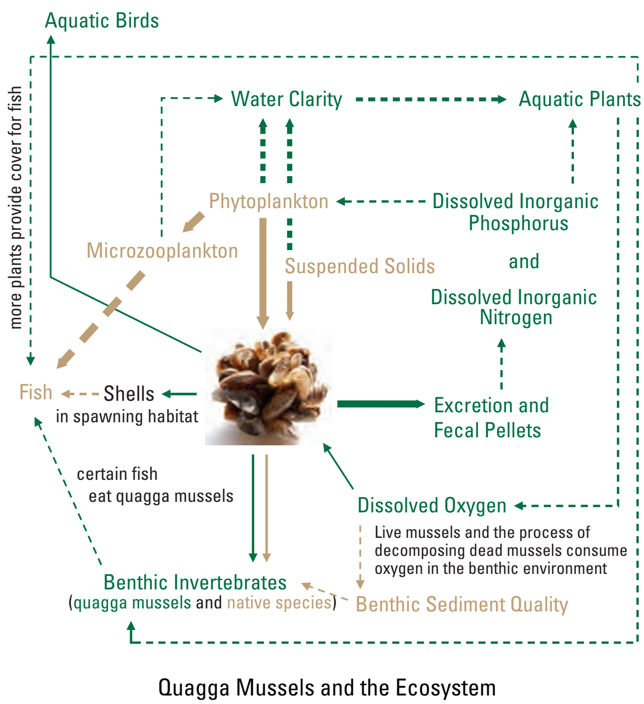



**Figure 6-12.** Simplified conceptual diagram of the potential ecological impacts of quagga mussels on the Lake Mead ecosystem (modified from Wong and others, in press). Enhancing/increasing effects (green) and lowering/decreasing effects (brown) are shown. Solid and dashed lines represent direct and indirect quagga mussel impacts, respectively. The wider the line, the greater the expected impact.

The New Zealand mudsnail was first discovered in Lake Mead in 2008 (Davis and Moeltner, 2010); however, information is sparse on its distribution throughout LMNRA. Although a small aquatic snail—the shell is typically 0.20 by 0.47 in. (5 by 12 mm)—it is hardy and robust, and likely why it has successfully invaded lakes and streams in Australia, Asia, Europe, and North America. In the United States, the New Zealand mudsnail was originally found in Idaho's Snake River in 1987, and currently (2012) is found throughout the Western United States (Benson, 2011); in some western streams, the New Zealand mudsnail occurs at densities greater than 0.5 million/m$^2$. Because the Western United States is well known for its world-class trout and salmon fishing, there is concern that the mudsnails may impact the food chain for native fish, in addition to changing the physical characteristics of the streams (Benson, 2011). Due to the lack of New Zealand mudsnail studies at Lake Mead, however, the potential environmental impacts of this species in LMNRA are unknown.

Asian clams, which are native to Southeast Asia, successfully invaded North American waters at the beginning of the 20th century. They are currently found in 36 States within the United States, as well as in northern and central Mexico (McMahon and Bogan, 2001). Asian clams live in soft sediment and are harvested in some locations for food. Similar to quagga mussels, Asian clams are bivalve mollusks that feed by filtering small food particles from the water. As a result of filter feeding, Asian clams can reduce algal loads, suspended-sediment particles, and some nutrients like phosphates, as well as increase water clarity (Karatayev and others, 2003). However, Asian clams also cause **bioturbation** of the lake bottom, disturbing other animals and plants by moving sediments to dislodge food or directly consuming benthic fauna (Karatayev and others, 2003). Moreover, because of the high density of clams in some areas or on some water intake structures, Asian clams have caused significant damage to some industries; for clogged water intakes in 1986, damage was estimated at $1 billion (Isom, 1986). The massive clogging of intake structures by Asian clams happens because the clams have a very high reproductive rate (greater than 68,000 pediveligers per adult per year) and adult numbers can exceed 2,000 individuals/m$^2$. Asian clams were first discovered at Lake Mead in 1959 (Counts, 1991) and have occurred at densities as high as 100 individuals/m$^2$ in the mid-1980s (Melancon, 1977; Peck and others, 1987), significantly less than densities found in other areas of the United States. Current population densities have been documented at less than 50 individuals/m$^2$ in Lake Mead (Wittmann and others, 2010), indicating that Asian clams seem to be declining, but reasons for the decline are unknown.

## Human Health, Pathogens, and Suitability for Recreation

By Kent Turner, Craig Palmer, and Peggy Roefer

All bodies of water, including those within LMNRA, have the potential to be contaminated by pathogenic bacteria and other disease-causing organisms due to fecal contamination by waterfowl, warm-blooded animals, and humans, even if the body of water is considered pristine. Water managers worldwide are concerned over the potential for human illness from microbial organisms, algal toxins, or other contaminants. Agencies responsible for water-quality standards and management at Lakes Mead and Mohave share this concern as the lakes are used for a wide variety of recreational opportunities that involve full-body contact with the water, including swimming, waterskiing, and personal watercraft use. The most common type of swimming related illness is gastroenteritis, an inflammation of the stomach and the intestines that can cause symptoms like vomiting, headaches, and fever (U.S. Environmental Protection Agency, 2010).

The potential for occurrence of illness-causing organisms can be increased by pollutants entering the water, either on a watershed scale through influences of nearby cities and communities, or on a more local scale through, for example, fecal material from the recreating public or from animals living in or near the water. Conditions that can lead to increased numbers of disease-causing organisms also can be triggered by warmer water temperatures, lower water levels, shallow and stagnant water, and in some cases, re-suspension of bacteria from sediments caused by wave action. Additionally, appreciable rainfall and runoff within an urbanized tributary can temporarily increase the potential for pathogenic bacteria in a lake.

Potential pathogenic bacteria and organisms usually occur in small numbers, which makes them difficult to isolate and monitor. For that reason, water managers typically use other bacteria as indicators of fecal contamination to assess a lake's potential to harbor pathogens and cause illness for recreational water users. For example, *Escherichia coli* is a type of **coliform bacteria** that is found in the feces of humans and other warm-blooded animals. U.S. Environmental Protection Agency (2011a) recommends using *E. coli* as an indicator bacteria for health risk from full-body contact in recreational waters (http://water.epa.gov/type/oceb/beaches/).

Lake Mead receives treated wastewater effluent and urban runoff from Las Vegas Valley via Las Vegas Wash. A discharge permit from the Nevada Division of Environmental

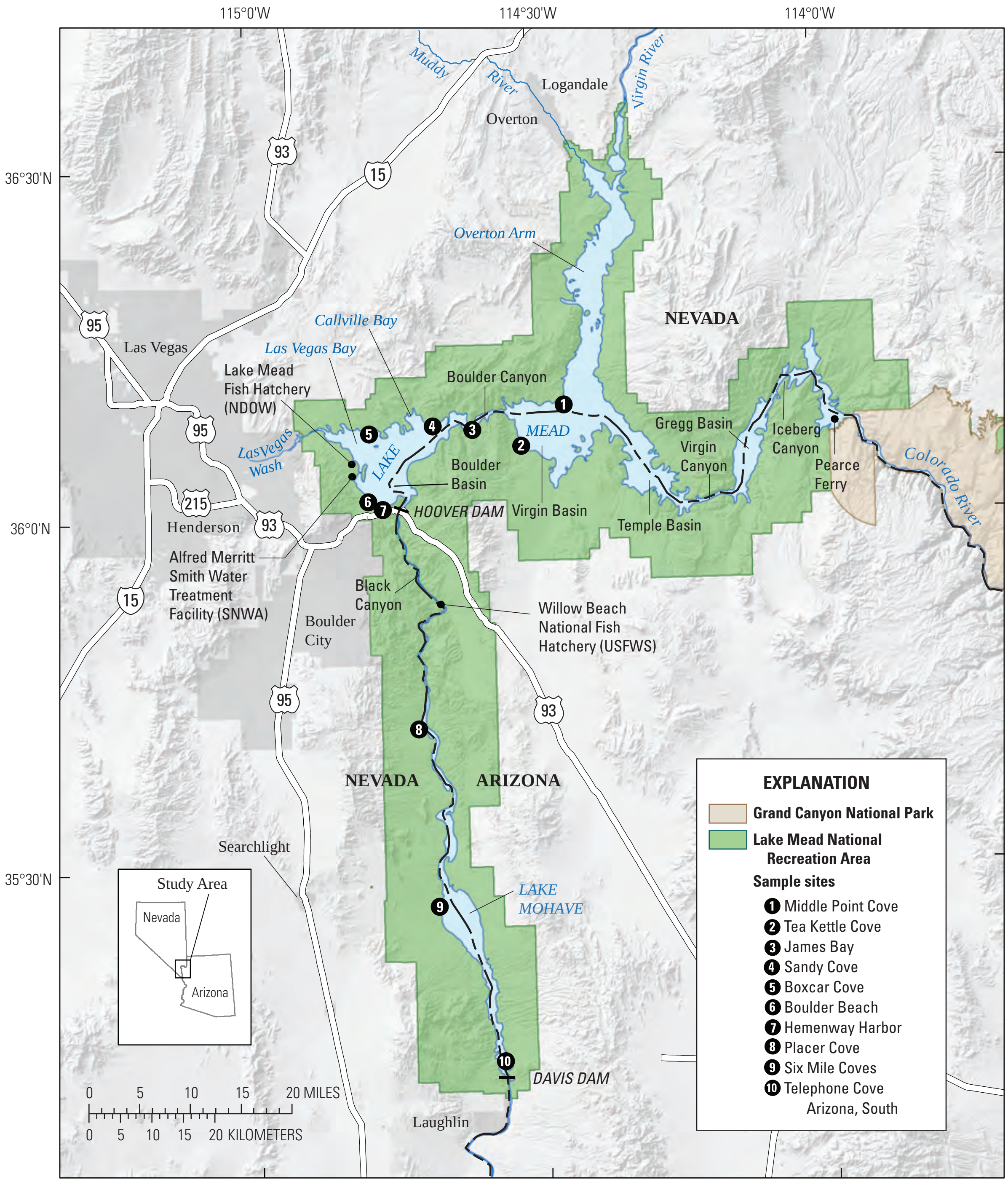
Protection (NDEP) is required for wastewater entering Las Vegas Wash. The urban runoff within the Wash is managed within regulations set by NDEP and the USEPA. The wastewater discharged into the Wash is treated and disinfected, and bacterial concentrations are normally well below established limits for body-contact recreation (even though Las Vegas Wash is not designated as a body-contact recreational water by NDEP). Indicator bacterial counts within Las Vegas Wash can be temporarily elevated above the limits recommended for body contact recreation, however, during periods of higher urban run-off or other inputs into the Wash (Southern Nevada Water Authority, 2011).

Because of the importance of Lake Mead as a recreation area and drinking-water source, NDEP has placed weekly to monthly monitoring requirements for indicator bacteria at a number of locations on Las Vegas Wash and Lake Mead. That monitoring indicates that surface-water quality consistently meets body-contact recreational standards. These standards are met even within the inner Las Vegas Bay, the area of the lake most impacted by the water quality of the Wash (LaBounty, 2005; Holdren and others, 2008). For example, during 2000–2004, there was never an occurrence when concentrations of either fecal coliforms or *E. coli* in the middle and outer portions of Las Vegas Bay exceeded full body contact standards (LaBounty and others, 2003; LaBounty, 2005). In addition, a review was conducted of 2000–2010 data from routine Lake Mead bacteriological water-quality monitoring at 29 sites for fecal coliforms, fecal *Streptococcus*, and *E. coli*, with more than 3,738 samples collected (Palmer and others, 2012). Results of the monitoring showed only 0.9 percent of samples contained *E. coli* concentrations that exceeded the limit set by USEPA for full-body contact in recreational waters (U.S. Environmental Protection Agency, 2011a). In addition, only 1.5 percent of samples exceeded the acceptable full-body contact limit for fecal *Streptococcus,* and 3.8 percent of the samples exceeded the acceptable limit for fecal coliform.

The USEPA National Lake Assessment (U.S. Environmental Protection Agency, 2010) collected and reviewed data for a number of ecosystem and human health indicators to characterize the state of the nation's lakes overall, and provide a context for evaluation of individual lakes (see U.S. Environmental Protection Agency National Lakes Assessment and Lake Mead in Chapter 4). These studies found that Lake Mead was well within the USEPA National Lake Assessment criteria for classification within the best or "good" range for suitability for recreation, as related to human health. USEPA's indicators of suitability for recreation included chlorophyll *a*, cyanobacteria (related to potential of algal toxins), and microcystin (related to algal toxins).

