National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Lake Mead National Recreation Area

Limnological and Riparian Resource Condition Assessment

Natural Resource Report NPS/LAKE/NRR—2019/1981



ON THE COVER
Fisherman's Trail
Photo courtesy of Lake Mead National Recreation Area, NPS

Lake Mead National Recreation Area

Limnological and Riparian Resource Condition Assessment

Natural Resource Report NPS/LAKE/NRR—2019/1981

Ka Lai N. Ryan[1], Dr. Marion E. Wittmann[1], Dr. Sudeep Chandra[1,] Kent Turner[2], Mark Sappington[2], Dr. Theresa Thom[2]

[1]Global Water Center
University of Nevada Reno
Reno, Nevada

[2]National Park Service
Lake Mead National Recreation Area
Boulder City, Nevada

This report was prepared under Task Agreement P14AC01260 (Cooperative Agreement P11AC8R001) between the National Park Service and University of Nevada, Reno.

September 25, 2018

August 2019

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

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

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

The majority of comments addressed during the peer-review process were to enhance the overall delivery of the information in a more concise manner. Some sections were moved to enhance document flow and readability. Chapter 4 of the document had the majority of technical comments, primarily to clarify data and graphs, and include specific literature provided by the technical experts reviewing the document. Most review comments were documented in a spreadsheet, alongside which the partner provided explanation of corrective/editorial actions taken, with rationale for dissent of a few comments. Broader comment statements and "scoring" based on a series of survey questions specific to NRCAs were provided via the WASO NRCA peer review form. LAKE natural resource management staff who are co-authors worked with the partner co-authors to address peer review comments which have been adequately incorporated into the final manuscript. Management review comments have been addressed by the LAKE natural resource staff co-authors.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Ryan, K. N., M. E. Wittmann, S. Chandra, K. Turner, M. Sappington, and T. Thom. 2019. Lake Mead National Recreation Area: Limnological and riparian resource condition assessment. Natural Resource Report NPS/LAKE/NRR—2019/1981. National Park Service, Fort Collins, Colorado.

NPS 602/159930, August 2019

Contents

Page

Figures vii

Tables xvii

Executive Summary xxv

Acknowledgements xxvii

Acronyms xxix

Program xxix

Unit xxx

1. NRCA Background Information 1

2. Introduction and Resource Setting 5

2.2. Introduction 5

2.2.1. Enabling Legislation 5

2.2.2. Geographic Setting and Regional Context 5

2.2.3. Recreation Values and Visitation Statistics 7

2.3. Natural Resources 8

2.3.1. Ecological Units and Watersheds 8

2.3.2. Resource Descriptions 11

2.3.3. Resource Issues Overview 19

2.4. Resource Stewardship 21

2.4.1. Management Directives and Planning Guidance 21

2.4.2. Status of Supporting Science (Existing Status and Desired Conditions) 24

2.5. Literature Cited 29

3. Study Scoping and Design 33

3.1. Preliminary Scoping 33

3.2. Study Design 34

3.2.1. Indicator Framework, Focal Study Resources and Indicators 34

3.2.2. Reporting Areas 42

Contents (continued)

Page

3.2.3. General Approach and Methods 42

3.3. Literature Cited 44

4. Natural Resource Conditions 47

4.1. Lake and Riverine Ecosystem Health 47

4.1.1. Lake Health 47

4.1.2. Hydrologic Function 108

4.1.3. Trophic Level 119

4.1.4. Tributary Condition 134

4.1.5. Tributary Inflows 148

4.1.6. Tributary Contaminants 156

4.1.7. Sedimentation 161

4.1.8. Land Use within Watershed 166

4.1.9. Literature Cited 170

4.2. Biotic Condition 175

4.2.1. Benthic Macroinvertebrates 175

4.2.2. Zooplankton 184

4.2.3. Phytoplankton 196

4.2.4. Food Web Dynamics 204

4.2.5. Native Fish 211

4.2.6. Sportfish 219

4.2.7. Forage Fish 228

4.2.8. Aquatic-dependent Birds 235

4.2.9. Riparian Vegetation 245

4.2.10. Aquatic Vegetation 251

4.2.11. Literature Cited 253

4.3. Ecological Processes 259

Contents (continued)

Page

4.3.1. Near Shore Processes 259
4.3.2. Hydrologic Regime 261
4.3.3. Sediment 268
4.3.4. Literature Cited 281
4.4. Recreation Suitability 283
4.4.1. Human Health Effects 283
4.4.2. Visual Water Quality 301
4.4.3. Literature Cited 306
4.5. Stressors and Disturbance Regimes 309
4.5.1. Contaminants 309
4.5.2. Aquatic Invasive Species 335
4.5.3. Development and Urbanization 345
4.5.4. Climate Change 347
4.5.5. Human Use 350
4.5.6. Literature Cited 351
5. Discussion 359
5.1. Introduction 359
5.2. Key Findings 360
5.2.1. Essential Ecological or Management Features Summary 360
5.2.2. Lake and Riverine Ecosystem Health 364
5.2.3. Biotic Condition 366
5.2.4. Ecological Processes 369
5.2.5. Recreation Suitability 371
5.2.6. Stressors and Disturbance Regimes 375
5.3. Observations 381

Contents (continued)

Page

5.4. Emerging Issues for Lakes Mead and Mohave Water Resources and Regional Implications 385

5.4.1. Hydrologic Dynamics 385

5.4.2. Impacts of changes in climate conditions 386

5.5. Management Recommendations 387

5.6. Literature Cited 389

Appendix A. Glossary (words highlighted in text) 391

Appendix B. Supporting tables, figures, maps, and data 393

Figures

Page

Figure 2.2.2-1. Lake Mead National Recreation Area showing nearby National Park units and n 3 n major cities and roads. 6

Figure 2.3.1-1. Colorado River Basin showing areas of the Upper and Lower Basins, including lakes Mead and Mohave, national parks and recreation areas boundaries, and locations of Colorado River mainstem dams. 10

Figure 2.3.2-1. Lake Mead water-quality conditions compared to U.S. Environmental Protection Agency indicators. 14

Figure 4.1.1-1. Time series of dissolved oxygen profile data collected from Boulder Basin and Virgin Basin stations. 60

Figure 4.1.1-2. Time series of dissolved oxygen concentration, conductivity, and pH from Las Vegas Bay station. 61

Figure 4.1.1-3. Time series of dissolved oxygen concentration, conductivity, and pH from Boulder Basin. 62

Figure 4.1.1-4. Time series of dissolved oxygen concentration, conductivity, and pH from Virgin Basin. 63

Figure 4.1.1-5. Time series of dissolved oxygen concentration, conductivity, and pH from Temple Basin. 64

Figure 4.1.1-6. Time series of dissolved oxygen concentration, conductivity, and pH from Gregg Basin. 65

Figure 4.1.1-7. Time series of dissolved oxygen concentration, conductivity, and pH from Overton Arm. 66

Figure 4.1.1-8. Time series of dissolved oxygen concentration, conductivity, and pH from Willow Beach, Placer Cove, Cottonwood Cove, and Katherine's Landing in Lake Mohave between 2007 and 2015. 67

Figure 4.1.1-9. Time series of salinity as total dissolved solids (TDS) measured at inflows of a) Muddy and b) Virgin Rivers, and c) Overton Arm. 70

Figure 4.1.1-10. Time series of salinity as total dissolved solids (TDS) measured at a) Colorado River inflow to Lake Mead, b) Gregg Basin, c) Temple Basin, and d) Virgin Basin. 71

Figure 4.1.1-11. Time series of salinity as total dissolved solids (TDS) measured at a) lower Las Vegas Wash, b) Las Vegas Bay, c) Boulder Basin, and d) station below Hoover Dam. 72

Figures (continued)

Page

Figure 4.1.1-12. Time series of salinity as total dissolved solids (TDS) measured at Lake Mohave. 73

Figure 4.1.1-13. Time series of total nitrogen (TN) concentration values from Las Vegas Bay and Boulder Basin. 75

Figure 4.1.1-14. Time series of total nitrogen (TN) concentration values from Lake Mohave stations: Willow Beach; Placer Cove, and Katherine's Landing. 76

Figure 4.1.1-15. Time series of nitrate-nitrite as nitrogen concentration values from Las Vegas Bay and Boulder Basin. 78

Figure 4.1.1-16. Time series of nitrate-nitrite as nitrogen concentration values at Colorado River main stem stations, Gregg Basin, Temple Basin, and Virgin Basin. 79

Figure 4.1.1-17. Time series of nitrate-nitrite as nitrogen concentration values at two Overton Arm stations, VR25.1 and VR6.0. 80

Figure 4.1.1-18. Time series of nitrate-nitrite as nitrogen concentration values at Willow Beach in Lake Mohave. 81

Figure 4.1.1-19. Time series of ammonia-nitrogen concentration values at Las Vegas Bay and Boulder Basin. 82

Figure 4.1.1-20. Time series of ammonia-nitrogen concentration values at Colorado River main stem stations: Gregg Basin, Temple Basin, and Virgin Basin. 83

Figure 4.1.1-21. Time series of ammonia-nitrogen concentration values at two Overton Arm stations. 85

Figure 4.1.1-22. Time series of total phosphorus concentration values from Las Vegas Bay and Boulder Basin stations ordered by distance from Las Vegas Wash confluence. 87

Figure 4.1.1-23. Time series of total phosphorus concentration values at Colorado River mainstem stations: Gregg Basin, Temple Basin, and Virgin Basin. Stations ordered by distance from Colorado River confluence. 89

Figure 4.1.1-24. Time series of total phosphorus and orthophosphates concentration values at two Overton Arm stations: VR25.1 and VR6.0. 90

Figure 4.1.1-25. Time series of total phosphorus (TP) concentrations at Willow Beach in Lake Mohave between 2013 and 2015. 91

Figure 4.1.1-26. Time series of orthophosphates concentration values from Las Vegas Bay and Boulder Basin. Stations ordered by distance from Las Vegas Wash confluence. 93

Figures (continued)

Page

Figure 4.1.1-27. Time series of orthophosphates concentration values at Colorado River main stem stations: Gregg Basin, Temple Basin, and Virgin Basin. 94

Figure 4.1.1-28. Time series of total organic carbon concentration data collected from Las Vegas Bay station and Boulder Basin station. 96

Figure 4.1.1-29. Time series of total organic carbon concentration data collected from Colorado River main stem stations, Gregg Basin, Temple Basin, and Virgin Basin. 97

Figure 4.1.1-30. Time series of total organic carbon concentration data collected from two Overton Arm stations, VR25.1 and VR6.0. 98

Figure 4.1.1-31. Time series of total organic carbon concentration data collected in Lake Mohave. 99

Figure 4.1.1-32. Time series of surface water temperatures by a) year and b & c) month recorded at Las Vegas Bay stations. Monthly averages from 2010 to 2015 are compared against long-term monthly averages. 101

Figure 4.1.1-33. Time series of surface water temperatures by a) year and b) month recorded at Boulder Basin. 102

Figure 4.1.1-34. Time series of surface water temperatures by a) year and b-e) month recorded at Colorado River main stem stations. 103

Figure 4.1.1-35. Time series of surface water temperatures by a) year and b-c) month measured at Overton Arm. 104

Figure 4.1.1-36. Time series of surface water temperatures by a) year and b) month measured at Willow Beach in Lake Mohave. 105

Figure 4.1.1-37. Time series of surface water temperatures by a) year and b-d) month measured at Placer Cove, Cottonwood Cove, and Katherine's Landing in Lake Mohave. 106

Figure 4.1.2-1. Time series of water column temperature from a) Las Vegas Bay station, b) Boulder Basin, c) Virgin Basin, and d) Temple Basin. 111

Figure 4.1.2-2. Time series of water column temperature from a) Gregg Basin and b) Overton Arm. 112

Figure 4.1.2-3. Time series of water column temperature from Willow Beach, Placer Cove, Cottonwood Cove, and Katherine's Landing in Lake Mohave between 2007 and 2015 113

Figures (continued)

Page

Figure 4.1.2-4. Time series of water column temperature profile data collected between 1992 and 2016 from Las Vegas Bay and Boulder Basin stations. 114

Figure 4.1.2-5. Time series of water column temperature profile data collected from Colorado River mainstem stations: Gregg Basin, Temple Basin, and Virgin Basin. 115

Figure 4.1.2-6. Time series of water column temperature profile data collected from Overton Arm. 117

Figure 4.1.3-1. Time series of Secchi depth data collected at Lake Mead from Las Vegas Bay stations, Boulder Basin station, Colorado River mainstem stations, and Overton Arm stations. 125

Figure 4.1.3-2. Time series of Secchi depth data collected at Lake Mohave from Willow Beach, Placer Cove, Cottonwood Cove, and Katherine's Landing monitoring stations. 126

Figure 4.1.3-3. Monthly surface and composite chlorophyll *a* concentrations measured at Las Vegas Bay and Boulder Basin, 2000–2015. 128

Figure 4.1.3-4. Monthly surface and composite chlorophyll *a* concentrations measured at Colorado River main stem stations, Gregg Basin, Temple Basin, and Virgin Basin. 129

Figure 4.1.3-5. Monthly surface and composite chlorophyll *a* concentrations measured at two Overton Arm stations, VR25.1 and VR6.0. 130

Figure 4.1.3-6. Chlorophyll *a* concentrations measured at Lake Mohave in 2014. 131

Figure 4.1.3-7. Burns Trophic Level Index (TLI) averaged scores for Lake Mead, 2000–2010, from three locations within Boulder Basin, including sampling sites LVB6.7, INTAKE, and CR346.4. 133

Figure 4.1.3-8. Burns Trophic Level Index scores from outer Boulder basin station CR346.4, 2005–2014. 133

Figure 4.1.4-1. Comparison of 2001–2015 water temperature measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average. 139

Figure 4.1.4-2. Comparison of 2001–2015 dissolved oxygen measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average. 140

Figure 4.1.4-3. Comparison of 2001–2015 conductivity measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average. 141

Figure 4.1.4-4. Comparison of 2001–2015 pH measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average. 142

Figures (continued)

Page

Figure 4.1.4-5. Comparison of 2005-2015 nitrite and nitrate as nitrogen concentrations measured in the Colorado and Virgin rivers and Las Vegas Wash to 2001–2009 average. 143

Figure 4.1.4-6. Comparison of 2001-2015 ammonia nitrogen concentrations measured in the Colorado, Muddy, and Virgin Rivers and Las Vegas Wash to 2001–2009 average..... 144

Figure 4.1.4-7. Comparison of 2001–2015 total nitrogen concentrations measured in Las Vegas Wash inflow to 2001–2009 average..... 145

Figure 4.1.4-8. Comparison of 2001-2015 dissolved orthophosphate concentrations measured in the Colorado, and Virgin Rivers and Las Vegas Wash to 2002–2009 average. 146

Figure 4.1.4-9. Comparison of 2001-2015 total phosphorus concentrations measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2002–2009 average. 147

Figure 4.1.5-1. Estimated annual inflows from regulated releases by Lake Powell to Lake Mead via the Colorado River. 152

Figure 4.1.5-2. Estimated annual inflow from Las Vegas Wash to Lake Mead. 152

Figure 4.1.5-3. Estimated annual inflow from the Virgin River. 153

Figure 4.1.5-4. Estimated annual inflow from the Muddy River. 154

Figure 4.1.5-5. Estimated annual inflow to Lake Mohave from Hoover Dam. 155

Figure 4.1.6-1. Selenium (Se) concentrations measured at three tributary inflow stations at Lake Mead, August 2015–August 2016..... 159

Figure 4.1.6-2. Perchlorate concentrations measured at a) Las Vegas Wash: LWLVB_B and b) inflow to Lake Mohave below Hoover Dam. 160

Figure 4.1.7-1. Time series depicting total suspended solids at Las Vegas Bay. 164

Figure 4.2.1-1. Changes in overall Lake Mead macroinvertebrate abundance between 1986 and 2008. 177

Figure 4.2.1-2. Total invertebrate density by depth comparison in soft sediments for 1986 and 2008, 2009, 2011 within three basins of Lake Mead. 179

Figure 4.2.1-3. Chironomidae density by depth comparison in soft sediments for 1986 and 2008, 2009, 2011 within three basins of Lake Mead. 180

Figure 4.2.1-4. Native gastropod density by depth comparison in soft sediments for 1986 and 2008, 2009, 2011 within three basins of Lake Mead. 181

Figures (continued)

Page

Figure 4.2.1-5. Oligocheatae density by depth comparison in soft sediments for 1986 and 2008, 2009, 2011 within three basins of Lake Mead. 182

Figure 4.2.1-6. *Corbicula fluminea* density by depth comparison in soft sediments for 1986 and 2008, 2009, 2011 within three basins of Lake Mead. 183

Figure 4.2.2-1. Zooplankton density and proportional representation for Las Vegas Bay. 188

Figure 4.2.2-2. Zooplankton density and proportional representation for Boulder Basin. 189

Figure 4.2.2-3. Zooplankton density and proportional representation for Virgin Basin. 190

Figure 4.2.2-4. Zooplankton density and proportional representation for Temple Basin. 191

Figure 4.2.2-5. Zooplankton density and proportional representation for Gregg Basin. 192

Figure 4.2.2-6. Zooplankton density and proportional representation for Overton Arm. 193

Figure 4.2.2-7. Zooplankton densities measured at various monitoring stations in Lake Mohave, a) Willow Beach, b) Placer Cove, c) Cottonwood Cove, and d) Katherine's Landing. 195

Figure 4.2.3-1. Quarterly measures of phytoplankton group biovolume and proportional representation from 2006 to 2015 for Las Vegas Bay, Boulder Basin, and Overton Arm. 199

Figure 4.2.3-2. Quarterly measures of phytoplankton group biovolume and proportional representation from 2006 to 2015 for Colorado River mainstem monitoring stations, Virgin Basin, Temple Basin, and Gregg Basin. 200

Figure 4.2.3-3. Total phytoplankton concentrations (cells/ml) (measured quarterly, 2012–2015) for all monitoring stations. 201

Figure 4.2.3-4. Relative percentages of major phytoplankton groups by concentration and biovolume in May 2013 for Las Vegas Bay and Boulder Basin monitoring stations. 202

Figure 4.2.4-1. Food web structure comparison over time of Las Vegas Bay (LVB), Lake Mead. 207

Figure 4.2.4-2. Food web structure comparison over time of Overton Arm (OA), Lake Mead. 208

Figure 4.2.4-3. Contemporary (2013–14) food web structure comparison of 3 basins in Lake Mead. 210

Figure 4.2.5-1. Gillnet survey native fish catch rates in Lake Mead, 1993–2014. 214

Figures (continued)

Page

Figure 4.2.5-2. Wild and repatriate razorback sucker population estimates in Lake Mohave based on field data collected in March between 2008 and 2015 by Marsh &Associates. 215

Figure 4.2.5-3. Gillnet survey catch rates by native fish species in Lake Mohave, 1993–2015..... 216

Figure 4.2.6-1. Cumulative gillnetting catch rates of sportfish species in Lake Mead, 1993–2014..... 223

Figure 4.2.6-2. Cumulative electrofishing catch rates of sportfish species in Lake Mead, 2006–2014..... 223

Figure 4.2.6-3. Gillnet survey catch rates by sportfish species in Lake Mead, 1993–2014..... 224

Figure 4.2.6-4. Angler catch rates in Lake Mead collected from creel surveys, 1984–2014..... 224

Figure 4.2.6-5. Cumulative gillnetting catch rates of sportfish species in Lake Mohave, 1993–2015..... 226

Figure 4.2.6-6. Gillnet survey catch rates by sportfish species in Lake Mohave, 1993–2015..... 226

Figure 4.2.6-7. Cumulative electrofishing catch rates of sportfish species in Lake Mohave, 1994–2015. 227

Figure 4.2.7-1. Cumulative gillnetting catch rates of forage fish species in Lake Mead, 1993–2015..... 231

Figure 4.2.7-2. Gillnet survey catch rates by forage fish species in Lake Mead, 1993–2015..... 231

Figure 4.2.7-3. Cumulative electrofishing catch rates of forage fish species in Lake Mead, 2006–2014. 232

Figure 4.2.7-4. Lake Mead shad peak production densities..... 232

Figure 4.2.7-5. Cumulative gillnetting catch rates of forage fish species in Lake Mohave, 1993–2015..... 233

Figure 4.2.7-6. Gillnet survey catch rates by forage fish species in Lake Mohave, 1993–2015..... 234

Figure 4.2.7-7. Cumulative electrofishing catch rates of forage fish species in Lake Mohave, 1994–2015. 234

Figures (continued)

Page

Figure 4.2.8-1. Percentages of the 10 most common species or species groups of aquatic birds in a) Lake Mead and b) Lake Mohave. 239

Figure 4.2.8-2. Monthly averages of total aquatic birds recorded per survey sites monitored during monthly surveys from March 2004 through August 2009. 240

Figure 4.2.8-3. Number of known occupied peregrine falcon territories within Lake Mead NRA from 1985 through 2010. 242

Figure 4.2.8-4. Number of bald eagles recorded from 2000 through 2016 during the winter counts at lakes Mead and Mohave. 243

Figure 4.3.2-1. Colorado River computed natural flows at the USGS gaging station at Lees Ferry, AZ. 265

Figure 4.3.2-2. Lake Powell observed unregulated inflow volume between April and July from 1964 to 2016. 265

Figure 4.3.3-1. Sedimentation patterns in Lake Mead. 272

Figure 4.3.3-2. Sedimentation patterns in Lake Mohave. 274

Figure 4.3.3-3. Landsat images of Colorado River confluence, and Gregg and Virgin basins taken in July of 1985, 1995, 2000, 2005, 2010, and 2015. 277

Figure 4.3.3-4. Landsat images of Lake Mead Virgin and Muddy River confluences taken in July of 1985, 1995, 2000, 2005, 2010, and 2015. 278

Figure 4.3.3-5. Landsat images of Las Vegas Wash confluences, Las Vegas Bay, and Boulder Basin taken in July of 1985, 1995, 2000, 2005, 2010, and 2015. 280

Figure 4.4.1-1. Concentrations of *Microcystis aeruginosa* in Lake Mead. 297

Figure 4.4.2-1. Average monthly Secchi depth at Boulder, Virgin, Temple, and Gregg basins, 2003–2015. 304

Figure 4.4.2-2. Quarterly Secchi depth measurements at Overton Arm, 2007–2015. 305

Figure 4.4.2-3. Average monthly Secchi depth for Lake Mohave, 2007–2014. 306

Figure 4.5.1-1. Map showing location of study area and sampling sites for VOC in Lake Mead by Lico & Johnson, 2007. 314

Figure 4.5.1-2. Map showing location of study area and sampling sites for VOC in Lake Mohave by Lico & Johnson, 2007. 315

Figures (continued)

Page

Figure 4.5.1-3. Caffeine and DEET concentrations detected at sampling site near Hoover Dam between 2008 and 2016. 326

Figure 4.5.1-4. Selenium (Se) concentrations measured at lakes Mead and Mohave, 2008–2015 327

Figure 4.5.1-5. Time series of perchlorate concentration data collected monthly between 2000 and 2015 from Las Vegas Bay stations and Boulder Basin station. 329

Figure 4.5.1-6. Time series of perchlorate concentration data collected monthly between 2014 and 2015 in Lake Mohave 331

Figure 4.5.1-7. Time series of bromide concentration data collected from Las Vegas Bay station, Boulder Basin station, Colorado River main stem stations and Overton Arm stations. 333

Figure 4.5.2-1. Quagga mussel adult abundance in Lake Mead from different depth zones. 339

Figure 4.5.2-2. Quagga mussel veliger abundance collected by BOR and SNWA Zooplankton Monitoring program in Lake Mead. 339

Figure 4.5.2-3. Lake Mohave quagga mussel veliger abundance. 340

Figure 4.5.2-4. Quagga mussel veliger abundance collected by BOR's veliger monitoring program in lakes Mead and Mohave. Excerpted from Wong, 2012. 341

Figure 4.5.2-5. Changes in New Zealand mudsnail average abundances between 2008 and 2011 at various depth zones. 342

Tables

Page

Table 2.4.1-1. Fundamental Resource Values and Desired Future Conditions, as related to water resources, from Lake Mead NRA Foundation Document and the Lake Mead NRA Resource Stewardship Strategy. 22

Table 2.4.2-1. Limnological and water quality parameters currently monitored at lakes Mead and Mohave by a partnership between BOR, SNWA, and Lake Mead NRA. 25

Table 2.4.2-2. Summary of key scientific findings, management implications, and recommendations for each resource component identified in the Lake Mead NRA Aquatic Resources Plan. 27

Table 2.4.2-3. Summary of key scientific findings, management implications, and recommendations for stressors identified in the Lake Mead NRA Aquatic Resources Plan. 28

Table 3.2.1-1. Fundamental Resource Values (FRVs) and Desired Future Conditions, as related to water resources as references in the Lake Mead NRA Foundation Document and Lake Mead NRA Resource Stewardship Strategy. 35

Table 3.2.1-2. Final Lake Mead National Recreational Area Limnological and Riparian Resource Condition Assessment (LRCA) Framework. 38

Table 3.2.3-1. Condition, trend, and level of confidence key used in the Lake Mead NRA LRCA. 43

Table 4.1.1-1. Overall assessment outcome of Lake Health. 47

Table 4.1.1-2. Assessment outcome for Surface Water Quality. 50

Table 4.1.1-3. Parameters/measures examined for determining the condition and trend of Lake Mead. 51

Table 4.1.1-4. Indicators, measurements, and scale of analysis used to assess surface water quality 53

Table 4.1.1-5. Sampling method descriptions and approximate monitoring frequencies of parameters examined. 55

Table 4.1.1-6. Metrics and excedence measures used to differentiate lake health condition status. 56

Table 4.1.1-7. Recommended water quality standards or criteria available for selected water quality parameters. 58

Table 4.1.2-1. Assessment outcome for hydrologic function 108

Tables (continued)

Page

Table 4.1.2-2. Data and measurements used to determine the condition status and trend of hydrologic function. 109

Table 4.1.2-3. Reference conditions for Hydrologic function used to determine the condition status and trend. 116

Table 4.1.2-4. Approximate location of thermal layers in Lake Mead at USGS water quality stations where thermal stratification was present between 2005–2009. 117

Table 4.1.2-5. Retention time of lakes Mead and Mohave. 118

Table 4.1.3-1. Assessment outcome for Trophic level. 119

Table 4.1.3-2. Data and methods used to determine the condition status and trend of Tropic level. 121

Table 4.1.3-3. List of Secchi depth and chlorophyll *a* monitoring sites in Lake Mead NRA examined showing period of record examined. 122

Table 4.1.3-4. Values of parameters that define boundaries for different Trophic Levels. 123

Table 4.1.3-5. Reference conditions used to determine the status and trend of trophic level. 126

Table 4.1.3-7. A summary of basin-specific conditions and trends for Secchi depth and chlorophyll *a* measurements. 131

Table 4.1.4-1. Overall assessment of the indicator tributary condition. 134

Table 4.1.4-2. Assessment outcome for Tributary physical characteristics and nutrient load. 136

Table 4.1.4-3. Data methods to determine used in the assessment of Tributaries. 137

Table 4.1.4-4. Reference conditions used in the assessment of tributaries. 138

Table 4.1.5-1. Assessment outcome for the indicator tributary inflows. 148

Table 4.1.5-2. Data and methods in the assessment of tributary inflows. 149

Table 4.1.5-3. Reference conditions for tributary inflows used in the assessment. 150

Table 4.1.6-1. Assessment outcome for tributary contaminants. 156

Table 4.1.6-2. Data and methods used in the assessment of tributary contaminants. 157

Table 4.1.6-3. Reference conditions for tributary contaminants used in the assessment. 157

Tables (continued)

Page

Table 4.1.6-4. USEPA and NDEP standards and recommendations for contaminant levels in drinking water and aquatic life ambient water quality. 158

Table 4.1.7-1. Assessment outcome for sedimentation. 161

Table 4.1.7-2. Data and methods for the assessment of sedimentation. 162

Table 4.1.7-3. Reference conditions of sedimentation used in the assessment. 162

Table 4.1.8-1. Assessment outcome for the indicator land use within watershed. 166

Table 4.1.8-2. Data and methods used in the assessment of land use within the watershed. 167

Table 4.1.8-3. Reference conditions for land use within the watershed used in the assessment. 168

Table 4.1.8-4. Land uses along the boundary of Lake Mead NRA. 168

Table 4.1.8-5. Land cover types and acreages covered in the three sub-watersheds, Duck Creek-Las Vegas Wash, Halfway Wash-Virgin River, and Lower Muddy River adjacent to Lake Mead NRA. 169

Table 4.1.8-6. Number of miles of tributaries that are urbanized and non-urbanized in the three sub-watersheds, Duck Creek-Las Vegas Wash, Halfway Wash-Virgin River, and Lower Muddy River adjacent to Lake Mead NRA. 169

Table 4.2.1-1. Overall Assessment outcome for condition status and trend for Benthic Macroinvertebrates. 175

Table 4.2.1-2. Data and methods used in the assessment of Benthic macroinvertebrates. 176

Table 4.2.2-1. Assessment outcome for the overall condition status and trend for Zooplankton. 184

Table 4.2.2-2. Data and used in the assessment of zooplankton. 185

Table 4.2.2-3. Reference conditions for zooplankton used in the assessement. 186

Table 4.2.3-1. Overall assessment outcome for the assessment of phytoplankton. 196

Table 4.2.3-2. Measurements and metrics used in the assessment of phytoplankton. 196

Table 4.2.3-3. Reference conditions of phytoplankton used in the assessment. 198

Table 4.2.4-1. Overall assessment outcome for condition status and trend of food web dynamics. 204

Tables (continued)

Page

Table 4.2.4-2. Indicators and measurements used in the assessment of food web dynamics. 205

Table 4.2.4-3. Reference conditions for food web dynamics used in the assessment. 206

Table 4.2.5-1. Overall assessment outcome of the condition status and trend for native fish 211

Table 4.2.5-2. Indicators and measurements used in the assessment of population trends. 213

Table 4.2.5-3. Reference conditions for native fish used in the assessment. 213

Table 4.2.6-1. Overall assessment outcome for the condition status and trend of sportfish. 219

Table 4.2.6-2. Indicators and measurements used in the assessment of sportfish. 220

Table 4.2.6-3. Reference conditions for sportfish, used in the assessment. 221

Table 4.2.6-4. Summary statistics on the number of fishing tournaments held in Lake Mead (T. 225

Table 4.2.7-1. Overall assessment outcome of the condition status and trend for forage fish 228

Table 4.2.7-3. Indicators and measurements used in the assessment of forage fish. 229

Table 4.2.7-3. Reference conditions of forage fish, used in the assessment. 230

Table 4.2.8-1. Overall assessment outcome of the condition status and trend of aquatic dependent birds. 235

Table 4.2.8-2. Indicators and measures used in the assessment of aquatic dependent birds 236

Table 4.2.8-3. Reference conditions of aquatic dependent birds used in the assessment. 237

Table 4.2.9-1. Overall assessment outcome for the condition status and trend of riparian vegetation. 245

Table 4.2.9-2. Indicators and measurements used in the assessment of riparian vegetation. 246

Table 4.2.9-3. Riparian vegetation classifications. 246

Table 4.2.9-4. Reference conditions for riparian vegetation used in the assessment. 247

Table 4.2.9-5. Riparian plant communities' coverage in lakes Mead and Mohave. 249

Tables (continued)

Page

Table 4.2.9-6. Summary of vegetation classification and mapping results from Vegetation Mapping of Lake Mead NRA. 250

Table 4.2.10-1. Overall assessment outcome for the condition status and trend of aquatic vegetation. 251

Table 4.2.10-2. Indicators and measurements used in the assessment of aquatic vegetation. 252

Table 4.3.1-1. Overall assessment outcome for the condition status and trend of near shore processes. 259

Table 4.3.1-2. Indicators and methods used in the assessment of near shore processes. 259

Table 4.3.1-3. Reference conditions for native plant and non-native plant abundance used in the assessment. 260

Table 4.3.2-1. Overall assessment outcome for the condition status and trend of hydrologic regime. 261

Table 4.3.2-2. Assessment outcome of the Colorado River Basin. 262

Table 4.3.2-3. Indicatiors and measurements used in the assessment of the hydrologic condition of the Colorado River Basin. 263

Table 4.3.2-4. Reference conditions of the Colorado River Basin used in the assessment. 264

Table 4.3.2-5. Assessment outcome for floodflows in streams with future projections. 266

Table 4.3.2-6. Indications and measures used in the assessment of floodflows in streams. 267

Table 4.3.2-7. Reference conditions for floodflows in streams used in the assessment. 267

Table 4.3.3-1. Overall assessment outcome for the condition status and trend of sediment. 268

Table 4.3.3-2. Assessment outcome for sediment accumulation. 269

Table 4.3.3-3. Indicators and measures used in the assessment of sediment accumulation. 270

Table 4.3.3-4. Reference conditions for sediment accumulation used in the assessment. 271

Table 4.3.3-5. Assessment outcome for alluvial delta changes. 275

Table 4.3.3-6. Indicators and measures used to in the assessment of alluvial delta changes. 276

Tables (continued)

Page

Table 4.4.1-1. Overall assessment outcome for condition trend and status of human health effects. 283

Table 4.4.1-2. Assessment outcome of pathogens. 285

Table 4.4.1-3. Indicators and measures used in the assessment of pathogens. 286

Table 4.4.1-4. Lake Mead NRA Human pathogen criteria. 288

Table 4.4.1-5. Fecal coliform average concentrations (cfu/100 ml) detected in lakes Mead and Mohave. 289

Table 4.4.1-6. *E. coli* average concentrations detected in lakes Mead and Mohave. 290

Table 4.4.1-7. Number of samples that exceeded the acceptable single sample limit for fecal coliform concentration for full-body contact in recreational waters. 292

Table 4.4.1-8. Assessment outcome for harmful algal blooms. 294

Table 4.4.1-9. Indicators and measures used in the assessment of harmful algal blooms. 295

Table 4.4.1-10. List of SNWA microcystin monitoring sites in Lake Mead NRA showing period of record examined. 295

Table 4.4.1-11. Lake Mead NRA Hazardous algae bloom/toxin (HAB) criteria. 296

Table 4.4.1-12. Assessment outcome for mercury in fish flesh. 298

Table 4.4.1-13. Indicators and measures used in the assessment of mercury in fish flesh. 299

Table 4.4.1-14. Reference conditions for mercury in fish flesh used in the assessment. 299

Table 4.4.1-15. Nevada Department of Wildlife Fish Consumption Advisory, based on methylmercury. 300

Table 4.4.2-1. Assessment outcome for condition status and trend of visual water quality**.** 301

Table 4.4.2-2. Indicators and measures used to in the assessment of visual water quality. 302

Table 4.4.2-3. Lake Mead NRA Aesthetics Criteria. 303

Table 4.5.1-1. Assessment outcome of condition status and trend of contaminants. 309

Table 4.5.1-2. A total of 7 indicators were examined for this resource attribute. 311

Table 4.5.1-3. Indicators and measurements used in the assessment of contaminants. 313

Table 4.5.1-4. List of contaminant monitoring sites in Lake Mead NRA from SNWA, BOR, and NPS monitoring programs examined for this assessment. 316

Tables (continued)

Page

Table 4.5.1-5. Reference conditions of contaminants used in the assessment. 317

Table 4.5.1-6. USEPA National Primary Drinking Water Regulations primary standards and recommendations for contaminant levels in drinking water and human health ambient water quality..... 318

Table 4.5.1-7. Pharmaceuticals and Personal Care Products (PPCPs) detected in Las Vegas Bay of Lake Mead between 2007 and 2009..... 323

Table 4.5.2-1. Assessment outcome of the condition status and trend for aquatic invasive species**.** 335

Table 4.5.2-2. Indicators and measures used in the assessment of aquatic invasive species. 337

Table 4.5.2-3. Reference conditions for aquatic invasive species used in the assessment..... 338

Table 5.2.1. Aggregated conditions and trends for the five essential ecological and management features examined in chapter 4. 361

Table 5.3–1. Summary of the findings for the key features of this LRCA. 383

Table B-1. List of major sampling stations within lakes Mead and Mohave..... 400

Table B-2. List of U.S. Geological Survey automated water quality stations on lakes Mead and Mohave showing site coordinates and period of record..... 404

Table B-4. List of fishes found in lakes Mead and Mohave and their conservation status..... 406

Table B-6. List of aquatic dependent birds of conservation concern based on the Great Basin Bird Observatory's Nevada Bird Conservation Plan (2010) and tailored to the bird species and habitats found within the Lake Mead National Recreation Area..... 412

Executive Summary

Natural Resource Condition Assessments (NRCAs) strive to report current conditions of important natural resources and indicators for National Parks. The Lake Mead National Recreation Area (NRA) Limnological and Riparian Resource Condition Assessment (LRCA) is a collaborative effort between the National Park Service (NPS) Lake Mead NRA staff and the University of Nevada at Reno (UNR). The goal of this report was to synthesize and interpret existing scientific data to evaluate the current status and forecast future conditions for limnological and riparian resources of lakes Mead and Mohave.

Lake Mead NRA was established in 1964 as the nation's first National Recreation Area. The park is located within Clark County, Nevada and Mohave County, Arizona, with Grand Canyon National Park and Grand Canyon-Parashant National Monument adjacent to the east. Three rivers feed into Lake Mead: the Colorado River provides the greatest inflow from the Grand Canyon to the east, and the Virgin River combines with the Muddy River and flows into the Overton Arm of Lake Mead to the north. Lake Mead is the largest reservoir by volume in the United States and provides domestic water to 25 million people throughout Nevada, California, and Arizona, as well as irrigating 2.5 million acres of cropland. Lake Mead NRA is in the top five highest visited units in the National Park System, providing significant economic value to the region, and boasts 185,000 acres of designated wilderness and backcountry.

Lake Mead NRA, as part of an inter-agency partnership, has committed to collect monitoring data since 2010. The active assessment for this LRCA began in 2015. The Long-Term Limnological and Aquatic Resource Monitoring and Research Plan, or LTAP (2010) provides a basis for the resource measures in this assessment. The Environmental Protection Agency's (EPAs) framework for Assessing and Reporting on Ecological Conditions aided in determining indicator measures for riparian and limnological health.

This assessment examines six Essential Ecological Attributes (EEA) that incorporate ecological structure, composition, and function of ecological systems at a variety of temporal and spatial scales:

- Lake and Riverine Ecosystem Health
- Biotic Conditions
- Ecological Processes
- Recreation Suitability
- Stressors and Disturbance Regimes

For each of the five EEAs, contributing resource attributes within Lake Mead NRA were defined. This resulted in 22 key resource attributes, with 32 limnological and riparian indicators and 45 associated measures of condition. Conditions and trends of each overall EEA were assigned based on the assessments of respective resource attributes and indicators.

At the EEA level, Lake and Riverine Ecosystem Health and Recreation Suitability were in overall good condition with declining trends. Uncertainty about maintaining Lake Mead-wide monitoring programs and future climate projections contributed to the downward trends and uncertainties in the assessments. Biotic Conditions and Stressors and Disturbance Regimes each warranted moderate concern. The introduction of invasive species and monitoring contaminants were the primary concerns leading to the moderate concern category for these resources. Ecological Processes warranted significant concern with a downward trend. This attribute condition is driven by the indicator hydrologic regime, which warrants significant concern due to persistent drought or drought-like conditions throughout the Colorado Basin. Further details on the condition and trend for each key resource under the EEAs are detailed in this report.

Evaluations of data collection and monitoring efforts have also resulted in the recognition of emerging issues and data gaps. First, though there is much data on the hydrologic properties of Lake Mead NRA, there are many unknowns regarding the entire hydrologic system surrounding lakes Mead and Mojave. Management of Hoover dam, the Colorado River Basin, and conditions of the Muddy and Virgin Rivers and Overton Arm could all have profound effects on the water quality and quantity of Lake Mead NRA. Second, predicted changes in climate conditions can have impacts on the prevalence of contaminants, invasive species trends, and riparian and aquatic vegetation health, among other concerns.

Safeguarding the water supply for the 25 million-plus people who depend upon the Lower Colorado River is a long-term challenge that will require the commitment, collaboration, and contributions of local, state, and federal governments through a comprehensive management program. Continued monitoring of lakes Mead and Mohave will remain to be an important aspect of understanding stressors, influences of individual basins, and understanding the inter-connectedness between river basins. We recommend that the NPS continue to participate in and lead ongoing networks, working groups, and inter-agency partnerships for future park planning and management.

Acknowledgements

The following reviewers guided the development of the final document and provided information which developed the findings in this document. These reviewers include: Cathy Schwerm, Dr. Chris Holdren, Peggy Roefer, Dr. Todd Tietjen, Dan Fischer, Gary Karst, Doyle Wilson, Joseph Barnes, Jon Sjöberg. Dr. Anne St. Amand assisted in the phytoplankton analysis and provided text for the report. The funding was provided by the National Park Service to S. Chandra via Cooperative Ecosystems Studies Unit Cooperative Task Agreement P14AC01260.

Acronyms

ADEQ:	Arizona Department of Environmental Quality
AHPRC:	Areas of high potential for resource conflict
AZGFD:	Arizona Game and Fish Department
BBAMP:	Boulder Basin Adaptive Management Plan
BLM:	U.S. Bureau of Land Management
BOR:	U.S. Bureau of Reclamation
CECs:	Contaminants of Emerging Concern
CWA:	Clean Water Act
CWC:	Clean Water Coalition
EDCs:	Endocrine Disruptor Compounds
ESA:	Endangered Species Act
FRVs:	Fundamental resources and values
FWPCA:	Federal Water Pollution Control Act
GIS:	Geographic Information Systems
HUC:	Hydrologic Unit Codes
I-MAP:	Interagency Management Action Plan
Lake Mead NRA:	Lake Mead National Recreation Area
LaMEM:	Lake Mead Ecosystem Monitoring Work Group
LCR:	Lower Colorado River
LCRMSCP:	U.S. Bureau of Reclamation Lower Colorado River Multi-Species Conservation Program
LRCA:	Limnological and Riparian Resource Condition Assessment
MCL:	Maximum Contaminant Level
MSL:	Mean Sea Level
MOJN:	Mojave Desert Inventory & Monitoring Network
MSHCP:	Clark County Multiple Species Habitat Conservation Plan
NAIP:	National Agriculture Imagery Program
NDEP:	Nevada Division of Environmental Protection
NDOW:	Nevada Department of Wildlife
NDPH:	Nevada Department of Public Health
NFWG:	Native Fish Work Group

NLA:	National Lakes Assessment
NPDES:	National Pollutant Discharge Elimination System
NPDWRs:	National Primary Drinking Water Regulations
NPS:	National Park Service
NRCA:	Natural Resource Condition Assessment
NVBR:	Nevada Basin and Range study unit
PCE:	Probable effect concentration
PPCPs:	Pharmaceuticals and Personal Care Products
RMHQs:	Requirements to maintain existing higher quality under the Nevada Revised Statutes
RWQC:	Recreational Water Quality Criteria
SDWA:	Safe Drinking Water Act
SNPLMA:	Southern Nevada Public Land Management Act
SNWA:	Southern Nevada Water Authority
SotP:	State of the Park
TDS:	Total dissolved solids
THM:	Trihalomethanes
TLI:	Burns Trophic Level Index
TOC:	Total organic carbon
TSS:	Total suspended solids
UNLV:	University of Nevada, Las Vegas
UNR:	University of Nevada, Reno
USEPA:	U.S. Environmental Protection Agency
USFWS:	U.S. Fish and Wildlife Services
USGS:	U.S. Geological Survey
VOCs:	Volatile organic compounds
YOY:	Young of year

Unit

acre-ft:	Acre-foot
cfs:	Cubic feet per second
cfu:	Colony forming units
CPUE:	Catch per unit effort
CPTD:	Catch per trap day

ha:	Hectare
L:	Liter
m2:	Square meter
m3:	Cubic meter
maf:	Million acre-feet
MF/100 ml:	Membrane filter per 100 ml
msl:	Mean sea level
PWC:	Personal water craft
yr:	Year

1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs Strive to Provide…

- *Credible condition reporting for a subset of important park natural resources and indicators*
- *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products; [4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing,

long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

---

[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

2. Introduction and Resource Setting

2.2. Introduction

2.2.1. Enabling Legislation

Annually, lakes Mead and Mohave within the Lake Mead National Recreation Area (Lake Mead NRA) 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 enabling legislation provides management direction to: "preserve, develop, and enhance the recreation potential, and in a manner that will preserve the scenic, historic, scientific and other important features of the area ... (providing) general recreation use, such as bathing, boating, camping and picnicking" (NPS, 2015a).

2.2.2. Geographic Setting and Regional Context

Lake Mead National Recreation Area

Lake Mead NRA is located within the sub-basin Lake Mead Basin (HUC 1501) in the lower Colorado River Basin (Batker, et al., 2014; Figure 2.2.2-1). The park contains vast backcountry and wilderness lands, including nine designated wilderness areas that cover more than 185,000 acres and several other proposed, eligible, or potential wilderness lands that encompass an additional 373,000 acres. These lands serve to preserve ecological resources and processes and provide exemplary opportunities for primitive recreation and desert solitude (NPS, 2014). The western end of Lake Mead NRA is adjacent to metropolitan Clark County, Nevada, containing the cities of Las Vegas, Henderson, and North Las Vegas. The eastern end of Lake Mead NRA is adjacent to Grand Canyon National Park and Grand Canyon-Parashant National Monument. At the northern end of Lake Mead NRA, the Virgin and Muddy Rivers combine to form the Overton Arm of Lake Mead. The Virgin River is influenced by rapidly developing St. George, Utah and Mesquite, Nevada. The Muddy River is influenced by urbanizing Overton and Logandale, Nevada (Holdren & Turner, 2010; Lake Mead NRA, 2010). At the southern end of Lake Mead NRA, Lake Mohave is adjacent to the cities of Laughlin, Nevada and Bullhead City, Arizona.