As an additional evaluation of potential lake-wide human health issues, LMNRA, in partnership with Southern Nevada Water Authority, has monitored a number of high-use recreational coves and beaches on Lakes Mead and Mohave for 9 years. Water samples were collected by the NPS between May and September at nine high-use recreation sites from 2003 to 2010. An additional sampling site (Placer Cove) was added in 2008. Analyses of 655 water samples for concentrations of fecal indicator bacteria showed that fecal coliforms were present in concentrations exceeding the USEPA acceptable limit for full-body contact in recreational waters in 3.1 percent of the samples (U.S. Environmental Protection Agency, 2011a). *Enterococcus* concentrations exceeded the acceptable limit in 6.0 percent of 496 samples analyzed and fecal *Streptococcus* concentrations exceeded the acceptable limit in 5.2 percent of 649 samples analyzed. *E. coli* concentrations exceeded the USEPA acceptable limit for full-body contact recreation in only 0.6 percent of the samples. Throughout the 9-year study, Six Mile Coves (fig. 6-13), Placer Cove, and Box Car Cove were identified as those with the highest single-occurrence frequency of unacceptable levels of indicator bacteria.

In addition to bacteria, water managers at LMNRA also are concerned with a number of viruses and protozoans that can occur in any body of water and cause human illness, particularly two protozoan parasites, *Cryptosporidium* and *Giardia*. *Cryptosporidium* is commonly found in lakes and rivers, especially when the water is contaminated with sewage and animal waste. *Giardia* is a parasite that lives in the intestine of infected humans or animals and is found on surfaces or in soil, food, or water that has been contaminated with the feces from infected humans or animals. Both of these intestinal parasites can be spread by wildlife and are now widely distributed throughout the Western United States (U.S. Environmental Protection Agency, 2011b). The Southern Nevada Water Authority routinely tests for both of these organisms as a part of its drinking-water monitoring requirements. Monitoring over the past 10 years has detected very low numbers (1–2) of *Giardia* cysts and *Cryptosporidium* oocysts, with most of detected organisms being *Giardia*. During 2010, neither organism was detected at the drinking-water intakes within Lake Mead (Southern Nevada Water Authority, 2011).




Base from National Park Service and U.S. Geological Survey digital data,1:675,000
Universal Transverse Mercator projection, Zone 11
North American Datum 1983

**Figure 6-13.** Map of bacteriological cove-monitoring sites at Lake Mead National Recreation Area. NDOW, Nevada Department of Wildlife; SNWA, Southern Nevada Water Authority; USFWS, U.S. Fish and Wildlife Service.

## Effects of Climate Change

Observations and studies have shown that many natural systems are being affected by regional climate changes, particularly temperature increases, and that these changes likely will affect the hydrological cycle, with associated impacts to water resources (Brekke and others, 2009). For example, drought in the Southwestern United States during 2000 to 2004, a consequence of both reduced precipitation and a series of the hottest years on record, resulted in streamflows that were lower than those during the Dust Bowl of the 1930s or the drought of the 1950s (Andreadis and Lettenmaier, 2006). Drought conditions caused by below average winter snow accumulation in the Rocky Mountains have periodically reduced surface-water levels and associated storage volumes in Lake Mead (fig. 6-14). Some of the reduced surface levels in the lake during historical regional droughts likely were caused by increased water demand for agriculture and municipal use (irrigating crops and watering lawns, etc). Water levels also were lower in Lake Mead when Lake Powell (a large reservoir upstream of Lake Mead) was being filled in the mid-1980s.

Drought in the Southwestern United States over the past 10 years has led to dramatic lowering of Lake Mead. The top of the white layer is where the lake level was in 1999. Photograph by Michael R. Rosen, U.S. Geological Survey.

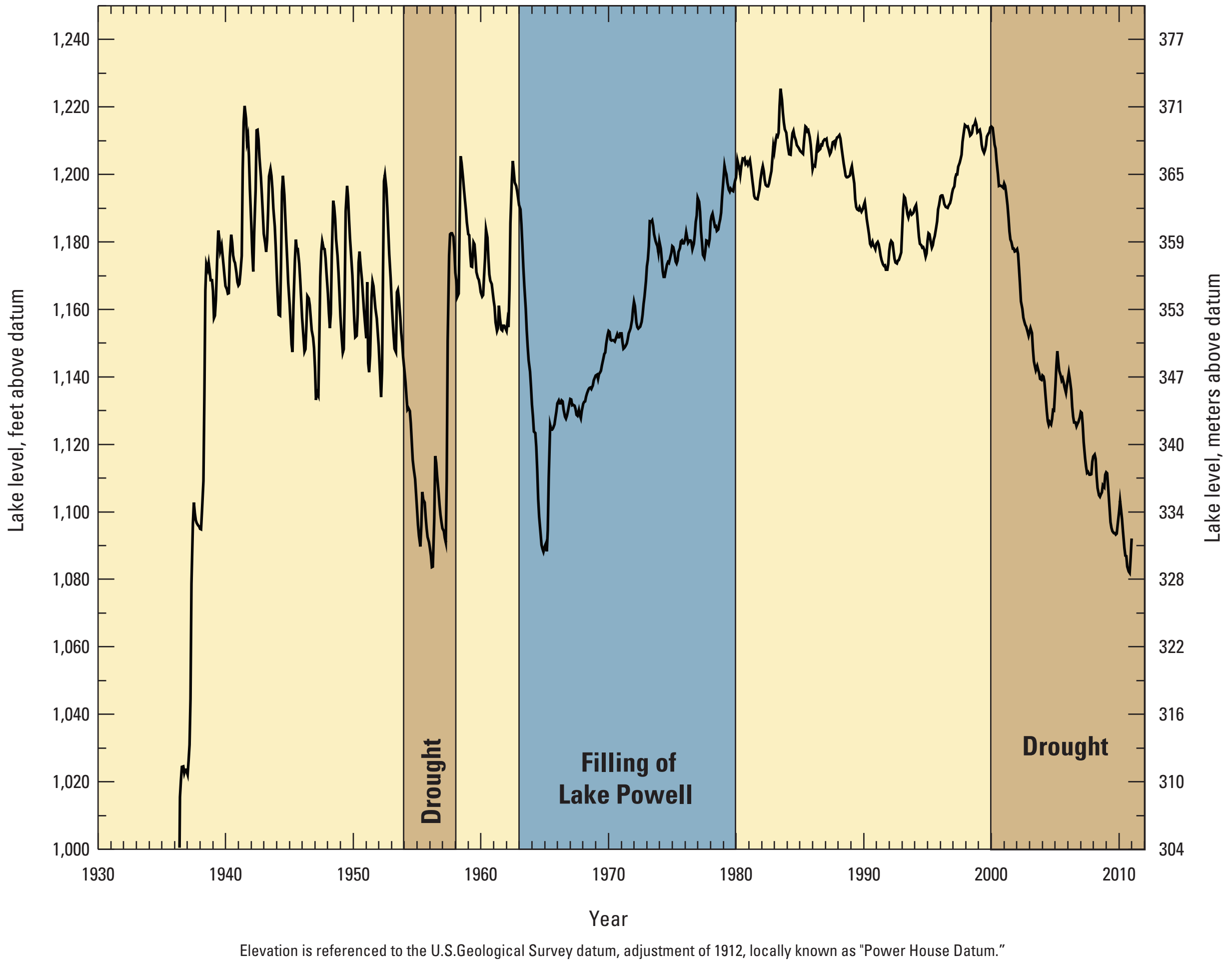



**Figure 6-14.** Lake Mead water levels show low levels during drought periods, 1930–2010.

Simulations made with models of future climate in the Southwest indicate that water levels in Lake Mead will be affected by increased evaporation as air temperatures increase, but also by over-allocation of water from the Colorado River (Barnett and Pierce, 2008, 2009). In fact, temperatures in the Colorado River Basin are projected to increase by 5–6°F (2–3 °C) in the 21st century, with slightly larger increases in the upper Basin (Bureau of Reclamation, 2011). Additionally, projections of precipitation indicate that the 30-year average in 2070–2099 will be drier in the Southwestern United States than in 1950–1979 (Bureau of Reclamation, 2011). Moreover, the models considered to be most accurate predict that flow in the Colorado River basin will be reduced by 5–20 percent from current levels (Ray and others, 2009). As a result of potential, future increases in air temperature and evaporation, and reduced precipitation and flow in the Colorado River Basin, water managers will be faced with difficult choices on how water in the Colorado River is utilized to prevent water shortages at Lake Mead and in the Southwest (Ackerman and Stanton, 2011).

Climate models for the Southwestern United States and the Colorado River Basin also have been applied to predictions of potential future changes in water quality at LMNRA. Most climate models forecast changes in rainfall patterns, including greater probabilities for higher intensity rainfall, flash floods, and storm events (Brekke and others, 2009). These events increase the potential for transfer of nutrients and pollutants, including pathogenic bacteria, to Lake Mead. Monitoring of indicator organisms has shown that unacceptable levels of indicator bacteria generally are associated with periods immediately following a major rainfall or storm event (Southern Nevada Water Authority, 2011). Moreover, forecasts of increased air and water temperature and evaporation, reduced precipitation, and resulting declines in surface-water levels at Lake Mead (Brekke and others, 2009) could possibly cause sediment to become exposed in certain areas, and increase the concentrations of resuspended sediment in the lake. As a result of these potential changes, some areas of the lake could become more conducive to local increases in algae and microorganisms that could possibly create toxic or infectious conditions. Additionally, warmer water temperatures have the potential to increase the spread of some disease-causing organisms. For example, the extremely rare amoeba *Naeglaria fowlerii* has been documented as the cause of three deaths within the Southern United States in 2011 (Centers for Disease Control and Prevention, 2012). And although rare, this amoeba is distributed worldwide, and generally lives in warm, shallow, stagnant water (Centers for Disease Control and Prevention, 2012).

Stormwater flows in Las Vegas Wash (2008). Photograph by Las Vegas Wash Coordination Committee.

Currently (2012), most of the research on climate influences and water availability at LMNRA is focused on human population effects, but no research has been initiated at LMNRA to show the potential effects of changing climate on ecosystem stressors or aquatic biota. For example, lowered surface-water levels likely will eliminate some shallow-lake areas and cause loss of habitat. Razorback suckers traditionally have used very specific and relatively shallow areas in Las Vegas Bay to spawn, such as Blackbird Point; however, effects of lowered lake levels on razorback sucker reproduction is unknown. Additionally, other studies have shown that the concentrations of some organic contaminants have increased over time, perhaps due to lower lake levels, but the influence of this trend on aquatic organisms also is unknown (Benotti and others, 2010). The potential, future influence of increased water temperature on the occurrence of algal blooms and associated, reduced oxygen levels in the lake (Poff and others, 2002) is another climate-induced ecosystem concern at LMNRA.

## Population Growth

The population of Clark County, and particularly the greater metropolitan Las Vegas area, has grown at an exponential rate since the 1940s (fig. 4-22). The 2010 census documented the population in Clark County at 1.95 million people, a 38 percent increase since 2000, for an average increase of 3.8 percent per year. After the economic downturn (recession) in 2008, however, population growth of Clark County has been quite variable, with increases of 1.0 percent growth in 2009 and 1.5 percent growth in 2010, but a decrease of 3.4 percent in 2011 (http://www.clarkcountynv.gov/Depts/comprehensive_planning/demographics/Documents/

HistoricalCCLVVAveragePopGrowthRate.xls). The cities of Mesquite, Nev., and St. George, Utah, both along the Virgin River north of Lake Mead, also grew rapidly between 1990 and 2010. Due to this growth, plans have been developed to construct a pipeline from Lake Powell to St. George, Utah, for delivery of more than 80,000 acre-ft of water annually, enough water for an additional 400,000 people.

Increases in population often are ecosystem stressors because of the increased water use and need for wastewater treatment, and also because of increased chemical use in households (personal-care products), and to maintain lawns and golf courses (fertilizers and pesticides). All of these contaminants may potentially enter LMNRA through treated wastewater discharge to tributary rivers, such as Las Vegas Wash or the Virgin River (see Chapters 1 and 2).

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Chapter 7

# Management Implications of the Science

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View of Boulder Basin, Lake Mead from Fortification Hill. Photograph by National Park Service.

*Lake Mead, particularly its Boulder Basin, is one of the most intensively monitored reservoirs in the United States. With its importance to societal needs and ecosystem benefits, interest in water quality and water resources of Lake Mead will remain high. A number of agencies have authorities and management interests in Lake Mead and maintain individual agency monitoring programs. These programs were enhanced on an interagency basis from 2004 to 2012 to facilitate intensive monitoring in all major basins of the lake. Recognition that increasing stressors and influences in individual basins can affect water quality throughout Lake Mead and gave rise to an even stronger effort towards the development of holistic and effective interagency approaches.*

*In 2010, agency monitoring programs were used to develop a management plan for water-dependent resources at Lake Mead National Recreation Area (LMNRA). The Long-Term Limnological and Aquatic Resource Monitoring and Research Plan for Lakes Mead and Mohave (the Plan; National Park Service, 2010) documented key management questions to be addressed through monitoring and research, and identified interagency strategic objectives for water quality and water-dependent resources. Moreover, the Plan provides a framework for summarizing water quality and water resource information in five resource categories: water quality and limnology; fish and aquatic biota; sediments; birds; and riparian vegetation. The Plan also addresses three stressors to lake resources: contaminants, invasive species, and climate change. For each of these topics, the current (2012) state of knowledge is summarized for LMNRA (table 7-1), including key scientific questions and findings, management implications, and information needs. A more detailed discussion for each topic follows.*

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**Table 7-1.** Key scientific findings, management implications, and recommendations.

| Resource component and related goals | Scientific findings | Management implications | Recommendations for data or information needs |
|---|---|---|---|
| *Water quality and limnology* | Basic water quality parameters are considered well within good ranges compared to both Nevada state standards and USEPA National Lake Assessment criteria. Potential problems with nutrient balance, algae, and dissolved oxygen can occur at times and in some areas of Lake Mead. High quality Colorado River water is detectable as underflow all the way to Hoover Dam, driving base hydrology and mixing. | Recent (2004–2012) intense and Lake Mead-wide scope of monitoring have provided a much better understanding of the hydrology and water quality; more information is needed for Lake Mohave. Highest productivity exists near tributary inflow areas; these areas also have greatest potential for early detection of nutrient related issues. | Maintaining existing (2012) level of lake-wide monitoring of physical and biological parameters of water quality is essential to assess trends and evaluate conditions. Monitoring is foundational to assessing impacts from quagga mussels (*Dreissena rostriformis bugensis*), continued urbanization within watersheds, and potential climate change impacts. Establishment of baseline monitoring for Lake Mohave is critically needed. More intensive information at depth, adjacent to quagga mussel beds, is needed to understand dissolved oxygen and nutrient cycling impacts of quagga mussels. |
| *Fish and aquatic biota* | Sport fish populations are sufficient in size and individual fish condition to support an important recreational fishery. Native fish populations within Lake Mohave are declining, even with intensive management. Lake Mead razorback sucker (*Xyrauchen texanus*) populations are small but important as a unique self-recruiting population. Zooplankton composition may be influenced by quagga mussels but no significant changes noted to date. | Productivity and fish populations for sport fishery appear stable and in balance with the last 20 years of reservoir operations. Quagga mussels and the introduced gizzard shad (*Dorosoma cepedianum*), as well as wastewater treatment technologies may impact that balance. It is important to continue to monitor status of spawning and use areas for razorback suckers, particularly for the Lake Mead population, and continue Lake Mohave razorback sucker management and augmentation activities. | Need to continue annual adult sport fish and threadfin shad (*Dorosoma petenense*) population monitoring now led by Nevada Department of Wildlife and Arizona Game and Fish Department as key baseline to assess impacts of quagga mussels, nutrient cycling and balance, and climate change. Native fish population monitoring prescribed by conservation and recovery plans is critical for assessing trends and evaluating management. Key need is to understand water contaminant effects on native fish and other wildlife populations. |
| *Sediment* | Sediment deposition in Lake Mead prior to creation of Lake Powell was significant; rate has greatly slowed since Lake Powell. Low concentrations of legacy pesticides and some organics are present in sediments, which appear to trap many contaminants so they can't reach overlying lake waters. | Deltas and sediment deposition may act as a sink for low levels of many contaminants. Re-suspension of contaminants could occur with water level fluctuations or increases in storm intensities. New delta deposits from lowering lake levels are good bird habitat for some species and potential new riparian habitats. | Better understanding of the relationship of contaminants in sediments to food web is needed. Characterize transport of sediments and potential re-suspension of contaminants related to lowering water levels. Monitoring delta deposition and geomorphology in response to lowering lake levels and development of potential new habitats and alteration of reservoir hydrology. |

**Table 7-1.** Key scientific findings, management implications, and recommendations.—Continued

| Resource component and related goals | Scientific findings | Management implications | Recommendations for data or information needs |
|---|---|---|---|
| *Birds* | Lakes Mead and Mohave provide important stopover habitat and wintering grounds for many aquatic birds along the Pacific Flyway. Trends include increasing numbers of wintering bald eagles and nesting peregrine falcons. Fluctuating water levels on Lake Mead have produced a variety of shorebird habitats and associated populations. Riparian habitats for songbirds are limited. Contaminant accumulations documented in birds and eggs in Las Vegas Wash; impacts to reproduction are not clear. | While aquatic bird habitats are often ephemeral, recent levels of fluctuation highlight challenges and opportunities created by large and often rapid changes in lake elevation. An understanding of habitats created at different water levels and different rates of water level change in relationship to aquatic and shorebird use is important to understand the continued role of Lake Mead in regional conservation. Understanding pathways of contaminants within the food web and to bird reproduction is needed to assess risks to population health. | Continued monitoring of population dynamics and relationship to available habitats needed to assess response to low water and evaluate bird responses to changes in lake ecosystems. Monitoring of contaminants and studies of the potential impacts to bird populations warranted. Research on potential impacts of quagga mussels on bird health needed, including impacts from bioaccumulation of contaminants, altered food-web dynamics, or avian pathogens induced by limnological effects of quagga mussels. |
| *Riparian and aquatic vegetation* | Lake Mead riparian vegetation is mostly limited to tributary deltas. Declining lake levels have exposed shoreline habitats; however, they present potential for invasive plants. Extensive deltas formed at confluence of the Virgin, Muddy, and Colorado Rivers. Lake Mohave is ringed with shoreline riparian habitats; mostly, however, non-native tamarisk. Mesquite groves line much of Lake Mohave's upper riparian fringe maintained by the consistent lake levels. Data for littoral and aquatic vegetation is limited. | New delta areas provide potential for riparian habitats with native species as a part of the composition. Newly exposed shoreline habitats have potential to spread non-native species. The near-shore band of riparian habitat of Lake Mohave requires active management, to ensure that the pockets of native vegetation remain, and to manage non-native tamarisk for recreation and habitat objectives. There is concern on the Lower Colorado River over spread of non-native aquatic vegetation; and potential effect of quagga mussel infestation on growth of littoral and aquatic vegetation. | Shoreline monitoring for invasive vegetation is needed for early detection and to guide management. This should include inventory for littoral and aquatic vegetation, due to concerns over spread potential of non-native aquatics, and potential quagga mussel impacts. Vegetation and community inventory and monitoring at Virgin River and Colorado River deltas is needed to inform management related to these habitats as a part of overall regional habitats, and to assess restoration potential. |
| *Contaminants* | Concentrations of legacy contaminants such as perchlorate and pesticides are declining due to regulations and mitigation. Emerging contaminants, including endocrine disrupting compounds well monitored and present in low concentrations, especially near Las Vegas Wash. Biomarkers of endocrine disruption documented in common carp (*Cyprinus carpio*) in several studies. | Emerging contaminants of concern are not seen at levels currently known to pose a problem to human health for drinking water or recreating public, but have been documented to cause a number of health effects to individual fish. Water in LMNRA is highly suitable for recreation and is not uniquely contaminated compared to other water bodies influenced by urban watersheds, but such contaminants pose risk to fish and wildlife. | Continued monitoring of legacy contaminants and inventory and monitoring of emerging contaminants of concern in the water column is needed. Greatest new need is for information related to population level of impacts from contaminants that have previously been documented in individual fish, particularly to native and sport fish. |

**Table 7-1.** Key scientific findings, management implications, and recommendations.—Continued

| Resource component and related goals | Scientific findings | Management implications | Recommendations for data or information needs |
|---|---|---|---|
| *Invasive species* | Quagga mussels have become the dominant benthic organism in vast areas of the lakes, with densities greater in areas with rocky bottoms. Quagga mussels are reproducing in lakes year around, with juvenile veliger larvae a significant proportion of zooplankton at certain times of the year. | Quagga mussels have potential to alter water quality and nutrient cycling, plankton composition, and a food-web dynamics. Quagga mussels can degrade recreational setting, although they increase water clarity. Quagga mussels are a significant threat to ecosystems of Lakes Mead and Mohave. | Interagency quagga mussel monitoring plan has provided quality baseline of quagga population. Existing adult and veliger larvae monitoring should continue. Additional work is needed to comprehensively assess ecosystem impacts and food-web dynamics. |
| *Climate change* | Climate models developed for the Southwestern U.S. and for the Colorado River watershed indicate probability of decline in watershed snowpack and thus reduced water availability. Models point to increased potential for summer thunderstorms and flash floods. | Models indicate high probability for longer periods of low water levels in Lake Mead. This would alter water circulation patterns, nutrient cycling, and potentially food-web dynamics. Potentially higher surface-water temperatures could raise productivity, as well as influence human pathogens. Enhanced thunderstorms and floods have potential to carry additional contaminant loading. | Monitoring and research for climate change and impacts on water availability within the watershed are expected to continue on interagency basis given societal needs within the Colorado River watershed. Information needed for Lakes Mead and Mohave related to potential impacts of low flows, lower water levels, increased air temperatures, and increased water temperatures on limnology, ecosystems, fish and wildlife, recreation, and potential pathogens. |

Enjoyment of Lakes Mead and Mohave starts at a young age. Photograph by Jennell M. Miller, University of Nevada, Las Vegas.

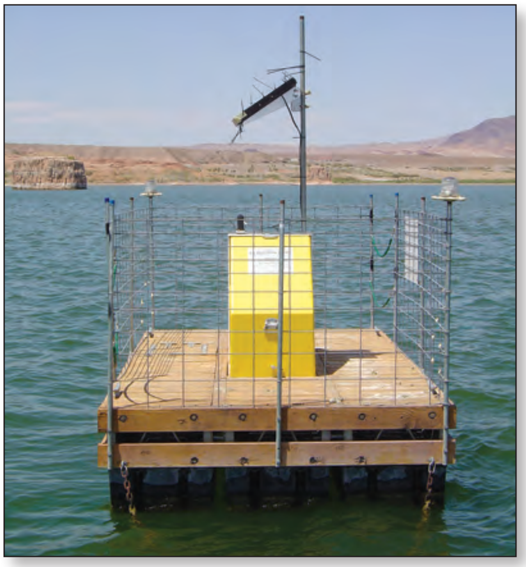
## Water Quality and Limnology

### Key Questions

- What is the status and trends of physical and chemical water-quality parameters (for example, conductivity, dissolved oxygen, nutrients, temperature, transparency, pH, and water levels)?
- What is the status and trends of biological water-quality parameters (for example, plankton and chlorophyll *a*)?
- What is the status and trends of contaminants in the water column?