Lake Mead and Lake Mohave

Lake Mead, formed by Hoover dam, and Lake Mohave, formed by Davis Dam, comprise the core of the Lake Mead NRA in Nevada and Arizona (Figure 2.2.2-1). Combined, the two reservoirs occupy approximately 140 miles of former Colorado River channel, plus nearly 30 miles of the former Virgin River channel within the Overton Arm of Lake Mead. Lake Mead is the largest reservoir by volume in the United States. It has a surface area of approximately 157,000 acres, and over 750 miles of shoreline. Its mean depth at full pool is 182 feet; the maximum is 532 feet (Rosen et al., 2012). The average hydraulic residence time for Lake Mead is 2.6 years. Approximately 97% of the tributary inflow to Lake Mead is from the Colorado River as it exits the Grand Canyon. Approximately 1% is from the combined flows of the Virgin and Muddy Rivers entering from the north, with approximately 2% of the tributary flow received from the urban Las Vegas Wash, which drains the Las Vegas Valley.

Lake Mohave operates as a re-regulation reservoir to provide stable downstream water releases. It has a surface area of approximately 28,000 acres, a mean depth of 85 feet and a maximum depth of 165 feet. Its hydraulic residence time is about 60 days (Holdren & Turner, 2010).

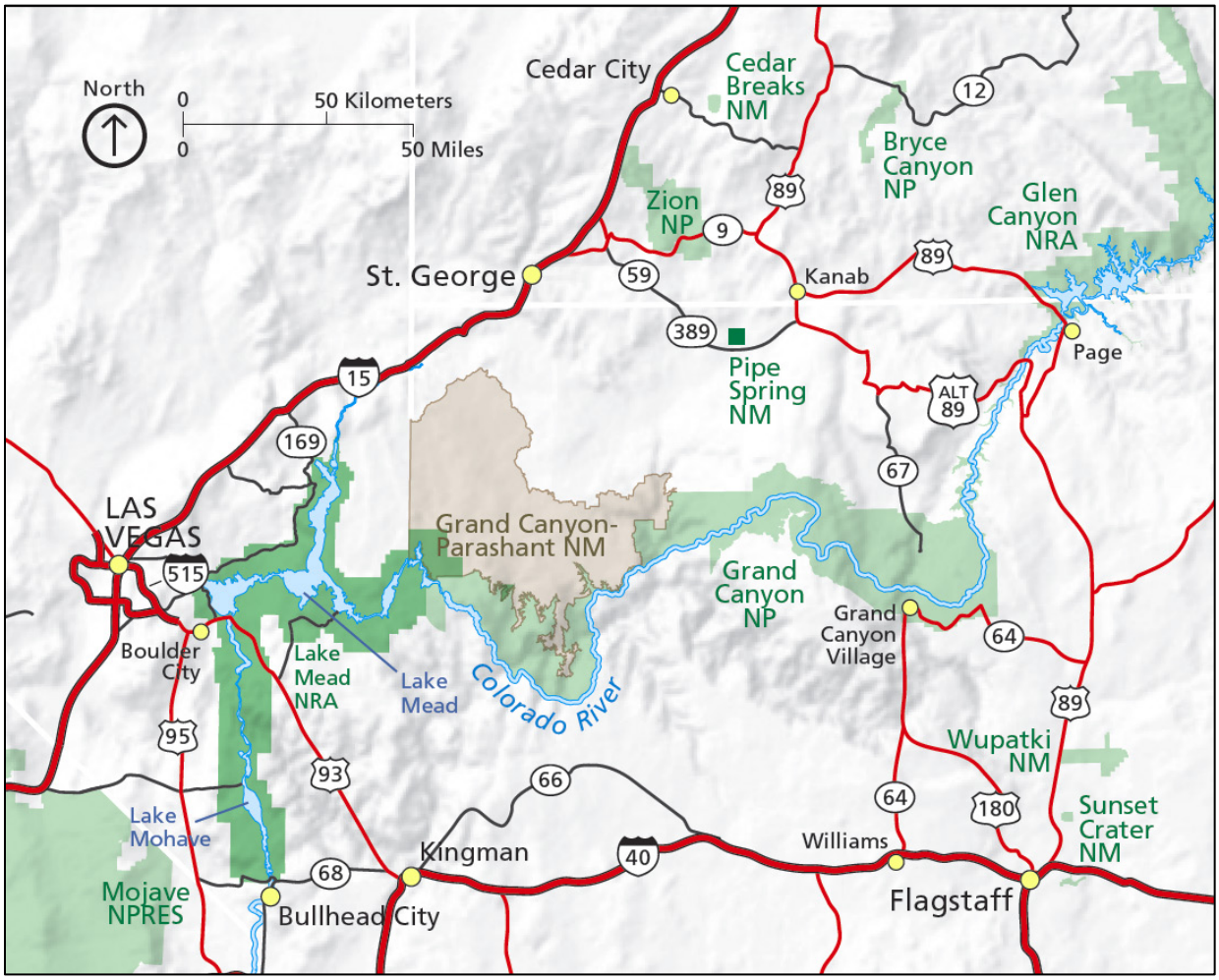


Figure 2.2.2-1. Lake Mead National Recreation Area (Lake Mead NRA) showing nearby National Park units and n 3 n major cities and roads (USGS).

The stored waters of Lake Mead, as re-regulated and delivered through Lake Mohave, provide domestic water supplies for 25 million people in the states of Nevada, California and Arizona and to the country of Mexico. Lake Mead water storage also irrigates more than 2.5 million acres of cropland. Hydropower from the Hoover Dam and Davis Dam provides electricity to Las Vegas, Phoenix, Los Angeles, Tucson and San Diego metropolitan areas. The many benefits of Lake Mead have enabled the modern development of the southwestern United States (Rosen et al., 2012).

There are four water reclamation districts that discharge treated wastewater effluent to Las Vegas Wash, a tributary to Lake Mead. These are the Clark County Water Reclamation District, which operates the valley's largest wastewater facility treating approximately 104 million gallons per day of wastewater; the City of Las Vegas, which treats 44 million gallons per day of wastewater; the City of Henderson, which treats approximately 25 million gallons per day, and the City of North Las Vegas, which treats approximately 17 million gallons daily (2017 2nd Qtr. SWAC Report). The wastewater reclamation plants provide tertiary wastewater treatment. The water reclamation districts maintain extensive water quality monitoring programs in Las Vegas Wash, Las Vegas Bay, and the Boulder Basin of Lake Mead to comply with their National Pollutant Discharge Elimination System (NPDES) discharge permits issued by the Nevada Division of Environmental Protection (NDEP) (Lake Mead NRA, 2010). The Las Vegas Wash also drains urban surface runoff for a portion of Clark County, Nevada. With increasing growth in the Las Vegas Valley, there has been a growing concern with the impact of associated increase in effluent and runoff volumes on Lake Mead's water quality. The Southern Nevada Water Authority (SNWA) diverts water from Lake Mead to meet drinking water needs for Clark County, Nevada, withdrawing approximately 450,000 acre feet per year. The Colorado River Commission of Nevada receives what is considered a return flow credit for the approximately 150,000 acre feet annually returned to Lake Mead via Las Vegas Wash. This credit is added to the annual Colorado River allocation for Nevada (300,000 acre feet) (Lake Mead NRA, 2010).

2.2.3. Recreation Values and Visitation Statistics

Lake Mead NRA generally is among the top five highest visited units of the National Park System. Visitation in 2015 was 7,298,465. During the past ten years (2006–2015) visitation has ranged from a low of 6,285,439 to a high of 7,777,753 (NPS, 2016). The great majority of park visitors incorporate the lakes into their visitation, either directly as water-based recreation, or as the focus for sight-seeing. While the majority of visitation occurs on Lake Mead, in 2015 Lake Mohave had over 2,200,000 visitors. Lake Mead, with four marinas, houses over 2,800 boat rental slips. Lake Mead NRA maintains six boat launch ramps on Lake Mead, and four launch ramps on Lake Mohave. Lake Mohave, with three marinas, has over 1,000 boat slips. The 2002 Lake Management Plan found that peak use on Lake Mead can be in excess of 4,000 boats on the water at one time; peak use on Lake Mohave was found to be over 1,000 boats on the water (Lake Mead NRA, 2002). In 2015, Lake Mead NRA recorded 152,007 overnight backcountry camping stays, consisting mainly of shoreline camping (NPS, 2016).

Lakes Mead and Mohave provide significant economic value to the regional economy through recreational expenditures. In 2014 the recreational industry value of Lake Mead was estimated to be

over $479 million annually; with the annual recreational value of Lake Mohave alone adding in excess of an additional $200 million (Batker, et al., 2014).

The stark contrast of deep blue lakes with spacious open water basins against a backdrop of mountain and canyon scenery creates an array of landscapes and water conditions enhancing the recreation experience of Lake Mead (Rosen, et al, 2012). To protect the existing quality of the recreational setting, and continue to provide for a safe and healthy recreational experience, in 2015 Lake Mead NRA developed a Recreation Suitability Guide (Lake Mead NRA, 2015). The guide documents those parameters which contribute to the recreational setting as well as parameters protective of public health. The guide also states that water quality and aesthetic condition are important resources within Lake Mead NRA, within the framework of protection of scenery per the National Park Service (NPS) Organic Act, the Lake Mead NRA enabling legislation, and NPS Management Policies (Lake Mead NRA, 2015).

2.3. Natural Resources

A summary of the **limnological** and **riparian** resources at Lake Mead NRA is presented in section 2.3.2 Resource Descriptions. Information known prior to the completion of this condition assessment is presented here. New information and data pertaining to each natural resource topic were gathered and compiled throughout this assessment process and are presented in chapter 4.

2.3.1. Ecological Units and Watersheds

Lake Mead consists of four large basins (Gregg, Temple, Virgin, and Boulder) and four narrow canyons (Iceberg, Virgin, Boulder, and Black). An additional feature is the 33 miles long former Virgin River channel, now called Overton Arm. The four basins are somewhat ecologically distinct due to the differing properties of their inflow tributaries (Holdren & Turner, 2010). Lake Mohave is riverine for 18 miles below the Hoover Dam within Black Canyon, then breaks into the broad but shallow Cottonwood Basin (Figure B-1). A variety of ecological conditions and influencing limnological characteristics exists across the two reservoirs due to the variety of physical habitats. These include sediment deltas at the inflows of the Colorado, Virgin and Muddy Rivers and Las Vegas Wash, deep basins within flooded canyons of the Colorado River channel, shallows over flooded former valleys and bajadas, and riverine habitats within narrow canyons (Lake Mead NRA, 2010).

The Colorado River provides approximately 97% of total inflow to Lake Mead. The Colorado River watershed above Lake Mead has a total area of 386,727 km² (149,316 mi²) (Holdren & Turner, 2010). Most of the land within this watershed is non-developed rangeland or forests; the Colorado River above Lake Mead flows over 500 miles contiguously through Canyonlands NP, Arches NP, Glen Canyon NRA, and Grand Canyon NP before entering Lake Mead at Gregg Basin (Figure B-1). The Overton Arm of Lake Mead collects the combined flows of the Muddy and Virgin Rivers, with a combined watershed area of 31,160 km² (12,030 mi²) (Figure B-1). These watersheds are also mostly rangeland, desert scrub, and forests; however, both the Virgin River and Muddy Rivers flow through rapidly urbanizing areas (St. George, Utah and Mesquite, Nevada for the Virgin River, and Logandale-Overton, Nevada for the Muddy River). These urban areas will continue to influence both water quality and water quantity entering Lake Mead.

Drainage entering Lake Mead via Las Vegas Wash includes both non-point source urban runoff and permitted discharges from four municipal wastewater treatment plants. The Las Vegas Wash watershed extends 5,680 km² (2,193 mi²) (Figure B-1). While the majority of the acreage can be classified as rangeland/desert scrub, the watershed also contains a metropolitan area of over 2 million residents. Since 2002, flows into Lake Mead from the Las Vegas Wash averaged more than 8 m³/sec (287 cfs), or 2.2% of the total inflow to Lake Mead (Holdren & Turner, 2010).

Annual flows of the Colorado River are almost entirely dependent upon winter snowfall within the watershed. More than 20 mainstem dams regulate the flows of the Colorado River (Figure 2.3.1-1). This regulated system is managed by the US Bureau of Reclamation (BOR) in coordination with the seven basin states (Colorado, Utah, New Mexico, Wyoming, Nevada, Arizona, and California) within a complex framework of law, regulations, compacts, treaties and policies often referred to collectively as the "Law of the River." (Holdren & Turner, 2010). For management purposes, the Colorado River watershed is divided into the Upper Basin, comprised of the watershed within the states of Colorado, Utah, New Mexico, and Wyoming, and the Lower Basin, comprised of the watershed within the states of California, Nevada, and Arizona (Figure 2.3.1-1). Annual system water availability is generally expressed as the natural inflow within the Upper Basin as measured at Lees Ferry, Arizona located at the boundary of the Upper and Lower Basins on the Colorado River (Figure 2.3.1-1). Reservoir storage capacity within the Colorado River watershed is approximately 60 million acre feet (maf), or approximately four times the 15.0 maf annual average inflow into the Upper Basin as measured during the period from 1906 through 2011 (Holdren & Turner, 2010).

Through a series of compacts and treaty obligations, the water rights to the Colorado River have been allocated to the seven basin states, along with a treaty obligation to Mexico. The overall allocations total 16.5 maf/yr, with 7.5 maf/yr apportioned to the states within the Upper Basin, 7.5 maf/yr apportioned to the Lower Basin states, and 1.5 maf/yr to Mexico. The two largest reservoirs in the system, Lake Powell, formed by Glen Canyon Dam and immediately upstream from Grand Canyon National Park, and Lake Mead, with a combined storage capacity of 50.2 maf provide nearly 85% of the available system storage. Lake Mead's storage capacity, approximately 28.8 maf, can alone store almost two years of the entire Colorado River long-term average annual inflow (Rosen et al., 2012).

The system is designed to provide certainty of water delivery by providing multi-year storage capacity of inflows from above average hydrologic inflow years. The Law of the River requires that the Upper Basin release 75 maf over a ten years' period to the Lower Basin. In an average water year, BOR releases 8.23 maf from Lake Powell to the Lower Basin, referred to as the minimum objective release. This average minimal release is intended to meet the 7.5 maf allocation needs of the Lower Basin, as well as the Upper Basin portion of the 1.5 maf to meet treaty obligations with Mexico (Holdren & Turner, 2010). Within the system, Lake Mead functions generally as a storage reservoir for the Lower Basin, and its water levels are reflective of fluctuations in Colorado River watershed hydrology as influenced by annual snowpack within the watershed and the management decisions related to the release of water.

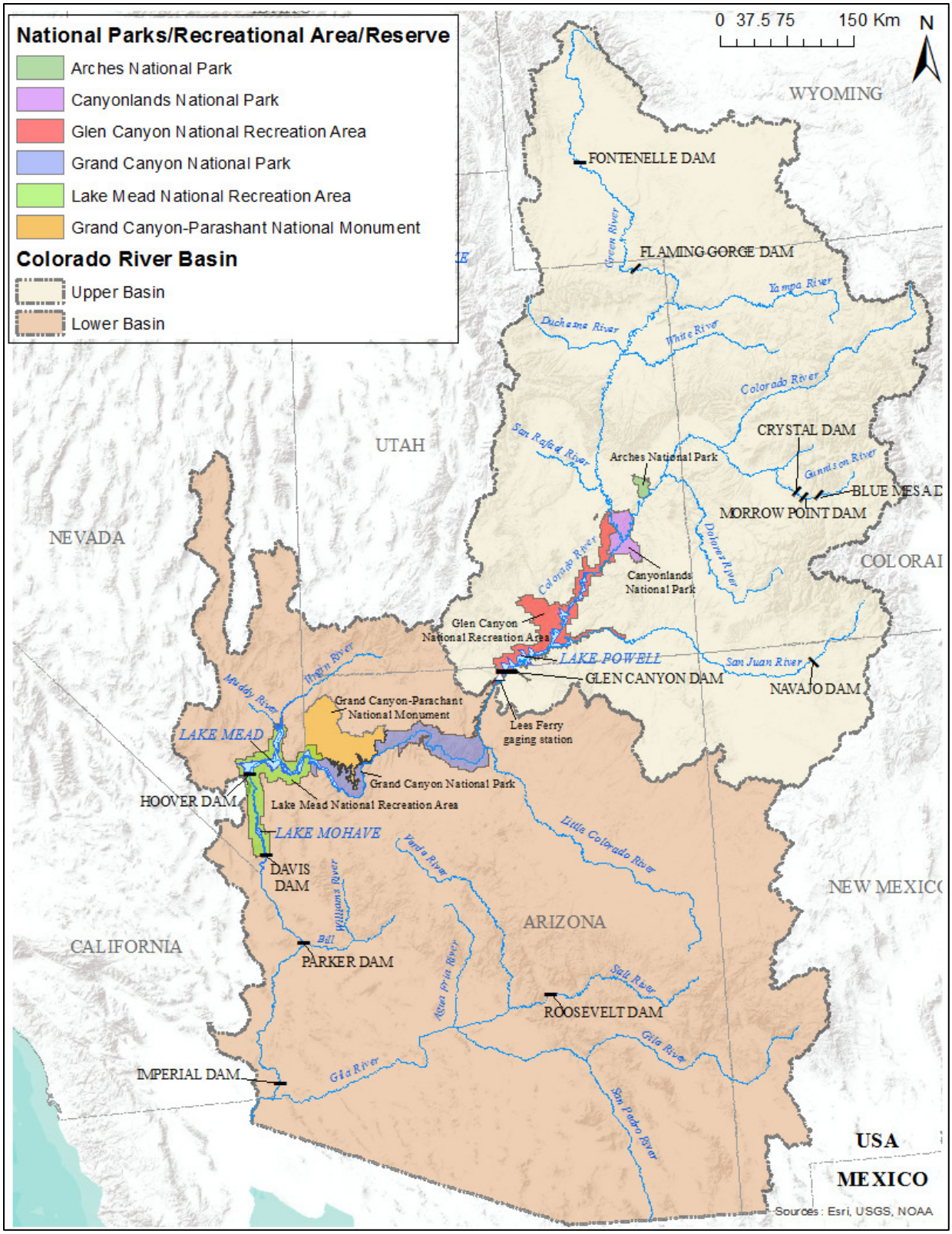


Figure 2.3.1-1. Colorado River Basin showing areas of the Upper and Lower Basins, including lakes Mead and Mohave, national parks and recreation areas boundaries, and locations of Colorado River mainstem dams (USGS, NOAA).

Water surface elevations on Lake Mead show large fluctuations with an approximate average annual inflow to Lake Mead from the Colorado River is 9.0 maf, comprised of the average year 8.23 maf minimum objective release from Lake Powell and tributary inputs between Lake Powell and Lake Mead (tributaries within the Grand Canyon, and the tributary inputs of the Virgin and Muddy Rivers). The approximate average outflow from Lake Mead is 9.6 maf, comprised of the Lower Basin water apportionments, Mexican Treaty allocations plus evapotranspiration and transmission losses. The annual surface evaporation loss for Lake Mead is 0.6 maf, with the aggregate Lake Mead average annual water budget showing a net loss of 1.2 maf (Rosen et al., 2012). Therefore, during years of minimum objective release (average system conditions), Lake Mead surface elevation decreases 12 feet. Storage capacity, or surface elevation, of Lake Mead will be stable or increase during periods of above average precipitation and snowpack within the watershed, Lake Mead's storage capacity and surface elevation should be stable or increase within the year. The Colorado River watershed has experienced a significant drought period since 2000, with tLake Mead elevation declining some 139 feet from 2000 through 2015 (Bureau of Reclamation, 2016). Such periods of long-term drought are not uncommon within the long-term hydrologic record of the Colorado River; and climate change models predict that water availability within the Colorado River watershed to be from 5 to 20 % less than current long-term averages by the end of the century (Rosen et al., 2012).

In contrast, Lake Mohave operates as a re-regulation reservoir, providing availability of consistent volume to meet prescribed downstream demands. Therefore, Lake Mohave surface elevations remain within a predictable annual range and are relatively stable (Lake Mead NRA, 2010).

While these reservoirs have modified the original free-flowing Colorado River ecosystem, lakes Mead and Mohave still provide significant habitat for fish and wildlife species. Critical habitat has been designated for the federally listed endangered razorback sucker (*Xyrauchen texanus*) in both reservoirs and the federally listed endangered bonytail chub (*Gila elegans*) in Lake Mohave. In addition, the lakes support large populations of non-native **sportfish**, including smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and striped bass (*Marone saxatilis*) (Rosen et al., 2012) (see Appendix Table B-4 for a list of fishes found in lakes Mead and Mohave and their conservation status). Lake Mead NRA has legislative mandates to support population sustainability of both the Colorado River native fish and the non-native sportfish; however, optimum requirements for these species are often in conflict. Lake Mead NRA is also a regionally important habitat for many birds, with 96 documented species of aquatic-dependent birds (Table B-5).

2.3.2. Resource Descriptions

Parts of this subsection are excerpted from Holdren & Turner, 2010; Lake Mead National Recreation Area, 2010; Rosen et al., 2012; and NPS, 2014.

Climate

Lake Mead NRA is located in the Mojave Desert, with a hot and arid climate. Winter temperatures are mild and range from 12–19 °C (53–66 °F), and summer temperatures range from 32–43 °C (90–110 °F). Precipitation occurs primarily in the form of rainfall, averaging 11 cm (4.5 in) annually.

Water Quality and Limnology

Based on several classification indices Lake Mead is **oligotrophic**, **mesotrophic, and eutrophic,** depending on the location, (Vollenweider, 1970; Carlson, 1977). As with other reservoirs, dam operations exert a significant influence on the water quality and ecology of the system (Thornton, 1990). Each basin within Lake Mead is ecologically unique, thus responds differently to the inflow-outflow regime regulated by operation authorities. The different sources of water entering Lake Mead often retain their identity and influence for substantial distances into the reservoir and do not necessarily mix completely with the rest of the water column (Ford, 1990). For example, Colorado River water is detectable as underflow all the way to Hoover Dam, driving base hydrology and mixing (Rosen et al., 2012). The incomplete mixing of inflows to Lake Mead with the surrounding water can lead to erroneous estimates of water retention time. It also influences the conveyance and fate of contaminants and nutrients transported into the reservoir.

The tributary Las Vegas Wash contains stormwater runoff and treated wastewater effluent from urban Clark County, Nevada (Las Vegas) (Figure B-1). Due to these flows, a large fraction of Lake Mead's **nutrient loading** is confined to the most downstream basin, Boulder Basin (Paulson & Baker, 1983; Prentki & Paulson, 1983; LaBounty & Horn, 1997). This situation is unusual for a reservoir since it is opposite the normal upstream-downstream decrease in the pattern of productivity, and results in several limnological features generally associated with upstream reaches (Kimmel et al., 1990). The combination of high concentrations of nutrients, salts, and other constituents from Las Vegas Wash and the lower concentrations, but higher flows, in Colorado River inputs combine to determine the observed conditions in Boulder Basin. In addition, there are periods of high alagal biomass near the Colorado River inflow (SNWA unpublished).

LaBounty and Burns (2005) examined water quality in Boulder Basin and concluded that Lake Mead is strongly phosphorus limited, which affects nutrient concentration gradients within Boulder Basin which is well-stratified. Secchi transparency shows a strong statistical inverse relationship with chlorophyll *a* and total phosphorus. Secchi transparency is generally lower in the tributary areas, reflecting higher nutrient availability. Secchi transparency in the open waters of Lake Mead has generally increased through 2011, but has declined slightly since then (see chapter 4) (Rosen et al., 2012).

Lake Mead was included in the first U.S. Environmental Protection Agency National Lakes Assessment (USEPA NLA), a baseline study of the condition of lakes in the United States during 2007 (USEPA, 2009). Using the criteria for evaluating lake condition and status from the USEPA NLA, the USGS Circular 1381, A Synthesis of Aquatic Science for Management of Lakes Mead and Lake Mohave utilized the more extensive water quality data existing for Lake Mead to evaluate Lake Mead based upon data collected in 2009 and 2010 (Rosen et al., 2012). In contrast to the USEPA NLA data points for Lake Mead, the USGS Circular 1381 was able to assess all four of the major basins, across the seasons within one year. Within the NLA, USEPA uses the parameters of the nutrients phosphorus and nitrogen, turbidity, dissolved oxygen, and chlorophyll *a* to characterize general lake ecosystem health. The suitability of the lake for recreation is characterized by indicators for fecal bacteria, cyanobacteria, microcystin algal toxin and chlorophyll *a* (USEPA, 2009). The

USGS Circular 1381 reviewed those parameters across the four major basins of the lake, using calendar year 2009 data for the ecosystem health parameters and 2010 data for the recreation suitability data (Rosen et al., 2012).

Water quality in Lake Mead compared favorably to the parameters within the USEPA NLA (see Figure 2.3.2-1). For the selected locations, representing all major basins, Lake Mead scored in the highest categories: "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 Gregg Basin, and within the "fair" range in Boulder Basin. Turbidity values for Boulder Basin were within the "good" range while turbidity in the Virgin Basin and Gregg Basin were within the "fair" range. These high-quality scores represent high water quality within the criteria USEPA uses to evaluate the ecosystem health of lakes across the United States (Rosen et al., 2012). The USEPA NLA further establishes criteria for and evaluates recreation suitability, asssessing the level of health risk to swimmers and water contact recreation. Those criteria include human pathogens as indicated by fecal bacteria, and the likelihood of exposure to algal toxins, as indicated by abundance of cyanobacteria, concentrations of the algal toxin microcystin, and chlorophyll *a* concentrations. Within the USEPA criteria, Lake Mead posed a low risk of exposure to algal toxins based upon microcystin concentrations and chlorophyll *a*. Cyanobacteria abundance values were within the low end of the "moderate risk" range; however, there has been detections of microcystin concentrations of 400ug/L at the pier in Las Vegas (SNWA unpublished). The great majority of the cyanobacteria species detected to date at Lake Mead are not species associated with algal toxin production (Rosen et al., 2012). Overall, evaluation of Lake Mead against the USEPA NLA criteria suggests that water quality for ecosystem health and water-based recreation is well within "good" ranges for criteria and equal to or better than that in many other Western lakes (Rosen et al., 2012). Basic water quality parameters in Lake Mead are considered well within Nevada state standards and good ranges for USEPA NLA criteria (Figure 2.3.2-1, Rosen et al., 2012). Even with water quality shown to be well within state standards and supportive of high-quality recreation setting, periodic problems with nutrient balance, algal blooms, and dissolved oxygen can occur in some areas of Lake Mead.

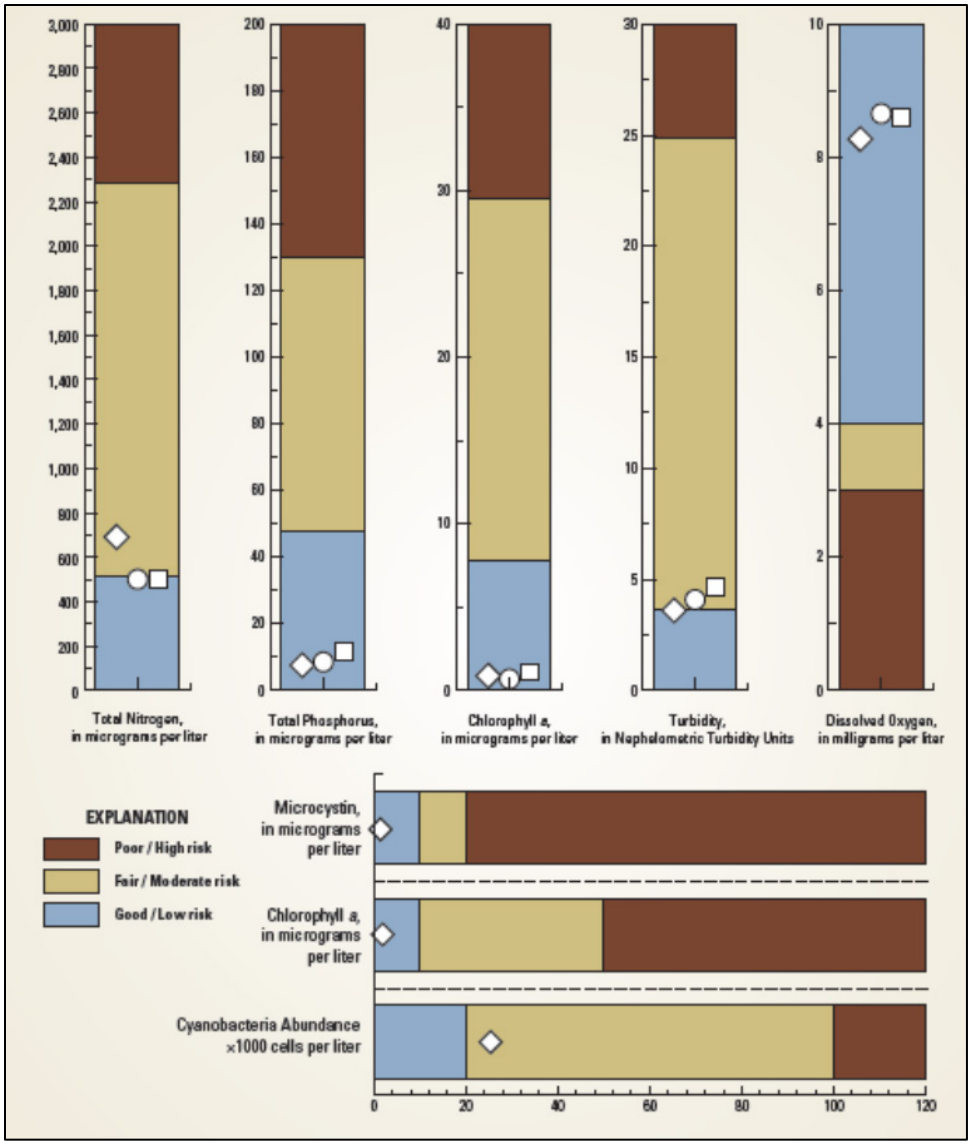


Figure 2.3.2-1. Lake Mead water-quality conditions compared to U.S. Environmental Protection Agency (2009, 2010) indicators. Boulder Basin (diamonds), the Virgin Basin (circles), and the upper Colorado River Arm (squares). Excerpted from Rosen et al., 2012.

Lake Mohave's only inflow comes from the releases through the Hoover Dam. Historically Lake Mohave has received limited water quality monitoring (Lake Mead NRA, 2010). NPS, BOR, and SNWA partnered to initiate lakewide routine monitoring for Lake Mohave in 2012. While this provides insufficient information to establish long-term trends, information from the first two years of monitoring (2012, 2013) was presented by the interagency monitoring team at the February 2014 Lake Mead Science Symposium (Tietjen et al., 2014). They surmised that the limited information to date showed that Lake Mohave to reflect the overall good water quality existing within Lake Mead. All parameters are generally reflective of the values and ranges of corresponding parameters on Lake Mead and well within the USEPA NLA "good" range. The monitoring that began in 2012, however, was initiated due to increasing concerns over noticeable accumulations of *Microcystis* algae in the

summer of 2011(NPS, 2014). While significant amounts or accumulations of *Microcystis* algae were not found by the interagency monitoring in 2013 or 2014 (Tietjen, et.al., 2014), in 2015 *Microcystis* algae accumulations in both Lakes Mohave and Lake Mead necessitated public advisories to park visitors (Lake Mead NRA, personnel communications).

In 2013, SNWA and BOR partnered in a study to examine the potential impacts of climate change and continued lowering Lake Mead surface elevations on water quality. They used an existing Lake Mead water quality model to simulate conditions at water levels down to 925 feet elevation mean sea level (msl) (Lake Mead is considered full at 1220 msl, surface elevation in May 2016 was 1074 msl). Their simulations found that Lake Mohave could face significant effects to water quality from lowering Lake Mead elevations resulting in discharges through Hoover Dam of **epilimnion** or surface waters from Lake Mead into Lake Mohave (Preston et al., 2014).

Fish and Aquatic Biota

Lakes Mead and Mohave are classified as moderately productive in terms of the basic sources of food that support fish and wildlife. Plankton, algae, zooplankton, and **benthic** invertebrates provide the base for this productivity measure. 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 is most productive in nutrient-rich inflow areas down gradient from Las Vegas Wash and at the confluence of the Muddy and Virgin Rivers.

The water column in Lake Mead supports more than 70 zooplankton species, including copepods, cladocerans, rotifers, and ostracods. The zooplankton community is an important food source for fish, particularly for threadfin shad (*Dorosoma petenense*), the primary **forage fish** in the system. Sporadic invertebrate surveys at Lake Mead since 1986 indicate a change in the benthic invertebrate community over the past 30 years. Changes observed are likely results of the combination of lowering lake levels, decreases in algal levels, invasion by new non-native invertebrates, e.g. quagga mussel (*Dreissena bugensis*), and other environmental factors (Umek et al., 2010; Wittmann et al., 2010; Wong, 2012; Davis et al.; 2014; and Caldwell et al., 2015). The most dramatic changes have been the introductions of the invasive quagga mussel and New Zealand mudsnail (*Potamopyrgus antipodarum*).

Lakes Mead and Mohave support diverse populations of aquatic species, including fish and invertebrates (see Table B-4 for a list of fishes found in lakes Mead and Mohave and their conservation status). Both Lake Mead and Lake Mohave are designated as critical habitat for the federally listed endangered razorback sucker. Lake Mead contains one of the few Razorback populations on the Colorado River where consistent natural recruitment from larval fish to adult has been documented (Rosen et al., 2012). Razorbacks are known to spawn in at least four locations on Lake Mead: the inner Las Vegas Bay on the West end of Boulder Basin, two areas of the Overton Arm, and the inflow area of the Colorado River. The total adult population is estimated to be fewer than 800 fish (Rosen et al., 2012). Adult Razorbacks are present throughout much of Lake Mohave,

where they nest on shallow gravel benches in scattered coves yearly from February through April. Successful spawning on Lake Mohave; however, has not been documented to lead to natural recruitment. As recently as the late 1980s the Lake Mohave Razorback population was estimated to exceed 50,000 adults. For over twenty-five years, state and federal biologists have actively captured larval razorback suckers in Lake Mohave, raised them in rearing ponds to sizes thought sufficient to avoid predation by non-native fish, and released them back to the lake. The BOR-led Lower Colorado River Multi-Species Conservation Program (LCRMSCP) funds these efforts. Interagency activities, documented in the U.S. Fish and Wildlife Service (USFWS) Recovery Plan for razorback sucker, include annual population monitoring and augmentation. Despite these efforts, the adult population in Lake Mohave is currently estimated at less than 2,500 fish.

Key sportfish species include striped bass, largemouth bass, smallmouth bass, and channel catfish (*Ictalurus punctatus*). In 1962 the Willow Beach National Fish Hatchery located at Willow Beach on Lake Mohave began stocking rainbow trout (*Oncorhynchus mykiss*) to utilize the cool water releases from Hoover Dam for a recreational fishery. Rainbow trout continued to be an important sportfish species below the Hoover Dam in Lake Mohave until the mid-1980s when striped bass from Lake Mead arrived in Lake Mohave. To support the sport fishery, and make lower level **trophic productivity** available to sportfish, threadfin shad were stocked in Lake Mead and Lake Mohave in 1954. They have been particularly important as a forage species supporting the striped bass fishery (Rosen et al., 2012). The gizzard shad (*Dorosoma cepedianum*) first observed in Lake Mead in 2007 is now found in both lakes in large numbers. Assumed to be an illegal introduction, it now comprises over 40% of the catch on sportfish annual surveys by NDOW (Rosen et al., 2012). It is unknown what the long-term ecological impacts from this species may be.

The original (pre-dam) habitats the Colorado River provided to its native fish were different from those now available in the reservoirs. Colorado River native fish now survive in low numbers in Lake Mead and Lake Mohave, with increased predation from non-native sportfish and competition with non-native forage fish. Lake Mead NRA has mandates to sustain populations of Colorado River native fish, and provide for recreational sportfishing opportunities. The optimal conditions for various fish species, particularly for non-native versus native species, are often in conflict. Lake Mead NRA works with a variety of agency partners for water quality and resource conditions in support of aquatic wildlife, including fish, that seeks to balance competing demands for water use, water recreation, and differing optimal conditions for wildlife.

Aquatic-dependent Birds

Lakes Mead and Mohave provide important stopover habitat and wintering grounds for many aquatic dependent birds along the Pacific and Intermountain Flyways of Western North America. The University of Nevada Las Vegas (UNLV) conducted an inventory of waterbirds on Lake Mead and Lake Mohave from 2004 through 2009 (Rosen et al., 2012). That inventory documented 92 species of waterbirds, and an additional 4 species that are associated with the lakes and shorelines: belted kingfisher (*Megaceryle alcyon*), bald eagle (*Haliaetus leucocephalus*), osprey (*Pandion haliaetus*), 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. The bald eagle

winters along both lakes Mead and Mohave, utilizing aquatic based prey, including waterfowl as well as fish. In 2011, surveys by crews covering both lakes in a single day documented 163 bald eagles (Rosen et al., 2012). Peregrine falcons on lakes Mead and Mohave have been documented to prey on 29 species of aquatic birds. In 2010, 33 Peregrine falcon occupied nesting territories were documented (Rosen et al., 2012).

Lake Mead has a greater diversity of aquatic-dependent bird species than Lake Mohave, with about a third of the species observed only on Lake Mead. This species diversity results primarily from the nutrient-rich and delta-forming inflows of the Muddy, Virgin, and Colorado Rivers, and Las Vegas Wash, which support a greater diversity of available shallow-water habitat (Rosen et al., 2012).

Riparian and Aquatic Vegetation

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 2015 exposed additional delta areas at Las Vegas Wash, Virgin River, and Muddy River tributaries, and at the main stem of the Colorado River. Newly exposed deltas provide significant acreages of mud and silt flats and new acreages of plant habitat. Although a large part of these new delta habitat areas quickly fill with non-native plants, particularly saltcedar (*Tamarix* sp.), the potential for native riparian habitat or mixed habitat exists. Newly exposed shoreline areas distant from tributaries and deltas serve as corridors for the spread of non-native vegetation (Rosen et al., 2012).

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 non-native saltcedar, with only a few areas where topography and soils present better conditions for the native Goodding's willow (*Salix gooddingii*); as a result, native recruitment of Goodding's 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*) (Rosen et al., 2012).

Littoral or shallow zone aquatic vegetation have received minimal inventory or monitoring to date. 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. Recently, a series of invasive aquatic plants threaten these areas, many of which have ecological and recreational impacts (Rosen et al., 2012)

Cove surveys by scuba divers within Las Vegas Bay 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 feet. In areas of Lake Mead that do not support vegetation, littoral vegetation can consist of grasses (*Phragmites australis*), rushes (*Juncus* spp), sedges (*Eleocharis rostellata, Scirpus Americana*), cattails (*Typha domingensis*), forbs, and aquatic species like sago pondweed (*Potamogeton 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 in LMNRA and increasing as lake levels decline. Other challenges to the development of littoral vegetation include increasing susceptibility to changes in lake chemistry with the introduction of human products, toxic algae and eutrophication.

Recreation

Today, the park receives approximately seven million recreational visits with about 50% of these originating in Southern California. The remaining visitors are primarily from Nevada, Arizona, Utah, and other western states. The 2002 Lake Management Plan set facility capacities for Lake Mead (amended in 2005). At high water levels where all facilities are operational, the marina capacity for Lake Mead was established at 3,357 slips with 460 rentals boats. The public launch capacity was established at 3,000 boats. The boating capacity for Lake Mead was set at 3,295 boats at any one time. Popular water-based recreation includes boating, swimming, personnel watercraft (PWCs), paddle craft, picnicking, and shoreline recreation (NPS, 2015a). Recreational fishing may be of additional particular importance as well.

The lowering lake levels observed between 2000 and 2015 have significantly affected public access to Lake Mead. Lake access points at Pearce Ferry, Government Wash, Las Vegas Bay, and Overton have been closed as lake waters have receded such that these areas can no longer provide reasonable access. Boulder Harbor operations have been reduced with the relocations of the Lake Mead Ferry Service and Lake Mead Marina. All other lake access points have been dramatically impacted. The park concessioners are having difficulty moving the marinas and extending utilities to keep the marinas operational at these water levels. These difficulties are impacting lake access and subsequently, visitor use at Lake Mead.

Lake Mohave alone received over 1.8 million visitors in 2014. Lake Mohave contains approximately 30 miles of riverine flow in the Black Canyon below Hoover Dam prior to widening into the Cottonwood Basin. Lake Mead NRA has established motor-craft free days weekly, and motor-craft free periods of the year, for the thirteen miles between Hoover Dam and Willow Beach, which has become a destination paddle craft area. The 30-mile section between Hoover Dam to Eldorado Canyon has been formally designated as the Black Canyon National Water Trail. Cottonwood Cove, Willow Beach, and Katherine's Landing on Lake Mohave all have marinas, boat launches, and local shoreline recreation and picnicking facilities. As Lake Mead's elevation drops, the relatively stable shoreline areas and sandy beaches of Lake Mohave have become even more heavily used (NPS, 2014).

Lake Mead NRA has mandated responsibilities to provide water-based recreation that is safe and healthy, in the context of an outstanding water-based recreational setting. In its 2003 Guidelines for Safe Recreational Water Environments, the World Health Organization (WHO) suggested that water recreation managers had a responsibility to provide experiences that were safe, healthy, and aesthetically pleasing (NPS, 2015a). The USEPA NLA (USEPA, 2009) utilized three indicators for what it termed "Suitability for Recreation." These indicators are (1) algal toxins, (2) fish tissue mercury contamination, and (3) human pathogen indicator bacteria. In 2015, Lake Mead NRA developed Recreation Suitability Guidelines documenting water quality parameters to assess the

recreational suitability of lakes Mead and Mohave (Lake Mead NRA, 2015). Indicators were chosen to encompass relevant Nevada state water quality standards, WHO recreational water guidelines, and USEPA guidelines. They include: (1) human pathogens, (2) hazardous algal blooms (HAB)/algal toxins, (3) fish tissue (mercury) contamination (relative to human consumption), and (4) the aesthetic/setting indicators of chlorophyll *a*, Secchi depth monthly averages, and the presence/absence of debris or surface scum. Given the importance of water-based recreation and existing recreation setting within the Lake Mead NRA's enabling legislation, managers consider the quality of the recreational setting as a park resource, analogous to other NPS experiential resources such as dark, night sky and natural quiet (NPS, 2015a).

Lake Mead NRA and interagency management actions to protect water resources and water recreation experience require aquatic invasive species (AIS) inspections for contract equipment and boats arriving via haul permit. For boats that have been slipped and moored in lakes Mead and Mohave, boats are required to have a Nevada AIS annual registration stickers for boats and meet USEPA fuel-injection standards. In additional there are motorized boat restrictions to create paddle craft only recreation experiences (NPS, 2015a).

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

2.3.3. Resource Issues Overview

Lake Mead NRA has worked within an extensive interagency partnership for over the past ten years to develop mutual interagency objectives for protecting water resources of lakes Mead and Mohave. That partnership spawned the Lake Mead Ecosystem Monitoring Work Group (LaMEM), a branch of the chartered Lake Mead Water Quality Forum coordinated by NDEP. LaMEM core participants include the NPS, SNWA, BOR, USGS, and NDOW, and its quarterly meetings and biennial symposia are attended by representatives of regional universities, wildlife agencies, wastewater reclamation districts, and water agencies.

The primary interest of the LaMEM is research and monitoring in support of the Lake Mead Water Quality Forum's Memorandum of Agreement objective to protect water quality for public and municipal water supply, aquatic life, wildlife, recreation, and other beneficial uses. Interest in aquatic life and wildlife includes all components of the food web, which maintain healthy native and sport fisheries and support aquatic-dependent wildlife (e.g. avian species), and extends to sediments and riparian and shoreline-dependent native vegetation. Physical and biological stressors with the potential to disturb the health of the ecosystem are of interest. In addition, also of interest to the LaMEM Workgroup are activities related to wastewater reclamation for return to the Colorado River system through Nevada's return flow credit system.

In 2010 Lake Mead NRA in coordination with the core members of LaMEM developed the Long-Term Limnological and Aquatic Resource Monitoring and Research Plan for lakes Mead and Mohave (LTAP) (Lake Mead NRA, 2010). The plan identified 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 identified three key stressors to lake resources: contaminants, invasive species, and climate change. Information related to those resource categories and stressors was summarized in the 2012 USGS Circular 1381, A Synthesis of Aquatic Science for Management of lakes Mead and Mohave (Rosen, et al., 2012).

Beginning in the summer of 2011, Lake Mead NRA park visitors and staff began to report unusual conditions on Lake Mohave; noticeable clumps of algae. Samples determined that *Microcystis* algae, historically present in low numbers, had increased in Lake Mohave. Monitoring during the summers of 2011–2014, however, did not detect algal toxin. In 2015, widespread aggregations of *Microcystis* algae were noticeable in numerous areas on Lake Mead and Lake Mohave. Testing for algal toxins found positive results for the first time, resulting in swim advisories (NPS, 2015b). However, it is uncertain as to the specific causes of these *Microcystis* events on Lake Mead and Mohave in 2015. There were no significant issues related to *Microcystis* levels in the summer of 2016. Issues related to blooms of *Microcystis* spp., and release of algal toxin have become widespread globally.

Changing conditions at Lake Mead and Lake Mohave, including lowering lake surface elevations, and the introduction of the non-native quagga mussel have been suspected in other areas in creating conditions that can enhance algae growth. Also, changing use patterns, particularly with shoreline use on Lake Mohave, have the potential to impact bacterial pathogen indicators. Given that changing reservoir conditions seemed to be increasing probabilities of human health related or recreational experience issues on the lakes, in 2015 park management developed the Lake Mead NRA Recreation Suitability Guide (Lake Mead NRA, 2015). The guide established indicators, criteria, and thresholds of recreation suitability. The guide outlined management actions should thresholds of those indicators point to the need for public notification, enhanced monitoring of the indicators, and information to guide mitigation of the problem (Lake Mead NRA, 2015). Importantly, the guidelines established a management interest in water quality that supports an outstanding recreational setting. These include aesthetic experiential values such as water clarity, freedom from significant algae or debris, and the quality of the recreation setting. This places recreation suitability, with its suite of indicators, as a resource component for protection.

The various interagency forums over the past decade have coalesced upon core water resources that are of interest to water managers of lakes Mead and Mohave. The resource components are outlined within the mission purpose of the LaMEM, and the interagency mutual objectives within LTAP (Turner et al. 2010). Of primary concern is maintaining water quality, as defined by the physical water quality and limnological indicators, within ranges that support regulatory prescribed water uses, societal needs, and conservation mandates of the reservoirs. In addition to the limnological, ecosystem, or recreational experience components of interest, LaMem has identified an interest in the physical and biological stressors with the potential to disturb the health of the ecosystem.

The LaMEM Workgroup's primary scope of geographic interest includes the waters of lakes Mead and Mohave, their tributaries, and shorelines. Understanding the inputs of the Las Vegas Wash, Colorado River, Muddy River, and Virgin River are considered critical to understanding Lake Mead. Since the aim of the LaMEM Workgroup is to render an ecosystem-level perspective, the group is also interested in the dynamics, processes, and emerging issues within the watershed of Colorado River basin and the upstream Colorado River as well as downstream concerns (LaMEM, 2012).

The interagency activities and framework, from above, guided inclusion into the environmental framework and parameters identified in Table 3.2.1-2. The framework for this Lake Mead NRA Limnological and Riparian Resource Condition Assessment (LRCA) is a derivative of over fifteen years of interagency collaboration. Components of interest include lake and riverine ecosystem health; aquatic biota including native and non-native fish, invertebrates, aquatic invasive species, aquatic-dependent birds, and riparian vegetation; ecological processes such as food web dynamics; and NPS visitor experiential values related to recreation suitability. System drivers of interest include tributary inputs, both water quality and quantity; reservoir management and Colorado River operations; and climate change. Stressors include contaminants, water fluctuations, declining reservoir elevations, and urbanization within the watersheds. Details of threats and stressors pertaining to each natural resource topic are described and discussed in chapter 4.

2.4. Resource Stewardship

2.4.1. Management Directives and Planning Guidance

Broader Goals and Objectives

The 2015 Lake Mead NRA Foundation Document states that the Lake Mead NRA is an expression of the national value of expanding outdoor recreation opportunities. Lake Mead NRA manages public access to the waters, shorelines, and surrounding lands of the park, including the largest reservoir in the United States. The park supports amongst the nation's highest levels of water recreation and backcountry use. Lake Mead NRA preserves a great diversity of biological resources, intact habitat, and ecological connectivity in the region, including many **endemic**, threatened and endangered species and rare natural communities (NPS, 2015a).

From the park's enabling legislation and other guiding mandates, the document outlines the following purpose statement:

> *"The purpose of Lake Mead NRA is to provide diverse public recreation, benefit and uses on lakes Mead and Mohave and surrounding lands in a manner that preserves the ecological, geological, cultural, historical, scenic, scientific, and wilderness resources of the park."*

Derived from the purpose, the Foundation Document also provided seven significance statements for Lake Mead NRA, four of which relate to the need to conserve water-related resources:

1) As the first and largest national recreation area in the national park system, Lake Mead National Recreation Area is an expression of the national value of expanding outdoor recreation

opportunities. It manages public access to the waters, shorelines, and surrounding lands of the park, including the largest reservoir in the United States.

2) Lake Mead National Recreation Area offers dramatic scenery and a diverse array of land-and-water-based recreation opportunities near several large urban centers of the southwestern United States. With approximately seven million visitors each year, the park supports some of the nation's highest levels of water recreation and backcountry use.
3) Situated in the northeastern Mojave Desert near the interface with both the Great Basin Desert to the north and the So'noran Desert to the south, Lake Mead National Recreation Area preserves a great diversity of biological resources, intact habitat, and ecological connectivity in the region, including many endemic, threatened and endangered species and rare natural communities.
4) Given its inherent association with the reservoirs of infrastructure managed by water supply agencies, Lake Mead National Recreation Area provides a focal point for scientific research and policy discussions of national importance, including: the implications of urbanization on water scarcity, the need for water use efficiency and sustainable land uses, the importance of maintaining high water quality, and the effects of climate change on the natural and human environment.

The Foundation Document established several fundamental resource values related to limnological and water resources, including abundant land and water recreation, opportunities to appreciate spectacular scenery, riverine and reservoir ecosystems, species of conservation interest, an array of geologic features and processes, and functional desert habitats (NPS, 2015a). The 2015 Lake Mead NRA Foundation Document provides some guidance on desired future conditions. The Foundation Document was informed on potential indicators identified by the interagency Long-term Limnology and Aquatic Resources Monitoring and Research Plan for lakes Mead and Mohave (Lake Mead NRA, 2010). The six fundamental resource values related to water resources and their corresponding desired future conditions are provided in Table 2.4.1-1. These condition indicators were considered within the scoping process that resulted in the selection of the environmental framework and indicators for this LRCA presented in chapter 3.

Table 2.4.1-1. Fundamental Resource Values and Desired Future Conditions, as related to water resources, from Lake Mead NRA Foundation Document (NPS, 2015a) and the Lake Mead NRA Resource Stewardship Strategy (NPS, 2014).

Fundamental Resource Value	Associated Desired Condition Indicators
Abundant Land and Water Recreation	• Acceptable water quality for full body contact (state standards, EPA) • Game fish suitable for human consumption • Game fish populations sustain recreational harvest
Opportunities to Appreciate Spectacular Scenery	• Visitor perceptions of visual resources (water aesthetics) • Changes in the viewshed (development)

Table 2.4.1-1 (continued). Fundamental Resource Values and Desired Future Conditions, as related to water resources, from Lake Mead NRA Foundation Document (NPS, 2015a) and the Lake Mead NRA Resource Stewardship Strategy (NPS, 2014).

Fundamental Resource Value	Associated Desired Condition Indicators
Riverine and Reservoir Ecosystems	• Lake Mead and Lake Mohave water quality meets state standards and Clean Water Act guidance, including requirements to maintain existing higher quality (RMHQs) • Condition of riverine flows (volumes) • Water quality of tributary Colorado, Virgin and Muddy Rivers • Water quality of tributary Las Vegas Wash
Species of Conservation Interest	• Persistent populations of razorback sucker • Persistent populations of bonytail chub • Persistent populations of Colorado River native fish • Persistence of bald eagles and peregrine falcons • Persistence of waterbirds
Diverse Array of Geologic Features and Processes	• Functional alluvial processes • Riverine delta formation stability
Functional Desert Habitats	• Persistent Native Riparian Vegetation • Persistent Native Plant Communities

Each national park develops a Resource Stewardship Strategy (RSS) as part of the park management planning process. Each RSS is designed to provide an objective basis for assessing the condition of natural and cultural resources relative to the qualitative desired conditions established in a park's General Management Plan (GMP) or Foundation Document (NPS, 2014). Indicators of resource condition, both natural and cultural, are selected by the park. After each indicator is chosen, a target value is determined, and the current condition is compared to the desired condition. RSS provides a logical, integrated and sequential planning framework to help guide park investment decisions in resource stewardship over 10–20 year timeframe. Lake Mead NRA completed an RSS in November 2014 (NPS, 2014). The Lake Mead NRA RSS has guided the selection of key limnological and riparian natural resources and indicators for its condition assessment.

Related to water quality and limnology, there are regulatory requirements that provide indicators and thresholds. The NDEP has issued Nevada state water quality standards for lakes Mead and Mohave, which include standards to maintain the existing high water quality of the open waters, regulate the overall water quality of the tributary Las Vegas Wash and its mixing zones, and for body contact recreation, specifically the fecal coliform human pathogen indicator. These indicators and standards are reflected in the selected indicator framework within this report. The NDEP standards are generally reflective of USEPA guidelines for protecting water quality and human health. NPS Management Policies (NPS, 2006) and NPS Director's Order 83, provide that parks maintain standards related to human health, and also that parks utilize state water quality standards as an evaluation of relative levels of impairment (NPS, 2006). Lastly, the USEPA and the WHO each have

guidelines related to the provision of healthy and pleasing aquatic environments. Lake Mead NRA relied on those guidelines within the 2015 Recreation Suitability Guide, particularly for algal toxins and aesthetic indicators of recreation experience (Lake Mead NRA, 2015).

2.4.2. Status of Supporting Science (Existing Status and Desired Conditions)

Long-term Monitoring

Due to the regional importance of Lake Mead, there are a number of long-term, water-quality-monitoring programs. NDEP requires water-quality monitoring related to the NPDES permits for wastewater discharge into Las Vegas Wash. This required monitoring includes permanent stations in Lake Mead, both in Las Vegas Bay and Boulder Basin. The individual parameters and stations require anywhere from monthly to weekly monitoring; data from this monitoring since the early 1990s is archived by SNWA (Lake Mead NRA, 2010).

Various agencies of the LaMEM have collaborated for monthly monitoring of 22 stations, including all basins and areas of Lake Mead since 2004. Principal agencies in this effort include BOR, SNWA, and Lake Mead NRA. Data collected is archived, under interagency agreement, by SNWA and is accessible through an online database by request (Lower Colorado River Water Quality Database; http://snwaexapps.lvvwd.com/). See Table 2.4.2-1 for a listing of the parameters assessed monthly at those stations, Figure B-3 for station locations, and Table B-1 for station descriptions.

From 2001 through 2016 the USGS maintains two floating platforms equipped with continuous real-time monitoring equipment; one on Lake Mead in the Boulder Basin upstream from Boulder Dam, and one in Lake Mohave downstream from Hoover Dam (Figure B-4 and Table B-2). Those platforms were supported by BOR, SNWA, and the wastewater reclamation districts along Las Vegas Wash. Those stations contain a water-quality sonde monitoring the following parameters from surface to lake bottom: water temperature, specific conductance, dissolved oxygen, pH, and turbidity (Rosen et al., 2012). During the period 2005 through 2010, an additional three such platforms were maintained in Lake Mead, within the Overton Arm, the Temple Basin, and the Virgin Basin (Figure B-4 and Table B-2). During that period, all Lake Mead platforms, in addition to the parameters above, also recorded wind speed and direction as well as wave height, providing information to construct the Lake Mead water-quality model (see below) (Rosen et al., 2012; Preston et al., 2014).

In 2012, BOR, SNWA, and Lake Mead NRA partnered to establish monthly monitoring of five stations on Lake Mohave (see Table 2.4.2-1 for parameters, Figure B-5 for station locations, and Table B-1for station descriptions).

Table 2.4.2-1. Limnological and water quality parameters currently monitored at lakes Mead and Mohave by a partnership between BOR, SNWA, and Lake Mead NRA (Lake Mead NRA, 2010). See Figure B-3 and Figure B-5 for locations of stations mentioned.

Parameter monitored	Lake Mead[1]	Lake Mohave[1]
Bromide	X	X[2]
Chlorophyll *a*	X	X
Conductivity	X	X
Dissolved Oxygen	X	X
E. Coli	X	X
Enterococci [3]	X	–
Fecal coliform	X	X
Fecal *streptococci* [4]	X	X
Nitrogen Ammonia Total	X	X
Nitrogen Nitrate Total	X	X
Nitrogen Total	X	X
Perchlorate	X	X[5]
pH	X	X
Soluble Orthophosphate	X	X
Phosphorus Total	X	X
Phytoplankton	X	–
Secchi Depth	X	X
Temperature Water	X	X
Total Dissolved Solids	X	X
Total Organic Carbon	X	X
Turbidity	X	X
Quagga Mussel Veligers	X	X
Zooplankton Total	X	X

[1] An “X” indicates that the paremeter is currently monitored.

[2] Bromide was monitored at CR342.0 (Lake Mohave) from 2002 – 2016.

[3] NPS monitors for *Enterococci* on both lakes Mead and Mohave.

[4] NPS monitors for Fecal *streptococci* on both lakes Mead and Mohave.

[4] Perchlorate was monitored at CR342.0 from 2003–2016 and at CR278.0, CR298.5W.5, CR316.34, and CR329.7 from 2014–2016 (Lake Mohave).

Since 2003 Lake Mead NRA has sampled for fecal coliforms and other human pathogen indicators at some ten locations on both lakes Mead and Mohave during May through September, the peak water recreation season (Rosen et al., 2012). Eleven additional locations were added to the monitoring program in 2015 and 2016 due to lowering lake levels and expansion of monitoring program. Locations were selected to include high recreational use areas. See Figure B-7 for current locations of NPS bacterial monitoring sites and Table B-3 for site descriptions.

In the mid 2000s, SNWA, the Clean Water Coalition (CWC, a consortium of the wastewater reclamation districts of Clark County, Nevada), and Lake Mead NRA jointly funded the development of a water quality model for Lake Mead. The Lake Mead Model utilizes the Estuary and Lake Computer Model (ELCOM, a 3-D hydrodynamic model assessing stratification, wind mixing, temperature, salinity and conservative tracers) and Computational Aquatic Ecosystem Dynamics Model (CAEDYM, a water quality module that traces algae as chlorophyll *a*, nutrients, TOC, DO and pH) within a 300 meter grid covering the entirety of Lake Mead. Data from the 22 monthly stations and the five USGS hydrolab platforms for the year 2006 were used to calibrate the model (Preston et al., 2014). The Lake Mead Model has been used in numerous recent interagency planning projects, including planning new wastewater treatment facilities along Las Vegas Wash, and modeling potential water quality impacts from climate change (Preston et al., 2014).

In 2010, Lake Mead NRA entered an agreement with USGS to develop a synthesis of findings from the above sources of monitoring, as well as numerous USGS studies of endocrine disrupting compounds and contaminants. That interagency collaboration led by USGS, resulted in the 2012 publication of USGS Circular 1381, A Synthesis of Aquatic Science for Management of lakes Mead and Mohave (Rosen et al., 2012). USGS Circular 1381 reviewed data for each of five resource components: water quality and limnology, fish and aquatic biota, sediment, birds, and riparian and aquatic vegetation; and three stressors: contaminants, invasive species, and climate change. For each resource component or stressor, the USGS Circular 1381 summarized key findings, management implications, and recommendations for additional data needs. The USGS Circular 1381 review is presented in Table 2.4.2-2 and Table 2.4.2-3.

Table 2.4.2-2. Summary of key scientific findings, management implications, and recommendations for each resource component identified in the Lake Mead NRA Aquatic Resources Plan (Adapted from USGS Circlar 1381, Rosen et al., 2012).

Resource Component	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	Sportfish 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 sportfish and threadfin shad (Dorosoma petenense) population monitoring now led by Nevada Department of Wildlife and Arizona Game and Fish Department (AZGFD) 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.
Birds	Lakes Mead and Mohave provide essential 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 impacts 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, though mostly 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 are needed to inform management related to these habitats as a part of overall regional habitats, and to assess restoration potential.

Table 2.4.2-3. Summary of key scientific findings, management implications, and recommendations for stressors identified in the Lake Mead NRA Aquatic Resources Plan (Adapted from USGS Circular 1381, Rosen et al., 2012).

Resource Stressors	Scientific Findings	Management Implications	Recommendations for Data or Information Needs
Contaminants	Concentrations of legacy contaminants such as perchlorate and pesticides are declining due to regulations and mitigation. Emerging contaminants, including endocrine disrupting compounds are 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 sportfish.
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.

USGS Circular 1381 summary findings included several key concepts which are summarized here:

1) Lake Mead has been extensively studied. Its basic hydrology is well understood and its base limnology has been and continues to be well documented.
2) Lake Mohave has not been sufficiently studied to draw long-term conclusions.
3) The period comprising much of the review period for USGS Circular 1381, found Lake Mead water quality generally improving due to wastewater treatment enhancements.
4) Most USEPA National Lakes Assessment parameters of Lake Mead and Lake Mohave health are found to be in "good" condition.
5) The tributary Las Vegas Wash drives a significant portion of Lake Mead's productivity through nutrient contributions.
6) The tributary Las Vegas Wash also contributes the majority of Lake Mead's contaminant load.
7) Lake Mead appears to be in transition, from a long period of relatively stable water levels and attendant "good" water quality, to greater influences to water quality and quantity from persistent drought conditions, species invasions, and climate change.
8) Lake Mohave is heavily and directly influenced by waters received through Hoover Dam. Stressors to water quality in the Boulder Basin of Lake Mead will quickly influence water quality in Lake Mohave.

2.5. Literature Cited

Batker, D., Christian, Z., Cooley, C., Graf, W., Jones, K., Loomis, J., & Pittman, J. (2014). Nature's Value in the Colorado River Basin. Earth Economics, 104p.

Bureau of Reclamation. (2016, April 4). Historic Reservoir Levels. Retrieved from Lower Colorado River Region: http://www.usbr.gov/lc/region/g4000/hourly/mead-elv.html

Caldwell, T., Rosen, M., Chandra, S., Acharya, K., Caires, A., Davis, C., Thaw, M., and Webster, D. (2015). Temporal and Basin-Specific Population Trends of Quagga Mussels on Soft Sediment of a Multibasin Reservoir. In W. Wong, & S. Gerstenberger (Eds.), Biology and Management of Invasive quagga and Zebra Mussels in the Western United States (pp. 566–587). Boca Raton, FL: CRC Press.

Carlson, R. (1977). A Trophic Status Index for Lakes. Limnology and Oceanography, 22:361–369.

Davis, C. J., Caldwell, T., Caires, A., & Chandra, S. (2014). Decadal Changes to Zoobenthos in a Subtropical Reservoir: Establishment of Non-native Invertebrates Shift Assemblage Structure. Lake Mead Science Symposium.

Ford, D. (1990). Reservoir Transport Processes. In K. Thornton, B. Kimmel, & F. Payne (Eds.), Reservoir Limnology-Ecological Perspectives. New York, NY: John Wiley and Sons, Inc.

Holdren, G., & Turner, K. (2010). Characteristics of Lake Mead, Arizona-Nevada. Lake and Reservoir Management, 26 (4): 230–239.

Kimmel, B., Lind, O., & Paulson, L. (1990). Reservoir Primary Production. In K. Thorton, B. Kimmel, & F. Payne (Eds.), Reservoir Limnology-Ecological Perspectives (pp. 133–193). New York: Wiley.

LaBounty, J., & Burns, N. (2005). Characterization of Boulder Basin, Lake Mead, Nevada-Arizona, USA-Based on analysis of 34 Limnological Parameters. Lake and Reservoir Management, 21:277–307.

LaBounty, J., & Horn, M. (1997). The Influence of Drainage form the Las Vegas Valley on the Limnology of Boulder Basin, Lake Mead, Arizona-Nevada. Lake and Reservoir Management, 13:95–108.

Lake Mead NRA. (2002). Lake Management Plan. National Park Services, 328p.

Lake Mead NRA. (2010). Long-term Limnology and Aquatic Resources Monitoring and Research Plan for Lakes Mead and Mohave: Boulder City, NV. Lake Mead National Recreation Area and University of Nevada, Las Vegas. Retrieved from http://www.nps.gov/lake/learn/nature/upload/Eco_Monitoring_Plan_for_Lakes_Mead_and_Mohave_4-27_update.pdf

Lake Mead NRA. (2015). Lake Mead National Recreation Area Resource Suitability Guidelines. Lake Mead National Recreation Area, NV-AZ: National Park Service, Pacific West Region.

LaMEM. (2012). Lake Mead Water Quality Forum Ecosystem Monitoring Workgroup. Retrieved from Lake Mead Water Quality Forum: https://ndep.nv.gov/forum/ecosystem.htm

NPS. (2006). Management Policies 2006 – The Guide to Managing the National Park System. Washington, D.C.: National Park Service. Retrieved from https://www.nps.gov/policy/mp2006.pdf

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region.

NPS. (2015a). Foundation Document. Lake Mead National Recreation Area, Arizona and Nevada: National Park Service, U.S. Department of the Interior.

NPS. (2015b, March 13). Swimming Advisory issued at Lakes Mead, Mohave. Retrieved from Lake Mead National Recreation Area: http://www.nps.gov/Lake Mead NRA/learn/news/2015-swimming-advisory.htm

NPS. (2016, March 31). National Park Service Visitor Use Statistics. Retrieved from NPS Integrated Resource Management Applications (IRMA): https://irma.nps.gov/Stats/Reports/Park/LAKE

Paulson, L., & Baker, J. (1983). Limnology in Reservoirs on the Colorado River. Technical Report No. 11. Las Vegas, NV: UNLV Lake Mead Limnology Research Center, University of Nevada, Las Vegas.

Prentki, R., & Paulson, L. (1983). Historical Patterns of Phytoplankton Productivity in Lake Mead. In M. Adams, & V. Lamarra (Eds.), Aquatic Resources Management of the Colorado River Ecosystem (Chapter 8, 105–123).

Preston, A., Tietjen, T., Roefer, P., & List, E. (2014, February). Changes in Thermal Structure and Water Quality of Lake Mead Due to Lower Lake Levels, presentation to the February 2014 Lake Mead Science Symposium. Retrieved May 31, 2016, from Lake Mead Ecosystem Monitoring Work Group: https://ndep.nv.gov/forum/2014Symposium.htm

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

Thornton, K. (1990). Perspectives on Reservoir Limnology. In K. Thornton, B. Kimmel, & F. Payne (Eds.), Reservoir Limnology – Ecological Perspectives. New York, NY: John Wiley and Sons, Inc.

Tietjen, T., Ryan, R., Watters, A., & Rinella, J. (2014, Feburary). Initial Assessment of Lake Mohave Water Quality, Presentation to the Februray 2014 Lake Mead Science Symposium. Retrieved May 31, 2016, from Lake Mead Ecosystem Monitoring Work Group: https://ndep.nv.gov/forum/2014Symposium.htm.

Turner, K., J.M. Miller, and C.J. Palmer. 2010. Long-term Limnological and Aquatic Resource Monitoring and Research Plan for Lakes Mead and Mohave. J8R07070010. Public Lands Institute, University of Nevada. Las Vegas, Nevada.

USEPA. (2009). National Lake Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. Washington, D.C.: U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, 102 p.

Umek, J., Chandra, S., Rosen, M., Wittmann, M., Sullivan, J., & Orsak, E. (2010). Importance of Benthic Production to Fish Populations in Lake Mead Prior to the Establishment of Quagga Mussels. Lake and Reservoir Management, 26:293–305.

Vollenweider, R. (1970). Scientific Fundamentals of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Report DAS/CSL/6827. Organization for Economic Co-operation and Development.

Wittmann, M., Chandra, S., Caires, A., Denton, M., Rosen, M., Wong, W., Tietjen, T., Turner, K., Roefer, P., and Holdren, G. (2010). Early Invasion Population Structure of Quagga Mussel and Associated Benthic Invertebrate Community Composition on Soft Sediment in a Large Reservoir. Lake and Reservoir Management, 26: 316–327.

Wong, D. (2012). Report: Quagga Mussel Monitoring in Lake Mead and Lake Mohave. Las Vegas, NV: University of Nevada, Las Vegas, Department of Environmental and Environmental Health, and Public Lands Institute.

3. Study Scoping and Design

This LRCA is a collaborative project between NPS Lake Mead NRA staff and the University of Nevada Reno (UNR) researchers. Stakeholders in this project include the superintendent and resource managers at Lake Mead NRA. The purpose of this condition assessment is to synthesize and interpret existing scientific information to evaluate current status and forecast future conditions for limnological and riparian resources in the recreation area. The assessment focused on a subset of limnological and riparian resources and processes selected by Lake Mead NRA staff for inclusion in the LRCA. LRCA products, findings, and conclusion will aid NPS managers in addressing the following efforts:

- Near-term strategic planning, such as prioritizing limited staff and budget allocations for natural resource protection and restoration;
- Resource Stewardship Strategy and State of the Park development;
- Justifications for natural resources conservation project proposals;
- Park efforts to communicate and partner with other stakeholders to address landscape-scale resource management issues and educational outreach; and
- Public information on park resources for website and social media and for NPS Centennial documents.

Lake Mead NRA encompasses approximately 1.5 million acres within its legislative boundary. The vast amount of this acreage, over 1.3 million acres, are terrestrial acres within the Mojave Desert or Great Basin ecoregions. The terrestrial acres and associated resources are included within a separate Natural Resource Condition Assessment (NRCA) in development for the Mojave Desert network of parks (Death Valley National Park, Mojave National Preserve, Joshua Tree National Park, Lake Mead NRA, and Manzanar National Historic Site). Considering the similarities among the desert habitats within the Mojave Desert network, and the differing complexities of the limnological resources found only within Lake Mead NRA, the decision was that managers would be best served with two separate NRCAs.

3.1. Preliminary Scoping

Prior to the onset of the LRCA development, natural resources issues in Lake Mead NRA had been prioritized in the Lake Mead NRA Foundations Document and more specific resource measures were identified in the "Long-Term Limnological and Aquatic Resource Monitoring and Research Plan for lakes Mead and Mohave" (LTAP, Lake Mead NRA, 2010) and the USGS "Circular 1381: A synthesis of aquatic science for management of lakes Mead and Mohave" (USGS 2012). Results of these important efforts have been presented in Lake Mead Science Symposia conducted in 2009, 2012, 2014, and 2016. 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. Circular 1381 had 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 to protect the environmental health of lakes Mead and Mohave. The Lake Mead NRA RSS completed in November 2014 has also guided the selection of key limnological and riparian natural resources and indicators for this condition assessment (See section 2.4.1).

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 (BOR), National Park Service (NPS), Southern Nevada Water Authority (SNWA), Nevada Department of Wildlife (NDOW), Arizona Game and Fish Department (AZGFD), U.S. Fish and Wildlife Service (USFS), U.S. Geological Survey (USGS), 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.

Building upon these previously published products and relationships, the selection of an appropriate ecological framework to be used and resources to assess resulted from a series of scoping meetings and subsequent discussions attended by researchers from the University of Nevada Reno (UNR), and project partners from the NPS, BOR, USGS and the SNWA. During these scoping meetings, participants determined the ecological framework for the assessment, and discussed the covered elements, and sources of data (including the NPS's Inventory and Monitoring Program, Park monitoring reports, spatial analyses using Geographic Information Systems, and other datasets from other federal/state agencies and academia) for use during the project. The particpants not only developed a study plan which specified the contents of the LRCA, but also an agreed upon timeline for project objectives, progress reporting and final products.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

The Lake Mead LRCA utilizes an assessment framework adapted from the Environmental Protection Agency (EPA)'s Framework for Assessing and Reporting on Ecological Condition (Young & Sanzone, 2002). This framework includes six Essential Ecological Attributes (EEA) that incorporate ecological structure, composition, and function of ecological systems at a variety of temporal and spatial scales (Young & Sanzone, 2002):

- Landscape Condition
- Biotic Condition
- Chemical and Physical Characteristics
- Ecological Processes
- Hydrology and Geomorphology
- Disturbance Regimes

Multiple ecological indicators may be associated with each EEA. Ecological indicators are measurable characteristics that characterize an ecosystem or one of its critical components (e.g. structure, composition, or functioning). One or several measures/specific monitoring variables are collected in the field and aggregated into one indicator. The framework provides a mechanism to aggregate monitoring data or indicators into a few scientifically defensible categories for assessing the condition of an ecological system (Young & Sanzone, 2002). The EPA framework does not work well in all cases for organizing indicators into a report. The EPA beta tested the framework on review of a regional water quality report, and suggested that the purpose of the framework may be better suited as a checklist and analytical tool than a report outline (Young & Sanzone, 2002).

In 2010 an interagency Lake Mead water quality partnership produced the LTAP (Lake Mead NRA, 2010). The LTAP documented interagency fundamental water quality objectives that have been used by the partnership to guide monitoring programs as well as organized summary reports and symposia. The LCRA scoping team reviewed those objectives, as well as specific aquatic related Fundamental Resource Values (FRVs) from the 2015 Lake Mead NRA Foundation Document and desired condition indicators from the 2014 Lake Mead NRA RSS to compare to the EPA framework to relate essential ecological attributes and provide guidance in final selection of a framework of attributes and indicators to guide the LCRA (NPS, 2014 & 2015). See Table 3.2.1-1.

Table 3.2.1-1. Fundamental Resource Values (FRVs) and Desired Future Conditions, as related to water resources as references in the Lake Mead NRA Foundation Document (NPS, 2015) and Lake Mead NRA Resource Stewardship Strategy (NPS, 2014). The table cross-walks objectives from the "Long-term Limnological and Aquatic Resource Monitoring and Research Plan" (LTAP) (NPS, 2010) and ecological attributes from "A Framework for Assessing and Reporting on Ecological Condition" (Young & Sanzone, 2002) as they relate to the FRVs.

LTAP Water Quatliy Objectives	**Fundamental Resource Value** ***(NPS, 2015)***	**Desired Future Condition Indicator** ***(NPS, 2014)***	**EPA 2002 Framework Ecological Attribute** ***(Young & Sanzone, 2002)***
Supports existing high-quality setting for water-based recreation	Abundant Land and Water Recreation	• Acceptable water quality for full body contact (state standards, EPA) • Game fish suitable for human consumption	• Landscape Condition • Biotic Condition
Supports a healthy sport fishery	–	• Game fish populations sustain recreational harvest	• Chemical and Physical Characteristics
Supports existing high-quality setting for water-based recreation	Opportunities to Appreciate Spectacular Scenery	• Visitor perceptions of visual resources (water aesthetics) • Changes in the viewshed (development)	• Landscape Condition • Chemical and Physical Characteristics
Supports regional and community needs for municipal and industrial uses	–	• Lake Mead and Lake Mohave water quality meets state standards and Clean Water Act guidance including RMHQs	–

Table 3.2.1-1 (continued). Fundamental Resource Values (FRVs) and Desired Future Conditions, as related to water resources as references in the Lake Mead NRA Foundation Document (NPS, 2015) and Lake Mead NRA Resource Stewardship Strategy (NPS, 2014). The table cross-walks objectives from the "Long-term Limnological and Aquatic Resource Monitoring and Research Plan" (LTAP) (NPS, 2010) and ecological attributes from "A Framework for Assessing and Reporting on Ecological Condition" (Young & Sanzone, 2002) as they relate to the FRVs.

LTAP Water Quatliy Objectives	**Fundamental Resource Value** ***(NPS, 2015)***	**Desired Future Condition Indicator** ***(NPS, 2014)***	**EPA 2002 Framework Ecological Attribute** ***(Young & Sanzone, 2002)***
Supports all six LTAP objectives	Riverine and Reservoir Ecosystems	• Condition of riverine flows (volumes) • Water quality of tributary Colorado, Virgin and Muddy Rivers • Water quality of tributary Las Vegas Wash	• Ecologic Processes • Hydrology and Geomorphology • Chemical and Physical Characteristics • Landscape Condition
	Diverse Array of Geologic Features and Processes	• Functional alluvial processes • Riverine Delta formation Stability	• Hydrology and Geomorphology
Supports healthy populations of native fish	Species of Conservation Interest	• Persistent Populations of razorback sucker • Persistent Populations of bonytail chub • Persistent Populations of Colorado River native fish	• Biotic Condition
Supports healthy populations of aquatic dependent wildlife	–	• Persistence of bald eagles and peregrine falcons	• Ecological Processes
Supports healthy populations of riparian, aquatic, shoreline native vegetation	–	• Persistence of waterbirds	–
Supports healthy populations of riparian, aquatic, shoreline native vegetation	Functional Desert Habitats	• Persistent Native Riparian Vegetation • Persistent Native Plant Communities • Prevalence of suitable Southwestern willow flycatcher habitat	• Landscape Condition • Biotic Processes • Ecological Processes

The above review led the LCRA scoping team to utilize a framework for this analysis and reporting purpose of five essential ecological or management features. The first three essential features; lake and riverine ecosystem health, biotic condition, and ecological processes are comprised generally of attributes and indicators that are commonly considered ecosystem and limnologic resources and for

which condition status is readily assessed. The fourth essential feature is recreation suitability, which is not an ecosystem resource per se, but relates to the park's legislated mandate to provide healthy and aesthetically pleasing water-based recreation and the primary management importance of the limnologic indicators that are related to it. The fifth essential feature is stressors and disturbance regimes, which include the attributes of contaminants, aquatic invasive species, climate change, development and urbanization, and human use. Those attributes are more considered system drivers and influences than resources, and their analysis in chapter 4 and discussion in chapter 5 will be more qualitative than quantitative.

For each of the five essential ecosystem features, contributing resource attributes within Lake Mead NRA were defined, with consideration of LRCA and previous scoping. The Lake Mead NRA LRCA identifies 22 key resource attributes, with 32 limnological and riparian indicators and 45 associated measures of condition (Table 3.2.1-2). This list of focal resource elements is not all inclusive for every limnological and riparian resource within the recreation area, but it includes resources and processes that were of greatest concern at the time of this assessment, and reflective of the extensive park planning in the Foundation Document and the interagency scoping within the 2010 LTAP (Lake Mead NRA, 2010; NPS, 2015).

Reference conditions are quantifiable or objective values for an indicator or measure that is intended to provide context for comparison with current condition values. Reference conditions typically represent an acceptable resource condition, supported with scientific or scholarly consensus (Reference Conditions and Reference Values, 2012). Reference conditions can be derived from conditions that existed prior to modern anthropogenic disturbance or conditions in a relatively undisturbed comparable system (Young & Sanzone, 2002). They can also be inferred from regulatory (e.g. federal or state) or program standards, predictive models, or professional opinion (Reference Conditions and Reference Values, 2012). Reference conditions may be qualitative or quantitative based on existing data and knowledge for a given resource. Quantitative or qualitative values for the reference condition of specific indicator/measure are developed and described in detail in Chapter 4.

Table 3.2.1-2. Final Lake Mead National Recreational Area (Lake Mead NRA) Limnological and Riparian Resource Condition Assessment (LRCA) Framework (Lake Mead NRA, 2010; NPS, 2015).

Essential Ecological or Management Features	Resource Attributes	Indicator(s)	Measurement(s)	Scale of Analysis
Lake and Riverine Ecosystem Health	Lake Health	Surface Water Quality	• Physical characteristics (Temporal trend): Dissolved oxygen (DO), conductivity, salinity, pH • Nutrient (Temporal trend – concentration): Total nitrogen (TN), total phosphates (TP), orthophosphates (PO_4-P), nitrate-nitrite as nitrogen (NO_3+NO_2-N), ammonium as nitrogen (NH_3-N)), total organic carbon (TOC) • Water temperature (temporal trend): Surface water temperature (whole lake)	Lake; Lake basin
	Lake Health	Hydrologic Function	• Turnover rate, • Water column temperature (whole lake), retention time and thermal stratification	Lake
	Lake Health	Trophic Level	• Secchi depth, • Chlorophyll a • Trophic index (Burns Trophic Level Index)	
	Tributary Condition	Tributary Physical Characteristics	• Temperature, dissolved oxygen (DO), pH, conductivity,	Tributary
	Tributary Condition	Tributary Nutrient Load	• Total nitrogen (TN), nitrate-nitrite as nitrogen (NO_3+NO_2-N), ammonia as nitrogen (NH_3-N), total phosphorus (TP); and dissolved orthophosphates (PO_4-P).	Tributary
	Tributary Condition	Tributary Inflows	• Total annual inflow volume (million acre-feet, maf) to Lake Mead from the Colorado, Virgin and Muddy Rivers, and Las Vegas Wash	Tributary

* The fifth essential feature is Stressors and Disturbance Regimes. Attributes included within are considered system drivers rather than resources, and their analysis in chapter 4 and discussion in chapter 5 may be more qualitative than quantitative.

Table 3.2.1-2 (continued). Final Lake Mead National Recreational Area (Lake Mead NRA) Limnological and Riparian Resource Condition Assessment (LRCA) Framework (Lake Mead NRA, 2010; NPS, 2015).

Essential Ecological or Management Features	Resource Attributes	Indicator(s)	Measurement(s)	Scale of Analysis
Lake and Riverine Ecosystem Health (continued)	Tributary Condition	Tributary Contaminants	• Perchlorate and Selenium	Tributary
	Tributary Condition	Sedimentation	• Suspended sediment discharge by tributaries	Tributary
	Tributary Condition	Sedimentation	• Nutrient loading associated with sediment (qualitative description if data not available)	Tributary
	Tributary Condition	Sedimentation	• Contaminant loading associated with sediment (qualitative description if data not available)	Tributary
	Tributary Condition	Land Use within Watershed	• Developed and non-developed acres • Urbanized miles of tributaries	Watershed (Based on USGS Hydrologic units, except for Colorado River); Tributary
Biotic Condition	Benthic Macroinvertebrates	Population Trend by Key Taxonomic Benthic Groups	• Benthic macroinvertebrates density	Lake
	Zooplankton	Population Trend by Key Taxonomic Groups	• Density	Lake
	Phytoplankton	Population Trend by Key Taxonomic Groups	• Density	Lake
	Food Web Dynamics	Changes in Foodweb Structure	• Trophic status and habitat energy provided to fishery	Lake
	Native Fish	Population Trend by Species	• Species abundance • Population estimate	Lake
	Sportfish	Population Trend by Species	• Population estimates • Angler catch rates	Lake

* The fifth essential feature is Stressors and Disturbance Regimes. Attributes included within are considered system drivers rather than resources, and their analysis in chapter 4 and discussion in chapter 5 may be more qualitative than quantitative.

Table 3.2.1-2 (continued). Final Lake Mead National Recreational Area (Lake Mead NRA) Limnological and Riparian Resource Condition Assessment (LRCA) Framework (Lake Mead NRA, 2010; NPS, 2015).

Essential Ecological or Management Features	Resource Attributes	Indicator(s)	Measurement(s)	Scale of Analysis
Biotic Condition (continued)	Forage Fish	Population Trend Species	• Species abundance • Catch rates	Lake
	Aquatic-dependent Birds	Population Trend of Key Shorebird Species	• Species occurrence and abundance	Lake
	Aquatic-dependent Birds	Peregrine Falcon	• Annual estimate of nesting pairs and nesting success	Lake
	Aquatic-dependent Birds	Bald Eagle	• Wintering population census	Lake
	Riparian Vegetation	Occurrence	• Presence/Absence	Lake
	Aquatic Vegetation	Occurrence	• Presence/Absence	Lake
Ecological Processes	Near Shore Processes	Plant Colonization	• Native plant species abundance vs. non-native species abundance	Lake
	Hydrologic Regime	Hydrologic condition of the Colorado River Basin	• Colorado River computed natural flow and unregulated inflow to Lake Powell (Annual flow volume, in million acre-feet, maf)	Tributary
	Hydrologic Regime	Flood Flows in Streams; Future Projections	• Elevation (intensity) and frequency	Tributary
	Sediment	Sediment Accumulation	• Total annual sediment yield per tributary (tons per year) and volume (acre-ft) accumulated, if data available; or qualitative description	Tributary
	Sediment	Alluvial Delta Changes	• Temporal changes in location (distance) and areal extent of tributary confluences and deltas	Tributary
Recreation Suitability	Human Health Effects	Pathogens	• Fecal coliform and E. coli concentration (cfu/ 100 ml)	Lake; Lake Basin

* The fifth essential feature is Stressors and Disturbance Regimes. Attributes included within are considered system drivers rather than resources, and their analysis in chapter 4 and discussion in chapter 5 may be more qualitative than quantitative.

Table 3.2.1-2 (continued). Final Lake Mead National Recreational Area (Lake Mead NRA) Limnological and Riparian Resource Condition Assessment (LRCA) Framework (Lake Mead NRA, 2010; NPS, 2015).

Essential Ecological or Management Features	Resource Attributes	Indicator(s)	Measurement(s)	Scale of Analysis
Recreation Suitability (continued)	Human Health Effects	Harmful Algal Bloom, (HAB)/Toxin	• Microcystin concentration	Lake; Lake Basin
	Human Health Effects	Mercury (Hg) in Fish Flesh (Consumption)	• Hg concentration	Lake; Lake Basin
	Visual Water Quality	Aesthetic Quality	• Chlorophyll a and Secchi depth	Lake; Lake Basin
Stressors and Disturbance Regimes*	Contaminants	• Volatile Organic Compounds (VOCs) • Endocrine Disrupting Contaminants (EDCs) • Selenium (Se) • Mercury (Hg) • Perchlorate (ClO_4) • Bromide (Br) • Pharmaceutical Compounds (PPCPs)	• Concentration related to standards or published guidelines that support aquatic life and safety of drinking water	Lake; Tributary
	Aquatic Invasive Species	• Quagga Mussel Adult and Veliger • New Zealand Mudsnail • Crayfish	• Density	Lake
	Development and Urbanization	Qualitative Discussion	–	Watershed; Lake
	Climate Change	Qualitative Discussion	–	Watershed; Lake
	Human Use	Qualitative Discussion	–	Watershed; Lake

* The fifth essential feature is Stressors and Disturbance Regimes. Attributes included within are considered system drivers rather than resources, and their analysis in chapter 4 and discussion in chapter 5 may be more qualitative than quantitative.

3.2.2. Reporting Areas

The reporting area for this LRCA is generally within the NPS authorized boundary for Lake Mead NRA covering the surface waters of lakes Mead and Mohave (Figure 2.2.2-1). However, due to the nature of some of the focal study resources, areas outside of the recreation area's boundary were also assessed to determine overall condition (e.g. land use within the watershed). Natural resource conditions were assessed at tributary, lake basin, lake, and watershed-scale levels based on the requirement of each indicator and/or measure that was analyzed.

Given the size of Lake Mead, each lake basin within Lake Mead is ecologically unique; therefore basic limnology and surface water quality within Lake Mead vary greatly among the different lake basins. Therefore, for indicators that were assessed at a whole-lake scale, a subset of key sampling stations that are representative of the lake basins was selected by the group for analysis.

Some of the spatial data were compiled and organized by major watershed that intersects with Lake Mead NRA (e.g. Figure B-2).

3.2.3. General Approach and Methods

This study involved reviewing existing literature and data for each of the resource attributes and indicators listed, and, where appropriate, analyzing the data to provide summaries or to create new temporal and spatial interpretations. Current conditions and trends were assigned to each indicator based on the information gathered.

Data Collection/Mining

Data and literature were collected from multiple sources. These include published NPS reports and monitoring plans (park, regional, and national level), other reports from various state and federal agencies, published and unpublished research documents, non-governmental organization reports, data from the NPS Inventory and Monitoring Program, databases and tabular data. Significant interagency data related to Lake Mead and Mohave maintained by SNWA, USGS, BOR, and NDOW were accessed for this project. Spatial data and spatial analyses results were provided by a NPS cartographic specialist. Data and literature acquired throughout the project period were inventoried and analyzed for relevancy and quality pertaining to the indicators identified in the project framework.

Subject Matter Experts

Relevant professional experts were consulted while developing this assessment. Consultations mainly relied on personal communication and reviews of the published, resource-related literature.

Data Analyses and Development

Analyses, development, and writing tasks were performed for specific resources based on the data collected and recommendations from NPS. Continued communication (e.g., quarterly coordination meetings and other communications) with NPS to address questions and comments concerning the various resource topics was maintained throughout the data collection, analysis and report writing phase to ensure accurate interpretation of compiled information. Specific methodologies for

individual analyses are presented in chapter 4. Where necessary, Geographic Information System (GIS) technology was used to graphically depict the status and distribution of assessed resources.

Final Assessments

Final assessments were made by incorporating comments provided by subject matter experts, technical reviewers, and NPS staff during the review of draft chapters.

Indicator/Measures Assessment Format

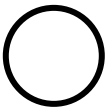
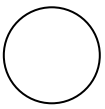
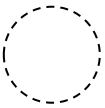
Indicator assessments are presented in a standard format that is consistent with *State of the Park* (SotP) reporting initiative and RSSs (NRCA Guidance Update, 2014). The major components are Condition Status, Trend in Condition, and Confidence in Assessment (Table 3.2.3-1). Each component is defined in the context of each specific indicator/measure in chapter 4. The background color of each icon represents the current condition status. The direction of the arrows summarizes the trend in condition and the thickness of the outside line represents the level of confidence in the assessment.

Each indicator may be represented by one or more measures or parameters. Scientific expertise provided by researchers, subject matter experts, reviewers, and NPS staff was adopted for aggregation of these findings to summarize overall condition status and trend for each resource indicator. A green symbol (good condition) would not be assigned as the combined condition status if a red symbol (significant concern) was assigned for any of the specific measures/parameters for the particular indicator. Aggregation rationales for specific indicators are provided in Chapters 3 and 4.

The overall trend assignment was summarized based on multiple trend arrows of the specific measure/parameters for the particular indicator. Specific rationales for the overall trends assigned are documented in Chapter 4.

The basic aggregation scheme is summarized here:

Table 3.2.3-1. Condition, trend, and level of confidence key used in the Lake Mead NRA LRCA.