### Key Scientific Findings

Based on standard limnological trophic indices, the U.S. Environmental Protection Agency's (USEPA) National Lake Assessment standard, State standards, and comparisons with a number of large recreational lakes around the country, Lakes Mead and Mohave generally are of high quality for recreational uses (see Chapter 4). The water surpasses guidelines and standards of quality in support of the beneficial uses of body-contact recreation, fish and wildlife populations, and as a source of drinking water. Measures of limnological characteristics and water-quality parameters are well within ranges considered "good" within the USEPA National Lakes Assessment (U.S. Environmental Protection Agency, 2010) and criteria for categorizing overall lake water quality (see Chapter 4). Trends in the quality of water in Lake Mead reported by SNWA for 2004–2009 show that bacteria, chlorophyll *a*, and algal levels are well within State standards protective of body contact recreation and aesthetics. Clarity, as measured in Secchi depth, has increased such that typical readings exceed 30 ft (9.1 m) and maximum readings exceed 60 ft (18.3 m), values approaching those measured in Lake Tahoe. Reductions in chlorophyll *a* and increases in water clarity most likely result from enhancements in phosphorus removal achieved by the wastewater reclamation districts, in part as a response to a significant algal bloom in 2001, although recent quagga mussel introduction may play a role (see Chapters 4 and 6). Recent (2007–2011) 5-year trends for most limnological measurements are within ranges observed over the past 20 years, indicating a general stability in water quality. However, dissolved oxygen concentrations decreased in the tributary confluence areas of Overton Arm (Muddy and Virgin Rivers) and Gregg Basin (Colorado River) as lake levels declined from 1999 through 2010 and nutrient inputs from tributaries into relatively shallow lake areas increased. The dissolved oxygen concentrations in these areas rose in 2011 as lake elevations rose due to significant increases in flows from the Colorado River. Most standard water-quality parameters and limnological characteristics classify the lake as slightly oligotrophic, and are within ranges to support interagency objectives for wildlife and fisheries, domestic water supply, and recreation.



Instruments used to monitor water quality on a near-continuous basis in Lake Mead. Photograph by National Park Service.

## Management Implications

The basic hydrology and limnology of Lakes Mead and Mohave are well understood, in part owing to the large volume of data from past monitoring efforts, particularly for Lake Mead. This understanding has been invaluable in assessing impacts of potential contaminants and assisting agencies in developing water-management facilities and programs. Increasing urbanization within the tributary watersheds of the Virgin and Muddy Rivers as well as Las Vegas Wash, along with emerging threats such as quagga mussels, endocrine disrupting compounds (EDCs), and potential for lower water-level conditions associated with climate change, necessitates ongoing monitoring to maintain the existing high-quality water.

For example, quagga mussels in other lake systems have been implicated in increases in the abundances of cyanobacteria (blue-green algae) species that can produce toxins (cyanotoxins). Although cyanobacteria cell counts in Lake Mead are sometimes within the USEPA's National Lake Assessment "moderate risk exposure" level, the species identified generally are not species with potential to create toxins (see Chapter 4). Analyses of a small number of individual samples on Lake Mohave since 2007 have shown brief periods of higher-than-usual cyanobacterial cell counts. Quagga mussels in other systems also have been found to decrease dissolved oxygen concentrations in lake-bottom areas, particularly during periods of lake stratification. The improved treatment of wastewater discharged into Las Vegas Wash, however, has resulted in higher concentrations of dissolved oxygen in Las Vegas Bay offsetting potential quagga mussel-mediated dissolved oxygen reductions in Boulder Basin.

Lower lake levels could alter basic hydrology and water-column mixing of Lake Mead, and thereby alter algal growth and composition, sediment distribution, and dissolved oxygen levels. Declining or significantly lower lake levels could result in the creation or growth of deltas at the confluences of Las Vegas Wash, the Virgin and Muddy Rivers, and Colorado River. Newly cut and exposed sediments and deltas have the potential to re-suspend contaminants bound within sediments to the open-water column. Reductions in dissolved oxygen concentrations were noted at times in the Muddy and Virgin Rivers and Overton Arm during extended low-flow conditions. To date, these periods of lower dissolved oxygen have not resulted in documented issues to fish or ecosystem health.

Contaminant inputs to Las Vegas Wash are the most significant influences to water quality in Lake Mead. While it appears that organic contaminants and compounds regarded as emerging contaminants of concern (for example, personal care products, pharmaceuticals, and EDCs; see Chapter 6) are not known to cause significant human health issues for Lakes Mead and Mohave, biomarkers of the effects of such contaminants (for example, intersex fish, reproductive tissue and organ impairments, and tumors; see Chapter 6) have been documented in common carp (*Cyprinus carpio*) from both lakes. Common carp were assessed for these biomarkers as surrogates for potential impacts to reproduction and population dynamics for razorback suckers (*Xyrauchen texanus*) as well as for recreational sportfish.

Increasing urbanization along the Muddy River and Virgin River tributaries has the potential to lower water quality in Lake Mead. Potential outcomes include algal blooms, higher salinity, or higher concentrations of emerging contaminants. Upgradient urban growth also may alter currents and mixing patterns of Lake Mead due to changes in the magnitude and timing of tributary discharge and inflow. The cooler and oxygen-rich inflow waters of the Colorado River are transported as an underflow all the way to the Hoover Dam (see Chapter 4), which influences the overall hydrology, water quality, and ecology of the lake.

## Data and Information Needs

The capability to characterize the current limnology and water quality of Lake Mead is a result of more than 20 years of regulatory monitoring in Las Vegas Wash and was enhanced by lake-wide monitoring efforts from 2004 to 2012. Ongoing lake-wide, long-term monitoring is needed to assess potential future resource changes such as increasing urbanization along tributaries or effects of changing climate. Longer-term datasets for important monitoring stations should include both physicochemical parameters of water quality, such as conductivity, dissolved oxygen, nutrients (nitrogen and phosphorus), temperature, transparency, pH, and water levels, and also the biological parameters of plankton and chlorophyll *a*. These datasets are essential for separating the affects from anthropogenic and natural influences; and evaluating statistically significant seasonal, annual, or decadal trends. Although a comprehensive baseline water-quality monitoring network has been established and operated on Lake Mead, no such monitoring has been conducted on Lake Mohave so that its historical water-quality data are sparse. Lake Mohave is a key recreational resource, serving more than 2 million visitors each year. It also provides critical habitat for razorback sucker. The shallower water of Lake Mohave may react differently than Lake Mead to impacts from increased nutrient inputs, contaminants, or climate change. It is important to establish baseline water-quality monitoring for Lake Mohave.

In addition to a core set of monitoring stations for both Lakes Mead and Mohave, lake-wide longer term monitoring and research should focus on priority information needs, such as potential issues related to periods of lowered water levels, invasive quagga mussels, or the relation of either of these two issues to nutrient loads and food-web dynamics. For example, monitoring is needed to enhance understanding of the influence of lowered water levels or invasive quagga mussels on zooplankton and cyanobacteria, or dissolved oxygen concentrations with depth.

Existing monitoring of inorganic contaminants, such as perchlorate and selenium, are likely to continue based on regulatory requirements. Coordination of this monitoring with efforts to reduce inputs of selenium and perchlorate to Las Vegas Wash will be protective of Lake Mead. Monitoring of emerging contaminants of concern is not a regulatory requirement, but is needed to better understand potential, future impacts to ecosystem health in LMNRA and downstream in the Lower Colorado River. Moreover, monitoring for EDCs at least at current levels can enhance the overall understanding of effects of these compounds and benefit regional and national regulatory agencies responsible for aquatic ecosystems influenced by anthropogenic sources of inflow.

## Fish and Aquatic Biota

### Key Questions

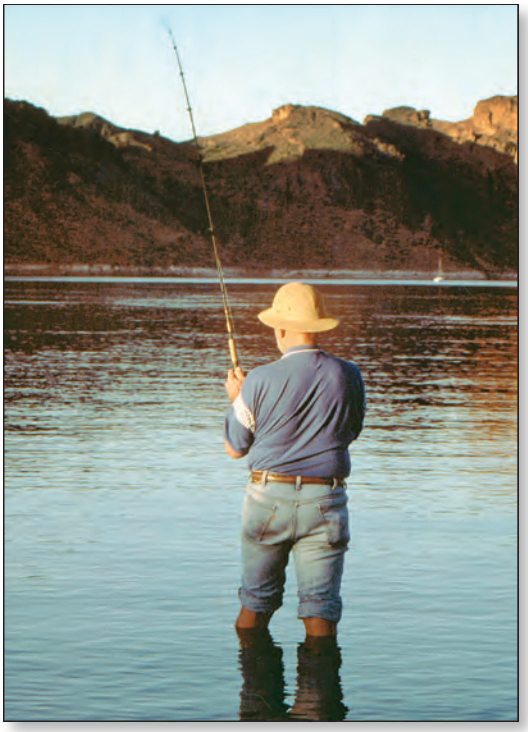
- What is the status and trends of the forage base?
- What is the status and trends in abundance and health of sportfish?
- What are the distributions, reproduction rates, and recruitment levels of native, non-native, and invasive fish?
- What is the biological, chemical, and physical condition of razorback sucker spawning and rearing habitat? Does improved water quality support recovery of razorback suckers?

### Key Scientific Findings

Given the size of the lakes, and their location along the original Colorado River channel, Lakes Mead and Mohave are important water resources for regionally and nationally significant wildlife populations. Although the lakes continue to provide habitat conditions that support many pre-reservoir plants and animals, the completion of the reservoirs has forever altered the Colorado River ecosystem by destroying original and providing new habitats.

Lakes Mead and Mohave are classified as moderately productive in terms of the basic sources of food that support fish and wildlife (see Chapter 4). Plankton, algae, zooplankton, and benthic invertebrates provide base productivity (see Chapter 5). The tributary inflow areas of Las Vegas Wash and the Muddy and Virgin Rivers (Overton Arm) provide the greatest base productivity, due to their higher nutrient inputs.

Phytoplankton forms the base of the aquatic food web and, in Lake Mead, has greatest productivity in nutrient-rich inflow areas downgradient of Las Vegas Wash and at the confluence of the Muddy and Virgin Rivers. Historically, Las Vegas Bay has had periods of increased nutrient concentrations that produced algal blooms. In response to an algal bloom in 2001, wastewater-treatment plants have significantly reduced the amounts of phosphorus released into Las Vegas Wash over the past decade. The reduced phosphorus has reduced alga concentrations in Boulder Basin (as measured by chlorophyll *a*) from the high levels measured in 2001. Although the base algal concentrations declined from 2001 to 2010, angler success, fish-body-condition factors, and catch rates during fishery monitoring show that algal levels have remained supportive of an active recreational sport fishery.



Fishing is one of most popular pastimes at Lake Mead National Recreation Area. Photograph by National Park Service.

The water column in Lake Mead supports more than 70 zooplankton species, including copepods, cladocerans, rotifers, and ostracods (Chapter 5). The zooplankton community is an important food source for fisheries, particularly for threadfin shad (*Dorosoma petenense*), the primary forage fish. Studies of other large lakes with longer-standing quagga mussel infestations show a negative impact on the overall composition and abundance of other zooplankton. However, current data (2007–2011) for Lakes Mead and Mohave indicate that although quagga mussel veligers can periodically be a dominant species of zooplankton, the overall biomass and composition of other zooplankton remain sufficient for fish forage species to support the fishery.

Comprehensive surveys at Lake Mead since 1986 show a change in the benthic invertebrate community over the past 30 years, but it is not clear whether such changes result from lowering lake levels, decreases in algal levels, invasion by new non-native invertebrates, or other factors. For example, since the 1980s, densities of Asian clams (*Corbicula fluminea*) and chironomids generally have decreased, oligochaeta densities have not changed significantly, and other taxa have increased in average density (Chapter 5). The most dramatic changes have been the introductions of the invasive quagga mussel and New Zealand mudsnail (*Potamopyrgus antipodarum*).

Lakes Mead and Mohave are home to at least 15 different species of fish. These include the native flannel mouth sucker (*Catostomus latipinnis*), razorback sucker, and bonytail chub (*Gila elegans*). The razorback sucker and bonytail chub are Federally listed as endangered and Lakes Mead and Mohave are listed as critical habitat for the razorback sucker. Lakes Mead and Mohave support a significant recreational sport fishery, with the primary sportfish including striped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), and smallmouth bass (*Micropterus dolomieu*). Striped bass numbers and condition factors fluctuate based on the availability of their primary forage species, threadfin shad. While numbers of largemouth bass have declined in recent years, the arrival of smallmouth bass, which now comprises 40 percent of the black bass catch, has increased opportunities for black bass anglers. Complicating the Lake Mead fishery management has been the non-intentional introductions of tilapia over the past 15 years, and gizzard shad (*Dorosoma cepedianum*) since 2007. Tilapia have become fairly established as a lesser-sought sportfish, and so far have not been shown to have negative impacts to the overall fishery. Although abundant young gizzard shad have so far provided an additional forage fish, their long-term impact is unknown.