Condition Status		Trend in Condition		Confidence in Assessment	
	Warrants Significant Concern		Condition is Improving		High
	Warrants Moderate Concern		Condition is Unchanging		Medium
	Resource is in Good Condition		Condition is Deteriorating		Low
No color	Current condition is unknown or indeterminate	No trend	Current trend is unknown or indeterminate	–	–

Each resource attribute and/or indicator assessment is generally structured based on the standard NRCA reporting guidelines (NPS, 2010), as follows:

1) Assessment Outcome: An indicator-level resource condition summary table represented by condition status and trend graphics (Table 3.2.3-1) is displayed within this section.
2) Description: This section provides information regarding the relevance of the resource attribute and respective indicators and their importance to lakes Mead and Mohave. If the resource attribute includes multiple indicators, indicators that were evaluated are identified in this section.
3) Data and Methods: This section describes the datasets used for evaluating the current conditions and trends of indicators/measurements. Methods used for evaluating and analyzing the data are also provided in this section.
4) Reference Conditions: This section identifies the appropriate reference conditions used to evaluate the current condition for each indicator. Literature or data sources used to derive the reference conditions are also presented in this section.
5) Condition and Trend: This section provides a summary of the key findings regarding current conditions and trend of indicators/measurements based on available literature, data, and expert opinions.
6) Assessment Confidence and Key Data Gaps: This section describes the overall confidence assigned and key uncertainties in regards to the condition findings for each resource attribute. Critical data gaps and needs are also identified in this section. Stressors and threats that could or are already impacting the indicator examined maybe briefly discussed in this section. A detailed discussion of stressors and threats to specific resource attributes and indicators are presented in section 4.5.1 Stressors and Disturbance Regimes.
7) Literature Cited: This section provides formal citation of all the literature or datasets used for each resource attribute. A DVD will be included in the final report with copies of all literature cited unless the citation was from a book or website. Links to websites are included, when possible.

3.3. Literature Cited

NPS. (2010). Standard NRCA Report Outline-Annotated Version. Retrieved from Guidance Documents and Useful References: http://www.nature.nps.gov/water/nrca/assets/docs/NRCA_Report_Outline_annotated_ver3-1.pdf

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region.

NPS. (2015). Foundation Document. Lake Mead National Recreation Area, Arizona and Nevada: National Park Service, U.S. Department of the Interior.

Lake Mead NRA. (2010). Long-term Limnology and Aquatic Resources Monitoring and Research Plan for Lakes Mead and Mohave: Boulder City, NV. Lake Mead National Recreation Area and University of Nevada, Las Vegas. Retrieved from http://www.nps.gov/Lake Mead

NRA/learn/nature/upload/Eco_Monitoring_Plan_for_Lakes_Mead_and_Mohave_4-27_update.pdf

NRCA Guidance Update. (2014, January). Guidance Documents and Useful References. Retrieved from National Park Service: http://www.nature.nps.gov/water/nrca/guidance.cfm

Reference Conditions and Reference Values. (2012). Retrieved from National Park Service: http://www.nature.nps.gov/water/nrca/conditionsandvalues.cfm

Young, T., & Sanzone, S. (Eds.). (2002). A Framework for Assessing and Reporting on Ecological Condition. Washington, DC. Prepared by the Ecological Reporting Panel, Ecological Processes and Effects Committee, EPA Science Advisory Board.

4. Natural Resource Conditions

In this chapter, background, methods, and condition assessment for a subset of important limnological and riparian resources and ecosystem process are presented. Indicator assessments are presented in a standard format that is consistent with *State of the Park* (SotP) reporting initiative and RSSs (NRCA Guidance Update, 2014). The major components are Condition Status, Trend in Condition, and Confidence in Assessment. Where possible, quantitative measures are used to assess conditions. In cases where quantitative measures are not applicable or not available, qualitative or categorical measures are presented to reflect conditions. Definition of good, moderate, or significant concern reference conditions in the context of each specific resource, indicator, or measure evaluated are described in this chapter.

4.1. Lake and Riverine Ecosystem Health

4.1.1. Lake Health

A summary of the parameters used assess lake health are shown in Table 4.1.1-1.

Table 4.1.1-1. Overall assessment outcome (condition and trend) of Lake Health.

Indicators	Measurements	Condition Status/Trend	Rationale
Surface Water Quality	• Physical characteristics (Temporal trend): Dissolved oxygen (DO), conductivity, salinity, pH • Nutrient (Temporal trend – concentration): Total nitrogen (TN), total phosphates (TP), orthophosphates (PO_4-P), nitrate-nitrite as nitrogen (NO_3+NO_2-N), ammonium as nitrogen (NH_3-N), total organic carbon (TOC)		Based on the U.S. Environmental Protection Agency's (USEPA) National Lake Assessment (NLA) standards, USEPA drinking water standards, State water quality standards, and comparisons with historic averages, lakes Mead and Mohave generally have high water quality for body-contact recreation, to support healthy fish and wildlife populations, and as a source of drinking water. Limited long-term data were available from Lake Mohave to establish condition and trend for some measurements.
	Temperature (Temporal trend): Surface water temperature (Whole lake), water column temperature (Whole lake)		While no significant trend for annual average of surface water temperatures were observed in Lake Mead for all stations during the periods examined, shifts in monthly average surface temperatures from long-term averages to warmer spring temperature was observed.

Table 4.1.1-1 (continued). Overall assessment outcome (condition and trend) of Lake Health.

Indicators	Measurements	Condition Status/Trend	Rationale
Hydrologic Function	Turnover rate		Little development of a thermocline at shallow areas in Lake Mead. Thermal stratification typically starts to form at deeper areas in May and peaks in August. Destratification typically began in October or November. No significant thermoclines were observed between January and April in Lake Mead. Increase in air temperature as projected by climate change models will likely result in increase in mean lake temperatures. Warming of surface waters will potentially increase the strength and length of thermal stratification, which will lead to subsequent reduced mixing.
	Retention time (Thermal Stratification)		Little development of a thermocline at shallow areas in Lake Mead. Thermal stratification typically starts to form at deeper areas in May and peaks in August. Destratification typically began in October or November. No significant thermoclines were observed between January and April in Lake Mead. Increase in air temperature as projected by climate change models will likely result in increase in mean lake temperatures. Warming of surface waters will potentially increase the strength and length of thermal stratification, which will lead to subsequent reduced mixing.
Trophic Level	Secchi depth		Secchi depth values greater than 1m (3 ft) is defined in the Lake Mead NRA Recreation Suitability Guidelines as an indication of very clear water. Overall, Lake Mead has high water clarity, ranging from 6 m to 18 m Secchi depths measured at open water locations. Lake Mohave has good water clarity with Secchi depth measurements ranging from 3m to 20 m. Willow Beach, located closest to the Hoover Dam discharge has the lowest water clarity in Lake Mohave but water clarity improves with distance from the discharge. Based on the Burns et al. (1999) categorization for trophic status in relations to Secchi depth, the current status of lakes Mead and Mohave would be considered between oligotrophic and mesotrophic. This corresponds to historic classifications for Lake Mead as mildly mesotrophic based on several classification indices.

Table 4.1.1-1 (continued). Overall assessment outcome (condition and trend) of Lake Health.

Indicators	Measurements	Condition Status/Trend	Rationale
Trophic Level (continued)	Chlorophyll *a*		Peak concentrations of Chlorophyll *a* have been less than 25 µg/L in Las Vegas Bay and less than 5 µg/L in Boulder Basin in most years following the 2001 algal bloom. Overall chlorophyll *a* concentrations measured from Lake Mead were within the NDEP water quality standard (≤ 5 µg/L) and the USEPA NLA "good" range (≤ 7.79 µg/L) for open water locations with concentrations ranging between 1µg/L and 5µg/L in most years, except during the 2001 algal bloom in Las Vegas Bay and Boulder Basin. Based on the Burns et al. (1999) categorization for trophic status in relations to chlorophyll *a*, the current status of Lake Mead would be considered between oligotrophic and mesotrophic. This corresponds to historic classifications for Lake Mead as mildly mesotrophic based on several classification indices. Limited data were available from Lake Mohave to establish condition and trend.
	Trophic index (Burns Trophic Level Index, TLI)		The TLI trend in Boulder Basin has been downward from 2000 to 2010 and remained stable since then with oligotrophic character, indicating that water quality has improved.
Lake Health overall			–

Overall Description

Lake Mead was formed by the completion of Hoover Dam in 1935. The intended purposes of the dam and Lake Mead were to provide flood control for the Colorado River, hydroelectric power, navigation, and a reliable water supply for agricultural and municipal use (Holdren & Turner, 2010). The Lake Mead NRA and surrounding areas provide numerous recreational opportunities as well as additional habitat for both aquatic and terrestrial wildlife. Downstream of Lake Mead, Lake Mohave was created in 1951 with the completion of Davis Dam to stabilize flows from Hoover Dam and to help provide required water deliveries. Lake Mohave also provides critical habitat to endangered aquatic species, e.g. razorback sucker (*Xyrauchen texanus*). Lakes Mead and Mohave play a key role in the entire storage capacity (approximately 50%) and operational framework of Colorado River Compact. Therefore, changes in lakes Mead and Mohave characteristics should be closely monitored for management and planning purposes (Table 4.1.1-2).

Table 4.1.1-2. Assessment outcome for Surface Water Quality.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Surface Water Quality	• Physical characteristics (Temporal trend): Dissolved oxygen (DO), conductivity, salinity, pH • Nutrient (Temporal trend – concentration): Total nitrogen (TN), total phosphates (TP), orthophosphates (PO_4-P), nitrate-nitrite as nitrogen (NO_3+NO_2-N), ammonium as nitrogen (NH_3-N), total organic carbon (TOC)		Based on the U.S. Environmental Protection Agency's (USEPA) National Lake Assessment (NLA) standards, USEPA drinking water standards, State water quality standards, and comparisons with historic averages, lakes Mead and Mohave generally have high water quality for body-contact recreation, to support healthy fish and wildlife populations, and as a source of drinking water. Limited long-term data were available from Lake Mohave to establish condition and trend for some measurements.
	Water temperature (Temporal trend): Surface water temperature (Whole lake)		While no significant trend for annual average of surface water temperatures were observed in Lake Mead for all stations during the periods examined, shifts in monthly average surface temperatures from long-term averages to warmer spring temperatures were observed.

Background and Importance

The Long-Term Limnological and Aquatic Resource Monitoring and Research Plan for lakes Mead and Mohave (NPS, 2010) established in 2010 agreed to maintain lakes Mead and Mohave water quality to:

- Support a healthy sports fishery.
- Support healthy populations of native fish.
- Support healthy populations of aquatic-dependent wildlife.
- Support healthy populations of riparian, aquatic, and shoreline dependent native vegetation.
- Support existing high-quality setting for water-based recreation.
- Support regional and community needs for municipal and industrial uses, including domestic water supply and Colorado River return flow credits.

With the ability to store approximately 29 million acre-feet of water, Lake Mead is the largest reservoir by volume in the United States. Lake Mead stores source water that supplies three western states (California, Arizona, and Nevada) and Mexico. Its uses, several of which are critical to life in the West, are diverse. Lake Mead stores water for approximately 25 million people for municipal and commercial uses, agricultural irrigation, habitat for numerous fish and other wildlife species, world-class recreational opportunities, and hydropower generation. Lake Mead's downstream neighbor, Lake Mohave, also serves a number of vital roles along the Colorado River System. Mohave re-regulates releases from the Hoover Dam to provide for required downstream deliveries, is the site of

the USFWS Willow Beach National Fish Hatchery (Figure B-1). In addition, lakes Mead and Mohave also provide critical habitat for fish and wildlife including federally listed endangered species and provides recreational opportunities (NPS, 2014).

NPS Management Policies (2006) state that national parks must work with other governmental agencies to obtain Clean Water Act standards for their water resources. Necessary action must be taken to maintain or restore surface water quality to the standards of the Clean Water Act or to meet federal, state, or local laws and regulations standards. The policies also mandate the fostering of partnerships with other agencies to maximize resources and expertise to maintain or restore park water resources (NPS, 2006). For these reasons, the water quality of lakes Mead and Mohave are of interest to and the responsibility of multiple federal, state, and local agencies.

Overall, Lake Mead is mildly mesotrophic. However, each lake basin within Lake Mead is ecologically distinct because the waters within them retain the properties of their source tributaries; therefore, basic limnology and surface water quality within Lake Mead vary greatly among the different lake basins. Gregg Basin and Temple basin are fed by the mainstrem of the Colorado River. The Virgin and Muddy Rivers flow into the Overton Arm, and then travels 25 miles 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 flows into Las Vegas Bay at the west end of Lake Mead's Boulder Basin (Rosen et al., 2012; Figure B-1). Lake Mohave, on the other hand, constrained by steep rock walls of Black Canyon, is long and narrow and is primarily riverine. South of Black Canyon, Lake Mohave widens into a larger basin (4 miles at its widest point across the basin) with lacustrine habitat (Figure B-1).

A total of 12 parameters/measures were examined for this indicator (Table 4.1.1-3).

Table 4.1.1-3. Parameters/measures examined for determining the condition and trend of Lake Mead.

Parameters/Measures	Description
Dissolved oxygen (DO), mg/L or % saturation	Dissolved oxygen (DO) concentration is a water quality parameter integral for biotic productivity in freshwater ecosystems and a primary indicator of the capacity of a water body to support and sustain aquatic life. The degree to which water is saturated with oxygen is determined by oxygen concentration, water temperature, salinity, and atmospheric pressure. Expression of DO by % saturation takes into account the ability of the water to hold oxygen. Warmer water can hold less oxygen.
Conductivity, µS/cm	Conductivity is a measure of the ability of water to conduct electricity and is proportional to the number of dissolved solids in water. Conductivity can differ among tributaries entering a lake, thus a traceable feature useful in tracking the path of one water source as it flows into another.
Salinity	Salinity or Total Dissolved Solids (TDS) is a measure of the total ionic concentration of dissolved minerals in water.

Table 4.1.1-3 (continued). Parameters/measures examined for determining the condition and trend of Lake Mead.

Parameters/Measures	Description
pH	pH measures the hydrogen ion activity in a water sample. In natural waters, pH is a measure of acid-base equilibrium achieved by dissolved compounds, salts, and gases in the water. pH can affect chemical and biological reactions in lake and river systems (Rosen et al., 2012). The degree of dissociation of weak acids and bases can be affected by changes in pH and in turn affect the toxicity of many compounds in the water column (USEPA, 1986). pH can also affect the solubility of metal compounds contained in bottom sediments or suspended material, thus affecting contaminant levels in a lake system. In addition, acidic water can be corrosive and adversely affect water treatment processes, such as coagulation and chlorination, and cause damages to treatment plant equipment and piping (USEPA, 1986).
Total nitrogen (TN), mg/L	Nitrogen is a building block of cellular proteins; therefore all organisms require nitrogen to survive. Nitrogen can exist in oxidized forms, such as nitrate (NO_3^-) or nitrite (NO_2^-), or in reduced forms, such as ammonia (NH_3) and organic nitrogen. The most common form of nitrogen in surface waters is nitrate, while ammonia is predominantly found in low oxygen environments (Holdren et al., 2008). In oxygenated natural water systems, nitrite is rapidly oxidized to nitrate (USEPA, 1986). High nitrate and nitrite concentrations in drinking water can cause serious illness to infants below the age of six months (USEPA, 2015). High concentrations of ammonia in water can be toxic to fish and other aquatic life. Ammonia toxicity to fish is affected by pH and temperature (USEPA, 2013).
Nitrate-nitrite as nitrogen (NO_3+NO_2-N), mg/L	
Ammonia as nitrogen (NH_3-N), mg/L	
Total phosphorus (TP), mg/L	Total phosphorus (TP) represents the sum of all phosphorus forms. Phosphorus can enter waterways and water bodies from various sources, such as weathering and leaching of phosphate-rich geological formations, atmospheric deposition, municipal and industrial effluent, urban runoffs, and agricultural discharges. Dissolved orthophosphate (PO_4-P) is more readily available and more rapidly used by algae, and thus can promote productivity (Rosen et al., 2012).
Dissolved orthophosphates (PO_4-P), mg/L	
Total organic carbon (TOC), mg/L	Total organic carbon (TOC) measures the gross amount of organic matter found in natural water, including visible particles from decaying organisms and dissolved molecules of carbon-containing compounds (Rosen et al., 2012). It is an indicator of the degree of biological production in reservoirs and can also be used as a measure of the amount of organic pollutants present in water (LaBounty & Burns, 2005). Total organic carbon is a precursor in the formation of trihalomethanes (THMs). THMs are byproducts of drinking water disinfection and are carcinogens at high concentrations. THMs are formed when TOC reacts with chlorine, a chemical used as a disinfectant during drinking water treatment process (LaBounty & Burns, 2005). Higher TOC concentrations in source water can result in production of more THMs in drinking water supplies.

Table 4.1.1-3 (continued). Parameters/measures examined for determining the condition and trend of Lake Mead.

Parameters/Measures	Description
Surface water temperature trend (whole lake)	Human use of water, whether as a drinking water source or through full body-contact recreation, is to some degree temperature-dependent. Water temperature also regulates aquatic organisms' metabolism, survival, and reproduction. Further, changes in water temperature can affect chemical reactions and other processes within the water column. For example, as water temperature increases, oxygen becomes less soluble, thus reducing DO concentration in the water. Water temperature is an important physical parameter that has far-reaching effects on both humans and aquatic life using the water (USEPA, 1986). Increase in water temperature can increase the potential for water-borne pathogens and affect human recreation. Water temperature is controlled primarily by climatic conditions with some influence from human activities. Temperature changes are important in driving the dynamics of productivity, nutrient availability, and water transport in lakes and reservoirs (Holdren et al., 2008). Water temperature is typically monitored as a part of the overall physical characterization of a lake. Surface water temperature trends are examined in this section. On the other hand, the formation of thermal stratification within the water column can have profound effects on the mixing process within a lake and impact the hydrology and ecology of a water body. Due to the importance of water column temperature for lakes Mead and Mohave to their hydrology, water column temperature trends are examined and discussed in section 4.1.1.2 Hydrologic Function. Water temperature also relates to the potential for algae growth and pathogen survival, and summations of water temperature trends are further discussed in those sections (e.g. 4.4 Recreation Suitability).

Data and Methods

Table 4.1.1-4 shows the data and methods used to assess surface water quality.

Table 4.1.1-4. Indicators, measurements, and scale of analysis used to assess surface water quality.

Indicator(s)	Measurement(s)	Scale of Analysis
• Dissolved oxygen • Conductivity • pH • Secchi depth • Chlorophyll *a* • nutrients (total nitrogen, total phosphates, orthophosphates, nitrate-nitrite as nitrogen, ammonium as nitrogen) • total organic carbon (TOC) • Surface water temp trend (whole Lake)	Dependent on parameter (Comparison with recommended water quality standards/criteria and/or temporal trend)	Lake Basin

Multiple local, states, and federal agencies have been collecting long-term water quality monitoring data at lakes Mead and Mohave at many locations to meet regulatory and operational requirements,

as well as research needs. Southern Nevada Water Authority (SNWA) maintains a program for drinking water source monitoring in compliance with the Clean Water Act (1972, as amended). Regional water reclamation districts monitor lakes Mead and Mohave to comply with their NPDES discharge permits, which are issued by the Nevada Division of Environmental Protection (NDEP). The Clean Water Coalition (CWC) led the development of the Boulder Basin Adaptive Management Program (BBAMP) and selected a series of monitoring sites and parameters in response to the Environmental Impact Statement for the Systems Conveyance Operation Program (SCOP). BOR monitors the lake quarterly. There are also regional wildlife conservation programs that monitor within this area, such as the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) by U.S. Bureau of Reclamation (BOR) and the Virgin River Habitat Conservation Program by U.S. Fish and Wildlife Service (USFWS), as well as Nevada Department of Wildlife (NDOW) and Arizona Game and Fish Department (AZGFD).

NPS, SNWA, and BOR combined resources and initiated monitoring at five locations on Lake Mohave in 2012. Between these interagency monitoring efforts, there are approximately 57 monitoring stations across Lake Mead and 5 permanent monitoring stations in Lake Mohave. Water samples are collected at these monitoring stations weekly or monthly depending on the specific parameter. SNWA, NPS, and BOR have partnered to enhance Lake Mead-wide monitoring to 24 stations monthly from 2004 through 2011. Since 2012, BOR has continued to conduct monthly monitoring at 22 stations on Lake Mead.

Data collected by these monitoring programs can be downloaded from the SNWA database (http://snwaexapps.lvvwd.com) and respective agencies websites (e.g., https://www.lcrmscp.gov/). Sampling locations used for this assessment are described in Figure B-3 and B-5, and Table B-1. Sites selected were based on site locations and data availability.

Water quality monitoring in Lake Mead

To capture conditions in different basins within Lake Mead, data were included from representative monitoring stations in Boulder, Virgin, Temple, and Gregg basins, Overton Arm, and Las Vegas Bay. The monitoring stations selected to represent conditions of each basin were discussed and approved by NPS Lake Mead NRA staff. Information on all monitoring stations used to elevate the lake basin water quality conditions is presented in Figure B-3 and Table B-1.

Values used for each site were computed as monthly averages for all samples (including those at all sample depths, where appropriate unless specified) collected from each year examined. Samples from Las Vegas Bay and Boulder Basin were collected on a weekly basis, and on a monthly schedule for all other locations.

For parameters where recommended water quality standards or criteria were available (see Reference Condition), computed values for each basin were compared against these criteria for condition status determination.

Water quality monitoring in Lake Mohave

To capture conditions in Lake Mohave, data were included from four monitoring stations: Willow Beach, Placer Cove, Cottonwood Cove, and Katherine's Landing (Figure B-5 and Table B-1). These stations represented a range of landscapes found within Lake Mohave and were characterized by riverine habitat surrounded by a narrow canyon or shallow, open basin. Values used for each site for comparison were computed as monthly averages of values for all samples (including those at all sample depths, where appropriate, unless specified) collected from each year examined. Most samples were collected on a monthly basis.

For parameters where recommended water quality standards or criteria were available (see Table 4.1.1-6, Reference Condition), estimated values for each basin were compared against these criteria for assessment of condition status (Table 4.1.1-5).

Table 4.1.1-5. Sampling method descriptions and approximate monitoring frequencies of parameters examined. Excerpted from LaBounty & Burns, 2005 and Holdren et al., 2008.

Sampling Method Descriptions and Approximate Monitoring Frequencies	**Parameters/Measures**
Profiles of multiple water quality parameters are collected at various depths, depending on the sampling protocol used. Over time, a variety of water quality sampling equipment has been used as the technology changes, including the use of multiple-parameter data collection equipment that can be deployed for extended length (up to three weeks).	Dissolved oxygen (DO), mg/L or % saturation
	Conductivity, µS/cm
	pH
	Surface water temp trend (whole lake)
Lee and Gazafy (1979) examined the 10-year salt load balance in Lake Mead between 1967 and 1976. The information provided by this study is limited because data were only collected from one sampling station between the intake towers near Hoover Dam and should not be used to infer condition of the entire Lake Mead NRA. Authorized by the CWA, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. In Nevada, NDEP issues NPDES permits to the dischargers to Lake Mead. TDS is one of the parameters monitored for permit compliance (NPS, 2010). As the water master of the Colorado River, BOR has been monitoring limnological conditions in Boulder Basin and other parts of lakes Mead and Mohave since 1990. These data are used to inform management decision regarding water resources of the lower Colorado River Basin. TDS is also one of the parameters monitored (NPS, 2010).	Salinity, Concentration (Total dissolved solids, TDS, mg/L)

Table 4.1.1-5 (continued). Sampling method descriptions and approximate monitoring frequencies of parameters examined. Excerpted from LaBounty & Burns, 2005 and Holdren et al., 2008.

Sampling Method Descriptions and Approximate Monitoring Frequencies	Parameters/Measures
Water samples were collected weekly from Las Vegas Bay (2008–present) and Boulder Basin (2003-present) sampling stations and monthly from Colorado River main stem stations (2005-present) and Overton Arm stations (2005–2012) for analysis of inorganic nutrients, including orthophosphates (PO_4-P), nitrate-nitrite as nitrogen (NO_3+NO_2-N), ammonium as nitrogen (NH_3-N), and organic nutrients, such as total nitrogen (TN) and total phosphorus (TP). Samples were collected using a Van Dorn sampler at all depths except the surface, where grab samples were collected. At the Boulder Basin station, two samples were collected within the epilimnion when it was ≤15 m in width; three to four samples within the **thermocline**, including one sample at peak conductivity; and up to four samples within the hypolimnion (LaBounty & Burns, 2005). Nutrient analyses samples were collected at eight depths for Colorado main stem stations and Overton Arm, depth permitting (Holdren et al., 2008). Fewer samples have been collected throughout the water column in recent years due to lower lake elevation.	Total nitrogen (TN), mg/L
	Nitrate-nitrite as nitrogen (NO_3+NO_2-N), mg/L
	Ammonia as nitrogen (NH_3-N), mg/L
	Total phosphorus (TP), mg/L
	Dissolved orthophosphates (PO_4-P), mg/L
Concentrations of total organic carbon (TOC) were analyzed from the water samples collected for nutrients analysis for Las Vegas Bay and Boulder Basin stations.	Total organic carbon (TOC), mg/L

Reference Conditions

Table 4.1.1-6 shows the refence conditions of surface water quality used in the assessement.

Table 4.1.1-6. Metrics and excedence measures used to differentiate lake health condition status (significant warrants concern, moderate concern, or is in good condition).

	Condition Status		
Measurement(s)	**Significant Concern***	**Moderate Concern***	**Good***
Dependent on parameter (Comparison with recommended water quality standards/criteria and/or temporal trend)	Chronic exceedance of published NDEP/ADEQ water quality standard or measure that is potentially harmful to lakes Mead and Mohave aquatic life. Or USEPA NLA “poor/high risk” condition designation	Slight or occasional exceedance of published NDEP/ADEQ water quality standard or measure that is potentially harmful to lakes Mead and Mohave aquatic life. Or USEPA NLA “fair/moderate risk” condition designation	Rare or no exceedance of published NDEP/ADEQ water quality standard or measure that is potentially harmful to lakes Mead and Mohave aquatic life. Or USEPA NLA “good/low risk” condition designation

* Depends on the parameter analyzed, where applicable.

In 2007, USEPA conducted a baseline study of the condition of lakes in the United States, including Lake Mead. The National Lakes Assessment (NLA) categorized Lake Mead into the EPA level-III Xeric ecoregion (USEPA, 2009). Data for six parameters (concentrations of total nitrogen, total

phosphorus, chlorophyll *a*, dissolved oxygen, turbidity, and an aggregate measure of the lakes' suitability for recreation) from Lake Mead were compared to other lakes in the Xeric ecoregion to assess conditions (Rosen et al., 2012). Total nitrogen, total phosphorus, chlorophyll *a*, and dissolved oxygen values were rated using a good/fair/poor scale relative to conditions found in reference lakes (USEPA, 2009). A reference lake in NLA definition would be a lake, either natural or human-made, with attributes (e.g. water quality) that come as close as practical to those expected in a natural state. Target lakes with indicator values above 25% of the reference range values within the same ecoregion are considered "good"; below the 5% reference threshold are considered "poor." The established NLA scale was used to evaluate current, whole-lake condition of three parameters examined (total nitrogen, total phosphorus, and dissolved oxygen) in this assessment (Table 4.1.1-7).

In addition, Nevada Department of Environmental Protection (NDEP) and Arizona Department of Environment Quality (ADEQ) promulgate standards for broad classes of water quality indicators to protect designated beneficial uses of the state's waters. These values are often reflective of guidelines established by USEPA protective of aquatic resources. The State of Nevada Water Pollution Control Regulations water quality standards for Lake Mead and ADEQ water quality standards were also considered when establishing reference conditions for the parameters in this assessment (NDEP, 2004; ADEQ, 2010) (Table 4.1.1-7).

The Federal Water Pollution Control Act (FWPCA) requires the Colorado River Basin States to review water quality standards relating to the salinity of the waters of the Colorado River at least once every three years. The Act requires the implementation of salinity control programs to reduce the salinity of and maintain the salinity concentrations at or below a set of numeric criteria at three stations on the lower main stem of the Colorado River (Colorado River Basin Salinity Control Forum, 2011). Currently the salinity criterion below the Hoover Dam is 723 mg/L (Table 4.1.1-7).

USEPA secondary standards are non-mandatory recommended levels of substances, which can affect the aesthetic quality of water, such as color, taste, or odor but are not considered to pose significant human health risk (USEPA, 2016). Salt (salinity) measured as TDS is considered one of those substances. Secondary MCL for TDS is set at 500mg/L by the USEPA (USEPA, 2016) (Table 4.1.1-7).

Congress passed the Safe Drinking Water Act (SDWA) in 1974 and then amended the SDWA in 1984 and again in 1996 to authorized risk-based standard-setting for contaminants that may affect public health (USEPA, 2015). The National Primary Drinking Water Regulations (NPDWRs) are legally enforceable standards that apply to all public water system and regulate over 65 contaminants. The rules are intended to provide public health protection by limiting the levels of contaminants in drinking water. USEPA set a Maximum Contaminant Level (MCL) for each contaminant. MCLs are enforceable standards of maximum levels of contaminants allowed in drinking water. For this assessment, MCLs for pH, Nitrate-nitrite as nitrogen (NO_3+NO_2-N), bromate, and trihalomethanes (THM) were used as thresholds for the reference conditions (Table 4.1.1-7).

Table 4.1.1-7. Recommended water quality standards or criteria available for selected water quality parameters (see Reference Condition, Table 4.1.1-6). Values computed for each basin were compared against these criteria for assessment of condition status.

Parameters	Condition Status			Source
	Significant Concern	**Moderate Concern**	**Good**	
Dissolved oxygen (DO), mg/L	<3 mg/L	3–5 mg/L	≥5 mg/L in the epilimnion	NDEP, 2004; USEPA, 2009; ADEQ, 2010
	<50%	–	>50% to meet the requirements of aquatic organisms and sustain a biological community.	Rosen et al., 2012
Salinity, mg/L	>723 mg/L at sampling station below Hoover Dam (designated criteria station)	Occasional exceedance USEPA secondary (aesthetic quality, e.g. color, taste, or odor) MCL for TDS of 500mg/L but do not exceed numeric criterion set by FWPCA (723 mg/L) at sampling station below Hoover Dam (designated criteria station)	≤USEPA secondary (aesthetic quality, e.g. color, taste, or odor) MCL for TDS of 500mg/L.	ADEQ, 2010; Colorado River Basin Salinity Control Forum, 2011; USEPA, 2016
pH	<6.5 or >9.0	–	6.5–9.0 for protection of aquatic life and drinking water.	USEPA, 1986; NDEP, 2004; ADEQ, 2010
Total nitrogen (TN), mg/L	>2.286 mg/L	>0.514–2.286 mg/L	≤0.514 mg/L	USEPA, 2009; ADEQ, 2010
Nitrate-nitrite as nitrogen (NO_3+NO_2-N), mg/L	>10 mg/L	–	≤10mg/L for safe drinking water.	USEPA, 1986; USEPA, 2015
Ammonia as nitrogen (NH_3-N), mg/L	>1.9 mg/L 30-d moving average or exceed 4.8 mg/L (at pH 7.0, 20°C) as a 4-day average within 30 days, more than once in three years on average.	–	≤1.9 mg/L 30-d moving average at pH 7.0 and temperature 20°C for protection of aquatic life.	USEPA, 2013
Total phosphorus (TP), mg/L	>0.130 mg/L	>0.048–0.130 mg/L	≤0.048 mg/L	USEPA, 2009; ADEQ, 2010
Total organic carbon (TOC),	> 0.08 mg/L	–	≤ 0.08 mg/L USEPA MCL for total THMs in drinking water	USEPA, 2015

Total organic carbon is a precursor in the formation of THMs. THMs are byproducts of drinking water disinfection with chlorine and are carcinogens in high concentrations. THMs are formed when TOC reacts with chlorine, a chemical used as a disinfectant during the drinking water treatment process. Total THM concentration is regulated under the EPA Disinfection By-Products Rule (USEPA, 2015).

The USEPA also provides recommended aquatic life water quality criteria for protection of aquatic life in US waters. The Aquatic Life Ambient Water Quality Criteria for Ammonia is presented here as a reference condition for ammonia concentration (USEPA, 2013) (Table 4.1.1-7).

For parameters where no recommended water quality standards or criteria were available, conditions were assessed based on temporal trends observed.

Condition and Trend

Dissolved oxygen (DO)

DO concentrations within Lake Mead generally meet the requirement (>50% saturation) to sustain a thriving aquatic community (Rosen et al., 2012).

Seasonal patterns of thermal stratification in Lake Mead influence DO conditions in the lake (Figure 4.1.1-1). During mixing periods in the fall and winter, DO concentrations can reach 10 mg/L or higher throughout the water column. As the water column begins to stratify in the spring and summer, DO concentrations are higher at the epilimnion where surface water is exposed to atmospheric oxygen. In the hypolimnion, seasonal restrictions from atmospheric oxygen have resulted in gradual decreases of DO concentrations (Figure 4.1.1-1). DO levels in the bottom few meters of the water column were less than 4 mg/L at both stations CR394.0 and CR390.0 from June through September 2009. Cold, dense underflows from the Colorado River enter Lake Mead at the hypolimnion, which has been observed to replenish and maintain DO concentrations at 4 to 5 mg/L during the fall and winter (Figure 4.1.1-1). In years when the water column mixes completely, oxygen is replenished through all thermal layers. During years of incomplete mixing, oxygen at the bottom of the water column is usually replenished by under flowing Colorado River waters (Rosen et al., 2012).

For all stations, there was no significant trend for DO concentrations during the time periods examined. Further, all DO concentrations recorded fell within the USEPA NLA “good” range (≥ 4mg/L, Table 4.1.1-2) at all selected stations in Lake Mead (Figure 4.1.1-2 to Figure 4.1.1-7).

At Lake Mohave, DO concentration data were available for 2007 to present from all four assessment stations. The Willow Beach station (closest to Hoover Dam discharge) had the lowest DO levels, relative to the other three stations considered. This station receives hypolimnetic discharge which is lower in DO than the surface waters from the reservoir. DO concentrations at Cottonwood Cove and Katherine’s Landing were similar, and highest amongst the stations examined (Figure 4.1.1-8). At all four stations examined in Lake Mohave, DO concentrations were also within the USEPA NLA “good” range (≥ 4mg/L, Table 4.1.1-7).

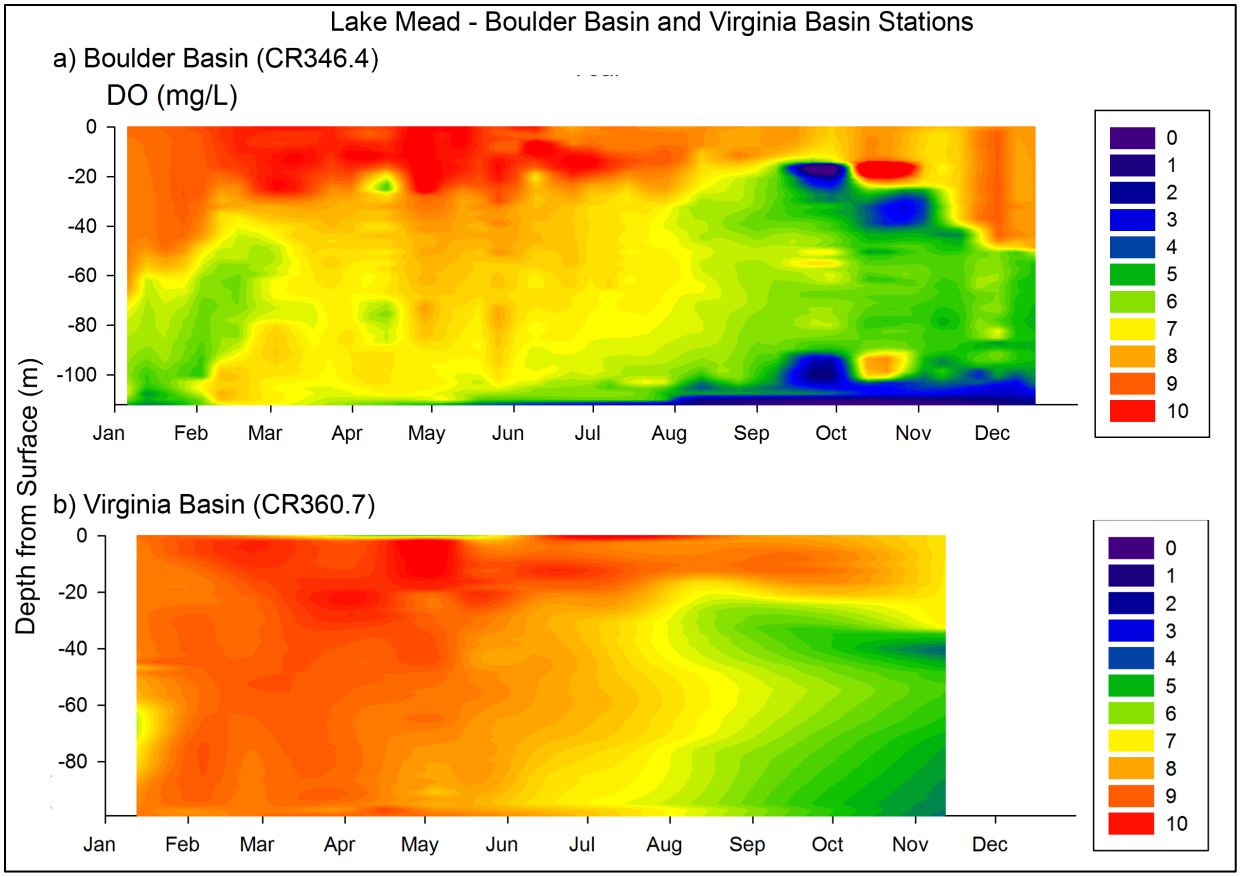


Figure 4.1.1-1. Time series (2015) of dissolved oxygen profile data collected from Boulder Basin (CR346.4) and Virgin Basin (CR360.7) stations.

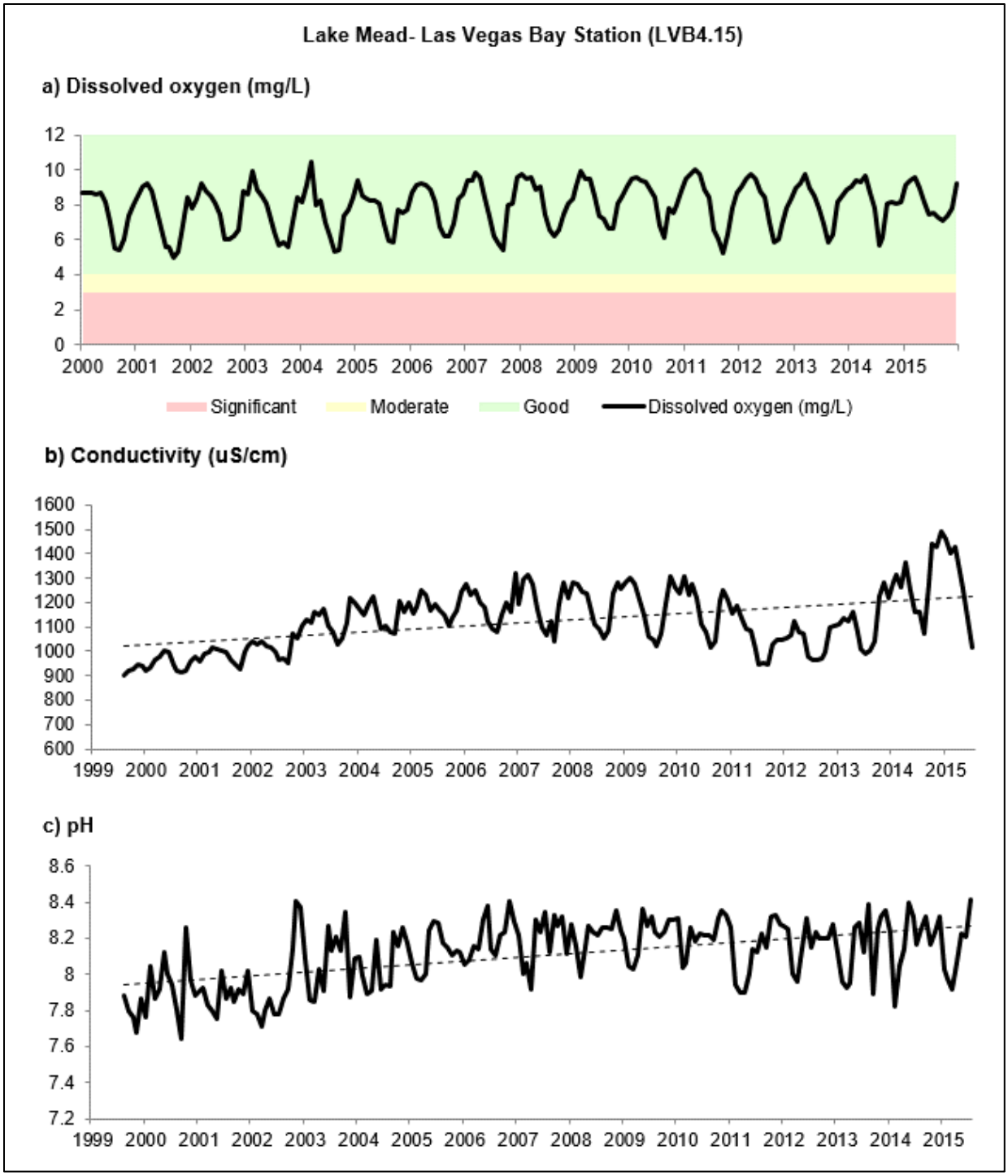


Figure 4.1.1-2. Time series (monthly averages) of dissolved oxygen concentration (2000–2015), conductivity (2000–2015), and pH (2000–2015) from Las Vegas Bay station (LVB4.15). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

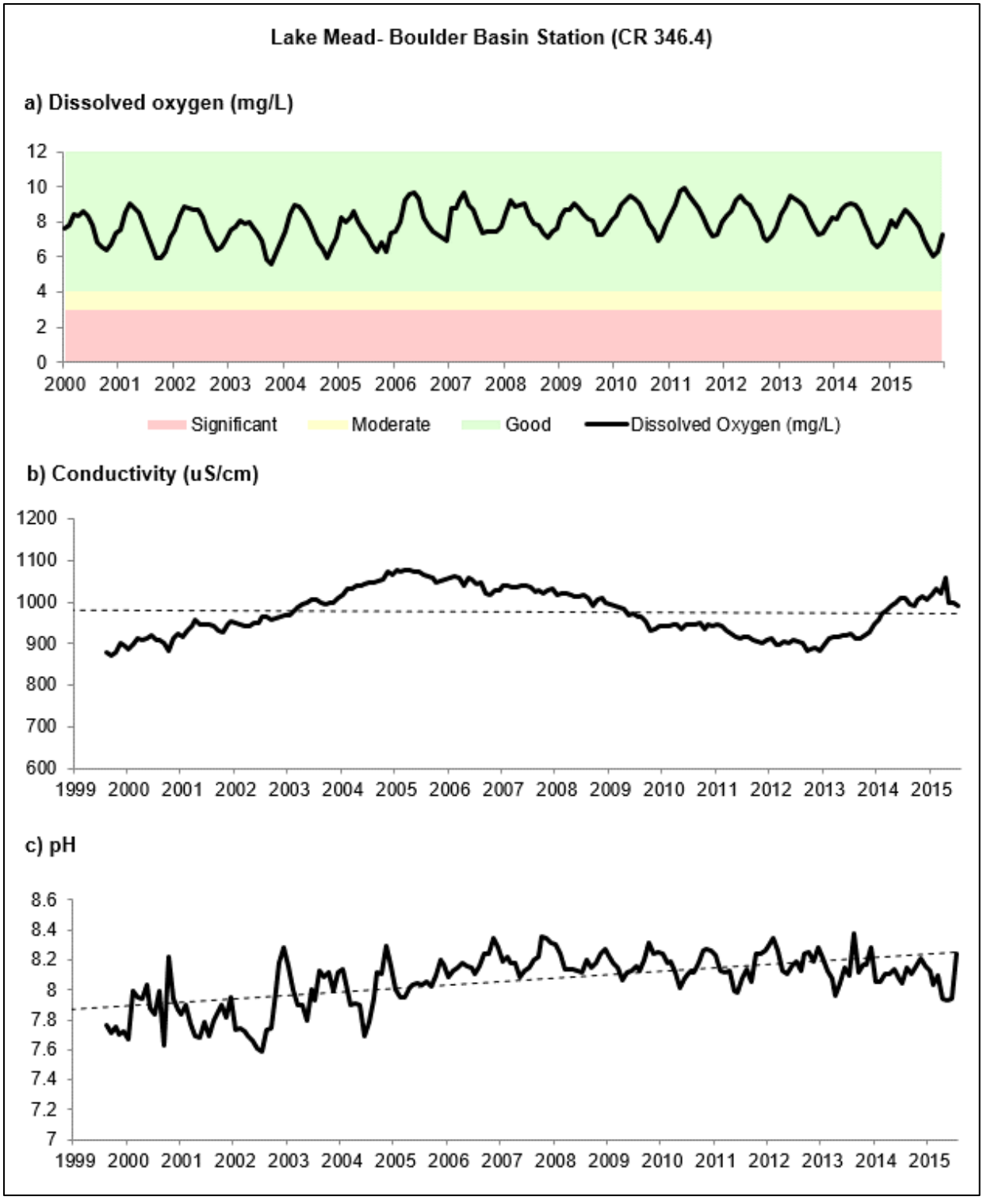


Figure 4.1.1-3. Time series (monthly averages) of dissolved oxygen concentration (2000–2015), conductivity (2000–2015), and pH (2000–2015) from Boulder Basin (CR346.4). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

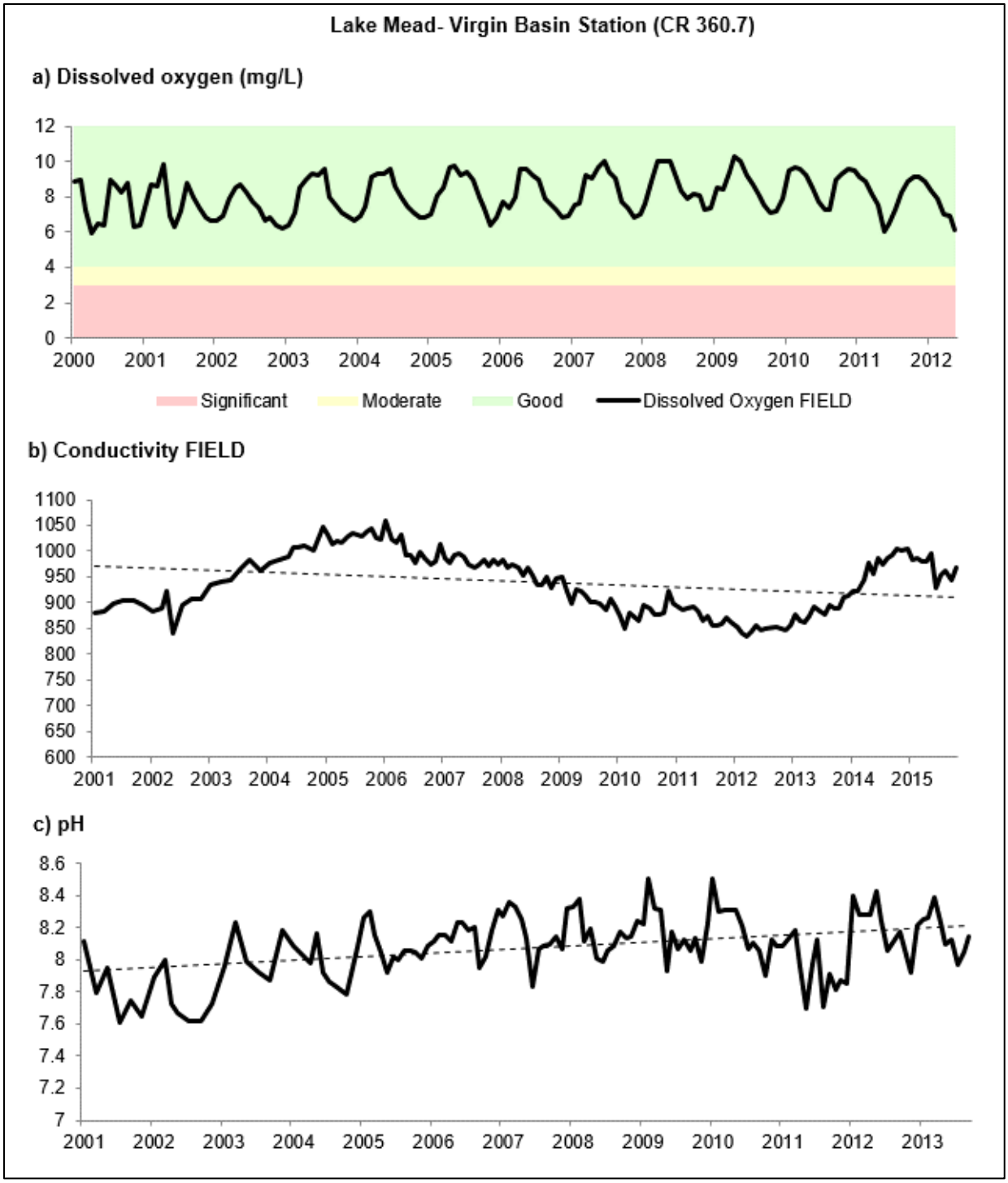


Figure 4.1.1-4. Time series (monthly averages) of dissolved oxygen concentration (2000–2015), conductivity (2001–2015), and pH (2001–2015) from Virgin Basin (CR360.7). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

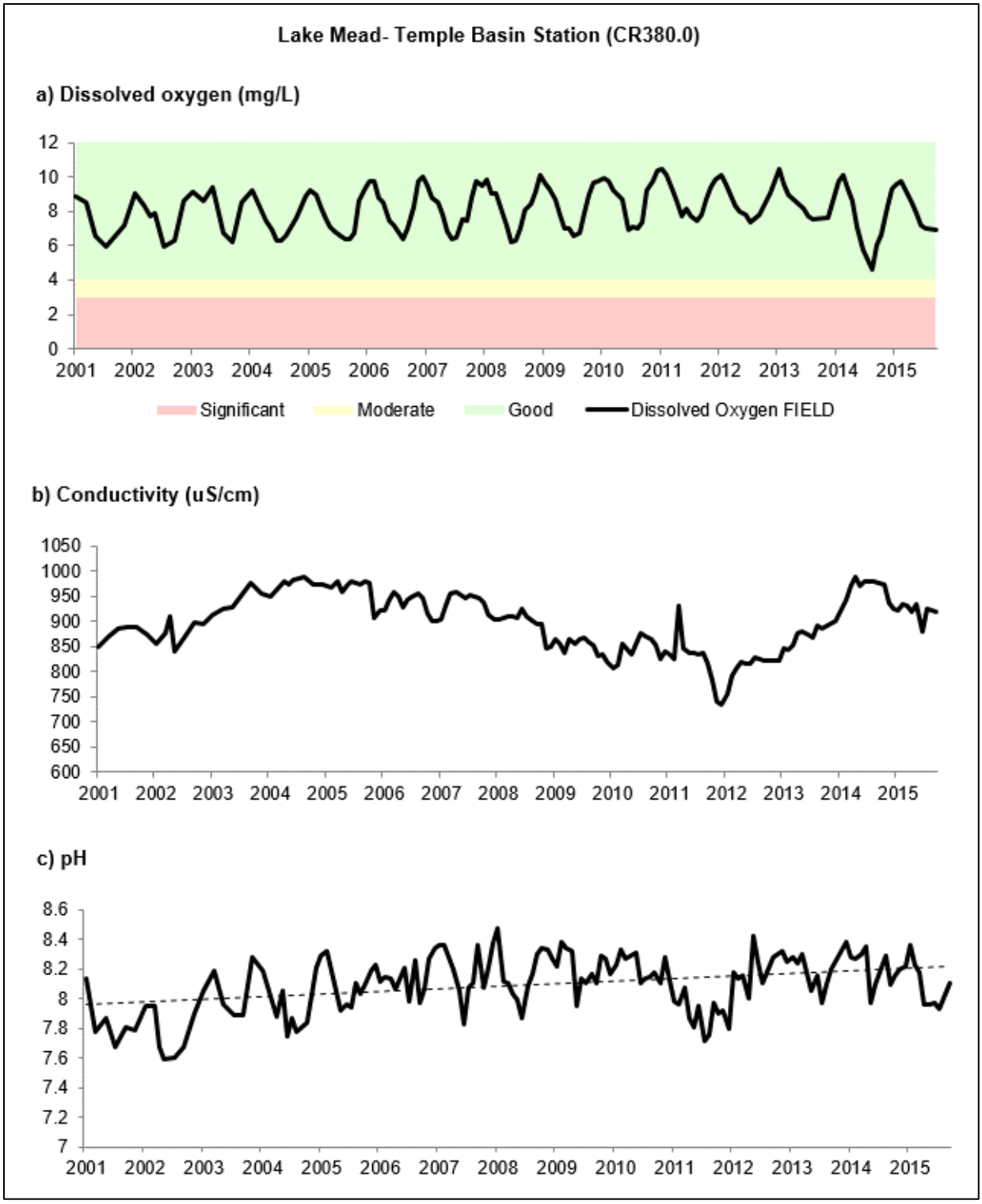


Figure 4.1.1-5. Time series (monthly averages) of dissolved oxygen concentration (2001–2015), conductivity (2001–2015), and pH (2001–2015) from Temple Basin (CR380.0). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

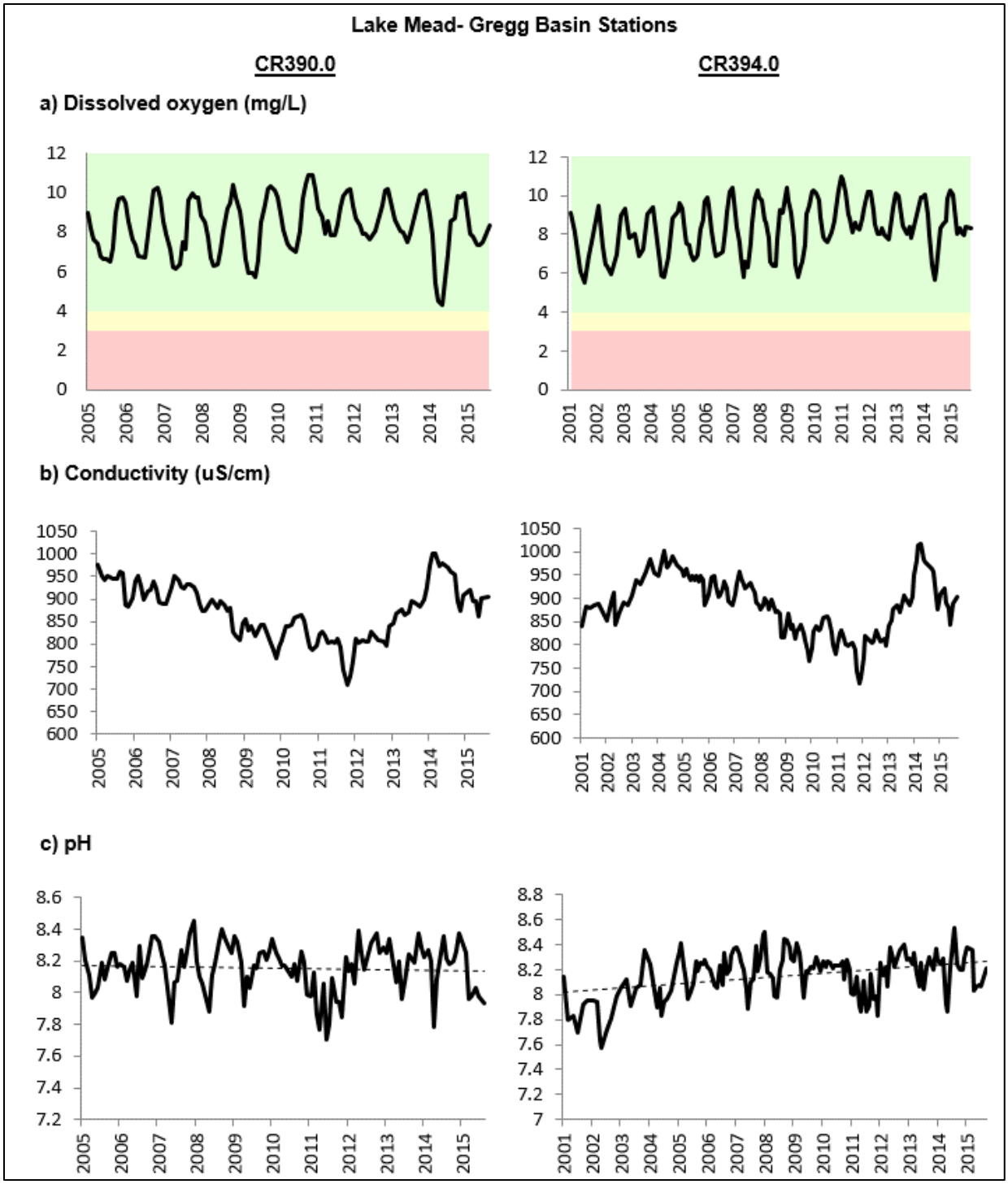


Figure 4.1.1-6. Time series (monthly averages) of dissolved oxygen concentration, conductivity, and pH from Gregg Basin (CR390.0: 2005–2015 and CR394.0; 2001–2015). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

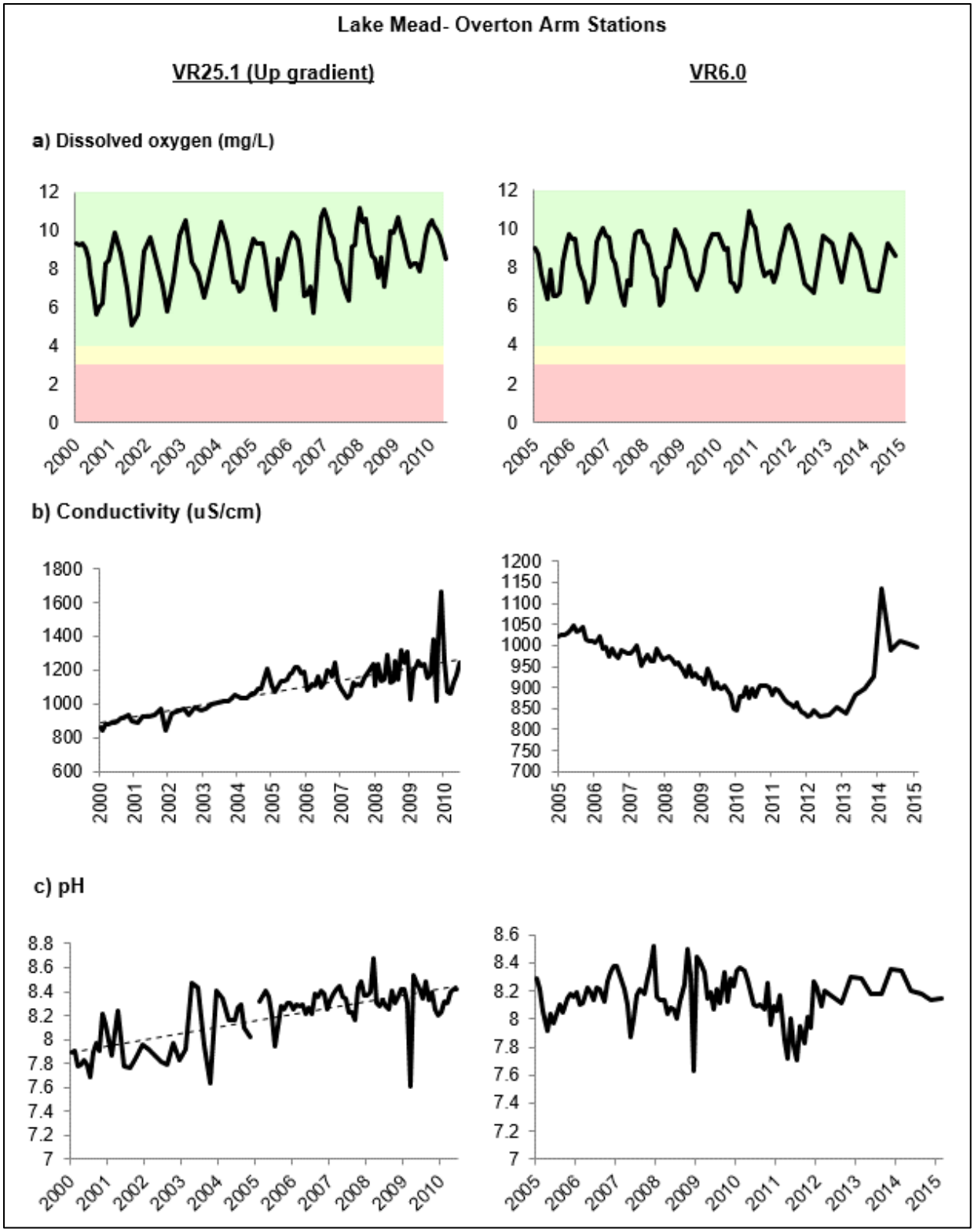


Figure 4.1.1-7. Time series (monthly averages) of dissolved oxygen concentration, conductivity, and pH from Overton Arm (VR6.0: 2000–2015 and VR25.1; 2005–2015). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

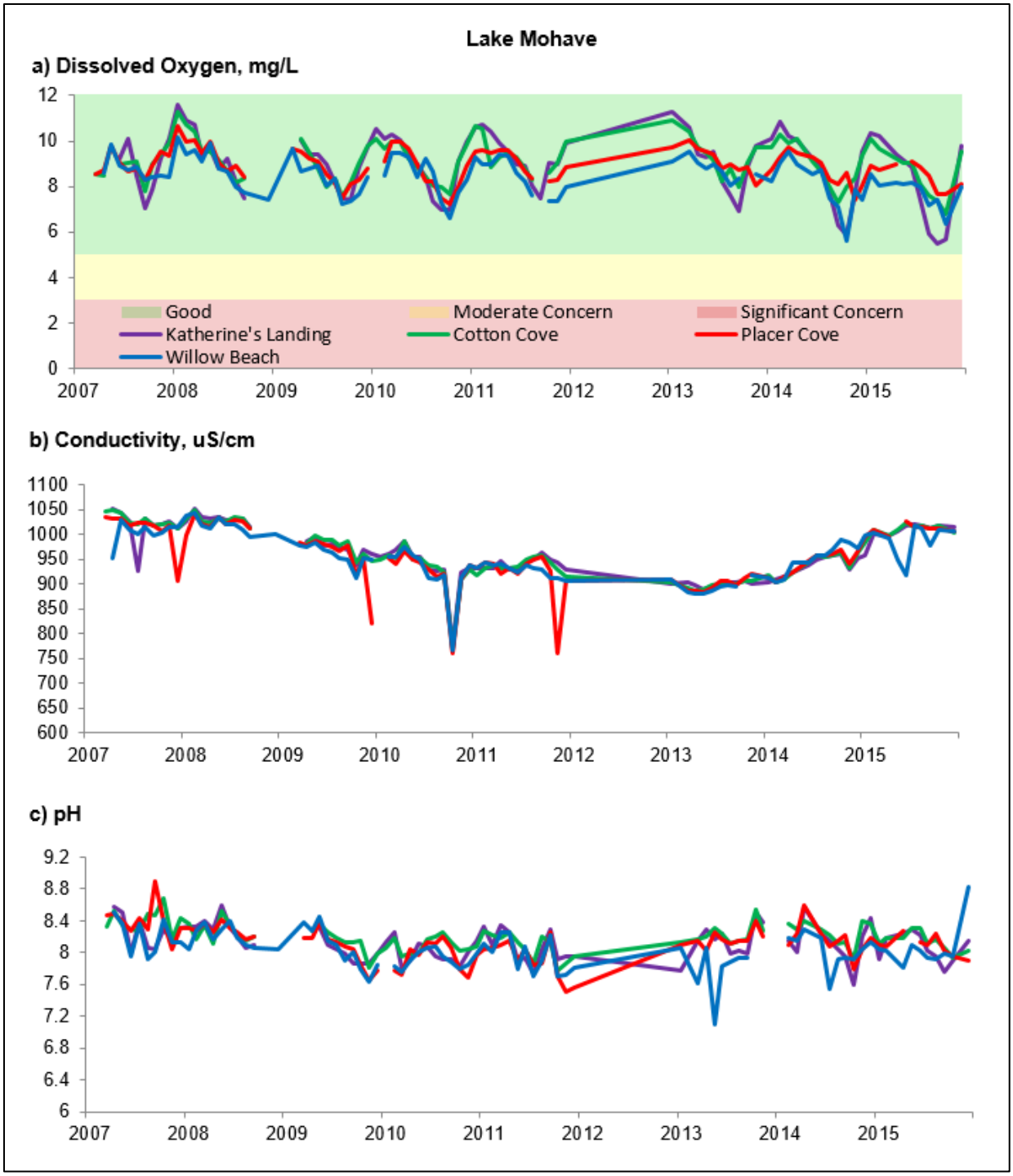


Figure 4.1.1-8. Time series (monthly averages) of dissolved oxygen concentration, conductivity, and pH from Willow Beach (CR329.7), Placer Cove (CR316.34), Cottonwood Cove (CR298.SW5), and Katherine's Landing (CR278.0) in Lake Mohave between 2007 and 2015. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-5 for station locations and Table B-1 for station descriptions.

Conductivity

Water conductivity in Lake Mead is controlled by a set of interrelated factors which include: higher conductivity inflow from tributaries other than the Colorado River, lower conductivity inflow from the Colorado River, and the evaporation of surface waters combined with water column stratification (Rosen et al., 2012). Conductivity values have increased at stations located closer to Las Vegas Wash in Las Vegas Bay (LVB4.15) from 1999 to 2015 and Muddy and Virgin rivers (VR25.1) confluences in Overton Arm from 2000 to 2015 (Figure 4.1.1-2 and Figure 4.1.1-7). The conductivity is increasing at the station closest to the Las Vegas Wash because it is a fixed station and the Las Vegas Wash is moving closer to it do to lowering lake levels. Same for the Virgin River site. Conductivity decreased from 2005 to 2012 at all stations except at LVB4.15 and VR25.1; however, upward trends in conductivity values have been observed at all stations in Lake Mead since 2012. This upward trend may be a consequence of significant lake level decline observed in recent years. As lake levels have declined, inflows with higher conductivity may be contributing a greater portion of water entering the lake. LaBounty and Burns (2005) examined the relationship of conductivity with lake evaluation and found that conductivity mirrored the wet and dry periods of the Colorado Basin.

A similar pattern was observed in Lake Mohave with overall declines in conductivity from 2005 to 2012 and upward trends recorded since 2012 (

Figure **4.1.1-8**).

pH

Seasonal trends in pH follow those of dissolved oxygen and water temperatures and can be illustrated through stratification patterns. In general, stratification of the water column establishes a barrier for equal distribution of pH in the water column and a concentration gradient is formed, with higher pH in the epilimnion. Production of phytoplankton may also change the pH. Overall, pH of Lake Mead has been slightly basic, averaging around 8 and fluctuating between 7.5 and 8.5 (Figure 4.1.1-2 to Figure 4.1.1-7). Slight increases in pH were observed between 2000 and 2015 at almost all stations examined. However, a significant change in pH at Lake Mead is unlikely as the dominance of carbonate minerals throughout the watershed ensures relative stability (Holdren et al., 2008). A carbonate buffering system, the equilibrium of carbon dioxide, water and carbonic acid, bicarbonate, and carbonate ions, at Lake Mead prevents large changes in pH and generally limits the importance of pH as a factor affecting water quality in Lake Mead regardless of phytoplankton and other inputs (Rosen, Turner, Goodbred, & Miller, 2012).

pH at all selected stations in lakes Mead and Mohave were within the USEPA standard for protection of aquatic life and drinking water (6.5 to 9, Table 4.1.1-2) for the examined period.

Salinity

The salinity of the Colorado River has been a significant water quality issue for the Colorado River basin and the reservoirs along the river, including Lake Mead and Lake Mohave. The major sources of salt loading are the saline soils of the Colorado Plateau and agricultural irrigation-return flows. Salinity concentrations in the headwaters of the basin generally are less than 50 mg/L but can increase to about 900 mg/L at the international boundary between the United States and Mexico

(USGS, 2000). Anthropogenic activities, such as urban development, mining, agricultural practices, and recreation can contribute to added salinity concentrations and other chemical constituent concentrations in the Colorado River (Colorado River Basin Salinity Control Forum, 2011).

Lakes Mead and Mohave also provide drinking water and recreational opportunities. While high salinity levels do not present any human health risk, salts can influence the quality of water, such as color, taste, or odor can be affected (USEPA, 2016).

Lake Mead:

Lee and Gazafy (1979) observed decreasing TDS concentrations (from 755 mg/L to 670 mg/L) from late 1969 to 1975 at the sampling station near Lake Mead's outlet. After 1975, TDS concentrations stabilized with slight increases observed in 1978. Highest TDS concentrations have been recorded at surface water and have decreased with increasing water depth (Lee & Gazafy, 1979).

All tributary inflows have TDS levels that were consistently higher than the FWPCA numeric criterion (723 mg/L) (Figure 4.1.1-9 to Figure 4.1.1-11). Virgin River inflow had the highest TDS levels among all tributary inflows between 2007 and 2012. TDS concentrations in Virgin River inflow decreased significantly between 2012 and 2015 (Figure 4.1.1-9). The salinity of the Colorado River inflow has ranged from 450 to 650 mg/L between 2000 and 2016 (Figure 4.1.1-10). Las Vegas Wash consistently has had higher TDS levels; however, these concentrations have been decreasing since 2006 (Figure 4.1.1-11).

Muddy and Virgin rivers inflows have influenced the Overton Arm TDS levels (Figure 4.1.1-9). Between 2000 and 2012, sampling site (VR25.1) closest to the inflow had higher TDS levels than site (VR6.0) located further down in Overton Arm. TDS concentrations at VR25.1 have also increased between 2000 and 2010 and exceeded the FWPCA numeric criterion between 2008 and 2010 (Figure 4.1.1-9).

Gregg, Temple, and Virgin basins have had similar TDS concentrations as the Colorado River inflow, which were below the FWPCA criteria but exceed the USEPA secondary MCL for drinking water (Figure 4.1.1-10).

Las Vegas Bay receives discharge from Las Vegas Wash, which has elevated TDS concentrations in the Bay. Boulder Basin TDS concentrations have been lower than Las Vegas Bay, but still exceeded the USEPA secondary MCL (Figure 4.1.1-11). TDS concentrations increased in Boulder Basin between 2000 and 2006. TDS levels at sampling stations below Hoover Dam are consistently below the FWPCA criteria (Figure 4.1.1-11).

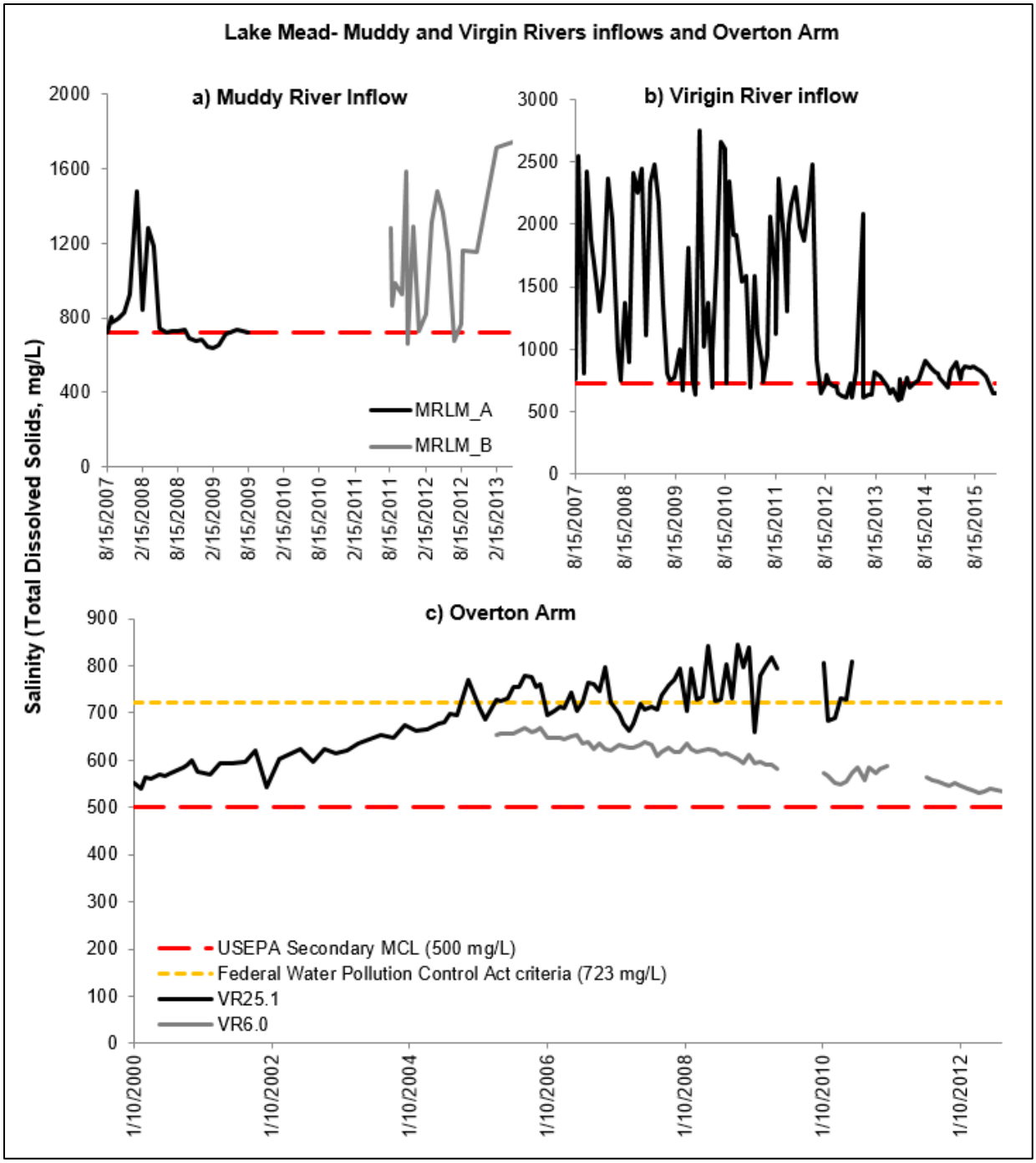


Figure 4.1.1-9. Time series of salinity as total dissolved solids (TDS) measured at inflows of a) Muddy (MRLM_A: 2007–2009 & _B: 2011–2013) and b) Virgin (VRLM_B: 2007–2015) Rivers, and c) Overton Arm (VR25.1:2000–2010 &VR6.0: 2005–2012). TDS concentrations were measured monthly at these stations. See Figure B-3 for station locations and Table B-1 for station descriptions.

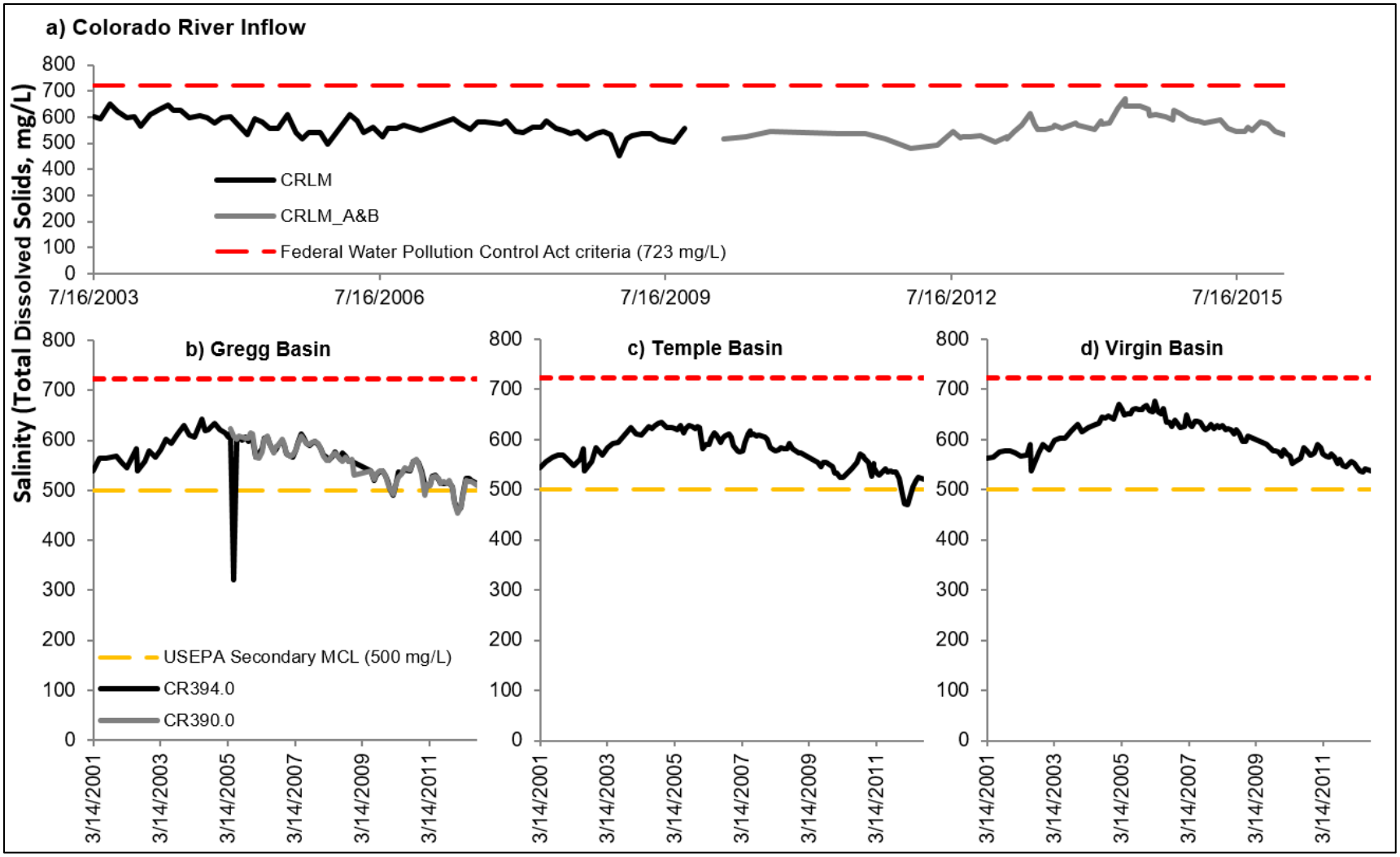


Figure 4.1.1-10. Time series of salinity as total dissolved solids (TDS) measured at a) Colorado River inflow to Lake Mead (CRLM: 2003–2009 and CRLM_A&B:2010–2015), b) Gregg Basin (CR394.0: 2001–2015 and CR390.0: 2005–2015), c) Temple Basin (CR380.0:2001–2012), and d) Virgin Basin (CR360.7: 2001–2012). TDS concentrations were measured monthly at these stations. See Figure B-3 for station locations and Table B-1 for station descriptions.

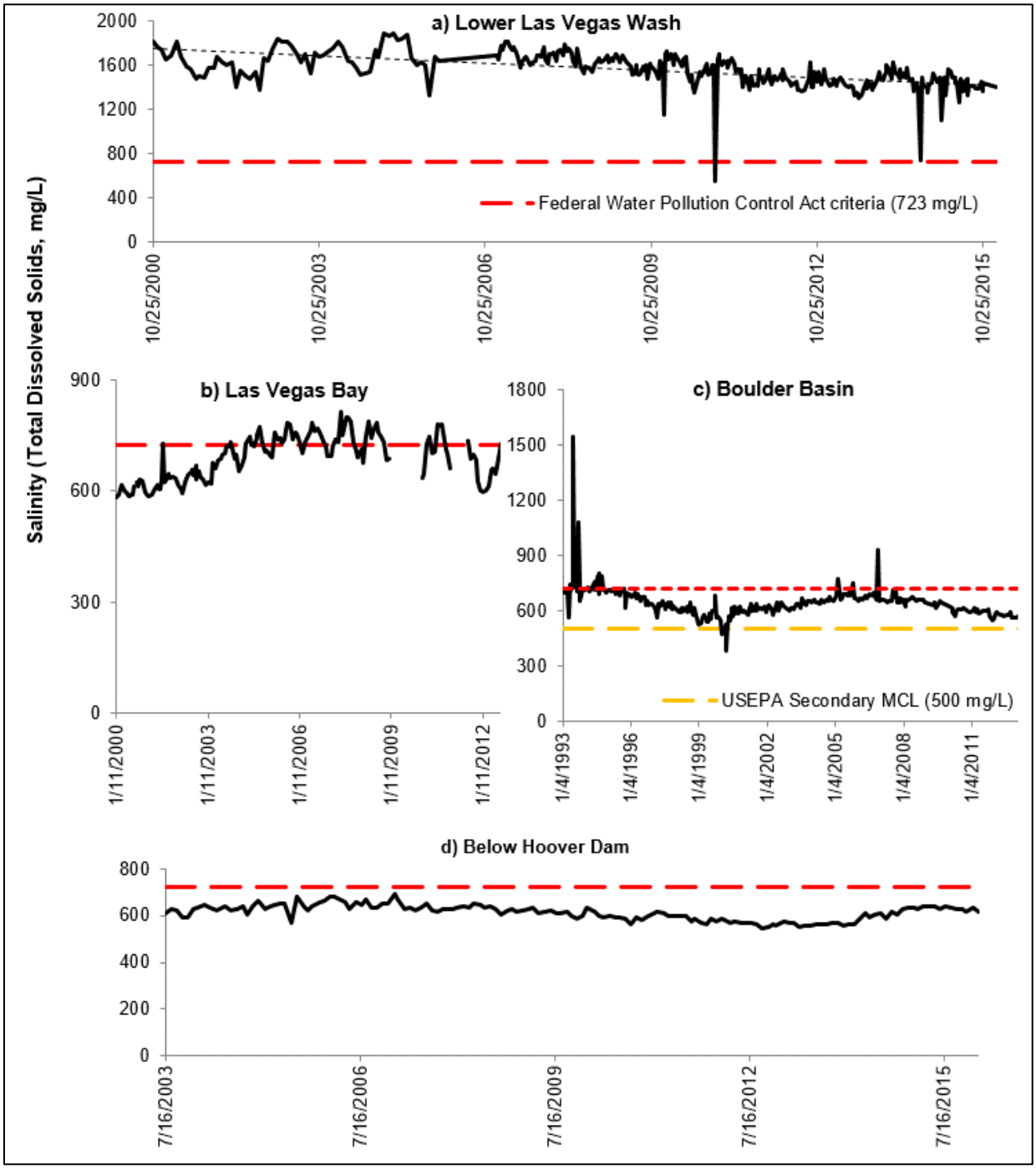


Figure 4.1.1-11. Time series of salinity as total dissolved solids (TDS) measured at a) lower Las Vegas Wash (LW0.8 and LW0.9: 2000–2015), b) Las Vegas Bay (LVB 4.15 and 4.95: 2000–2012), c) Boulder Basin (CR346.4: 1993–2012), and d) station below Hoover Dam (CR342.0: 2003–2015). TDS concentrations were measured monthly at these stations. See Figure B-3 for station locations and Table B-1 for station descriptions.

Lake Mohave:

TDS levels detected at sampling stations in Lake Mohave were consistently below the FWPCA criteria and show a slight downward trend (Figure 4.1.1-12).

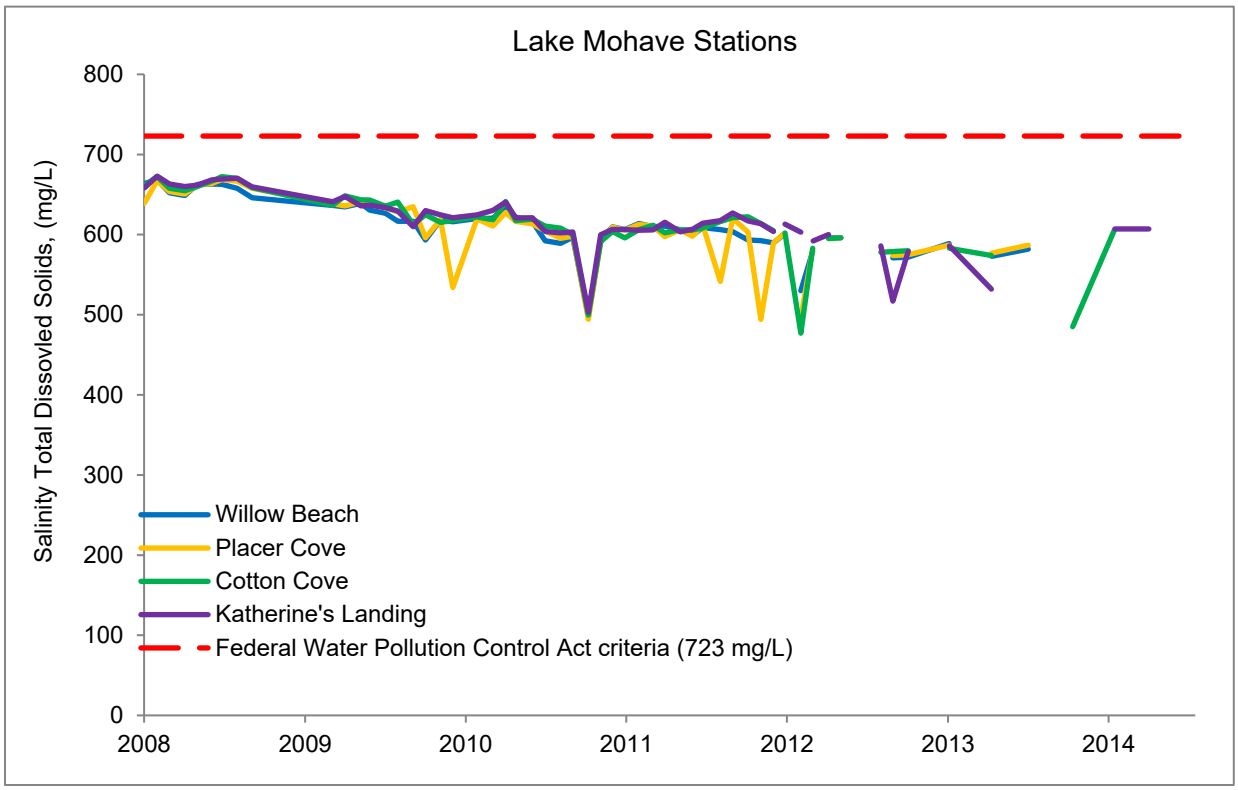


Figure 4.1.1-12. Time series of salinity as total dissolved solids (TDS) measured at Lake Mohave (2008–2014). TDS concentrations were measured monthly at these stations. See Figure B-5 for station locations and Table B-1 for station descriptions.

Nutrients

Phosphorus and nitrogen compounds are the major nutrients required for the growth of algae and other biological organisms in lakes. The dissolved inorganic nutrients, such as soluble orthophosphate (PO_4-P), nitrate and nitrite-nitrogen ($NO_3 + NO_2$ -N), and ammonia-nitrogen (NH_3-N), are nutrient forms readily available to support aquatic growth, while total phosphorus and total nitrogen concentrations are indicators of the maximum achievable growth. Nutrients, notably phosphorus drive the level of primary productivity in a lake. Productivity in lakes Mead and Mohave are typically low. However, an increase in nutrient load from inflowing tributaries can result in too much primary production and decrease water quality at the lakes and in turn degrades conditions for fish and other wildlife.

Total Nitrogen (TN)

Lake Mead:

Background concentrations of TN in Lake Mead were high and loading from the Colorado River watershed generally dominated the overall source of nitrogen loading to the lake (SNWA, 2010).

Another major point sources of nitrogen entering Lake Mead are municipal and industrial wastewaters from Las Vegas Wash (Rosen et al., 2010).

TN concentrations can be characterized as within the low end of the "moderate concern" range for Boulder Basin between 1993 and 2015, averaging at around 0.69 mg/L (Figure 4.1.1-13). Elevated values of TN observed in Boulder Basin have been a result of nitrogen loading from Las Vegas Wash and Las Vegas Bay. Generally, TN concentrations in Las Vegas Bay have increased from the low end of NLA moderate concern range (0.514–2.286 mg/L) in 2001 and 2002 to moderate and significant concern (>2.286 mg/L) range from 2007 to 2015. Significantly higher intra-annual variability was observed during this period. Lower concentrations (similar to historical range of 0.5 to 1 mg/L) were recorded in the winter months, ranging to much elevated concentrations (up to 4 mg/L) detected in the summer months.

TN concentrations were collected from Colorado River main stem stations (Gregg, Temple, and Virgin Basins) and Overton Arm stations from 2005–2015 and 2005 to 2012, respectively. All samples contained TN concentrations below detection limits of 0.5 mg/L or were close to the detection limit (0.5 – 0.7 mg/L), thus were within the NLA good range.

Lake Mohave:

TN concentrations can be characterized between the good and moderate concern range for all stations during the periods examined in Lake Mohave (Figure 4.1.1-14). However, the period of record examined for Placer Cove and Katherine's Landing were short between 2013 and 2015, and thus may not be representative of long-term trend and conditions (Figure 4.1.1-14).