As recently as the 1980s, Lake Mohave was thought to have a population of 50,000 or more adult razorback suckers, but most of these fish have been lost to old age. Although razorback spawning has been documented and continues in Lake Mohave, this has not resulted in natural recruitment or survival of naturally spawning fish to adults. Despite campaigns to capture larval razorback suckers and grow them to a size sufficient to avoid non-native predators such as striped bass when released, the population in Lake Mohave has declined to less than 2,500 adults. Moreover, the bonytail chub is believed extirpated from the Lower Colorado River, and is known to survive only as a handful of adults within Lake Mohave.

The Lake Mead razorback sucker population also is small, with only 80 fish captured at all monitoring stations in 2008–2009. However, the razorback sucker population at Lake Mead is significant because it is one of the few populations on the Colorado River that continues to have recruitment solely from naturally spawning adults. Like the razorback sucker, the flannel mouth sucker has been captured in small numbers during monitoring surveys conducted at the mouth of the Colorado River inflow (52 captures in 2010) and the Virgin and Muddy River inflows (5 captures in 2009–2010).

## Management Implications

The current status of plankton, zooplankton, and invertebrate base productivity appears well within ranges to support existing populations of native fish and an active recreational sport fishery in LMNRA. However, a variety of influences on base productivity will require continued monitoring and management. For example, within the phosphorus-limited system of Lake Mead, increases in concentrations of phosphorus or alterations in the mixing of the tributary inflows with seasonal availability of nutrients can have an immediate effect on overall algal production. Continued monitoring of overall nutrient loading and algal production is necessary to assess success in meeting water-quality objectives for recreational experience, sport fishing, and drinking water.

Quagga mussels have the potential to alter the food-web dynamics of Lakes Mead and Mohave, including changes to native fish and sportfish. Similar to changes seen in the Great Lakes fishery, quagga mussels have the potential to impact zooplankton populations and forage fish productivity. Gizzard shad also have the potential to influence the overall forage base, including threadfin shad, and alter food-web dynamics at Lake Mead. Although threadfin shad populations fluctuate in periodic cycles, they appear to have reached an equilibrium that adequately supports the current sport fishery.

Biomarkers of impacts to fish from emerging contaminants of concern and EDCs have been documented at LMNRA, including biomarkers with the potential to impact reproductive fitness. Although the impacts appear to be greatest in Las Vegas Bay of Lake Mead, biomarkers of masculinization of female common carp (Chapter 6) have been documented in Lake Mohave downstream of the Hoover Dam.

## Data and Information Needs

Current (2012) monitoring of zooplankton, threadfin shad, and other forage fish is essential to provide information on status and trend of the base productivity and forage base. Continued monitoring of adult fish populations also is important to document fish population dynamics. Trend data on the food base and adult sportfish are necessary in assessing food-web dynamics, and assessing issues of nutrient balance, quagga mussel impacts, and contaminants towards meeting objectives of healthy fish and wildlife populations.

For native fish, information on population dynamics, spawning areas and habitats, and forage base and food sources is needed. This information supports management related to issues of nutrient loading and transport, as well as potential impacts from quagga mussels and gizzard shad.

Research is needed on the population effects of contaminant-related biomarkers for native and sportfish. Continued monitoring of emerging contaminants of concern also is needed, with improved understanding of contaminant fate and transport. More information is needed on how contaminants are affecting not only native fish and sportfish, but also aquatic birds and other wildlife. Baseline conditions for EDCs should be established in the Muddy and Virgin River watersheds prior to potential increases in urban populations and associated increases in wastewater effluent and urban runoff to the Overton Arm of Lake Mead.

# Sediments

## Key Questions

- What is the status and trend of resuspension and transport of contaminants and nutrients from sediments?
- What is the status and trend of sediment delivery at tributaries?

## Key Scientific Findings

Sediment cores and survey maps show that large volumes of sediment have accumulated on the floor of Lake Mead since the closure of Hoover Dam, but that most of the sediments were deposited prior to the completion of the upstream Glen Canyon Dam in 1965 (Chapter 3). The early deposition of sediments was significant, with approximately 2.7 million acre-ft of sediment, or 12 percent of the original lake volume, filled by the 1965 closing of Glen Canyon Dam. Glen Canyon Dam greatly reduced sedimentation rates and was estimated to have increased the life of Lake Mead by 500 years. The thickest sediments are along the original Colorado River channel, where they are as much as 279-ft (85.0-m) thick at the upper end of the lake near the entry of the Colorado River, thinning to about 82-ft (25.0-m) thick at the base of Hoover Dam (Chapter 3). Sedimentation at the entry of the Colorado River to Lake Mead has formed thick delta deposits that advanced rapidly into the lake during the first 13 years of its formation, then advanced at a slower rate from 1950 to 1965, and has nearly stopped since 1965 (Chapter 3; Twichell and others, 2005). Sediment and geologic maps of the lake bottom also have been used to help identify potential differences in quagga mussel colonization around the lakes because quagga mussel densities are greater within hard rock substrate areas than in areas of soft sediments (Chapter 5; Wong and others, 2011).

Sediment inflow at the main stem of a river or at tributary areas may bind contaminants during deposition and, for certain contaminants, may provide a tool for evaluating sediment deposition rates and depositional history. For example, several sediment cores were taken in Las Vegas Bay, Boulder and Virgin Basins, and Overton Arm to determine changes in sedimentation rates and chemical inputs from the completion of Hoover Dam to 1998, when the cores were collected (Chapter 3; Rosen and Van Metre, 2010). Results from those studies also showed that compared to other lakes in the United States influenced by urban discharge, the concentrations of inorganic and organic chemical and compounds in Lake Mead are relatively low (Chapters 4 and 6).

Tributary deltas moved into the lake during a period of declining lake levels from 1999 through 2010. Subsequent incision by tributary streams have eroded delta sediments, periodically suspending and transporting sediments and bound contaminants into Lake Mead.

Sediment sample collected from Las Vegas Bay. Photograph by Michael R. Rosen, U.S. Geological Survey.

## Management Implications

The erosion of sediment deposits at tributaries has the potential to resuspend contaminants previously bound within the sediments. For many contaminants, the concentrations within sediments are low, and resuspension of the sediments would not likely create significant increases in overall contaminant concentrations. However, for some contaminants, such as dichlorodiphenyltrichloroethane (DDT), for which significant reductions have been made in upstream concentrations in recent years, resuspension of sediments could increase concentrations in the lake.

Migrating and expanding sediment deltas at tributary inflow areas as a consequence of lower lake levels have created extensive potential new wildlife habitats. Declining lake levels, however, also have potential to create additional areas of shallow water, which can result in increases in water temperature and encourage algal growth, as well as alter overall lake mixing and hydrology. Differing bottom materials, such as either hard rock surfaces or deposits of soft sediments, create different habitats for fish and wildlife, including differing population potentials for the invasive quagga mussel.

## Data and Information Needs

Periodic collection and analysis of sediment cores in previously sampled areas will provide information on status and trends to indicate if rates of contaminant inputs are changing, or if additional pollutants may be accumulating. More information is needed on potential for resuspension and transport of contaminants and sediments, particularly in light of projections of higher probabilities for lower lake levels. As tributary delta areas are important ecologically, and shift in relation to lake levels, information on status and trend of sediment delivery and accumulation at tributaries, and impacts to habitats and water mixing is necessary. Finer resolution sediment maps will be helpful in assessing food-web dynamics and wildlife shifts related to invasive quagga mussel.

# Birds

## Key Questions

- What is the distribution, species composition, and abundance of shorebirds, wading birds, waterfowl, and other classes of birds? What is 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?

## Key Scientific Findings

Lakes Mead and Mohave provide important stopover habitat and wintering grounds for many aquatic birds along the Pacific and Intermountain Flyways of Western North America. During recent, multi-year monitoring, 92 species of aquatic birds were documented, along with four additional species strongly associated with these lakes [belted kingfisher, (*Megaceryle alcyon*), osprey (*Pandion haliaetus*), bald eagles (*Haliaeetus leucocephalus*), and peregrine falcon (*Falco peregrinus*)]. The most common species was the American Coot (*Fulica americana*), a migratory herbivore that winters in large numbers in these lakes.

Lake Mead has a greater diversity of aquatic bird species than Lake Mohave, with about a third of the species observed only on Lake Mead. This greater species diversity results primarily from the nutrient-rich and delta-forming inflows of the Muddy, Virgin, and Colorado Rivers, and Las Vegas Wash. Recent (2004–2009) lake-wide aquatic bird surveys found that the fluctuating water level of Lake Mead also produced a diversity of dynamic habitats, including temporary mudflats and open beaches preferred by many shorebirds (Chapter 5). Such ephemeral habitats have attracted breeding by snowy plovers (*Charadrius nivosus*), a species considered threatened along the Pacific Coast. In contrast, Lake Mohave maintains a more regular surface-water level and has limited tributary inflow and nutrient input. Moreover, other than periodic floods from local drainages, source waters to Lake Mohave are cold, clear waters released from Lake Mead; the lesser diversity of avian habitats and tributary sources results in lower bird species diversity for Lake Mohave.

Lakes Mead and Mohave are home to osprey, bald eagles, and peregrine falcon that take advantage of aquatic prey. Osprey and bald eagles can be observed in any season, but use shifts seasonally, particularly for bald eagles, which typically

Common loon (*Gavia immer*) on the water in Lake Mead. Photograph by Joseph G. Barnes, University of Nevada, Las Vegas.

are present in higher numbers during non-breeding winter months. Bald eagle numbers have trended upwards over the past decade, with 163 counted during a 1-day winter survey in the 2011. Peregrines falcon numbers also have grown dramatically since the first breeding pair was noted in 1985, and in 2010, 33 nesting territories were known to be occupied in areas around the lakes.

Riparian habitats that support songbird populations are limited along the shores of Lakes Mead and Mohave. Of conservation importance, surveys for the Federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*) conducted through the Lower Colorado River Multi-Species Conservation Program have found low numbers of migrating flycatchers along Lake Mohave, but none along Lake Mead. Nesting habitat for southwestern willow flycatchers occurs along the Virgin River adjacent to LMNRA, and tributary delta areas of Lake Mead have potential to become new habitats, particularly where declining lake levels have exposed new riparian areas near tributary inflows of the Virgin and Muddy Rivers.

Shorebird habitat has been relatively abundant on Lake Mead during the past several years due to declining and fluctuating water levels that have produced mudflats and beaches. The extent and conditions of these habitats are always variable, becoming overgrown with emergent vegetation through time or easily inundated when waters rise. Slowly rising water levels that inundate terrestrial vegetation establish shallow-water conditions favorable to many species of waterfowl.

### Management Implications

Fluctuating water levels are a historical component of managing Lake Mead, although not the extreme declines that have occurred over the past decade. Research aimed at understanding the influence of large and often rapid changes in lake elevation on aquatic and shorebird habitats and use will assist managers in assessing the potential of Lake Mead in regional strategies for conservation of aquatic birds.

Some preliminary evidence suggests that omnivorous diving ducks at Lakes Mead and Mohave may be changing their migration patterns in response to the availability of quagga mussels, similar to patterns observed at the Great Lakes (Chapter 5). However, additional monitoring is necessary to determine if changes in occurrence of these species is due to the use of quagga mussels as a food source or the influence of other dynamic changes occurring at these lakes. More importantly, quagga mussels can bioaccumulate contaminants that may negatively affect birds that use them as a food source. For example, selenium has been found to bioaccumulate in quagga mussels in the Great Lakes (Rutzke and others, 2000). Past tributary inflow from Las Vegas Wash has contained elevated selenium concentrations, giving rise to similar concerns at Lake Mead on the bioaccumulation of selenium in quagga mussels and subsequent potential impacts to aquatic birds within LMNRA.

### Data and Information Needs

The initial 5-year inventory of aquatic birds (2004–2009) documented habitat use, species, and species abundance (Chapter 5). Continued monitoring is needed on the status and trends of species composition, distribution, and abundance of shorebirds, waterfowl, and other aquatic birds. For conservation management purposes, such monitoring should indicate which species spend a significant amount of their life history within LMNRA and are nesting residents. Related to conservation management, in light of potential for continued decline and fluctuations in water levels, inventories are needed to assess status and trend of shorebird habitat and forage and nesting sites of other aquatic bird species.

Research on potential impacts of quagga mussels on bird health may be warranted, particularly if quagga mussels become a food source for large numbers of birds. Monitoring has shown that general contaminant loading associated with Las Vegas Wash has resulted in the accumulation of contaminants in birds and bird eggs, but impacts to reproduction were not clear. Such findings demonstrate the need for monitoring of contaminants and studies of the potential impacts to bird populations and other species.