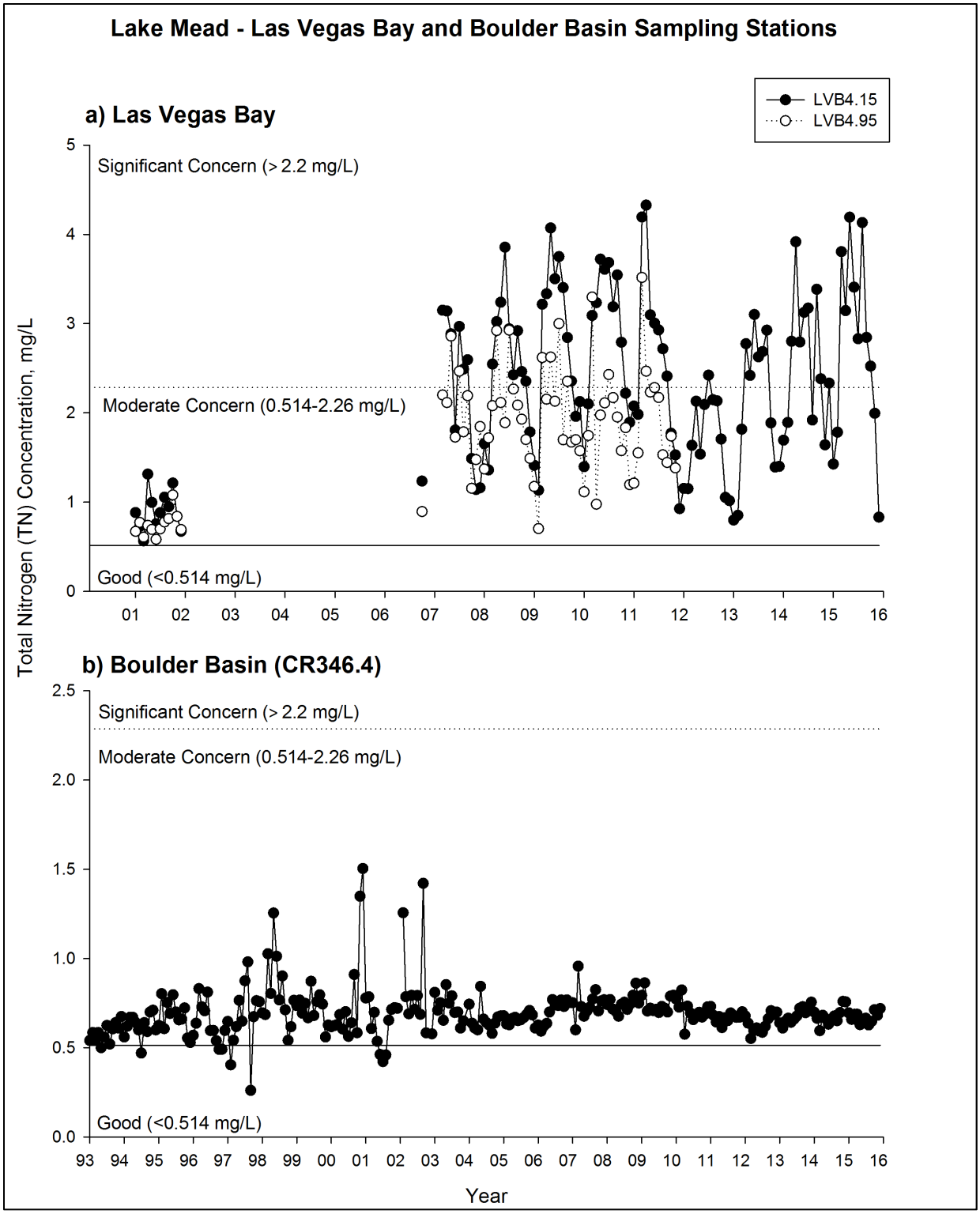


Figure 4.1.1-13. Time series (monthly averages) of total nitrogen (TN) concentration values from Las Vegas Bay (LVB4.15 and LVB4.95: 2001–2015) and Boulder Basin (CR346.4: 1993–2015). Stations ordered by distance from Las Vegas Wash confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

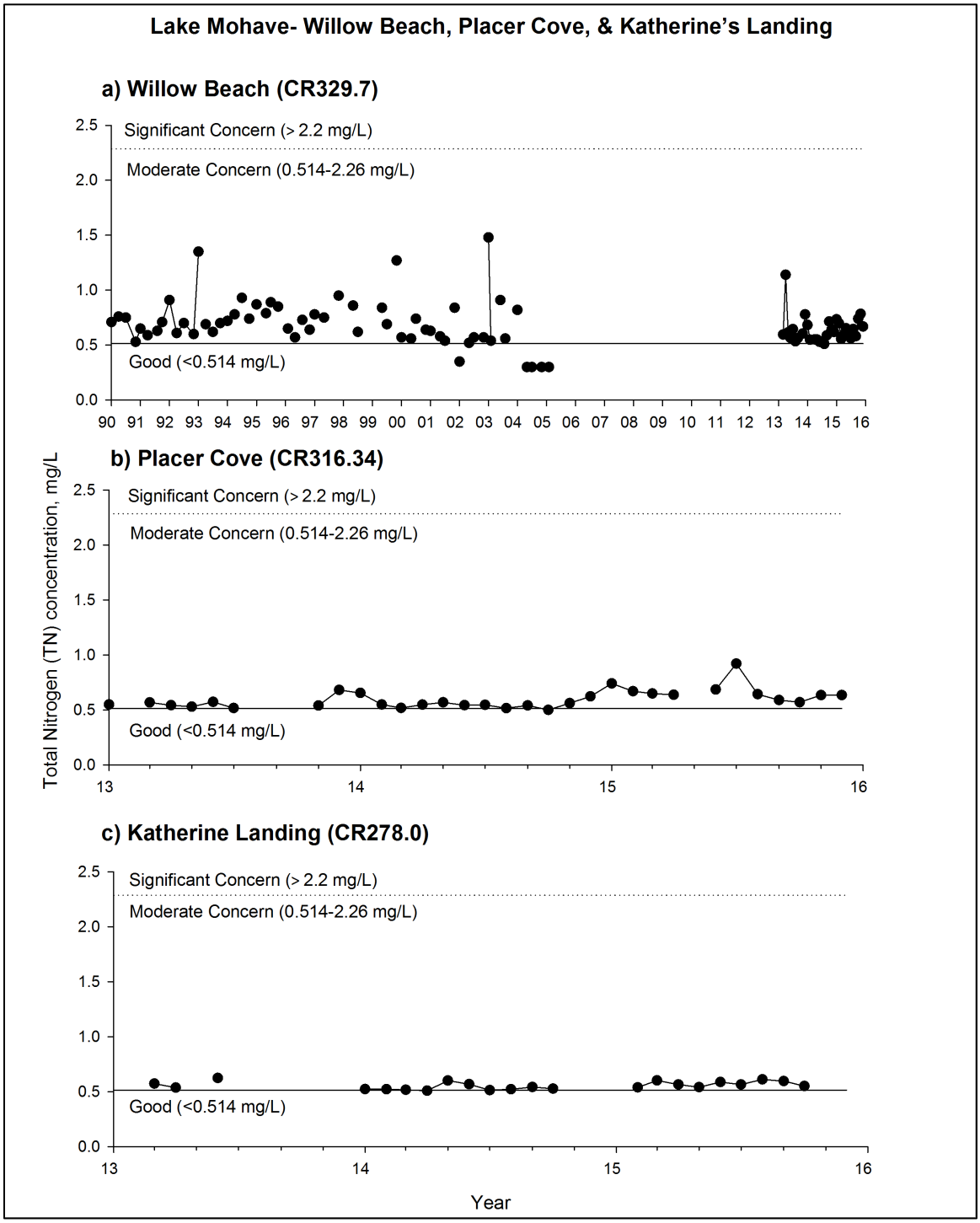


Figure 4.1.1-14. Time series (monthly averages) of total nitrogen (TN) concentration values from Lake Mohave stations: Willow Beach (CR329.7: quarterly1999–2005 and monthly 2013–2015); Placer Cove (CR316.34: 2013–2015), and Katherine's Landing (CR278.0: 2013–2015). Stations ordered by distance from Hoover Dam. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-5 for station locations and Table B-1 for station descriptions.

Nitrate and nitrite as nitrogen (NO_3+NO_2-N)

Since the initiation of tertiary treatment in 1994 at wastewater treatment facilities, nitrate (NO_3) has been the most common form of nitrogen entering Lake Mead (Holdren et al., 2008). Nitrate concentrations entering Lake Mead from Las Vegas Wash were the highest among all stations examined with elevated levels into Las Vegas Bay (concentrations between 1 to 4.5 mg/L) (Figure 4.1.1-15). NO_3 +NO_2 -N concentrations decreased with distance from the Las Vegas Wash confluence and NO_3 +NO_2 -N concentrations at Boulder Basin were measured to be below 1 mg/L (Figure 4.1.1-15). From 2004 to 2015, NO_3 +NO_2 -N concentrations followed a sigmoidal trend at Boulder Basin station with increasing concentrations from 0.4 mg/L in 2004 to 0.75 mg/L in 2008, followed by a decreasing trend until 2013, and an upward trend from 2013 onward (Figure 4.1.1-15).

Colorado River mainstem stations NO_3 +NO_2 -N concentrations were slightly higher than those in the Overton Arm, but were less than concentrations measured in Boulder Basin. Gregg Basin stations (CR394.0 and CR390.0) had the highest NO_3 +NO_2 -N concentrations amongst the Colorado River main stem stations and decreased with distance from the Colorado River confluence (Figure 4.1.1-16). NO_3 +NO_2 -N concentrations were in the range of 0.2 to 0.4 mg/L at all the Colorado River main stem stations (2005–2015) (Figure 4.1.1-16).

NO_3 +NO_2 -N concentrations at the Overton Arm stations were the lowest (> 0.4 mg/L) amongst all stations considered in this assessment between 2000 and 2012 (Figure 4.1.1-17). Intra-annual variability is high at the Overton Arm station (VR25.1) closer to the Virgin and Muddy rivers confluence and stabilized with distance from the confluence (VR6.0). Agricultural operations and urban development along the Virgin and Muddy rivers above Overton Arm were likely the main contributors to the Overton Arm NO_3 +NO_2 -N load.

Different laboratories have assessed NO_3 +NO_2 –N concentrations in Lake Mead since 2000. The Nevada State Public Health Laboratory analyzed water samples for NO_3 +NO_2 -N from Willow Beach between 2000 and 2005, and this laboratory had a detection limit of 0.1 mg/L. The Sierra Foothill Laboratory conducted the analysis for the Willow Beach station in 2008 and 2009 with a detection limit of 0.05 mg/L. The Southern Nevada Water Authority (SNWA) has been analyzing the water samples for nutrients since 2013 at Willow Beach, Placer Cove, Cottonwood Cove, and Katherine's Landing with the detection limit of 0.052 mg/L.

Surface water samples collected from Willow Beach in 2000–2005 had NO_3 +NO_2 –N concentrations between 0.2 to 0.6 mg/L. NO_3 +NO_2 –N concentrations between 2013 and 2015 had less intra-annual variability and ranged between 0.35 and 0.6 mg/L (Figure 4.1.1-18).

Grab samples were collected at Placer Cove, Cottonwood Cove, and Katherine's Landing in 2013 and 2014. NO_3 +NO_2 –N concentrations ranged from 0.25 to 0.45 mg/L.

All stations had NO_3 +NO_2 –N concentrations significantly below the USEPA threshold for safe drinking water (10 mg/L, Table 4.1.1-7) during the examined period.

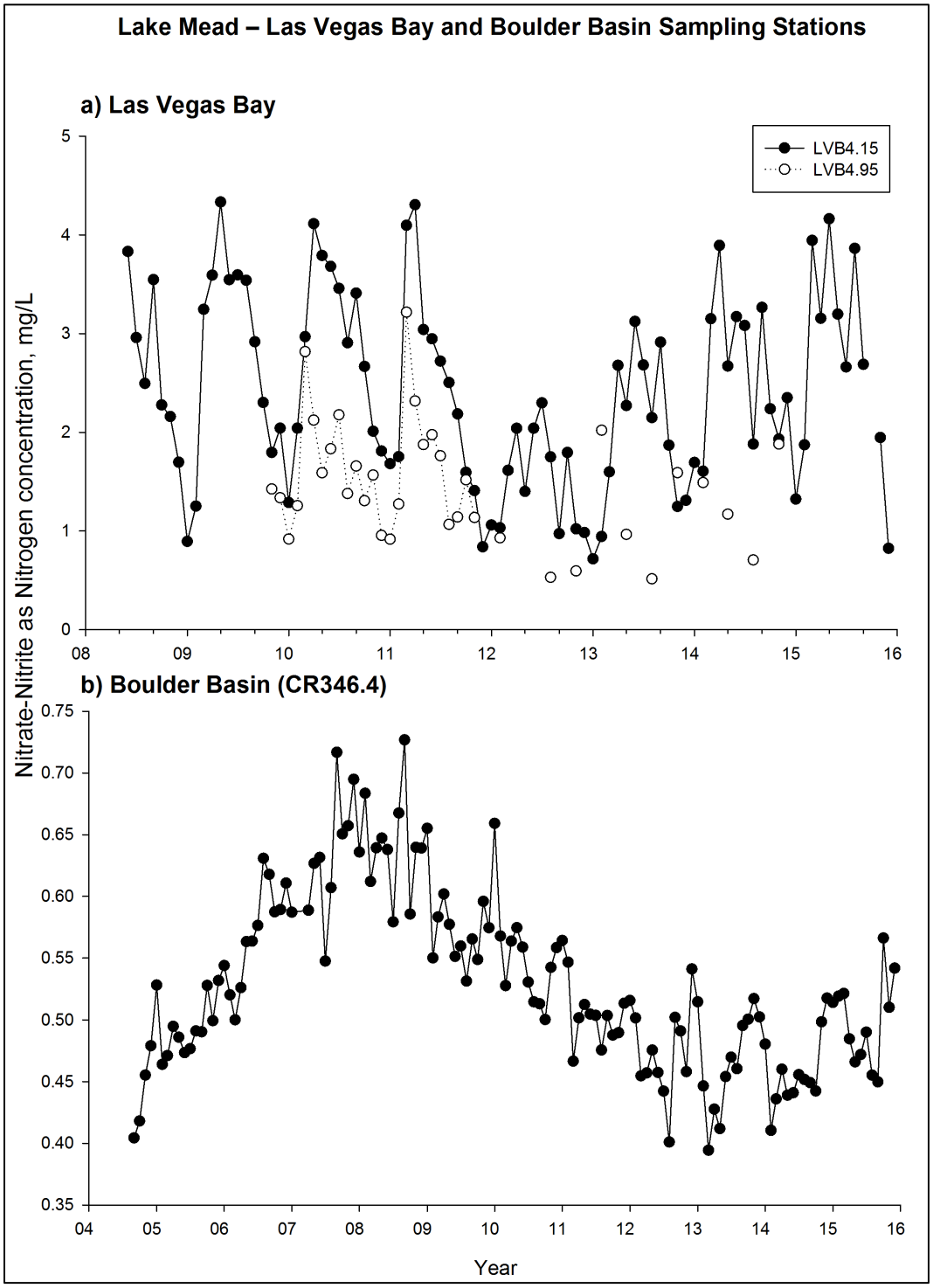


Figure 4.1.1-15. Time series (monthly averages) of nitrate-nitrite as nitrogen concentration values from Las Vegas Bay (LVB4.15 and LVB4.95: 2008–2015) and Boulder Basin (CR346.4: 2004–2015). Stations ordered by distance from Las Vegas Wash confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

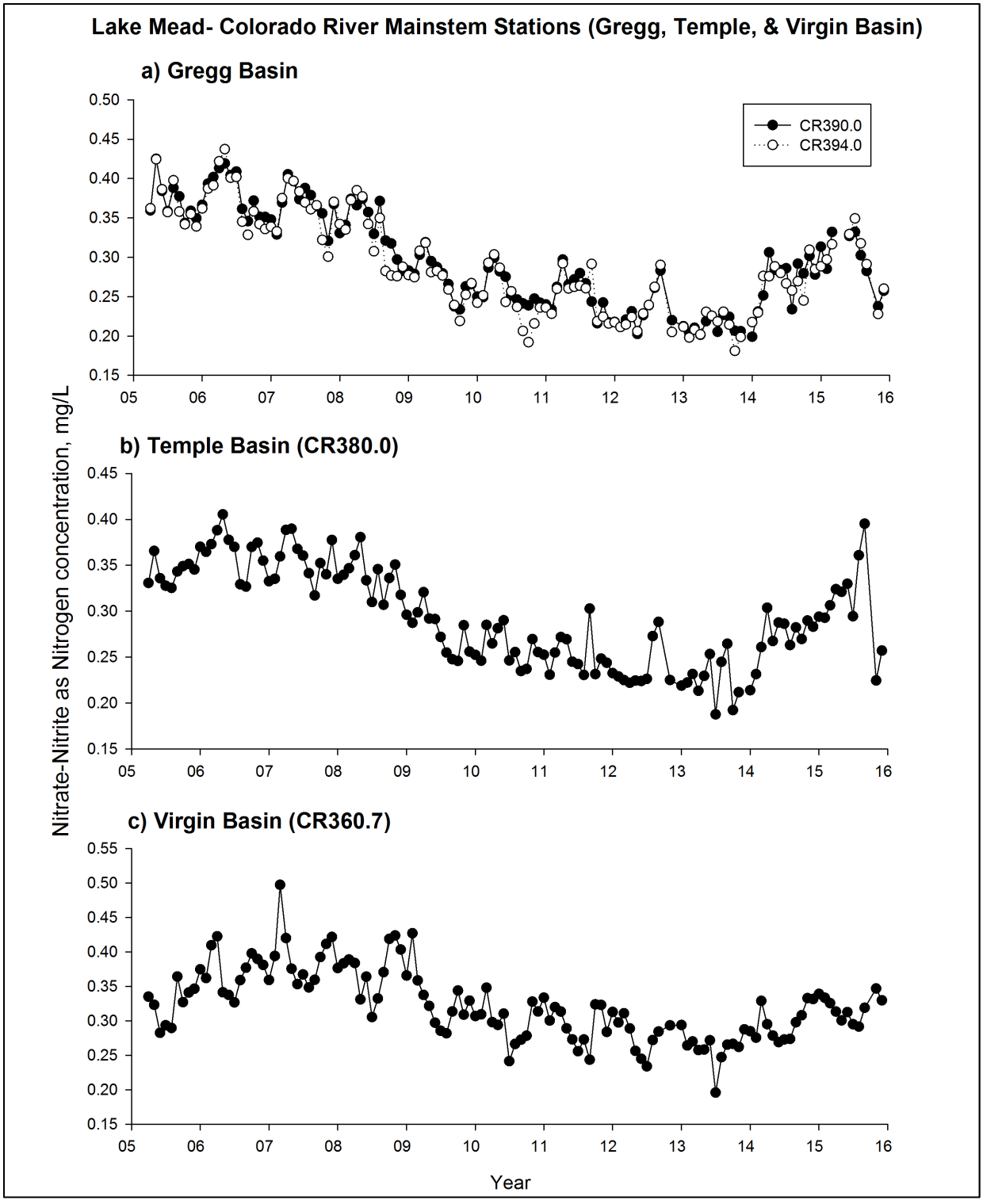


Figure 4.1.1-16. Time series (monthly averages) of nitrate-nitrite as nitrogen concentration values at Colorado River main stem stations, Gregg Basin (CR394.0 and CR390.0), Temple Basin (CR380.0), and Virgin Basin (CR360.7). Stations ordered by distance from Colorado River confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

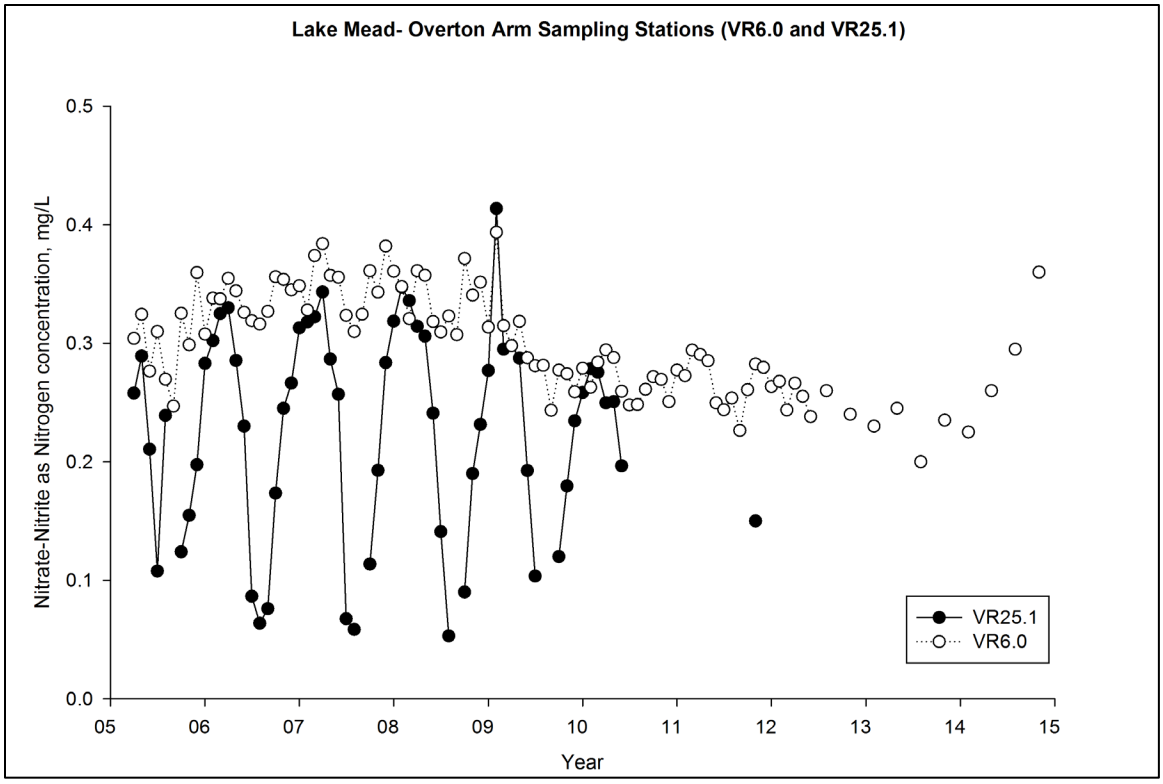


Figure 4.1.1-17. Time series (monthly averages) of nitrate-nitrite as nitrogen concentration values at two Overton Arm stations, VR25.1 (2000–2010) and VR6.0 (2001–2012). Stations ordered by distance from Virgin and Muddy confluences. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

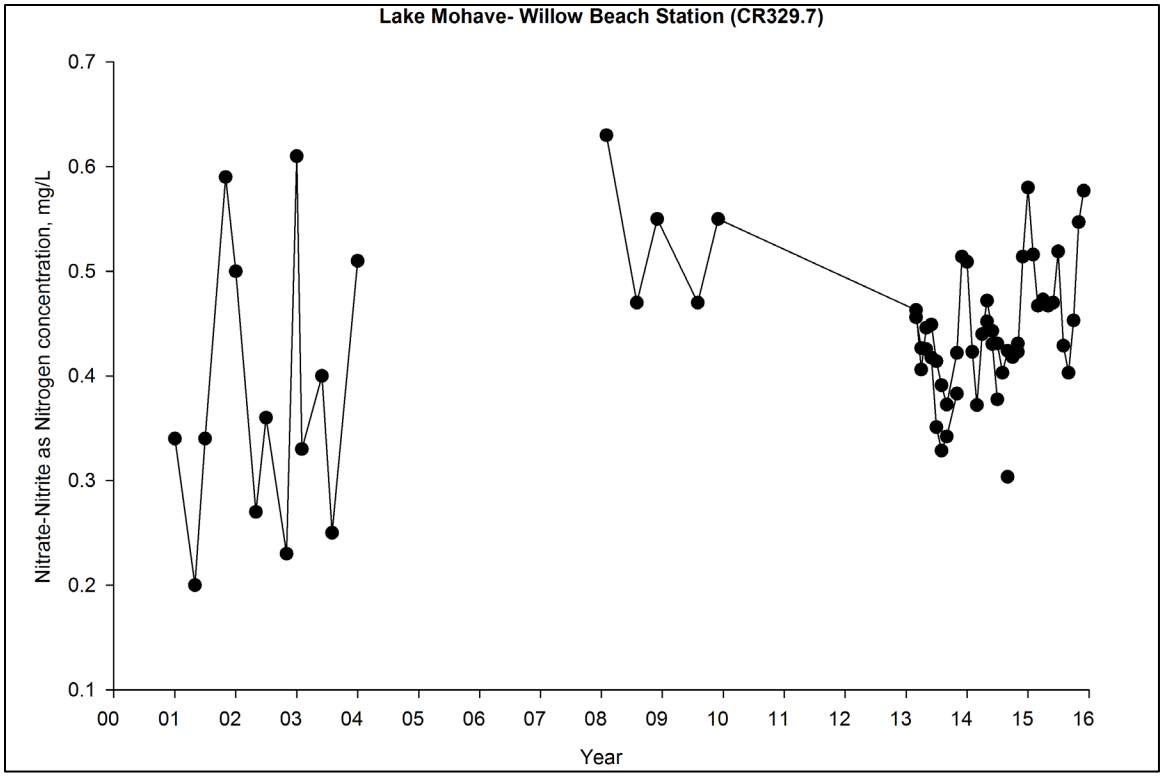


Figure 4.1.1-18. Time series (monthly averages) of nitrate-nitrite as nitrogen concentration values at Willow Beach (CR329.7: 2000–2015) in Lake Mohave. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-5 for station locations and Table B-1 for station descriptions.

Ammonia as nitrogen (NH_3-N)

The analytical capabilities and detection limits (0.003 to 0.1 mg/L) for NH_3-N have shifted throughout the years making them problematic for comparison herein.

Lake Mead:

From 2008 – 2015, NH_3-N concentrations were measured to be highest at Las Vegas Bay station, LVB4.15, and ranged between 0.02 and 0.07 mg/L with an average of 0.04 mg/L (Figure 4.1.1-19). This is likely the result of leading through Las Vegas Wash. NH_3-N levels were generally lower at Boulder Basin with an average of 0.036 mg/L from 2004 to 2015 (Figure 4.1.1-19). Detectable concentrations were found in 48% of all Boulder Basin samples between 2004 and 2015 with peak concentrations observed in December 2010, and April and September 2011 (Figure 4.1.1-19). The rest of the samples had NH_3-N concentrations below detection limits at the time of analysis.

NH_3-N concentrations at the Colorado River main stem stations decreased with distance from the Colorado River confluence (Figure 4.1.1-20). Only 30% of samples from Gregg Basin between 2005 and 2015 were below detectable NH_3 -N concentrations, and over 70% of samples from Virgin Basin were below detectable NH_3-N concentrations. All NH_3-N concentrations for the Colorado River main stem stations were below 0.10 mg/L except for three peaks detected in April 2006 (0.107 mg/L), 2011 (0.123 mg/L), and 2014 (0.1135 mg/L) (Figure 4.1.1-20).

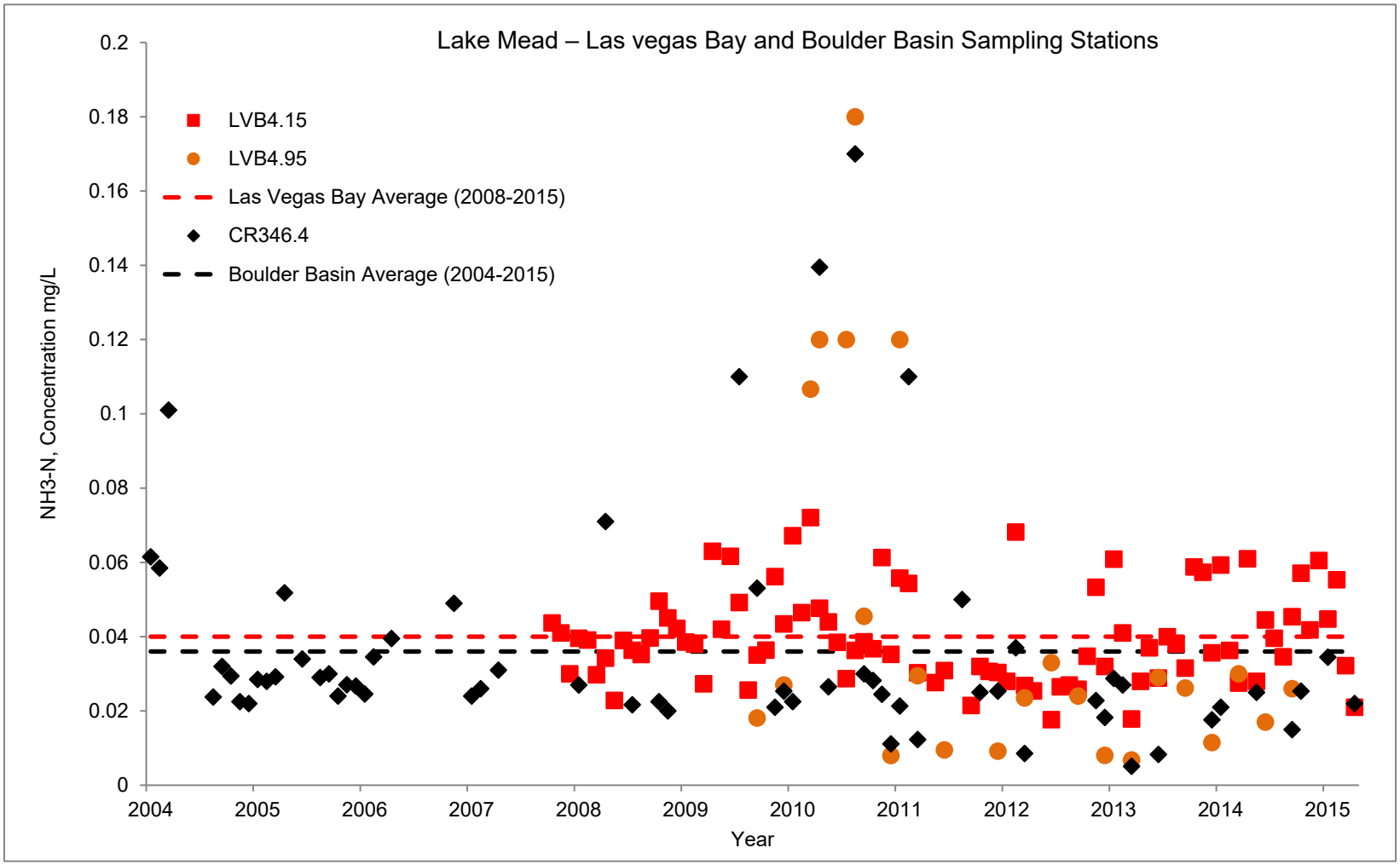


Figure 4.1.1-19. Time series (monthly averages) of ammonia-nitrogen (NH_3-N) concentration values at Las Vegas Bay (LVB4.15 and 4.95: 2008–2015) and Boulder Basin (CR346.4: 2004–2015). Stations ordered by distance from Las Vegas Wash confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

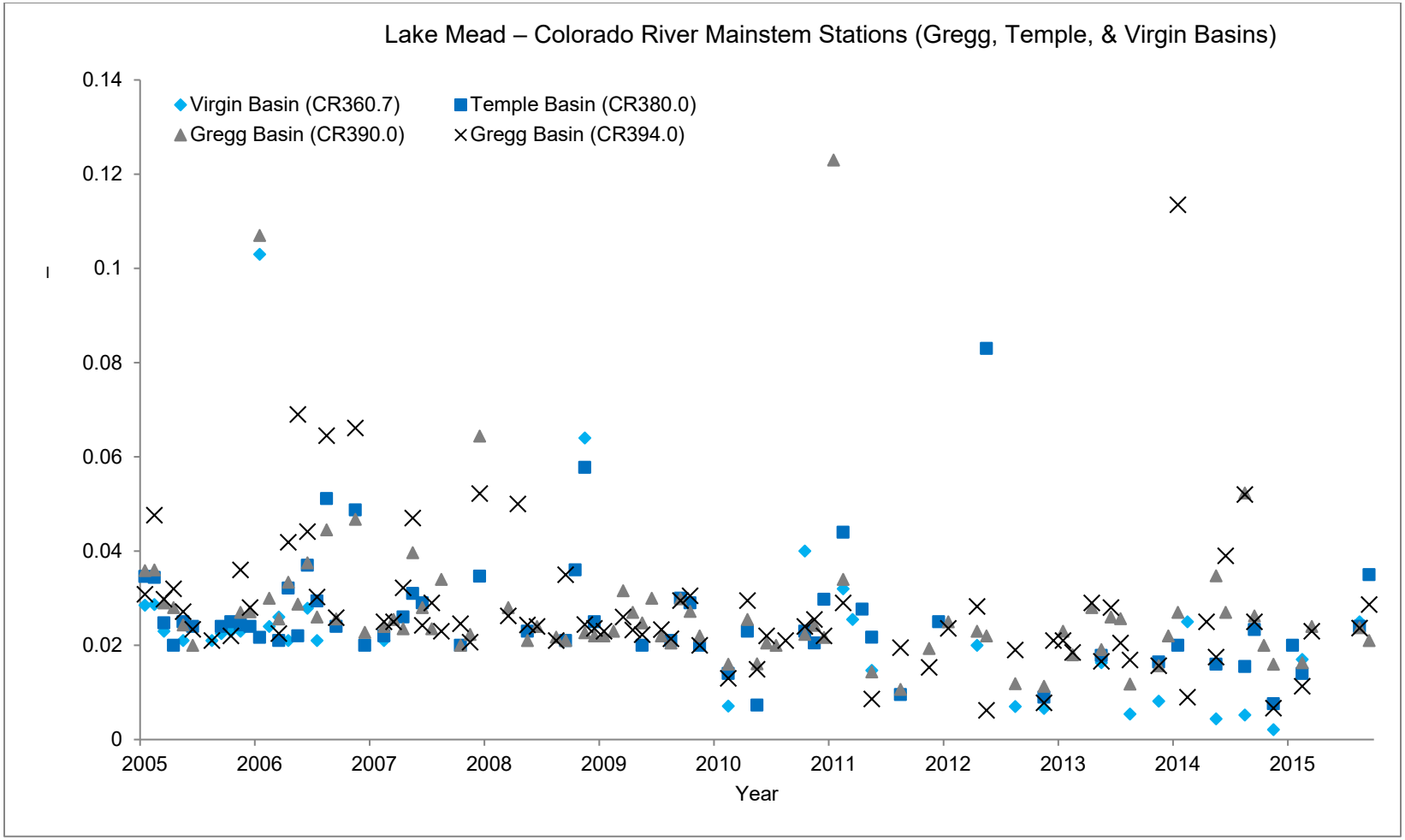


Figure 4.1.1-20. Time series (monthly averages) of ammonia-nitrogen (NH_3-N) concentration values at Colorado River main stem stations (2005–2015): Gregg Basin (CR394.0 and CR390.0), Temple Basin (CR380.0), and Virgin Basin (CR360.7). Stations ordered by distance upstream of the Narrows. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

Overton Arm NH_3 -N concentrations were generally less than 0.1 mg/L (Figure 4.1.1-21). NH_3 -N concentrations were higher at VR25.1, the station closer to the Muddy and Virgin rivers confluences. Greater intra-annual variability was found from the VR25.1 station with 66% of all samples from VR25.1 where NH -N concentrations above the detection limits (2005–2010). All VR6.0 station levels were below 0.04 mg/L, except for two peaks of 0.079 mg/L and 0.068 mg/L detected in October 2005 and Jan 2009, respectively (Figure 4.1.1-21).

The Nevada State Public Health Laboratory analyzed water samples from Willow Beach between 2000 and 2005 and the NH_3 -N detection limit was 0.1 mg/L. Sierra Foothill Laboratory conducted the analysis in 2008 and 2009 with the detection limit of 0.005 mg/L. Southern Nevada Water Authority (SNWA) has been analyzing the water samples for nutrients since 2013 with the detection limit of 0.02 mg/L.

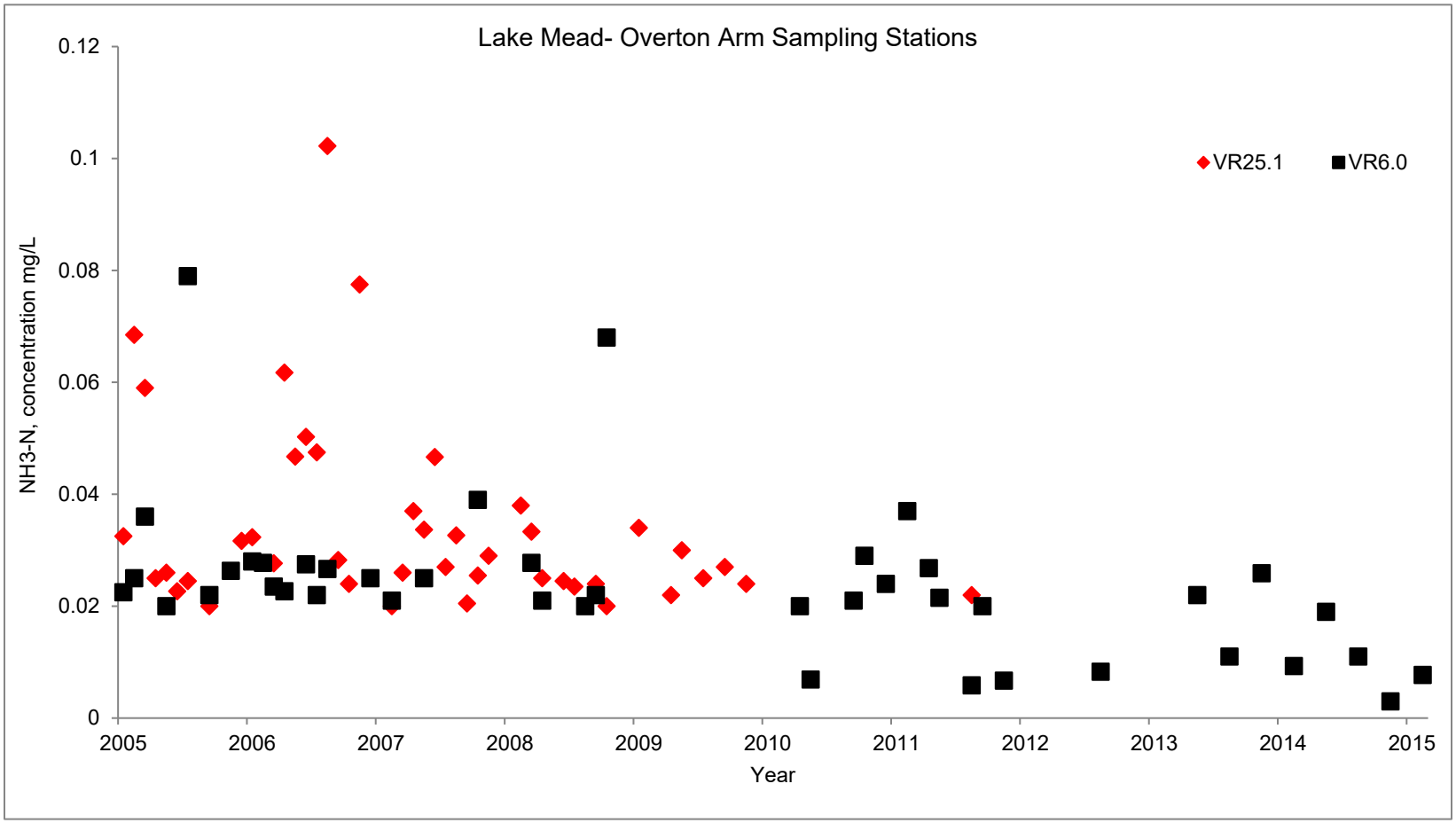


Figure 4.1.1-21. Time series (monthly averages) of ammonia-nitrogen (NH_3-N) concentration values at two Overton Arm stations (VR25.1: 2005–2011 and VR6.0: 2005–2015). Stations ordered by distance from Muddy and Virgin rivers confluences. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

Lake Mohave:

Surface water samples collected quarterly from Willow Beach in 2000–2005, 2008–2009, and 2013–2015 all had NH_3-N concentrations below respective detection limits.

Grab samples were collected monthly at two depths between 6–18 m at Placer Cove between March 2013 and November 2014. All samples had NH_3-N concentrations below detection limit of 0.02 mg/L.

Grab samples were collected monthly at the **metalimnion** and **hypolimnion** at Cottonwood Cove between March 2013 and November 2014. Most samples had NH_3-N concentrations below detection limit of 0.02 mg/L. Above detection limit levels were detected between July and September of 2013 and in September 2014, concentrations ranged from 0.02 to 0.048 mg/L.

Grab samples were collected monthly at the metalimnion and hypolimnion at Katherine's Landing between March 2013 and November 2014 and most samples had NH_3-N concentrations below the detection limit of 0.02 mg/L. Above detection limit levels were recorded between July and November of 2013 and in September 2014, and concentrations ranged from 0.024 to 0.06 mg/L.

All stations at lakes Mead and Mohave had NH_3 -N concentrations significantly below the USEPA ambient water quality criteria of ammonia for protection of freshwater aquatic Life (1.9 mg/L, Table 4.1.1-7) during the examined period.

Total Phosphorus (TP)

The analytical capabilities and detection limits for TP have shifted throughout the years making them problematic for comparison herein.

Wastewater process improvements at the Clark County, City of Las Vegas, and City of Henderson wastewater treatment plant beginning in 1994 have significantly reduced total and dissolved phosphorus loading into Boulder Basin via Las Vegas Wash (Holdren et al., 2008). However, as the Las Vegas Valley population grew throughout the 1990s and early 2000s, phosphorus concentrations increased in wastewater (Rosen et al., 2012). In response to this population growth, wastewater facilities enhanced phosphorus removal treatment in 2002 and 2005 (LaBounty & Burns, 2005), which successfully reduced phosphorus inputs. By 2009, total phosphorus concentrations in Las Vegas Bay and Boulder Basin typically were less than 0.01 mg/L (Rosen et al., 2012). Total phosphorus load was reduced by as much as 98 percent relative to the concentrations measured in the 1970s and 1980s. Similar to other nutrient concentrations, total phosphorus (TP) concentrations decreased with distance from the Las Vegas Wash confluence (Figure 4.1.1-22). TP concentrations were between 0.01 to 0.05 mg/L at Las Vegas Bay from 2007 to 2014 with increased concentrations measured at the LVB4.15 station (closer to Las Vegas Wash confluence) to 0.1 mg/L during Fall 2015. Boulder Basin had lower TP concentrations below 0.03 mg/L between 2005 and 2015 (Figure 4.1.1-22). TP concentrations have decreased to approximately 0.01 mg/L at Boulder Basin since 2007 with occasional spikes (0.03 mg/L) in 2014.

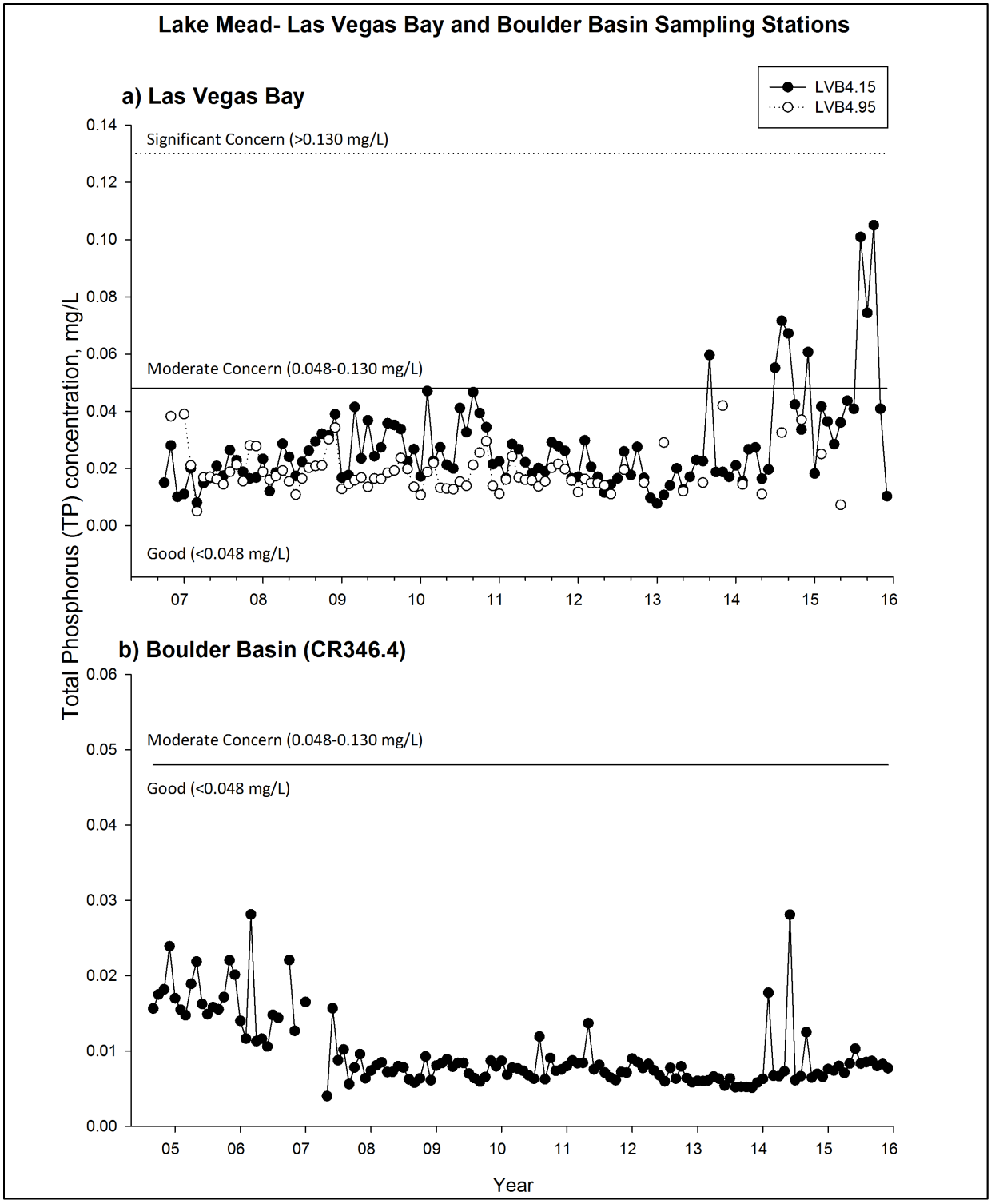


Figure 4.1.1-22. Time series (monthly averages) of total phosphorus concentration values from Las Vegas Bay (LVB4.15 and LVB4.95; 2007–2015) and Boulder Basin (CR346.4: 2005–2015) stations ordered by distance from Las Vegas Wash confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

Between 2005 and 2015, phosphorus concentrations at the mainstem stations (Gregg, Temple, and Virgin Basins) of the Colorado River were found to be generally low with concentrations at about 0.01 mg/L (Figure 4.1.1-23). A peak of 0.5 mg/L was detected at Temple and Virgin Basin in October 2005, and peak concentrations of 0.8 and 0.16 mg/L were measured at the Gregg Basin station CR394.0 in August 2013 and October 2015, respectively.

TP concentrations were generally below 0.05 mg/L in Overton Arm between 2005 and 2015. Overall, the VR25.1 station (closer to Muddy and Virgin River confluences) had higher TP concentrations than VR6.0. TP concentrations were below 0.01 mg/L at the open water station VR6.0 in Overton Arm and at VR25.1 spiked to 0.2 mg/L at VR25.1, falling within the NLA significant concern range in 2009 and 2010 (Figure 4.1.1-24). The very high TP values in 2009 and 2010 resulted from the Virgin River inlet approaching, and overtaking, that station since the station is fixed.

Between 2013 and 2015, TP concentrations were low at Willow Beach station in Lake Mohave, ranging between 0.004 and 0.008 mg/L (Figure 4.1.1-25).

All stations at lakes Mead and Mohave, except stations in Las Vegas Bay had TP concentrations at the USEPA NLA good range (<0.048 mg/L, Table 4.1.1-7) with rare exceedance, during the examined period.

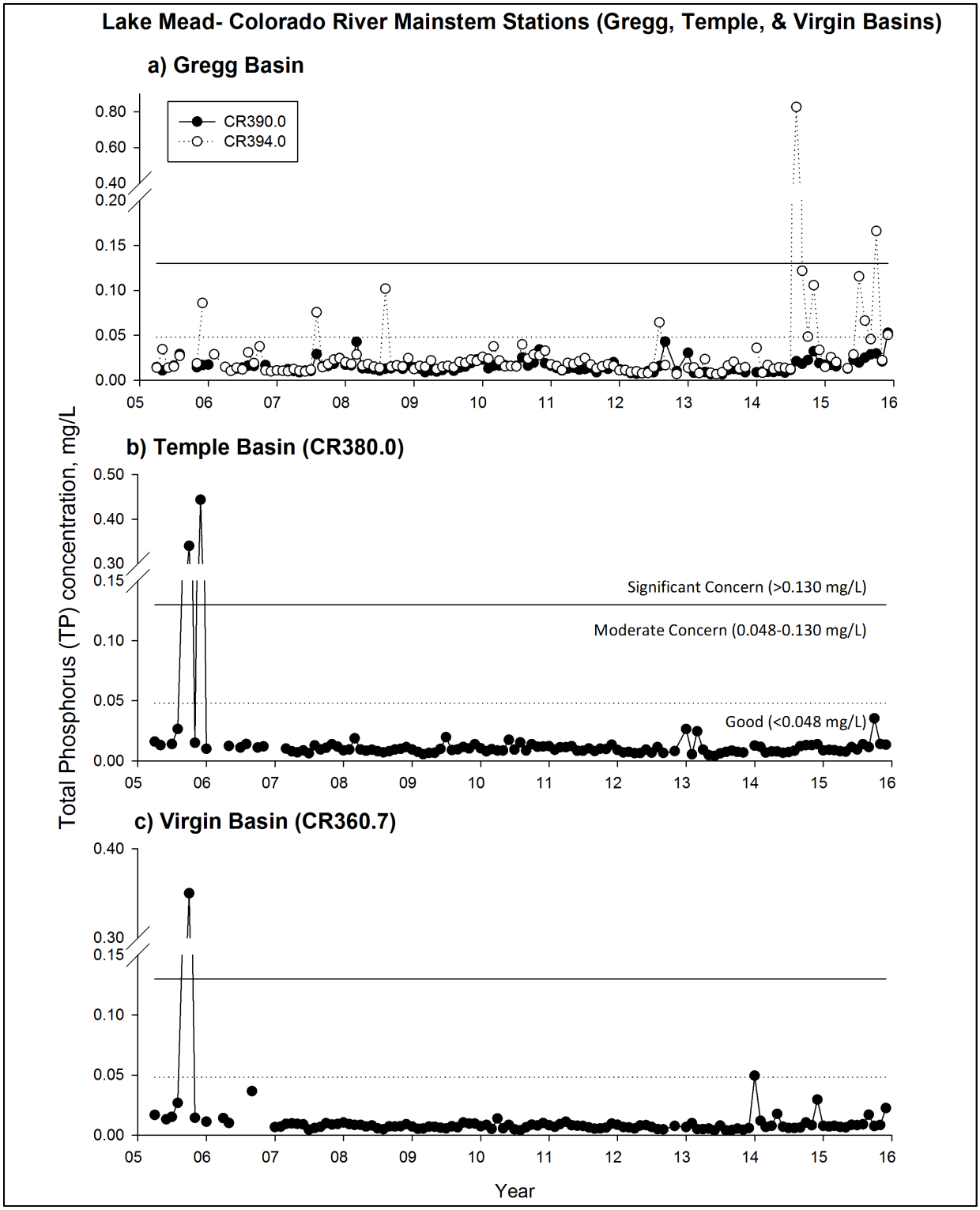


Figure 4.1.1-23. Time series (monthly averages) of total phosphorus concentration values at Colorado River mainstem stations (2005–2015): Gregg Basin (CR394.0 and CR390.0), Temple Basin (CR380.0), and Virgin Basin (CR360.7). Stations ordered by distance from Colorado River confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

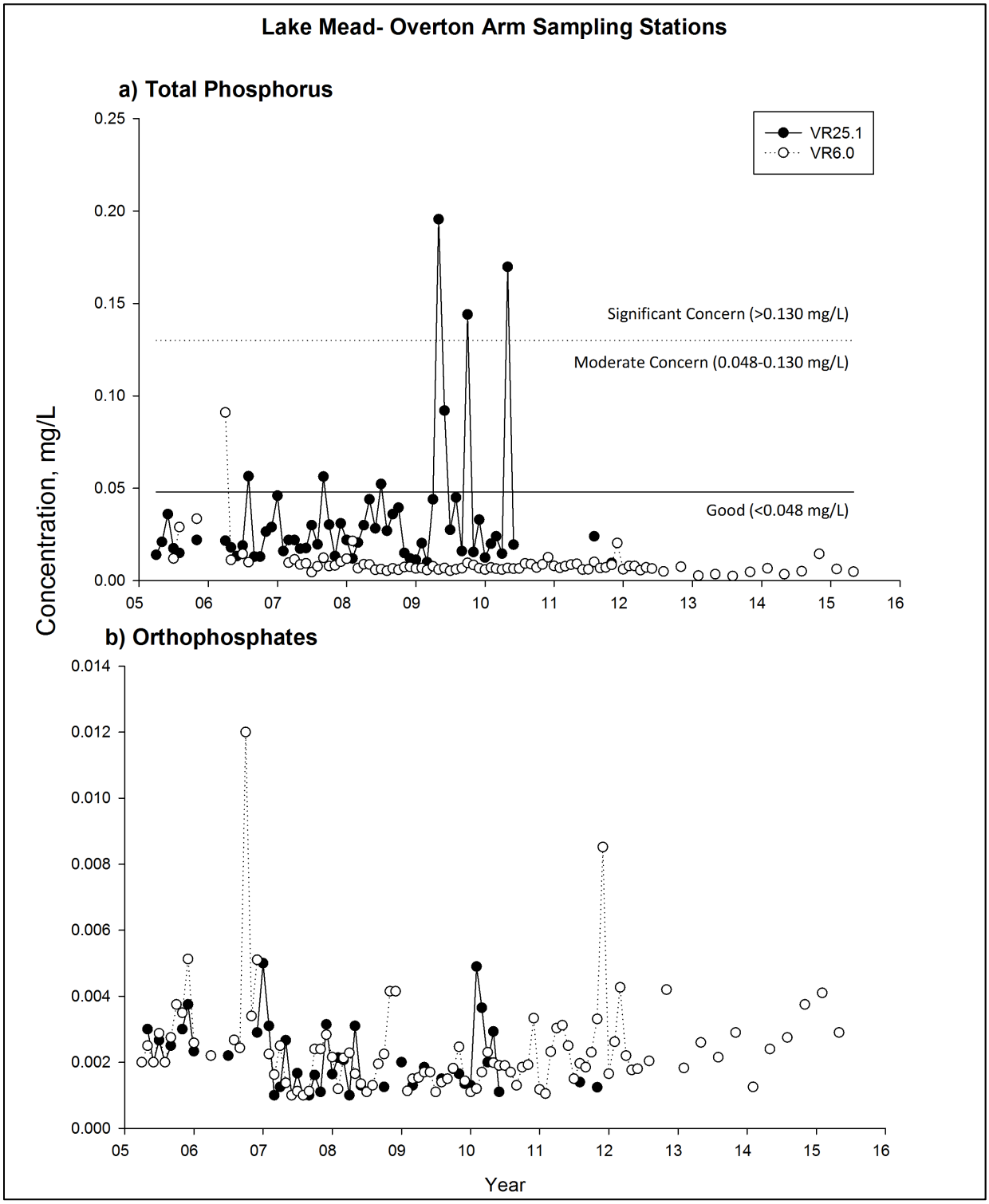


Figure 4.1.1-24. Time series (monthly averages) of total phosphorus and orthophosphates concentration values at two Overton Arm stations: VR25.1 (2005–2011) and VR6.0 (2005–2015). Stations ordered by distance from Virgin and Muddy confluences. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

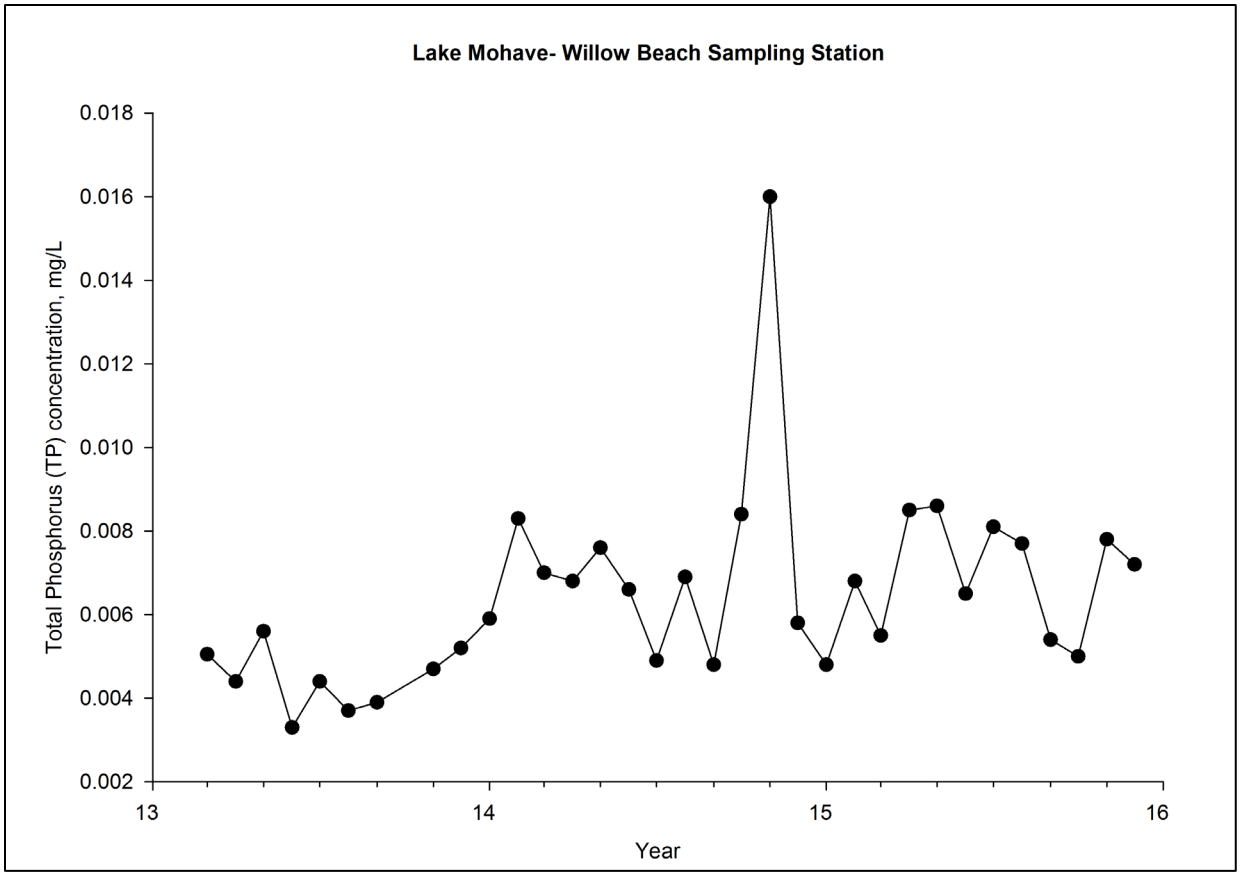


Figure 4.1.1-25. Time series (monthly averages) of total phosphorus (TP) concentrations at Willow Beach in Lake Mohave between 2013 and 2015. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-5 for station locations and Table B-1 for station descriptions.

Orthophosphates (PO_4-P)

While dissolved orthophosphate (PO_4-P) loads from the Colorado River and Las Vegas Wash are approximately 100 times smaller than the total phosphorus load, it is more readily available and more rapidly used by algae, and thus can promote productivity (Rosen et al., 2012).

Past evaluations of nutrients in Lake Mead have identified phosphorus as the primary limiting nutrient for algal growth from tributary inflow. Recent studies on nutrient-budget identified that most phosphorus entering Lake Mead through the Colorado River is bound to sediment particles and is not available for use by algae in downgradient areas of the lake (Rosen et al., 2012).

PO_4-P concentrations were generally low (below 0.01mg/L) in both lakes across years. The Las Vegas Bay stations had PO_4-P concentrations between 0.002 and 0.020 between 2006 and 2015 and peaked at 0.035 mg/L in 2015 at LVB4.15 (Figure 4.1.1-26). PO_4-P concentrations at the Boulder Basin station (CR346.4) were below 0.01 from 2004 to 2015. On average, concentrations were low at approximately 0.004 mg/L between 2006 and 2015 (Figure 4.1.1-26). Effluent treatment process improvements at the Clark County, City of Las Vegas, North Las Vegas, and City of Henderson

wastewater treatment plants were the major factor leading to the phosphorus reductions in Boulder Basin (Holdren et al., 2008).

PO_4-P concentrations decreased with distance from the Colorado River confluence, with Gregg Basin stations having the highest PO_4-P concentrations in 2005–2015 (Figure 4.1.1-26 and Figure 4.1.1-27). Intra-annual variability was low in 2005 to 2012 at Gregg Basin but has increased since 2012 ranging from 0.003 to 0.012 mg/L. PO_4-P concentrations at Temple and Virgin basins averaged at 0.004 mg/L with higher intra-annual variability at Temple Basin between 2005 and 2015 (Figure 4.1.1-26 and Figure 4.1.1-27).

PO_4-P concentrations at Overton Arm were low (0.001 to 0.005 mg/L) between 2005 and 2015, and similar between the two stations (VR25.1, VR6.0). Two peaks were detected in 2006 and 2012 at 0.012 and 0.009 mg/L, respectively (Figure 4.1.1-24).

PO_4-P concentrations were at or below the detection limit (0.001 mg/L) at all Lake Mohave stations between 2013 and 2015.

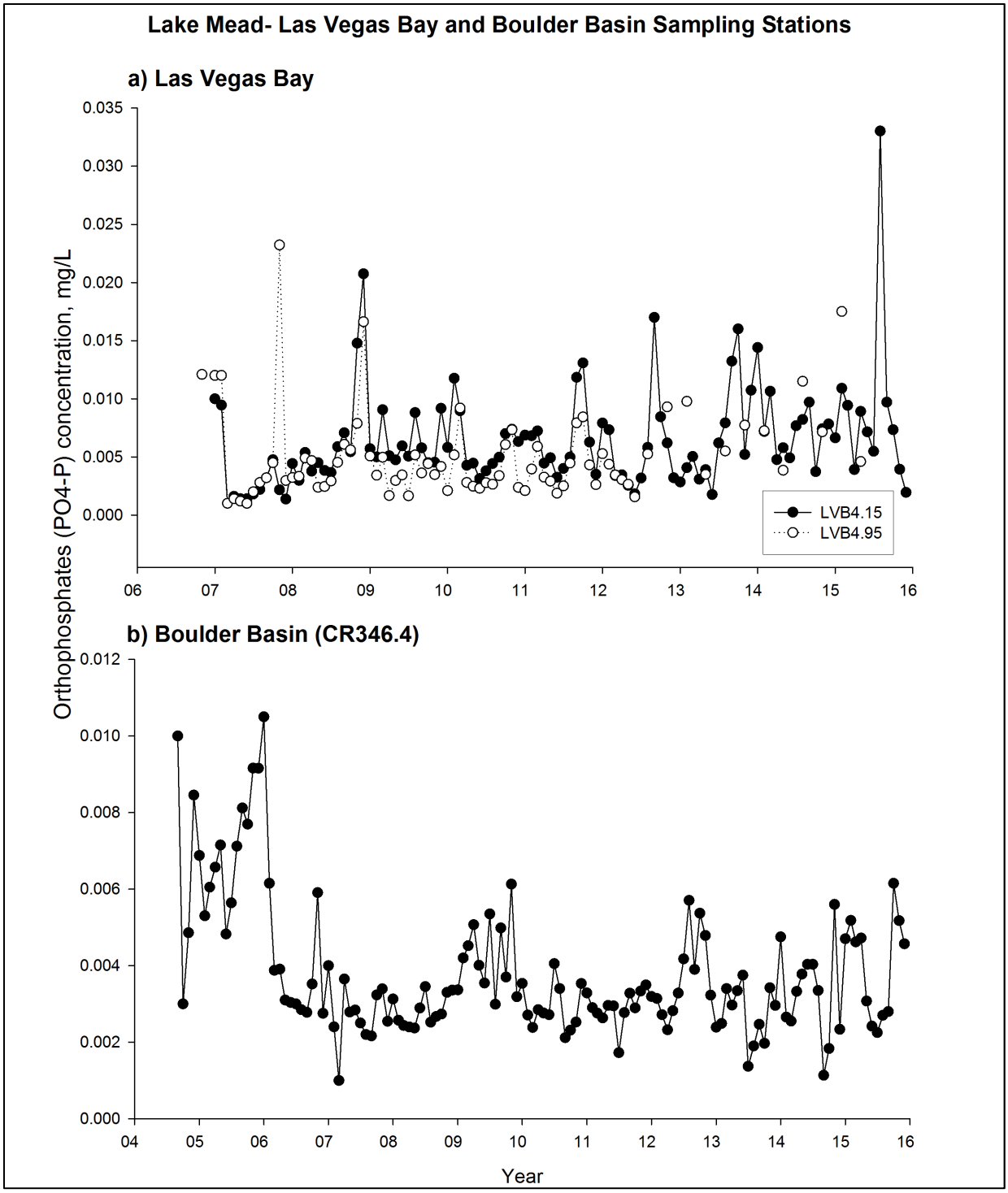


Figure 4.1.1-26. Time series (monthly averages) of orthophosphates concentration values from Las Vegas Bay (LVB4.15 and LVB4.95: 2006–2015) and Boulder Basin (CR346.4: 2004–2015). Stations ordered by distance from Las Vegas Wash confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

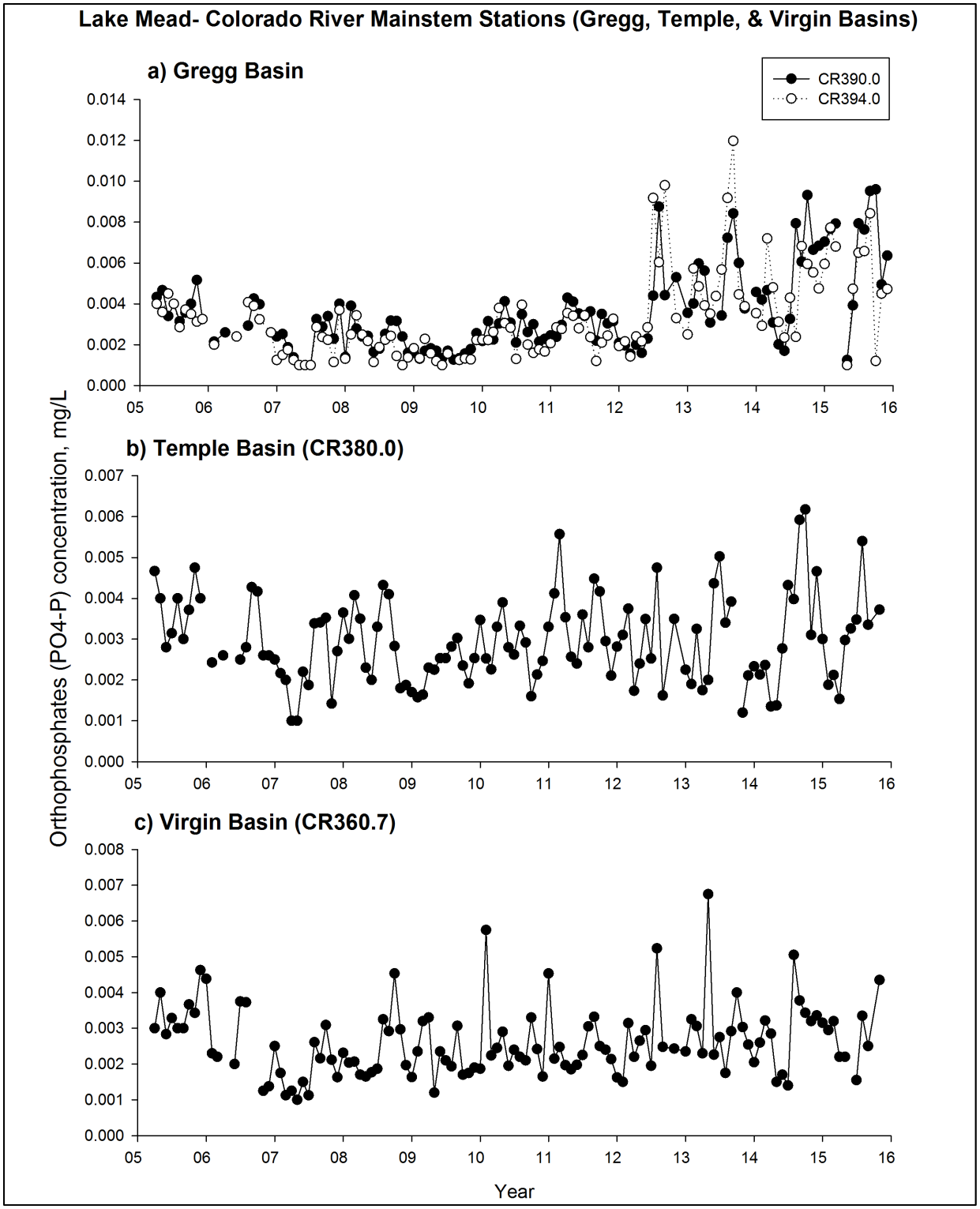


Figure 4.1.1-27. Time series (monthly averages) of orthophosphates concentration values at Colorado River main stem stations (2005–2015): Gregg Basin (CR394.0 and CR390.0), Temple Basin (CR380.0), and Virgin Basin (CR360.7). Stations ordered by distance from Colorado River confluence. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

Total organic carbon (TOC)

Most organic matter present in lakes and reservoirs is not produced within the system but from land-derived sources, such as leaves and tree litter, and inflowing rivers. However, given the size of Lake Mead in proportion to shoreline vegetation and relative low tributaries inputs, TOC levels in Lake Mead are generally low (Rosen et al., 2012).

Total organic carbon (TOC) in Lake Mead is derived mainly from two sources: from within-lake production by phytoplankton and from organic matter introduced by the tributaries (SNWA, 2010). As a result, TOC concentrations have been measured to be slightly elevated at the stations located closer to tributary confluences (e.g. LVB4.15) in Las Vegas Bay, and at stations CR394.0 and CR390.0 in Gregg Basin (Figure 4.1.1-28 and Figure 4.1.1-29).

Dissolved organic carbon concentrations worldwide have averaged between 2 to 3 mg/L. TOC concentrations at open water stations (CR346.4, CR360.7, CR380.0, and VR6.0) in Lake Mead have been within this range since 2006 (Figure 4.1.1-28 to Figure 4.1.1-30). Before 2006, there was a higher degree of intra-annual variability in TOC concentrations; however, from 2006 forward, overall TOC concentrations and associated intra-annual variability have declined (Figure 4.1.1-28 to Figure 4.1.1-30). This shift can be attributed in large part to enhanced effluent discharge phosphorus removal practices that have been implemented since 2005 (SNWA, 2010).

Within Boulder Basin, TOC concentrations were different between the three thermal zones with relatively higher TOC concentrations in the epilimnion (Figure 4.1.1-28). Since 2006, a consistent seasonal pattern has developed where elevated concentrations (up to ~3.5 mg/L) were observed during the growing season in the epilimnion and lower concentrations during the rest of the year and in the hypolimnion (~2.5 mg/L). TOC concentrations have been trending slightly upward ($p = 0.01$) since 2006 in Las Vegas Bay and Boulder Basin (Figure 4.1.1-28).

TOC is a precursor in the formation of carcinogenic trihalomethanes (THMs), a disinfection byproduct. Higher concentrations of TOC can result in the increased production of THMs in drinking water. According to 2014 and 2015 LVVWD water quality reports, THM concentrations in drinking water averaged between 0.053 and 0.075 mg/L, and thus did not exceed the USEPA THM standard (LVVWD, 2016). Increase in TOC concentrations corresponded with increased contributions of discharge from Las Vegas Wash observed in recent years.

Quarterly reports of TOC concentrations were available for Lake Mohave between 2013 and 2014. As such, no long-term trends can be derived from any of the four locations sampled in Lake Mohave. TOC concentrations values collected between 2013 and 2014 were comparable to values detected in Lake Mead. Concentrations range from 2 to 5 mg/L, with the highest concentrations recorded at the epilimnion at Willow Beach station (Figure 4.1.1-31).

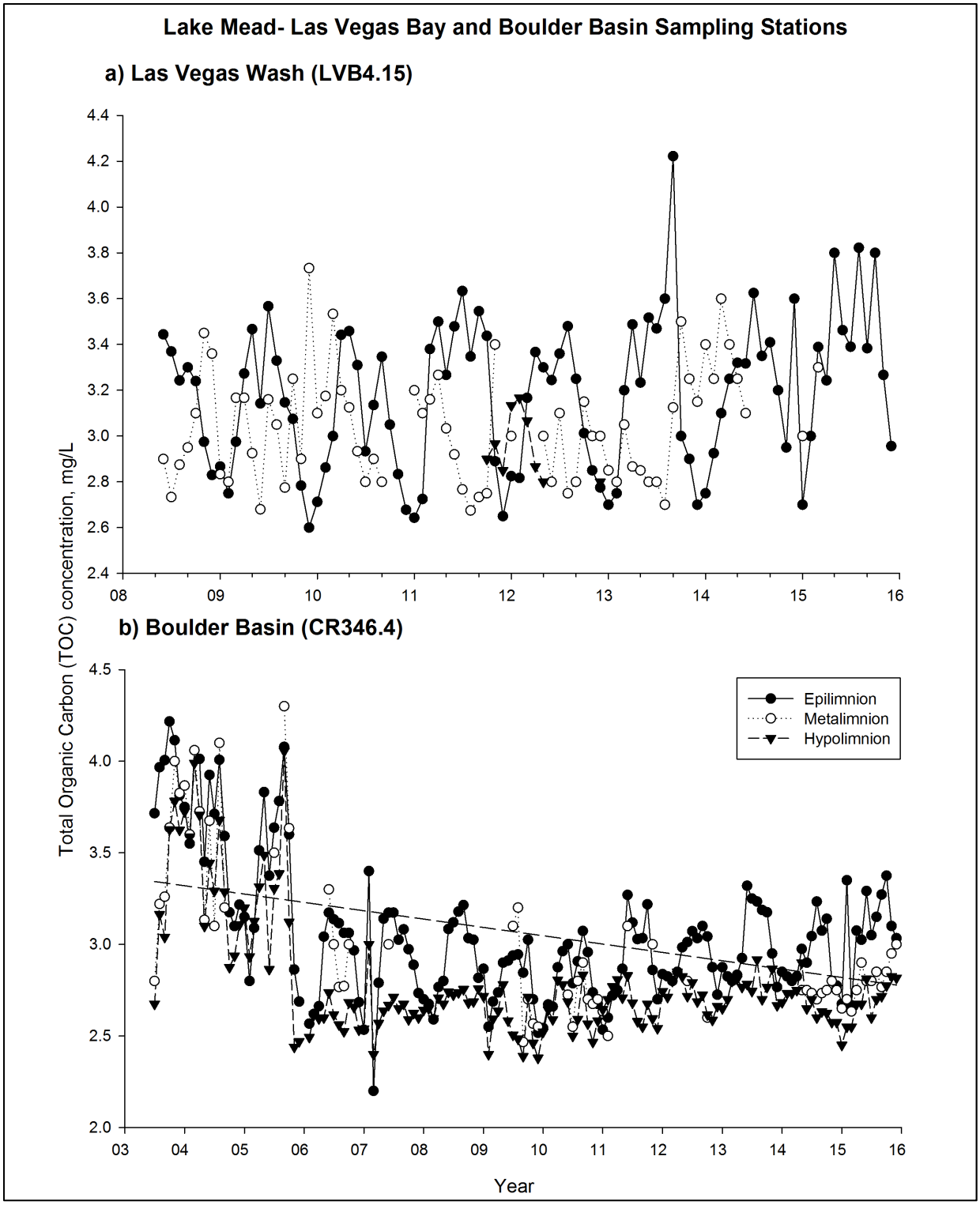


Figure 4.1.1-28. Time series (monthly averages at epilimnion, metalimnion, and hypolimnion) of total organic carbon (TOC) concentration data collected from Las Vegas Bay station (LVB4.15: 2008–2015) and Boulder Basin station (CR346.4: 2003–2015). Stations ordered by distance from Las Vegas Wash confluence. See Figure B-3 for station locations and Table B-1 for station descriptions.

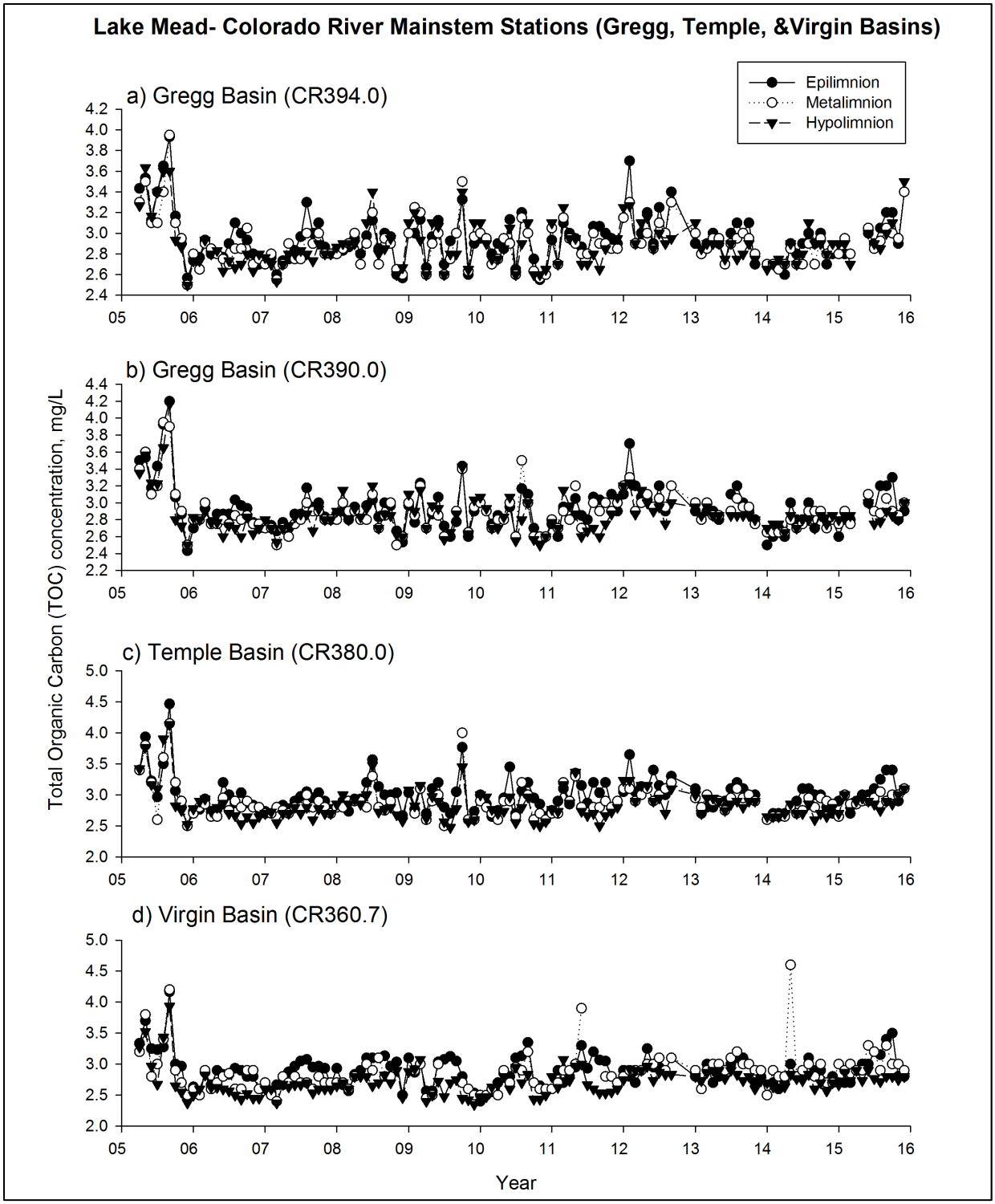


Figure 4.1.1-29. Time series (monthly averages at epilimnion, metalimnion, and hypolimnion) of total organic carbon (TOC) concentration data collected from Colorado River main stem stations (2005–2015), Gregg Basin (CR394.0 and CR390.0), Temple Basin (CR380.0), and Virgin Basin (CR360.7). Stations ordered by distance from Colorado River confluence. See Figure B-3 for station locations and Table B-1 for station descriptions.

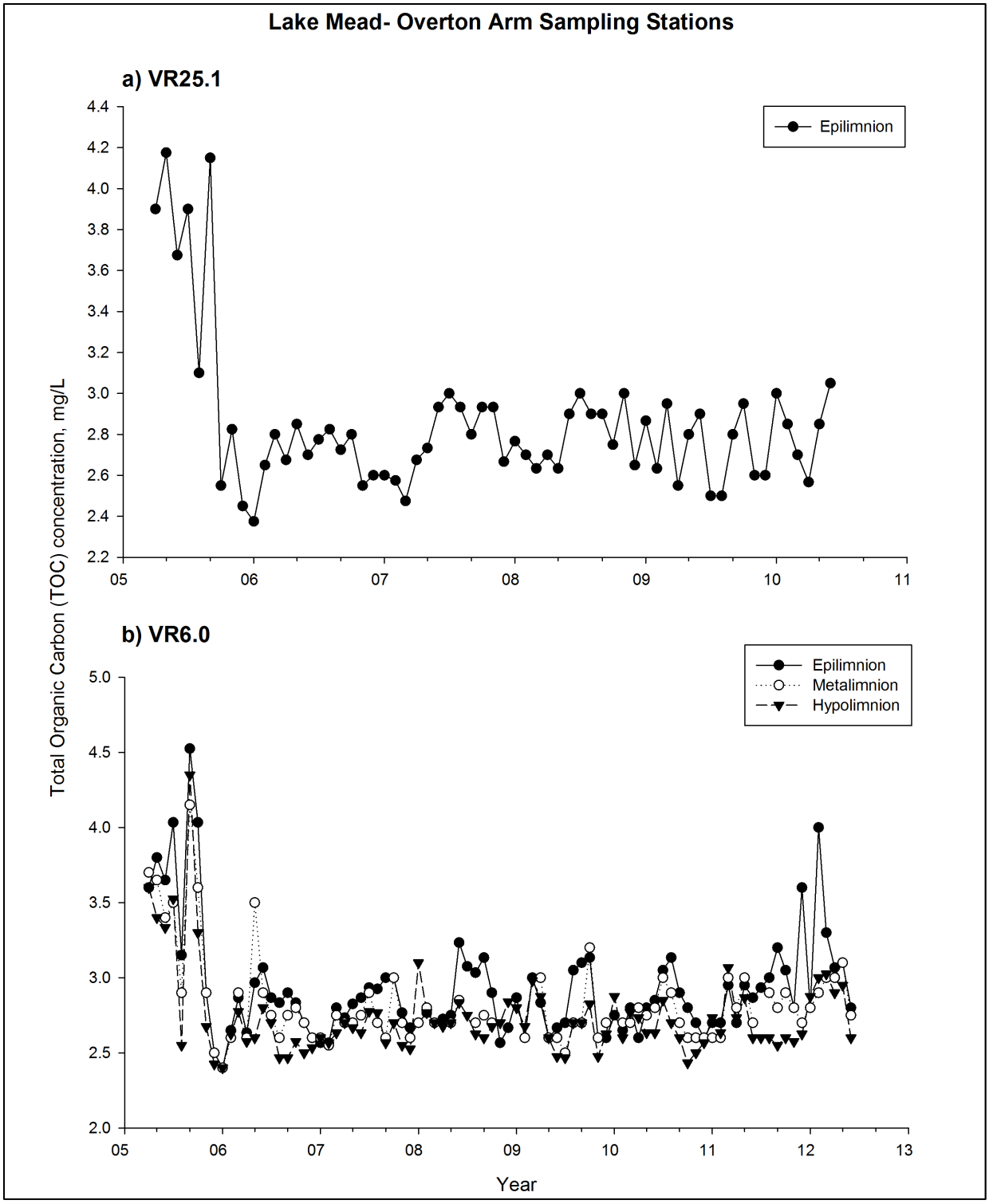


Figure 4.1.1-30. Time series (monthly averages at epilimnion, metalimnion, and hypolimnion) of total organic carbon (TOC) concentration data collected from two Overton Arm stations, VR25.1 (2005–2010) and VR6.0 (2005–2012). Stations ordered by distance from Virgin and Muddy rivers confluences. See Figure B-3 for station locations and Table B-1 for station descriptions.

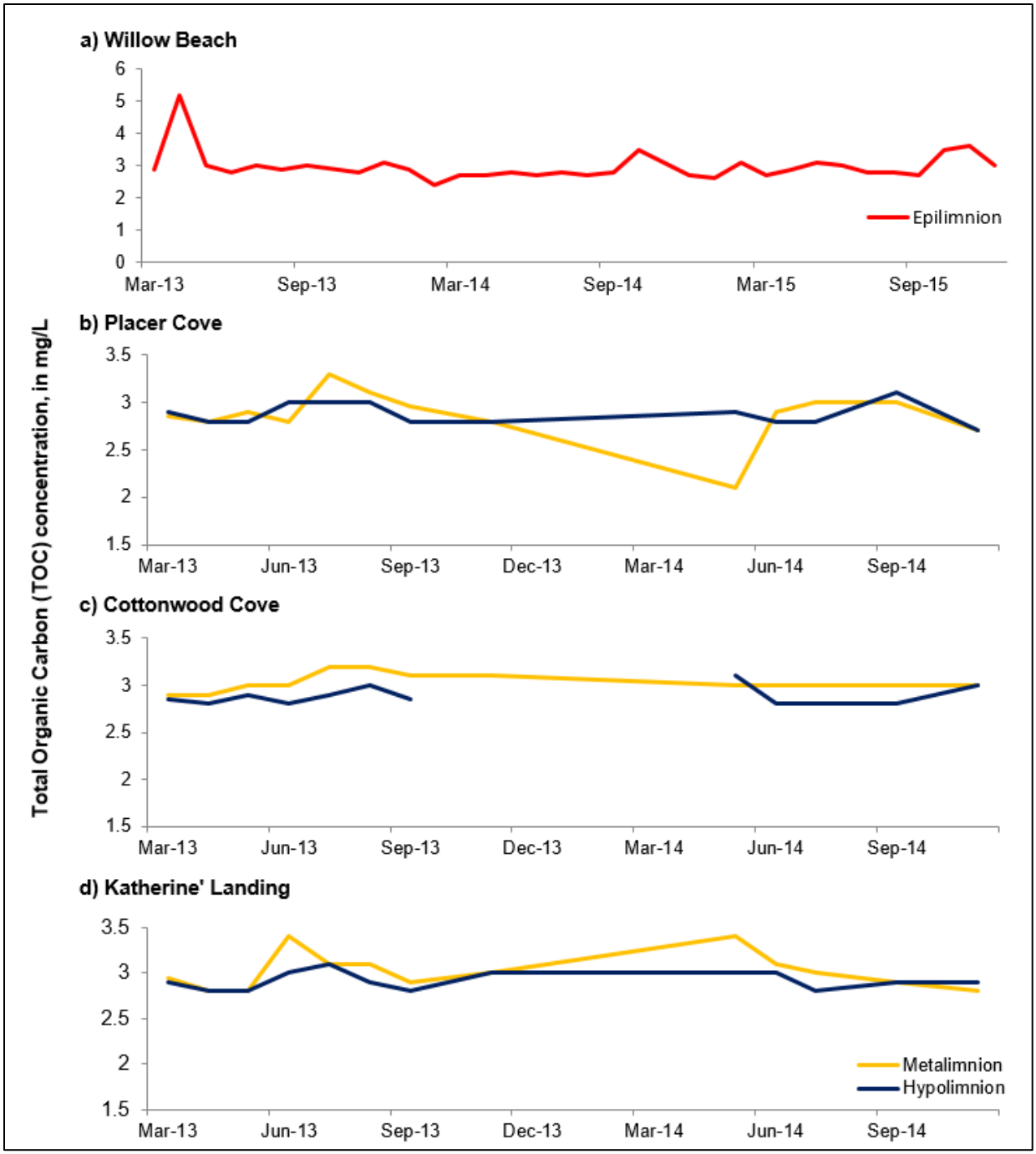


Figure 4.1.1-31. Time series (monthly averages at epilimnion, metalimnion, and hypolimnion) of total organic carbon (TOC) concentration data collected in Lake Mohave. Stations ordered by distance from Hoover Dam discharge (closest to furthest). See Figure B-5 for station locations and Table B-1 for station descriptions.

Surface water temperature trend (whole lake)

Surface water temperature is affected by local short term climatic condition. Near-surface heating and cooling by the atmosphere can affect surface water temperatures on short temporal scales. For discussion on water column temperature trends, see section 4.1.1.2 *Hydrologic Function*.

While no significant trend for annual average of surface water temperatures can be observed in Lake Mead for all stations during the periods examined, shifts in monthly average surface temperatures from long-term averages were found (Figure 4.1.1-32 to Figure 4.1.1-35). In 2015, at Las Vegas Bay and Boulder Basin, January to March and June surface water temperatures were above the long-term average (1990–2015) of the respective months (Figure 4.1.1-32). This change in monthly temperatures was also observed at the Colorado River main stem stations (Figure 4.1.1-34). However, these observed changes were within the historical range of variability. Warmer spring surface water temperature may have contributed to the cyanobacteria growth noted in Lake Mead during the fall-winter of 2014–2015, and algae growth persisted through March 2015 (Lake Mead NRA, 2015). Limited data were available from Overton Arm to derive a trend.

At Lake Mohave, surface water temperatures have increased at the Willow Beach station between 1990 and 2015 with greater intra-annual variability ($p<0.01$; Figure 4.1.1-36). Willow Beach station is located in the riverine section of Lake Mohave (Figure B-5) below Hoover Dam, thus surface water temperature recorded at this station is directly influenced by the water temperature of the hypolimnetic discharge from Hoover Dam which decreased from the 1990s to presentcor. The linear increase in surface water temperature observed at Willow Beach suggests that the temperature of Hoover Dam releases had likely increased. On the other hand, surface water temperatures at downstream lacustrine locations were generally higher than temperatures measured at Willow Beach (Figure 4.1.1-37). Surface water temperatures at these downstream locations have remained stable as the relatively colder Hoover Dam discharge generally travels as an underflow in Lake Mohave throughout most of the year (Figure 4.1.1-37; Paulson et al., 1980). The location of the stratification interface has been observed from just below Willow Beach and is dependent on Hoover Dam discharge volume and Lake Mohave water level (Paulson et al., 1980).

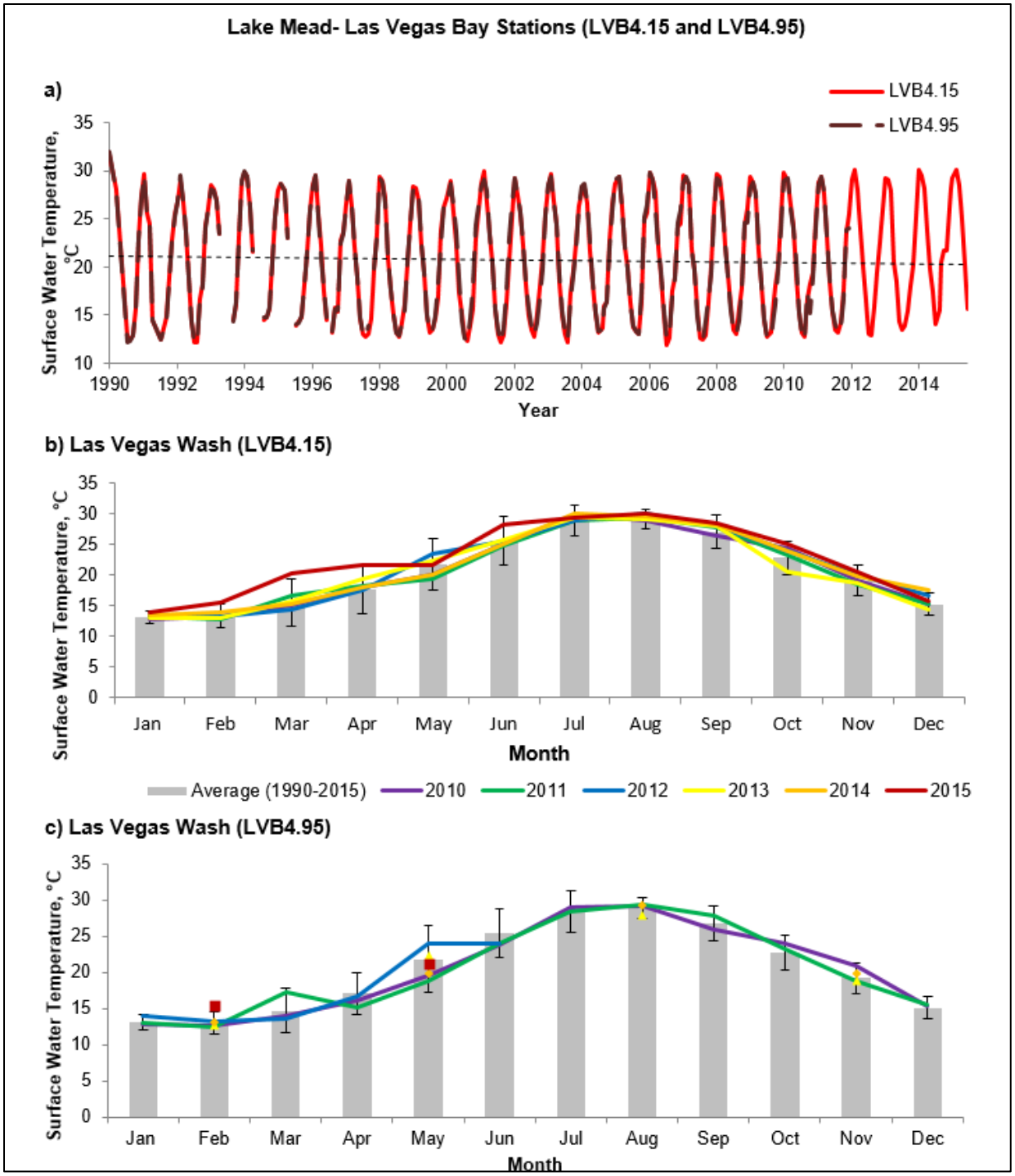


Figure 4.1.1-32. Time series of surface water temperatures by a) year (1990–2015) and b & c) month recorded at Las Vegas Bay stations (LVB4.15 & LVB4.95). Monthly averages from 2010 to 2015 are compared against long-term (1990–2015) monthly averages. See Figure B-3 for station locations and Table B-1 for station descriptions.