## Riparian and Aquatic Vegetation

### Key Questions

- What are the trends in distribution, connectivity, and abundance of riparian vegetation (native and non-native)?
- Is riparian vegetation maintained or restored to a condition that supports key riparian functions?

### Key Scientific Findings

Aside from deltas at tributary inflow areas, and a few small areas containing shoreline springs, the vast majority of the shoreline surrounding Lake Mead does not provide substantial areas of riparian habitat. More than a decade of lowered lake levels from 1999 through 2011 exposed additional delta areas at Las Vegas Wash, Virgin River, and Muddy River tributaries, and at the main stream of the Colorado River. Newly exposed deltas provide significant acreages of mud and silt flats, and new acreages of plant

Cove with shoreline riparian vegetation. Photograph by National Park Service.

habitat. Although a large part of these new delta habitat areas quickly fill with non-native plants, particularly saltcedar tamarisk (*Tamarix ramosissima*), the potential for native riparian habitat or mixed habitat exists. Newly exposed shoreline areas distant from tributaries and deltas serve as corridors for spread of non-native vegetation.

With its predictable lake level fluctuation range of 15 ft/yr (4.6 m/yr), Lake Mohave provides more stability for potential formation of shoreline riparian habitat. The majority of the shoreline habitat at Lake Mohave consists of the non-native saltcedar tamarisk, with a few areas where topography and soils present better conditions for the native Goodings Willow (*Salix gooddingii*); as a result, native recruitment of Goodings Willow currently (2012) is minimal. However, Lake Mohave does support substantial mesquite groves that line much of the upper riparian habitat fringe created by the more consistent lake levels. These groves contain two native mesquite species; screwbean mesquite (*Prosopis pubescens*) and honey mesquite (*P. glandulosa*).

Littoral or shallow zone aquatic vegetation has not been well studied. A limited number of surveys have outlined the species that comprise the near-shore habitat zone, primarily grass-like plants such as the non-native phragmites, and native rushes, sedges, and cattails. Formation of extensive areas of littoral vegetation has been limited.

## Management Implications

The main threats to riparian vegetation at Lakes Mead and Mohave are invasion by non-native species such as tamarisk, and impacts that occur from extended periods of water-level change. For tamarisk-dominated shorelines, the presence of the tamarisk leaf beetle (*Diorhabda carinulata*) released as a biological control will likely change species composition and densities within the current riparian vegetation stands. Over the long-term, this management technique may potentially increase native vegetation and enhance habitat; ongoing monitoring and assessing changes within riparian habitats as tamarisk is defoliated, and developing restoration plans as the beetle spreads along shoreline tamarisk stands will be important for understanding health and diversity of native vegetation. The screwbean and honey mesquite groves along the upper fringes of the riparian habitat have potential to benefit from the tamarisk beetle defoliations and expand their cover.

Treatment and removal of invasive exotics and re-planting of areas with native vegetation, particularly in newly exposed areas or areas of tamarisk leaf beetle defoliation, will increase the regional availability of high-quality riparian habitats. Moreover, protection of existing native vegetation from harvesting and firewood collecting would be useful to allow regrowth.

## Data and Information Needs

Littoral vegetation areas and aquatic vegetation have received minimal inventory or monitoring to date. Inventories are needed of species that comprise the near-shore habitat zone, such as the non-native phragmites, and native rushes, sedges, and cattails. These areas are threatened by a series of invasive aquatic plants, many of which would have ecological and recreational impacts. Monitoring is needed to better understand changes caused by declining lake levels on (1) the trends in distribution, connectivity, and abundance of riparian vegetation, (2) the potential establishment of non-native species in riparian habitats near the tributaries of Las Vegas Wash and the Virgin and Muddy Rivers, and (3) the limited formation of shoreline littoral vegetation. Additional monitoring and management for prevention of non-native vegetation from accidental transport by recreational boating also would be beneficial to limit future and current non-native species establishing in the lakes and their riparian zones. Concurrent with ongoing monitoring, research should be performed to assess whether riparian vegetation has been maintained or restored to a condition that supports key riparian functions.

## Contaminants

### Key Questions

- What is the status and trends of contaminants in the water column [for example, emerging contaminants, endocrine disruptors, VOCs, radionuclides, priority pollutants (USEPA and State), and pathogens]?
- 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 human health?

### Key Scientific Findings

Las Vegas Wash is the most significant contributor of contaminants to Lake Mead. Contaminants entering through the Wash have included inorganic chemicals, such as perchlorate, selenium, and other metals; legacy organic chemicals, such as DDT, that was once manufactured in Las Vegas Valley; currently used organic chemicals that include pesticides and PAHs; emerging contaminants of concern, such as personal care products and EDCs; and periodic high bacteria loads, particularly after storm events. Sediments may bind certain contaminants during deposition, and thus, remove them from active biological processes. However, sediments can be re-suspended by storms or by re-exposed delta deposits at tributaries due to declining water levels, and through these processes may be periodically transported and interact with the water column. Moreover, a number of factors exist that may alter concentrations of these contaminants—some contaminants may bioaccumulate within the food chain, some may be influenced by invasive species such as quagga mussel, and some contaminant concentrations may change in response to regional and global climate trends that affect water levels in the lakes.

Passive samplers used to monitor organic contaminants in the water. Photograph by Michael R. Rosen, U.S. Geological Survey.

The concentrations of the chief inorganic contaminants of concern, perchlorate and selenium, are within current (2012) established guidelines for the protection of health and wildlife. The concentrations of perchlorate have decreased more than 90 percent during the past 10 years due to a mitigation program at its manufacturing location on the former BMI site in Henderson, Nevada. Selenium concentrations have not been an issue for the open waters of Lake Mead, but are of concern for birds in Las Vegas Wash. Mercury levels in fish tissues and sediment are relatively low compared to those in other lakes in Nevada and nationally. The mean concentration of mercury in the tissues of fish sampled from Lake Mead are less than the USEPA concentrations recommended to protect human health; however, individual fish samples did have concentrations that exceeded USEPA recommended for mercury, and the Nevada Department of Wildlife has published fish consumption advisories for Lakes Mead and Mohave (Chapter 6). Certain trace metals within the water column are monitored through regulatory programs, and concentrations are all within Safe Drinking Water Act protection criteria (Chapter 4).

Organic contaminants, including legacy chemicals, such as DDT and other pesticides, and emerging contaminants of concern, such as personal care products and pharmaceuticals, have been well studied both within Las Vegas Wash and Boulder Basin (Chapter 6). Although these compounds represent a threat to water quality and ecosystem health, more information is needed to assess impacts and develop mitigation plans. Individual fish evaluated in Las Vegas Bay, Overton Arm, and Willow Beach in Lake Mohave have biomarkers indicating health and endocrine effects from compounds in the water column. In male common carp, these biomarkers include reduced male hormone levels, the presence of egg-yolk precursor, reduced testicular growth and sperm quality, lesions, and liver and kidney abnormalities (Chapter 6). In female common carp, biomarkers that showed health and endocrine effects include an intersexed ovary at

Willow Beach and skewed ratios of sex steroid hormones at Las Vegas Wash (Chapter 6). Many organic contaminants present within the water column are monitored by Southern Nevada Water Authority, and concentrations are less than the Safe Drinking Water Act protection criteria (see Chapter 4). Volatile organic compounds (VOCs) related to gasoline and boating traffic at LMNRA are not present in the open water column at concentrations of immediate concern. Current (2012) VOC concentrations should decrease even further as LMNRA has adopted regulations to phase out the use of two-stroke engines on the lakes and meet USEPA fuel-efficient engine standards by 2013.

## Management Implications

The water-quality and contaminant issues related to Las Vegas Wash are the most significant contaminant influences to ecosystem health in Lake Mead, particularly in Las Vegas Bay and Boulder Basin. Reducing contaminant loads from Las Vegas Wash is important in protecting the overall water quality of Lake Mead. As a result, interagency partnerships for the protection and management of water quality along Las Vegas Wash, including the Lake Mead Water Quality Forum and the Las Vegas Valley Watershed Advisory Committee, have been formulated to coordinate and implement monitoring, research, and mitigation. The efforts of these partnerships have resulted in significant improvements along Las Vegas Wash over the past decade in water quality, floodwater management, and restoration of riparian vegetation and wildlife habitat.

Increasing urbanization along the Muddy River and Virgin River tributaries has the potential to create additional sources of contaminants to Lake Mead through future wastewater-treatment discharges or urban runoff contaminant loads. Additionally, increased discharge volumes to these rivers and ultimately Overton Arm may alter hydrological and mixing patterns of Lake Mead and influence the transport and dispersal of contaminants in the lake.

Although it appears that organic chemicals regarded as emerging contaminants of concern (personal care products, pharmaceuticals, EDCs) are not known to be significant human health issues for Lakes Mead and Mohave, biomarkers indicative of poor fish health have been documented in carp from both lakes. The extent and nature of population-level impacts of these compounds is not yet known.

## Data and Information Needs

Current monitoring (2012) in Las Vegas Wash and Lake Mead should continue for status and trends of contaminants in the water column [VOCs, radionuclides, priority pollutants (USEPA and State), and pathogens]. In Lake Mohave, additional information is needed to understand which contaminants might be causing endocrine and reproductive effects in fish from Willow Beach.

Existing programs for monitoring inorganic contaminants, such as perchlorate and selenium are likely to continue, based on regulatory requirements. Most of the existing monitoring is performed within Las Vegas Wash and at its confluence with Las Vegas Bay. More information may be needed on the fate and distribution of these compounds in Lake Mead.

Extensive monitoring for emerging contaminants of concern is not a regulatory requirement, but is an issue for ecosystem health within Lakes Mead and Mohave, as well as for downstream users of the Lower Colorado River. Continued monitoring of emerging contaminants in the water column and sediments would contribute to an improved understanding of contaminant fate and transport. Research is needed on the population effects of contaminant-related biomarkers for native fish and sportfish. More information is needed on how contaminants are impacting not only native fish and sportfish, but also aquatic birds and other wildlife.

Pathogens are monitored in Las Vegas Wash and the Boulder Basin of Lake Mead. This monitoring is conducted in compliance with regulatory requirements for wastewater discharges and for the drinking-water intake on the western side of Boulder Basin. The National Park Service currently monitors bacteria at selected high-use areas of Lakes Mead and Mohave during peak use periods. Additional monitoring is needed to assess which contaminants or pathogens, if any, may pose a risk to human health.

## Invasive Species

### Key Questions

- What are the trends in abundance and distribution of aquatic invasive species (for example, quagga mussel, Asian clam, New Zealand mudsnail)?
- What are the potential impacts of invasive species on nutrients?
- What are potential impacts of invasive species on lake ecosystems?

### Key Scientific Findings

The unintentional introduction of the invasive quagga mussel into Lakes Mead and Mohave has been the most significant change to the LMNRA ecosystem within the past 30 years. The quagga mussel infestation has been pervasive, with rapid expansion into all basins of Lakes Mead and Mohave and an order of magnitude increase in total population over the 5-year period since the first discovery in Lake Mead in 2007. Densities of quagga mussels are greatest on hard surfaces and substrates, with lower densities in areas of soft sediments. Quagga mussels have been detected to depths of 355 ft (108.2 m), but the greatest densities of adult mussels occur between 30 and 40 ft (9.1 and 12.1 m) deep. The densities in shallower zones are thought to be related to availability of food sources and higher temperature in the water above the thermocline.

Quagga mussel veligers (floating larval forms) are now a significant component of Lake Mead's zooplankton community. Veliger abundance in Boulder Basin increased from 0.9 individuals/L in 2007 to 4.5 individuals/L in 2008. At some times of the year, quagga mussel veligers can be the greatest single species in the zooplankton composition by numbers (40 percent), although not by weight. In 2010, the overall numbers of other zooplankton species in Lakes Mead and Mohave were sufficient to maintain a healthy sport fishery.

Quagga mussels attached to a boat motor before cleaning. Photograph by National Park Service.

The impacts of quagga mussels on ecosystem functions, including nutrient cycling, has not been documented within Lakes Mead or Mohave. However, impacts resulting from dreissenid mussels have been well documented in the Great Lakes and may serve as a template for possible ecosystem-level change within LMNRA. In the Great Lakes, quagga mussels have increased water clarity and altered food-web dynamics by removing suspended particles, such as phytoplankton, debris, silt, and micro-zooplankton from the water column and increasing nutrient loading on the lake bottom. Quagga mussels also can affect other organisms by direct colonization or by indirect competition for food and space. Moreover, quagga mussels can affect nutrient dynamics as they primarily use particulate nutrients for food and excrete waste nutrients either in the dissolved form, such as ammonium, or in the particulate form (fecal pellets).

The New Zealand mudsnail was first found in Lake Mead in 2008 (Davis and Moeltner, 2010), and the abundance and distribution of this invasive species in the lakes is unknown. The density of Asian clams was more than 100 individuals/$m^2$ in the mid-1980s and has declined to less than 50 individuals/$m^2$ in Lake Mead in recent years; however, the cause for these declines is not known.

### Management Implications

The establishment of quagga mussel has the potential for significant ecosystem-wide effects on the resources of Lakes Mead and Mohave. Although quantifiable ecosystem impacts from adult quagga mussels have not been documented, research is underway on their natural life history and on potential impacts to food-web dynamics. One predicted outcome of quagga mussel infestations is increased water clarity through filtering of the water by the mussels. Although increases in water clarity at Lake Mead have been documented, this condition is believed to be primarily influenced by recent enhancements in phosphorus removals from treated wastewaters discharged into Las Vegas Wash.

Ecosystem-wide consequences of quagga mussels might include reducing biomass and changing species composition of phytoplankton and zooplankton. As a result, nutrients and food resources could be shifted from the pelagic community to the benthic community, which would benefit bottom dwelling invertebrates and fish but potentially harm open-water fish. This transfer of energy to the lake bottom can create negative effects associated with increased bottom algal growth and a decrease in available dissolved oxygen. Although some areas of the lake bottom have been noted to be covered with more bottom algae, overall trends and impacts are unknown and will require additional monitoring.

Additionally, quagga mussels have the potential to cause an increase in concentrations of dissolved inorganic phosphorus and nitrogen that may benefit aquatic plants.

Quagga mussel encrustations have had significant impacts on infrastructure including water-supply intakes at Hoover Dam and LMNRA, and the docks and marinas located on Lakes Mead and Mohave. Significant costs are incurred to keep infrastructure and operations free of clogging infestations of quagga mussels. In addition, the States of Nevada and Arizona, in cooperation with LMNRA, have been forced to implement new boating management and education programs to prevent the spread of quagga mussels into other water bodies. Although the effects of quagga mussels on infrastructure are well documented elsewhere, they have not been documented to date in large areas of Lakes Mead or Mohave.

Non-native crayfish has become an important food resource for many fish species within Lakes Mead and Mohave (Chapter 5). Although not known to have negative consequences in Lakes Mead and Mohave, crayfish have created significant negative impacts on nearby desert spring and stream resources, and in some cases they have eliminated native species. Care is needed to prevent the spread of crayfish from Lakes Mead and Mohave into adjacent bodies of water. Additionally, New Zealand mudsnails are abundant in certain areas of the lake bottom, but have not been noted to generate significant ecosystem impacts. Similarly, Asian clams have not been found to have a significant impact to lake ecosystems or recreational values and their populations have declined substantially in recent years.

### Data and Information Needs

Agencies with management responsibilities for Lakes Mead and Mohave developed interagency response, monitoring, and research plans for quagga mussels shortly after their detection in Lake Mead. There has been a significant volume of coordinated monitoring for both adult and juvenile quagga mussels to date, as well as monthly monitoring from stations around both lakes for quagga mussel veligers. Quagga mussel monitoring should continue at current (2012) levels to determine (1) trends, (2) address questions on abundance and distribution, (3) establish rates of change to the ecosystem and infrastructure, and (4) inventory potential recreational impacts, such as piles of dead shells on beaches or algal mats resulting from quagga mussel infestation. Moreover, additional research is needed on quagga mussel ecosystem effects, such as potential changes in food-web dynamics, plankton composition, and in dissolved oxygen or nutrient cycling.

Detection monitoring for other potential non-native nuisance aquatic species, for example giant Salvinia (an aquatic fern from Brazil), is needed to assist managers in timely and appropriate responses for spread prevention.

## Climate Change

### Key Questions

- What are the potential impacts of climate change on water quality related to drinking water and recreation?
- What are the potential impacts of climate change on ecosystems, especially to fish or other aquatic-living resources, and to birds?

### Key Scientific Findings

Observations and studies have shown that many natural systems are being affected by regional and global climate changes, particularly temperature increases. Because these changes will likely affect the hydrological cycle, changes in climate may have a large impact on water resources and management of those resources. For example, reduced precipitation and a series of the hottest years on record from 2000 to 2004 in the Southwestern United States resulted in streamflows that were lower than those during the 1930s Dust Bowl or the 1950s drought. Declines in lake levels have occurred previously in response to precipitation patterns; however, conditions from 2001 to 2010 have been unprecedented in their effect on lake levels and lake management.

Models of future climate in the Southwest indicate that Lake Mead water levels will be affected by declines in snowpack within the watershed, increases in evaporation, and increases in water use and supply demands. Temperatures in the Colorado River Basin are projected to increase from 5 to 6ºF (2 to 3ºC) in the 21st century, with slightly larger increases in the Upper Colorado River Basin. Lower lake levels have serious implications for the availability of water for irrigating crops, drinking water, and power generation (Chapters 1 and 2). Moreover, projections of precipitation in the Southwestern United States show the 30-year average in 2070–2099 will be drier than average conditions during 1950–1979. The most accurate models project that flow in the Colorado River Basin will be reduced by 5–20 percent from current flows.

### Management Implications

With projections of increased temperatures and reduced precipitation and flows in the Colorado River Basin, managing and preventing water shortages will involve difficult choices on how water is used. Reduced Colorado River flows, combined with increasing demands for water uses, will result in the potential for longer periods of low water levels in Lake Mead. Long periods of lower water levels have the potential to alter water mixing within the lake, which can in turn cause alterations in water temperatures, basic water-quality

Low water levels from 2001 to 2010 caused the formation of a bathtub ring made of salts precipitated out of the water. Photograph by National Park Service.

measures, and food-web dynamics. Lower lake levels also change tributary inflows, create more areas of broad shallow deltas, and result in formation of new stream channels with the potential to re-suspend sediments. These conditions may expose new shoreline areas below the previous high water lines, creating expanded or additional riparian habitats near tributary inflows, but also extensive new areas subject to invasive plants.

Lowered lake levels may cause various changes to habitat and limnology. Razorback suckers have historically used very specific areas in Las Vegas Bay to spawn; further research is needed to understand how lower lake levels would affect reproduction of these fish. Organic contaminant concentrations also have increased over time, perhaps due to lower lake levels, but the influence of this trend on aquatic organisms is unknown. Additionally, increased water temperature corresponding to lower lake levels and increasing air temperatures will influence the potential for algal blooms, which can further reduce oxygen levels in the water column.

Projected changes in climate also include increased summer rainfall intensities and the potential for more frequent flash floods. Past flooding events in Las Vegas Wash have resulted in elevated nutrient and sediment loads as well as temporary spikes in bacteria and potential pathogens.

Working together, high water quality can be maintained for future generations to enjoy. Photograph by National Park Service.

## Data and Information Needs

Recent research (Bureau of Reclamation, 2011) on climate influences within the Colorado River watershed is focused on water availability and supply. No such research, however, has been conducted on the potential effects of chronically lower water levels in Lake Mead on lake configurations, hydrology, and water quality. Information is needed on aquatic biota and the ecosystem in general, including impacts from ecosystem stressors. Many of these effects would be synergistic, enhancing potential impacts from the invasive quagga mussel or environmental contaminants. Research is needed to develop an understanding of biotic and water-quality responses to changes resulting from lowered lake levels, increased lake water temperatures, environmental contaminants in water and sediment, and impacts of invasive species. Modeling lake configurations also will assist managers in responding to infrastructure and management adjustments necessary with differing water-level regimes.

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# Glossary

**Alluvial Fan** A fan-shaped pile of sediment (clay, silt, sand, gravel, or other particulate material) that forms where a rapidly flowing mountain stream enters a relatively flat valley. As water slows down, it deposits sediment (alluvium) that gradually builds a fan.

**Alluvium** Sediment eroded by water, wind, and gravity that are deposited by rivers and streams in a valley bottom.

**Bathymetric (also bathymetry)** The measurement of the depth of water relative to a fixed point (for example, sea level, a certain elevation or datum).

**Benthic** Something that is attached to or resting on the bottom or living in the bottom sediments of a water body.

**Bioaccumulate** Absorption by an organism from all sources (for example, water, food, air, etc.) of environmental contaminants, such as pesticides, other organic chemicals, or heavy metals, at a rate greater than that at which the substance is lost from the organism.

**Biomagnify** A series of processes in an ecosystem by which greater concentrations of a particular chemical are reached in organisms higher up the food chain or food web, generally as one organism higher in the food chain eats organisms that are lower in the food chain.

**Biological diversity** Used to describe species richness, ecosystem complexity, and genetic variation in a particular area.

**Bioturbation** The process of extensively reworking sediment by worms, crustaceans, or other organisms.

**Chlorophyll** Green pigments of plants. Chlorophyll *a* and *b* are the two most common green pigments in plants.

**Coliform bacteria** Total coliform bacteria are a particular group of bacteria that are used as indicators of possible sewage pollution. This group includes coliforms that inhabit the intestine of warm-blooded animals and those that inhabit soils.

**Effluent** Outflow from a particular source, such as a stream that flows from a lake or liquid waste that flows from a factory or sewage-treatment plant.

**Endemic** Animals that are only found in a certain area or region.

**Epilimnion** The top layer of a lake where the sunlight penetrates and provides energy for plants and algae to grow. See **Thermal Stratification**.

**Estrogenicity** The degree to which a compound can stimulate female hormones to be produced in an organism.

**Euphotic zone** Zone to which light penetrates in a water body, such that photosynthesis can take place and plants can grow.

**Eutrophic** The condition of a water body when nutrient concentrations are high enough to limit oxygen for organisms in a water body.

**Eutrophication** The process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates, which typically promote excessive growths of algae. As the algae die and decompose, the amount of available oxygen in the water is depleted, in turn causing the death of other organisms, such as fishes.

**Extirpation** Complete loss of a species in a certain geographic area, although the species still exists elsewhere in its range.

**Feeding guild** A group of species having similar ecological resource requirements and foraging strategies and therefore having similar roles in the community.

**Feminization** Developmental changes resulting in the occurrence of female reproductive tissue in genetic males.

**Food web** A summary of the feeding relationships within an ecological community.

**Forage fish** Any fish eaten by large predatory fish, birds, or mammals associated with an aquatic ecosystem.

**Forb** A broad-leaved herb (not a grass), especially one growing in a field, prairie, or meadow.

**Full pool** The volume of water at which a reservoir is fully utilized for all purposes.

**Geomorphic** Pertaining to landforms, or contour of the land, and processes that form landforms.

**Hormone** A chemical substance produced within the body of an organism; once secreted, hormones travel through the bloodstream to control and regulate the activity of specific tissues and cells in other parts of the body.

**Hypolimnion** The usually cold, dense bottom layer of a stratified lake. See **Thermal Stratification.**

**Intersex** An organism that possesses a mixture of male and female reproductive tissues.

**Invasive species** An introduced alien species that is likely to cause harm to the natural ecosystem, the economy, or human health.

**Legacy pesticides** Persistent, toxic substances previously used to repel or destroy pests; though no longer in use, these substances remain in the environment due to their decades-long half-lives.

**Lentic** Standing water including ponds, lakes, and reservoirs.

**Limiting nutrient** A chemical necessary for plant growth but is available in smaller quantities than needed for plants to increase their abundance.

**Limnology** The study of inland waters focusing on ecological systems interacting with their drainage basins and the atmosphere.

**Littoral** Pertaining to the shallow area of a water body adjacent to the shore.

**Macrophyte** An aquatic plant that grows in or near water that can be observed without the use of optical magnification.

**Mesotrophic** Waters that have a moderate amount of dissolved nutrients that are usually clear and have beds of submerged aquatic plants.

**Micronutrients** Chemicals required by living organisms throughout life in small quantities to control important physiological functions.

**Nutrient loading** Quantity of nutrients entering an ecosystem in a given period of time.

**Oligotrophic** Waters that are poor in nutrients have low primary productivity and are usually very clear.

**Passive samplers** Devices able to acquire a sample of environmental chemicals from a discrete location without the active media transport by pumping or purge techniques.

**Pathogen** Disease-causing organisms that may be present in any body of water. Inadequately treated drinking water may contain human pathogens, and pathogens may also be of concern to recreational waters as well as wildlife. Pathogens include various types of bacteria, viruses, protozoan parasites, and other organisms.

**Perennial plants** A plant that lives for more than 2 years.

**Photosynthesis** Synthesis of chemical compounds by organisms with the aid of light. Carbon dioxide is used as a raw material for photosynthesis and oxygen is a product.

**Phytoplankton** Phytoplankton are microscopic organisms that live in watery environments, both salty and fresh.

**Planktonic** Related to floating or weakly swimming organisms at the mercy of the waves and currents. Animals of the group are called zooplankton and the plants are called phytoplankton.

**Productivity** A measure of the rate at which new organic matter is formed and accumulated through photosynthetic and chemosynthetic activity of producer organisms; in lake management,it is frequently used to express levels of primary production of plankton.

**Riparian** Areas adjacent to rivers and streams with a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

**Recruitment** The addition of new individuals into a fish or wildlife population by reproduction, commonly measured as the proportion of young in the population just before the breeding season

**Reservoir** A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

**Return flow** That part of a diverted body of water that is not consumptively used and is returned to its original source or another body of water.

**Specific Conductance** A measure of the ability of water to conduct an electrical current as measured using a 1-cm cell and expressed in units of electrical conductance, i.e. Siemens per centimeter at 25°C. Specific conductance can be used for approximating the total dissolved solids content of water by testing its capacity to carry an electrical current.

**Supersaturation** A solution that contains a higher than saturation concentration of a solute.

**Thermal Stratification** Vertical temperature stratification that shows the following: The upper layer of the lake, known as the epilimnion, in which the water temperature is virtually uniform; a stratum next below, known as the thermocline, in which there is a marked drop in temperature per unit of depth; and the lowermost region or stratum, known as the hypolimnion, in which the temperature from its upper limit to the bottom is nearly uniform.

**Thermocline** The area of marked temperature change usually between a warm top layer of a lake and the cold bottom part of the lake. However, in some lakes the contrast in temperatures can be reversed. See **Thermal Stratification.**

**Trophic** Pertaining to nutrition or a position in a food web or food chain.

**Turbidity** Reduced clarity of water because of suspended particles, usually sediments.

**Xenobiotic** A chemical found in an organism that is not normally produced, or expected to be present in the organism, naturally. Often used in the context of pollutants.

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# Appendix A.—List of 96 species compiled from observations made during monthly aquatic bird surveys on Lakes Mead and Mohave over a 5-year period (2004–2009).

[Species names follow the checklist of the American Ornithologists' Union. General status of each species is listed, along with its relative abundance on each lake (blanks spaces indicate non-detection of the species). **Status:** R, resident; S, summer visitor; M, migrant; W, winter visitor; U, unknown, few observations; B, breeding documented or highly suspected. **Relative abundance (observation frequency) on each lake:** a, abundant: regularly observed, often in large numbers; c, common: regularly observed; i, common but infrequently observed: observed often but sporadically and in low numbers; r, rare: few observations; blank space, not detected]

| Common name | Status | Relative abundance (observation frequency) | |
|---|---|---|---|
| | | Mead | Mohave |
| **Diving birds** | | | |
| Red-throated Loon | U | r | |
| Pacific Loon | U | | r |
| Common Loon | W | i | i |
| Pied-billed Grebe | R | c | c |
| Horned Grebe | M | i | i |
| Red-necked Grebe | U | | r |
| Eared Grebe | M | a | a |
| Western Grebe | M,W,B | a | c |
| Clark's Grebe | M,W,B | a | c |
| Brown Pelican | U | r | |
| American White Pelican | M | a | r |
| Double-crested Cormorant | R,M,B | c | c |
| **Wading birds** | | | |
| Least Bittern | U | r | |
| Great Blue Heron | R,B | c | c |
| Great Egret | M,W | i | i |
| Snowy Egret | M,S | c | i |
| Reddish Egret | U | r | |
| Cattle Egret | U | r | |
| Green Heron | S | r | i |
| Black-crowned Night-Heron | M | i | i |
| White-faced Ibis | M | i | i |
| **Waterfowl** | | | |
| Greater White-fronted Goose | U | r | |
| Snow Goose | M,W | i | r |
| Ross's Goose | U | r | |
| Canada Goose | M,W | c | r |
| Mute Swan | U | r | |
| Tundra Swan | U | r | |
| Wood Duck | U | r | r |
| Gadwall | W | a | r |
| American Wigeon | M,W | a | r |
| **Waterfowl—Continued** | | | |
| Mallard | R,W,B | c | c |
| Blue-winged Teal | M | i | r |
| Cinnamon Teal | M | a | i |
| Northern Shoveler | M,W | a | r |
| Northern Pintail | M,W | a | r |
| Green-winged Teal | M,W | a | r |
| Canvasback | M,W | i | r |
| Redhead | M,W | i | i |
| Ring-necked Duck | W | i | i |
| Greater Scaup | U | r | |
| Lesser Scaup | W | c | c |
| Surf Scoter | U | r | r |
| White-winged Scoter | U | | r |
| Black Scoter | U | | r |
| Long-tailed Duck | U | r | r |
| Bufflehead | W | i | i |
| Common Goldeneye | W | i | a |
| Hooded Merganser | M | r | i |
| Common Merganser | M,W | a | c |
| Red-breasted Merganser | M | i | i |
| Ruddy Duck | M | a | c |
| **Aquatically associated raptors** | | | |
| Osprey | M,W | i | i |
| Bald Eagle | M,W | c | c |
| Peregrine Falcon | R,B | i | i |
| **Marsh birds** | | | |
| Black Rail | U | r | |
| Virginia Rail | W | r | |
| Sora | M,B | i | |
| Common Moorhen | U | r | r |
| American Coot | M,W,B | a | a |

# Appendix A.—List of 96 species compiled from observations made during monthly aquatic bird surveys on Lakes Mead and Mohave over a 5-year period (2004–2009).—Continued

[Species names follow the checklist of the American Ornithologists' Union. General status of each species is listed, along with its relative abundance on each lake (blanks spaces indicate non-detection of the species). **Status:** R, resident; S, summer visitor; M, migrant; W, winter visitor; U, unknown, few observations; B, breeding documented or highly suspected. **Relative abundance (observation frequency) on each lake:** a, abundant: regularly observed, often in large numbers; c, common: regularly observed; i, common but infrequently observed: observed often but sporadically and in low numbers; r, rare: few observations; blank space, not detected]

| Common name | Status | Relative abundance (observation frequency) | |
|---|---|---|---|
| | | Mead | Mohave |
| **Shorebirds** | | | |
| Black-bellied Plover | U | r | |
| Snowy Plover | M,S,B | i | |
| Semipalmated Plover | M | i | |
| Killdeer | R,B | c | c |
| Black-necked Stilt | M | c | i |
| American Avocet | M | a | i |
| Spotted Sandpiper | M,W,B | i | i |
| Spotted Redshank | U | r | |
| Greater Yellowlegs | M | i | |
| Willet | M | i | |
| Lesser Yellowlegs | M | r | |
| Whimbrel | M | r | |
| Long-billed Curlew | M | r | r |
| Marbled Godwit | M | r | |
| Sanderling | M | r | |
| Western Sandpiper | M | a | r |
| Least Sandpiper | M | a | |
| White-rumped Sandpiper | U | r | |
| Baird's Sandpiper | U | r | |
| Pectoral Sandpiper | U | r | |
| **Shorebirds—Continued** | | | |
| Dunlin | M | r | |
| Long-billed Dowitcher | M | i | |
| Wilson's Snipe | M | r | |
| Wilson's Phalarope | M | i | |
| Red-necked Phalarope | M | r | r |
| **Aerialists** | | | |
| Sabine's Gull | U | r | |
| Bonaparte's Gull | M | i | r |
| Franklin's Gull | M | i | r |
| Ring-billed Gull | M | a | a |
| California Gull | M | c | c |
| Herring Gull | M | i | r |
| Caspian Tern | M | c | |
| Black Tern | U | r | r |
| Common Tern | M | i | r |
| Forster's Tern | M | i | r |
| Parasitic Jaeger | U | r | |
| Belted Kingfisher | W | i | i |

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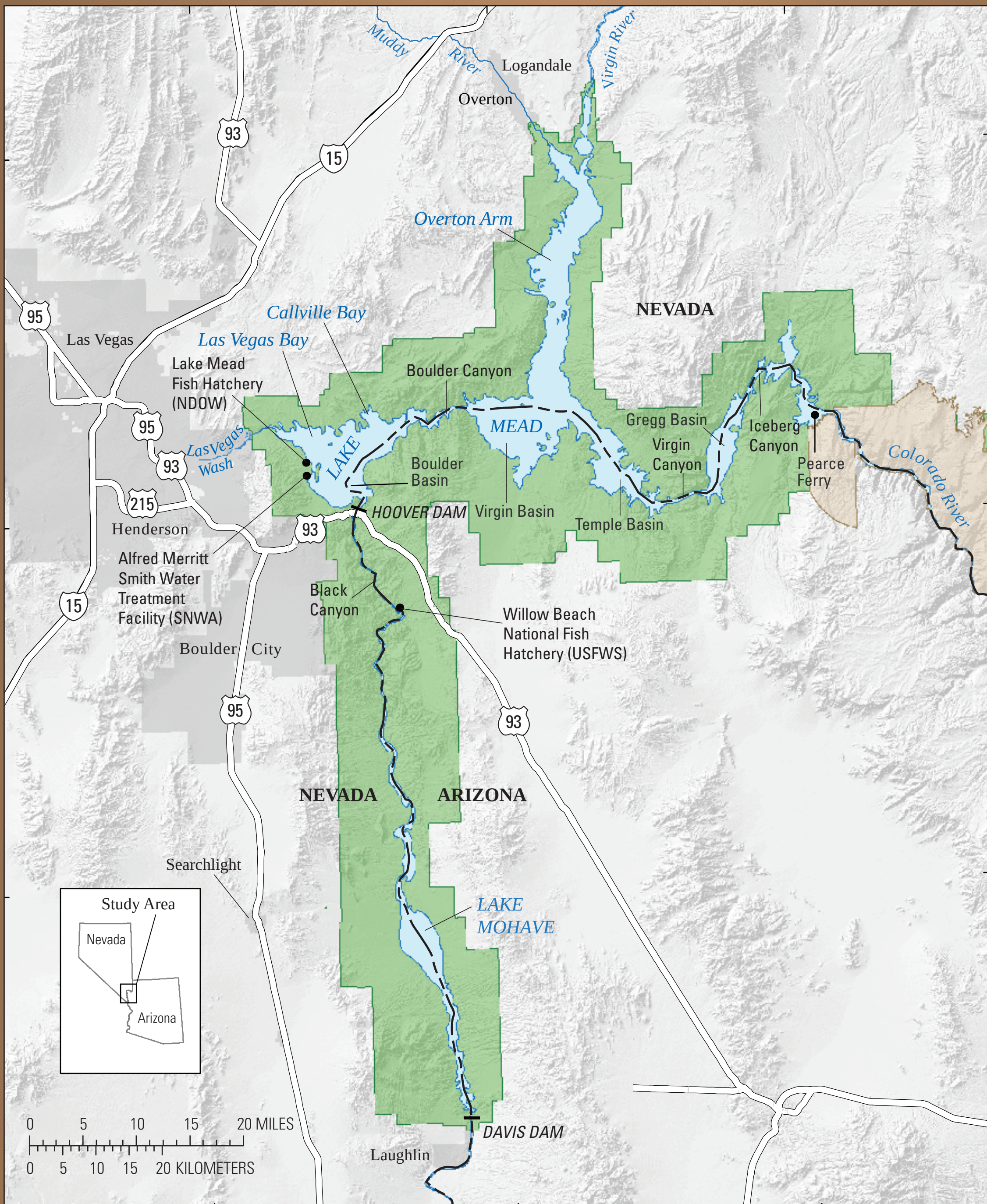


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