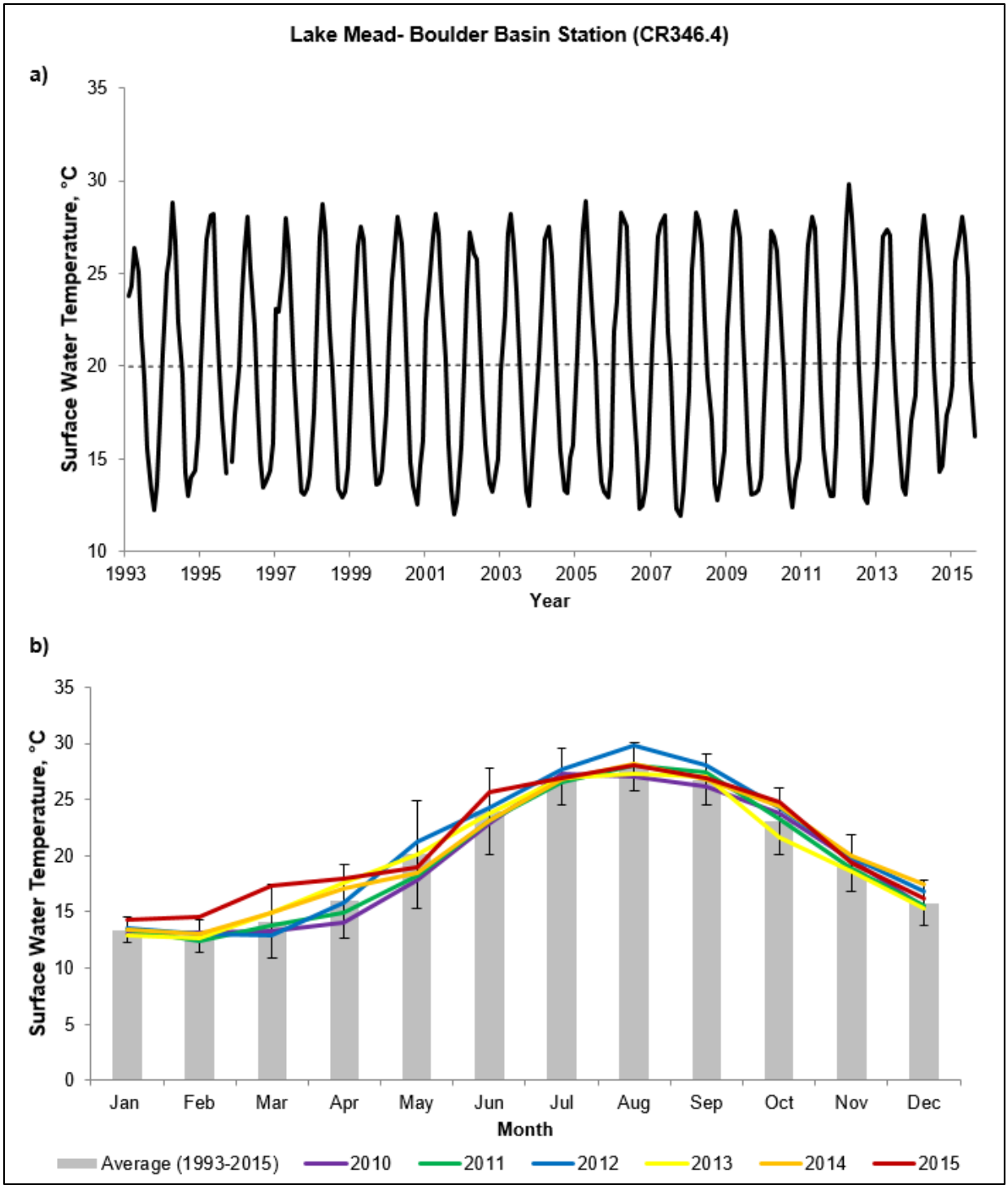


Figure 4.1.1-33. Time series of surface water temperatures by a) year (1993–2015) and b) month recorded at Boulder Basin. Monthly averages from 2010 to 2015 are compared against long-term (1993–2015) monthly averages. See Figure B-3 for station locations and Table B-1 for station descriptions.

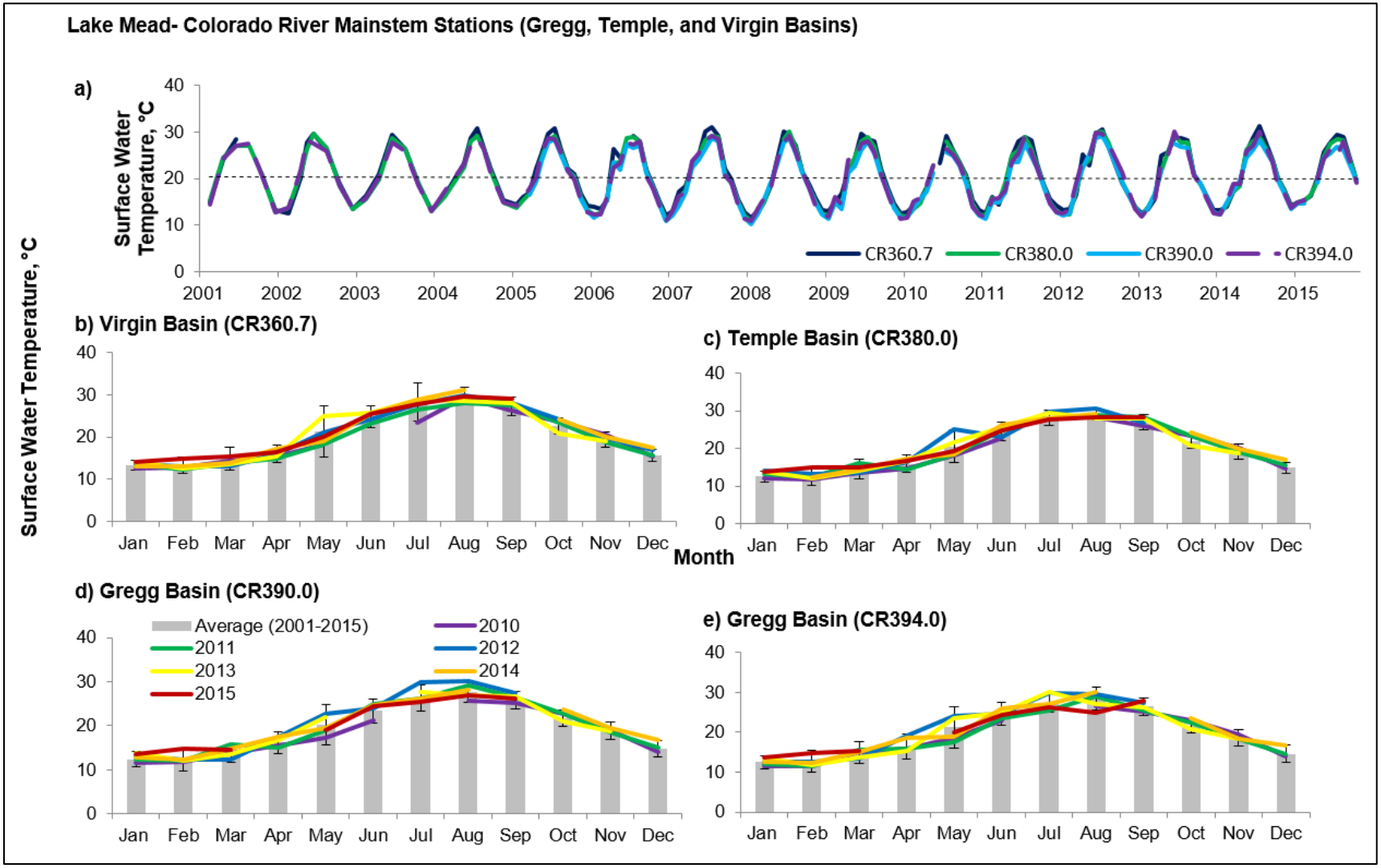


Figure 4.1.1-34. Time series of surface water temperatures by a) year (2001–2015) and b-e) month recorded at Colorado River main stem stations. Monthly averages from 2010 to 2015 are compared against long-term (2001–2015) monthly averages. See Figure B-3 for station locations and Table B-1 for station descriptions.

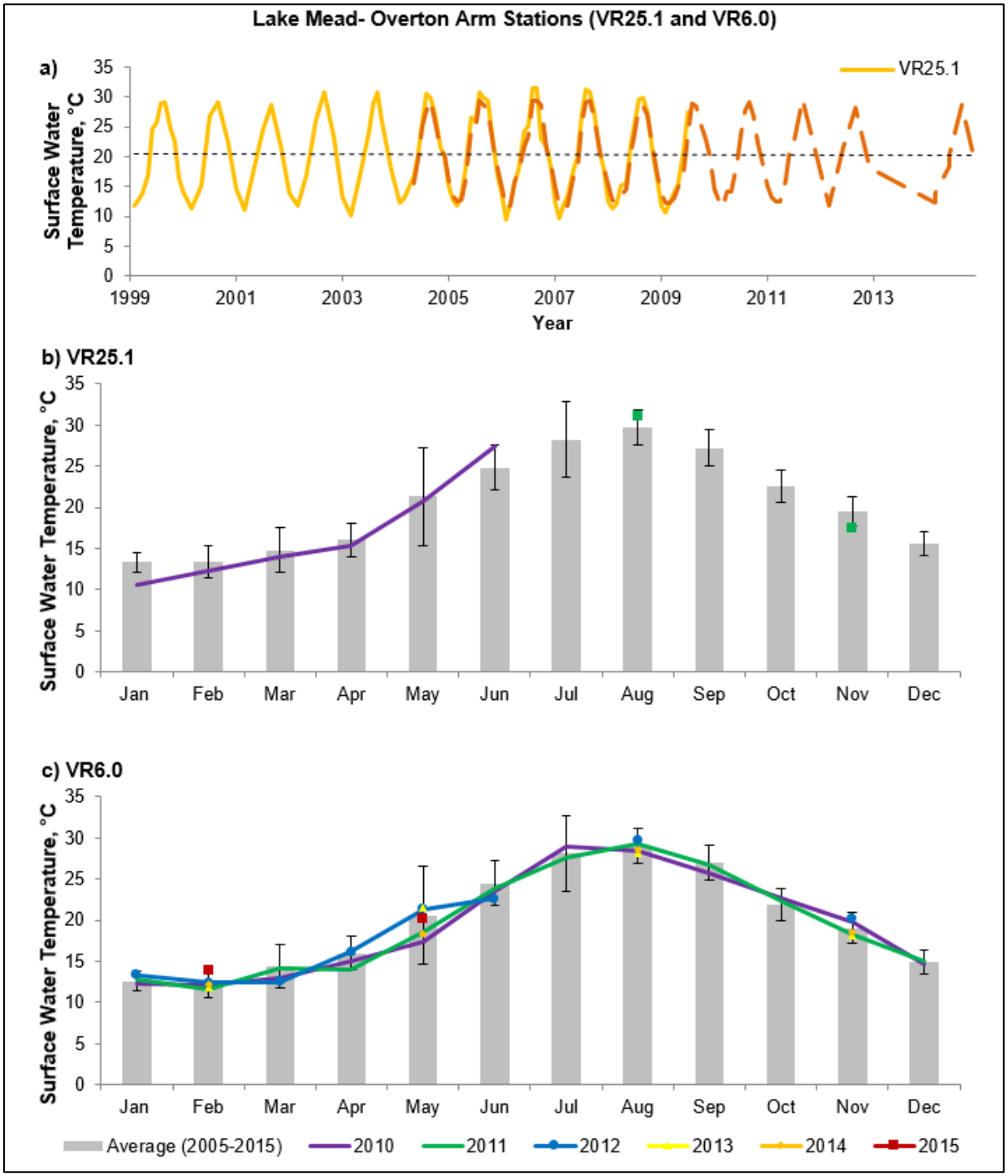


Figure 4.1.1-35. Time series of surface water temperatures by a) year (2000–2015) and b-c) month measured at Overton Arm. Monthly averages from 2010 to 2015 are compared against long-term (2005–2015) monthly averages. See Figure B-3 for station locations and Table B-1 for station descriptions.

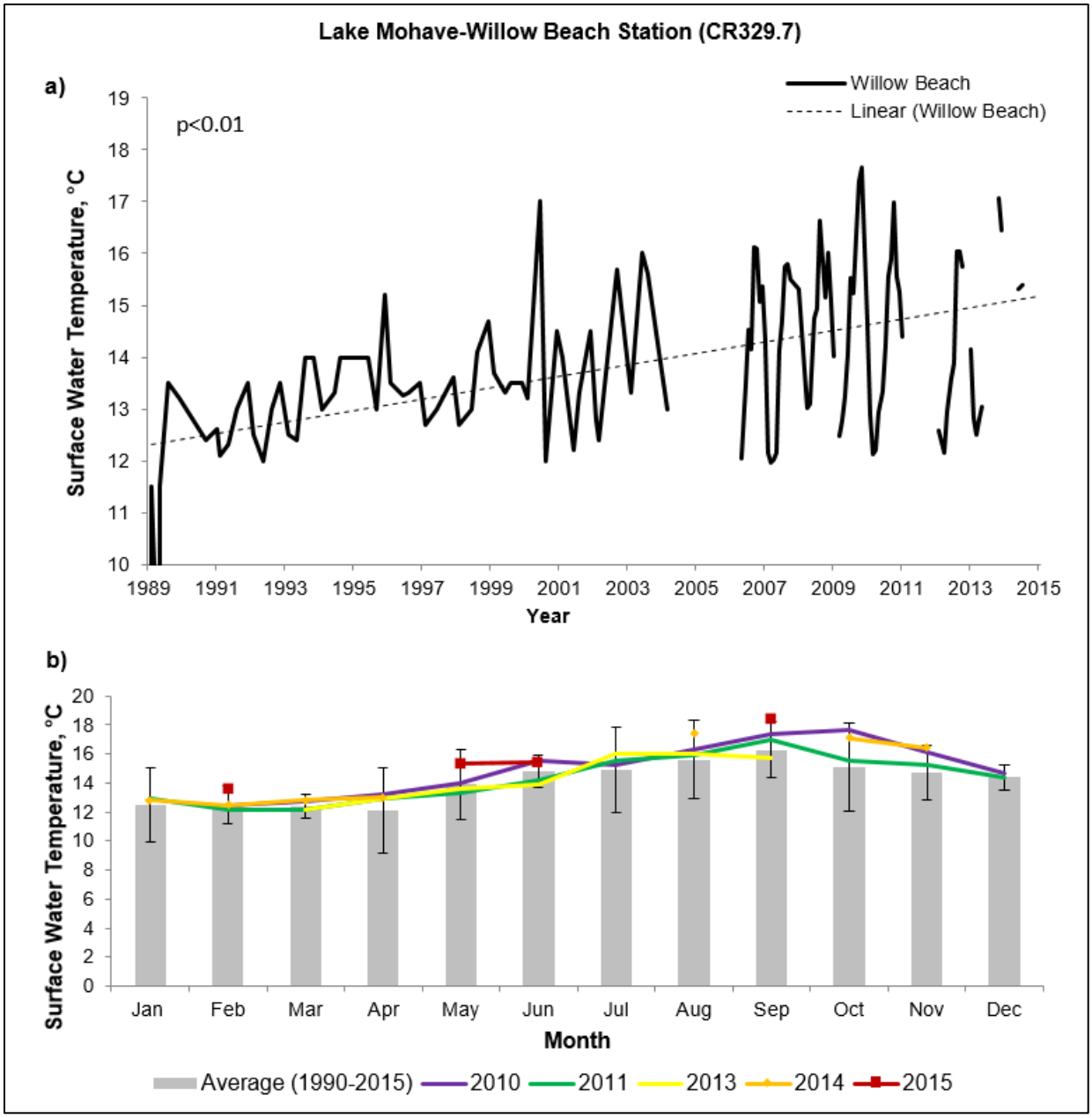


Figure 4.1.1-36. Time series of surface water temperatures by a) year (1990–2015) and b) month measured at Willow Beach in Lake Mohave. Monthly averages from 2010 to 2015 are compared against long-term (1990–2015) monthly averages. Statistically significant (p<0.01) linear increase in annual surface water temperature at Willow Beach is observed. See Figure B-5 for station locations and Table B-1 for station descriptions.

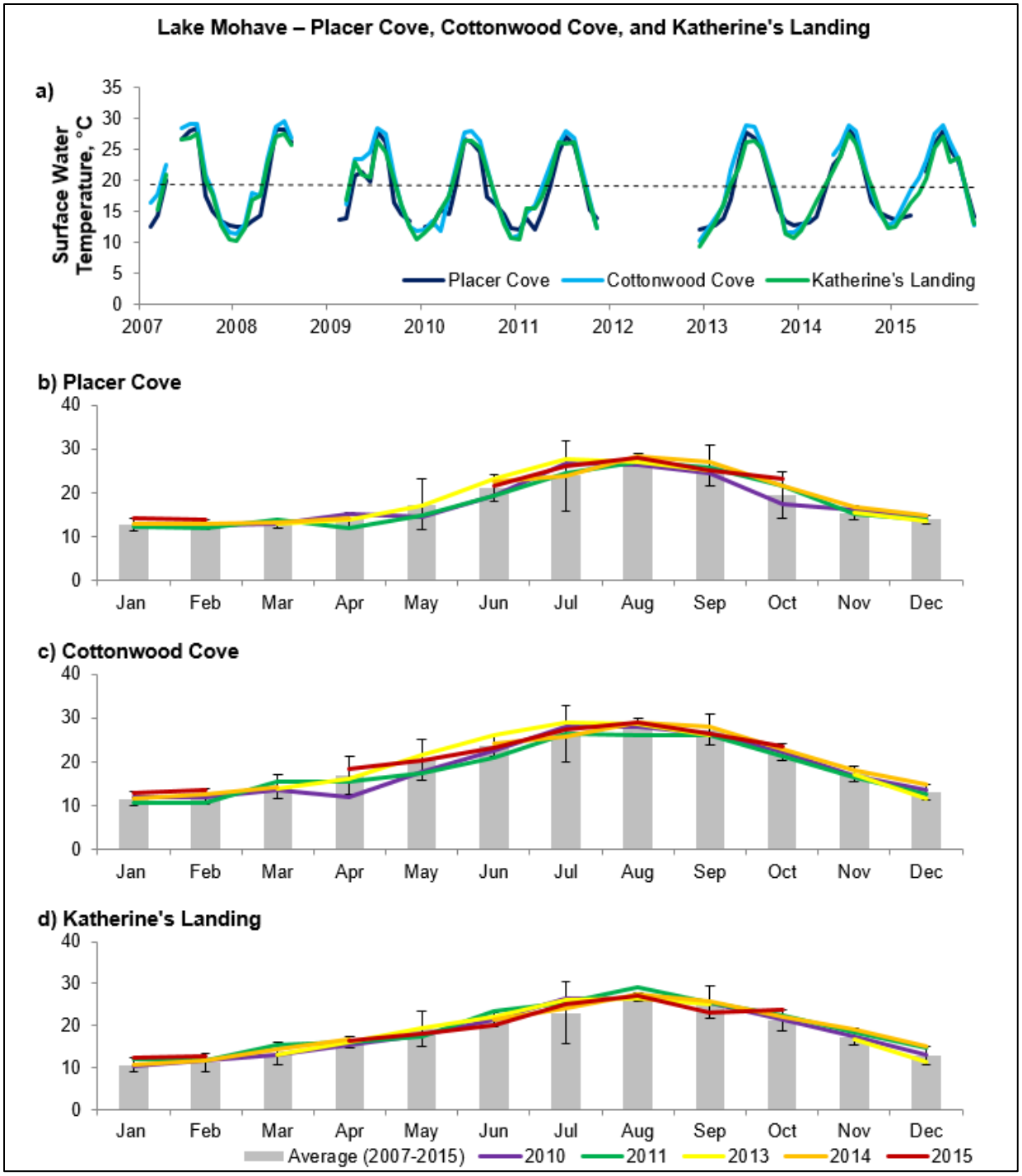


Figure 4.1.1-37. Time series of surface water temperatures by a) year (2007–2015) and b-d) month measured at Placer Cove, Cottonwood Cove, and Katherine's Landing in Lake Mohave. Monthly averages from 2010 to 2015 are compared against long-term (2007–2015) monthly averages. See Figure B-5 for station locations and Table B-1 for station descriptions.

Assessment Confidence and Key Data Gaps

The overall assessment confidence for water quality of Lake Mead is moderate to high. Lake Mead water quality parameters have been heavily monitored by multiple agencies for many years at many locations using standardized sampling methods. Water quality data in Lake Mead is most comprehensive in Las Vegas Bay and Boulder Basin. Relative to these locations, the number of monitored parameters and monitoring frequencies are less in Virgin and Gregg Basin, as well as in Overton Arm, however still provide a rich dataset to deduce water quality indicator assessments. On the other hand, the analytical capabilities and detection limits for some of the measurements (e.g. total phosphorus) have shifted throughout the years making them problematic for comparison. In addition, lowering water levels have caused sampling stations at shallower locations to move or be discontinued.

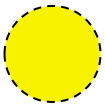
Assessment confidence for water quality of Lake Mohave is moderate to low and dependent on the specific water quality parameter examined. While the data used for this assessment were from a subset of monitoring stations, these stations were selected based on data availability and locations of stations to ensure the best representation of the different basin conditions observable in lakes Mead and Mohave. Relative to Lake Mead, the number of parameters monitored and monitoring frequencies have been much lower at Lake Mohave. Basic, monthly information from along the length of Lake Mohave was lacking.

Maintaining or increasing existing levels of lake-wide monitoring of physical and biological parameters of water quality is essential to assess trends and evaluate conditions in lakes Mead and Mohave. Establishment of a comprehensive baseline monitoring network for Lake Mohave is important as historic water quality data are sparse for Lake Mohave. Physical characteristics, such as bathymetry or water depth and the resultant associated ecosystem dynamics, of Lake Mohave may react differently than Lake Mead to impacts from various stressors.

4.1.2. Hydrologic Function

A summary of the parameters used assess lake hydrologic function are shown in Table 4.1.2-1.

Table 4.1.2-1. Assessment outcome for hydrologic function.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Hydrologic Function	• Turnover rate • Water column temperature (whole lake), retention time and thermal stratification		Little development of a thermocline at shallow areas in Lake Mead. Thermal stratification typically starts to form at deeper areas in May and peaks in August. Destratification typically began in October or November. No significant thermoclines were observed between January and April in Lake Mead. Extensive but incomplete mixing has been observed more frequently in recent years at deeper, open water sites (e.g. Boulder Basin) Increase in air temperature as projected by climate change models will likely result in increase in mean lake temperatures. Warming of surface waters will potentially increase the strength and length of thermal stratification, which will lead to subsequent reduced mixing.

Description

Thermal stratification of lakes refers to the change in water temperature with depths in the water column and is a result of a change in water density with temperature (Wetzel, 2001). In Lake Mead solary energy and wind play a critical role in transfering heating to develop temperature changes at depth. Water is most dense at 4°C and becomes less dense at both higher and lower temperatures. Because of this water density-temperature relationship, many lakes in temperate climates tend to stratify with seasonal cycle. As the weather warms, surface water heats up, decreases in density and remaines buoyant and creates a vertical thermal stratification. When the temperature and density of the surface water become equal to the bottom water, little wind energy is needed to cause the lake to mix completely. Turnover is defined as the complete mixing of lake water. The stability of a lake's stratification and depth of mixing can be influenced by exposure of the lake to wind, inflowing and outflowing water, lake size, depth, and shape. Retention time is defined as the amount of time it would take water to travel through a lake, and is calculated from average inflow and lake volume. Lakes with short retention time typically do not develop persistent thermal stratification. The longer the water remains in a lake, the more likely it is subjected to local processes such as heating or cooling, sedimentation, biological and chemical transformations.

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), nutrient such as phosophorus remain bound to sediments which can settle to the lake bottom (Wetzel, 2001). In the hypolimnion (lowest layer), oxygen concentrations are typically lower unless cooler water inflows penetrate to the lake bottom. 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 (Wetzel, 2001).

Data and Methods

Table 4.1.2-2 shows the data and methods used to assess hydrologic function.

Table 4.1.2-2. Data and measurements used to determine the condition status and trend of hydrologic function.

Indicator(s)	Measurement(s)	Scale of Analysis
Hydrologic Function	Turnover rate (mixing)	Lake
	Water column temperature (whole lake), retention time and thermal stratification	Lake

Qualitative data and descriptive information were compiled from several sources to provide condition and trend assessment on hydrologic function: Paulson et al., 1980; LaBounty & Horn, 1997; LaBounty, 2005; LaBounty & Burns, 2005; Holdren & Turner, 2010; Veley and Moran, 2011 and Rosen et al., 2012.

A study conducted by Veley and Moran (2011) with USGS examined thermal stratification patterns at several locations in Lake Mead. Water quality data collection stations using automatic profiling systems equipped with multiparameter water-quality sondes were deployed in shallow water (<20 m) at Las Vegas Bay (site # 3) and Overton Arm, and in deep water (>20 m) near Sentinel Island and at Virgin and Temple Basins (see Figure B-4 and Table B-2 for station locations and details; see Veley & Moran., 2011 for detail description of equipment and data collection methods). Data were collected from October 2004 through September 2009. Visual observations of temperature profiles at each station along with published information were examined to identify thermal stratification patterns in the Lake.

Profiles of water column temperatures are collected at around the lakes as part of a long-term water quality monitoring program. Data collected were downloaded from the SNWA database (http://snwaexapps.lvvwd.com) and respective agencies websites (e.g., https://www.lcrmscp.gov/). Sampling locations used for this assessment are described in Figure B-3 and B-5, and Table B-1. Sites selected were based on site locations and data availability.

Condition and Trend

Lake Mead was formed by the completion of Hoover Dam in 1935, and Lake Mohave was created by the construction of Davis Dam in 1951 (Rosen et al., 2012). Since lakes Mead and Mohave are reservoirs and not natural lakes, they are directly influenced by the quality and quantity of water releases from the dams that impound the lakes. Water entering Gregg Basin in Lake Mead is influenced by Glen Canyon Dam releases from Lake Powell into the Colorado River upstream whereas water entering Lake Mohave is influenced by Hoover Dam releases from Lake Mead. The location of the released water in the water column directly influences water characteristics but especially water column temperature and dissolved oxygen, which directly influence how water circulates throughout the system.

In Lake Mead, water column temperatures ranged from 10 to 30°C seasonally (Figure 4.1.2-1 and Figure 4.1.2-2). Water column temperatures in Lake Mead have followed patterns typical of a warm **monomictic** lake (see section 4.1.1 for surface water temperature description and assessment) which can be characterized by thermal stratification of the water column for most of the year with a single complete mixing period (Wetzel, 2001). Therefore, the general temperature profile trend in Lake Mead is fairly predictable from year to year. Beginning in March, Lake Mead's near-surface waters typically warmed at different rates in two general areas: near inflowing tributaries and in the open waters that are distant from the shores and tributary influences. 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 has been detected near the tributaries (e.g. Figure 4.1.2-4 Las Vegas Bay stations). Subsequently, as daylight periods and air temperatures have increased, open water temperatures have also increased. In Lake Mead, stratification has usually been 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 (Figure 4.1.2-4 to Figure 4.1.2-5; Rosen et al., 2012). Destratification typically has begun in November (LaBounty & Burns, 2005) and has been most complete in January and February. LaBounty & Burns (2005) found that areas of Lake Mead shallower then 70m do turnover on an annual basis from November through January. However, deeper and more open water areas of Lake Mead do not completely turnover on an annual basis (Figure 4.1.2-4 to Figure 4.1.2-5; LaBounty & Horn, 1997; LaBounty, 2005). Between 1995 and 2004, Boulder Basin had a 40% chance of not completing a seasonal destratification (LaBounty & Burns, 2005). While mixing does occur each year for about a two month period to a depth of 60 to 70 m, complete turnover of Lake Mead rarely occurs due to the great depth and relatively constant temperature gradient (LaBounty & Burns, 2005). In recent years however with lower lake levels complete mixing may occur (Table 4.1.2-3).

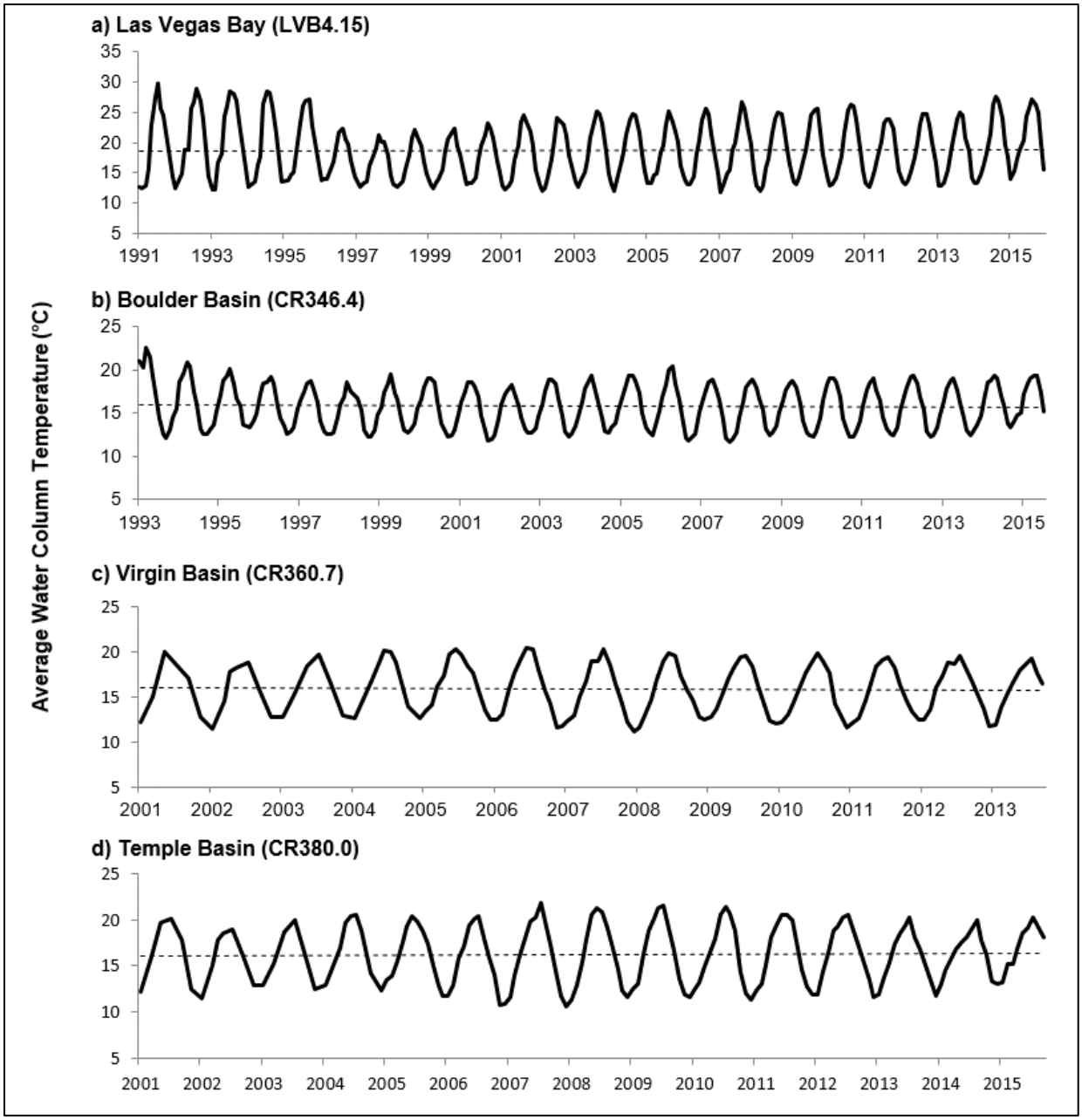


Figure 4.1.2-1. Time series (monthly averages) of water column temperature from a) Las Vegas Bay station (LVB4.15; 1991–2015), b) Boulder Basin (CR346.4; 1993–2015), c) Virgin Basin (CR360.7; 2001–2013), and d) Temple Basin (CR380.0; 2001–2015). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

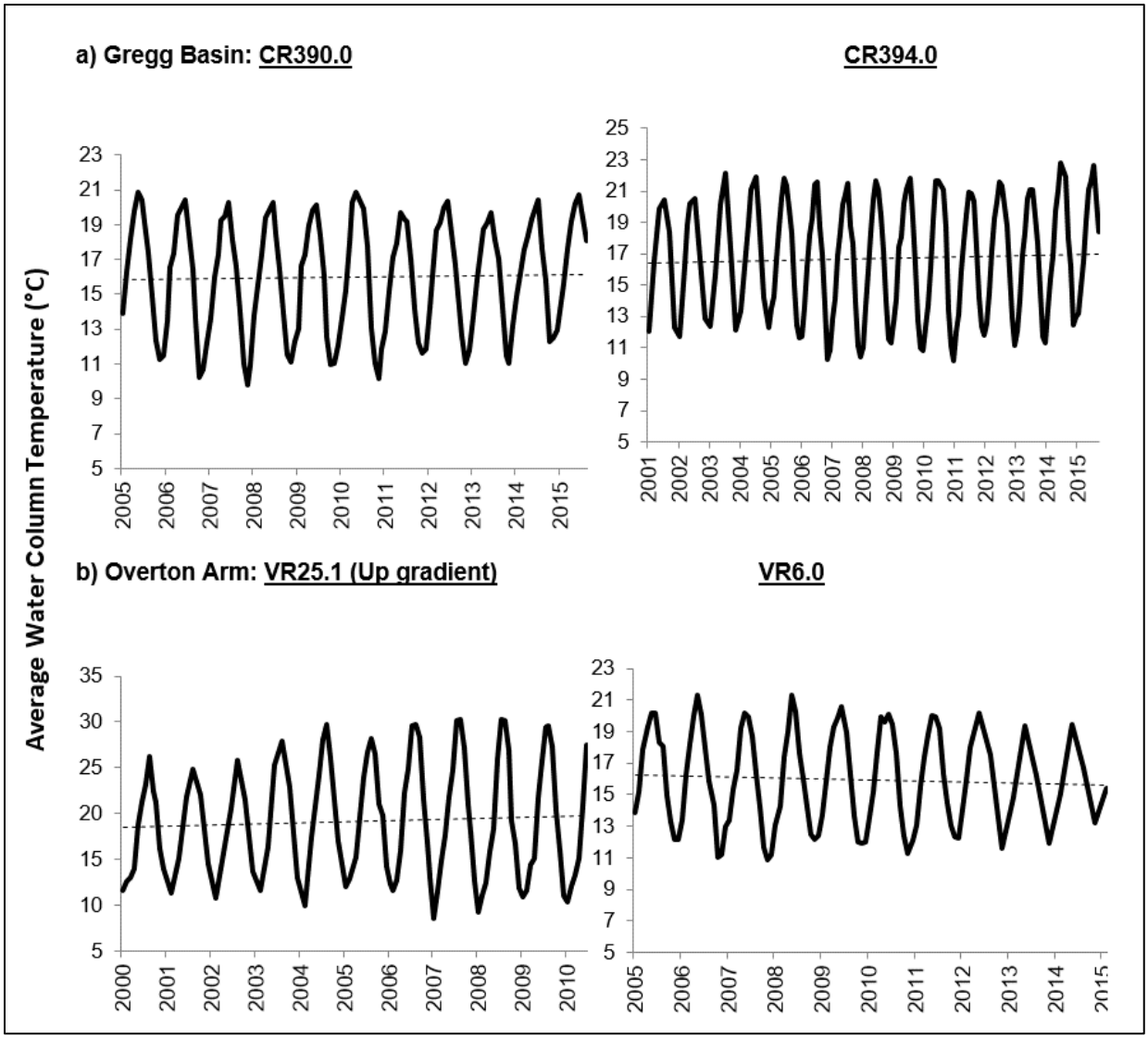


Figure 4.1.2-2. Time series (monthly averages) of water column temperature from a) Gregg Basin (CR390.0: 2005–2015 and CR394.0; 2001–2015) and b) Overton Arm (VR6.0: 2000–2015 and VR25.1; 2005–2015). Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-3 for station locations and Table B-1 for station descriptions.

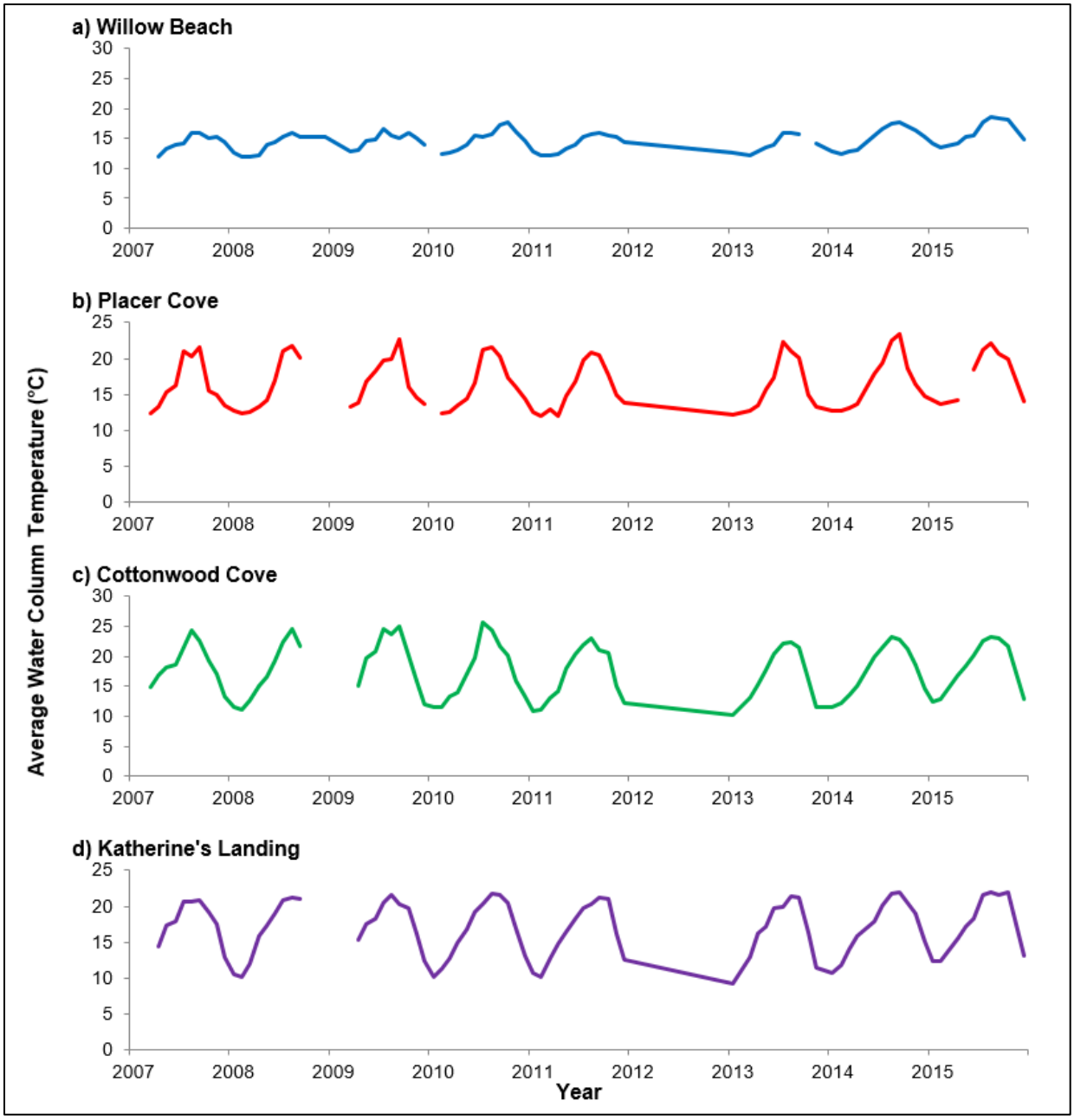


Figure 4.1.2-3. Time series (monthly averages) of water column temperature from Willow Beach (CR329.7), Placer Cove (CR316.34), Cottonwood Cove (CR298.SW5), and Katherine's Landing (CR278.0) in Lake Mohave between 2007 and 2015. Values computed for each station are averages of values for all samples collected from each year and include those from all sample depths. See Figure B-5 for station locations and Table B-1 for station descriptions.

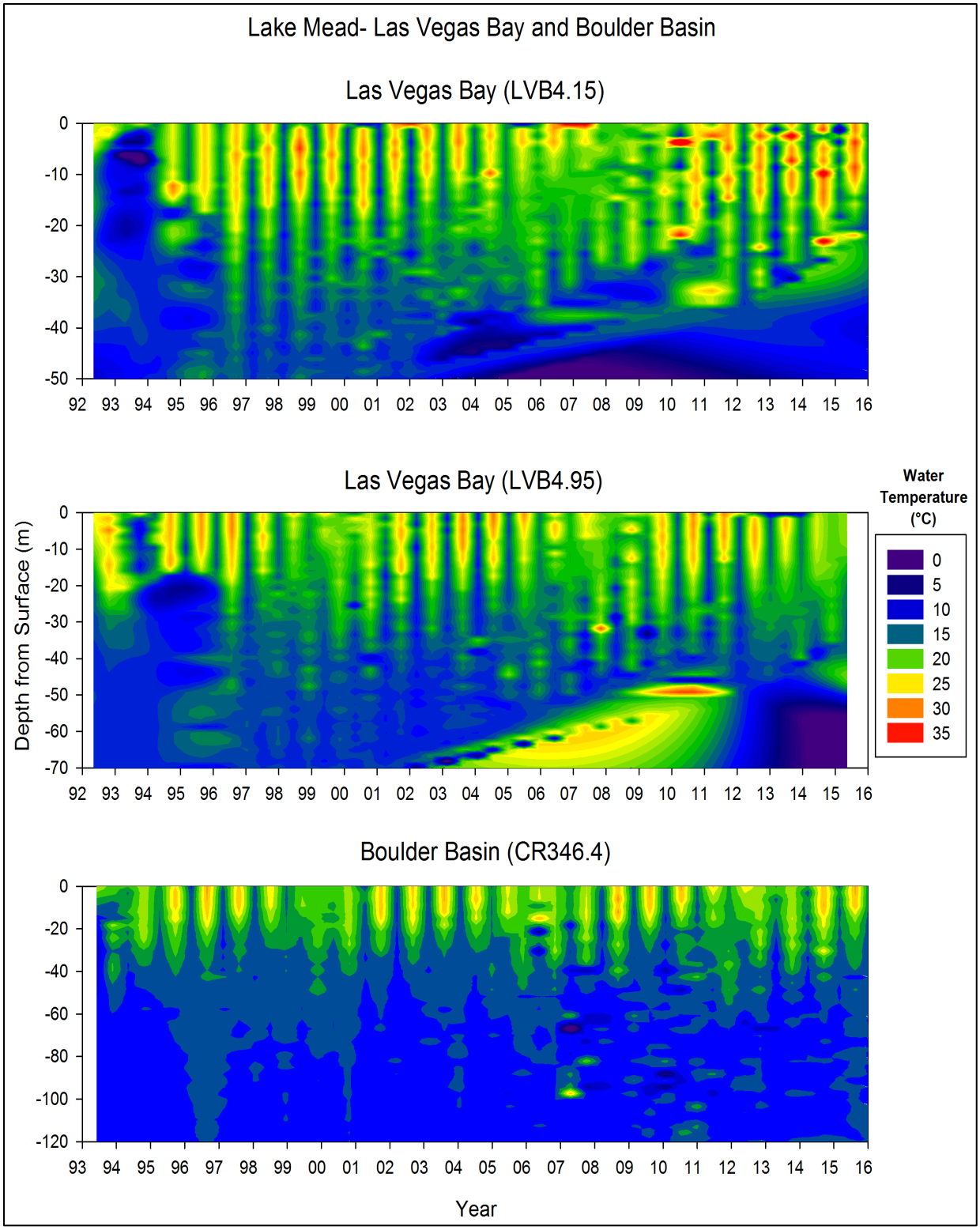


Figure 4.1.2-4. Time series of water column temperature profile data collected between 1992 and 2016 from Las Vegas Bay (LVB4.15 and LVB4.95) and Boulder Basin (CR346.4) stations. Profile data were collected biweekly. See Figure B-3 for station locations and Table B-1 for station descriptions.

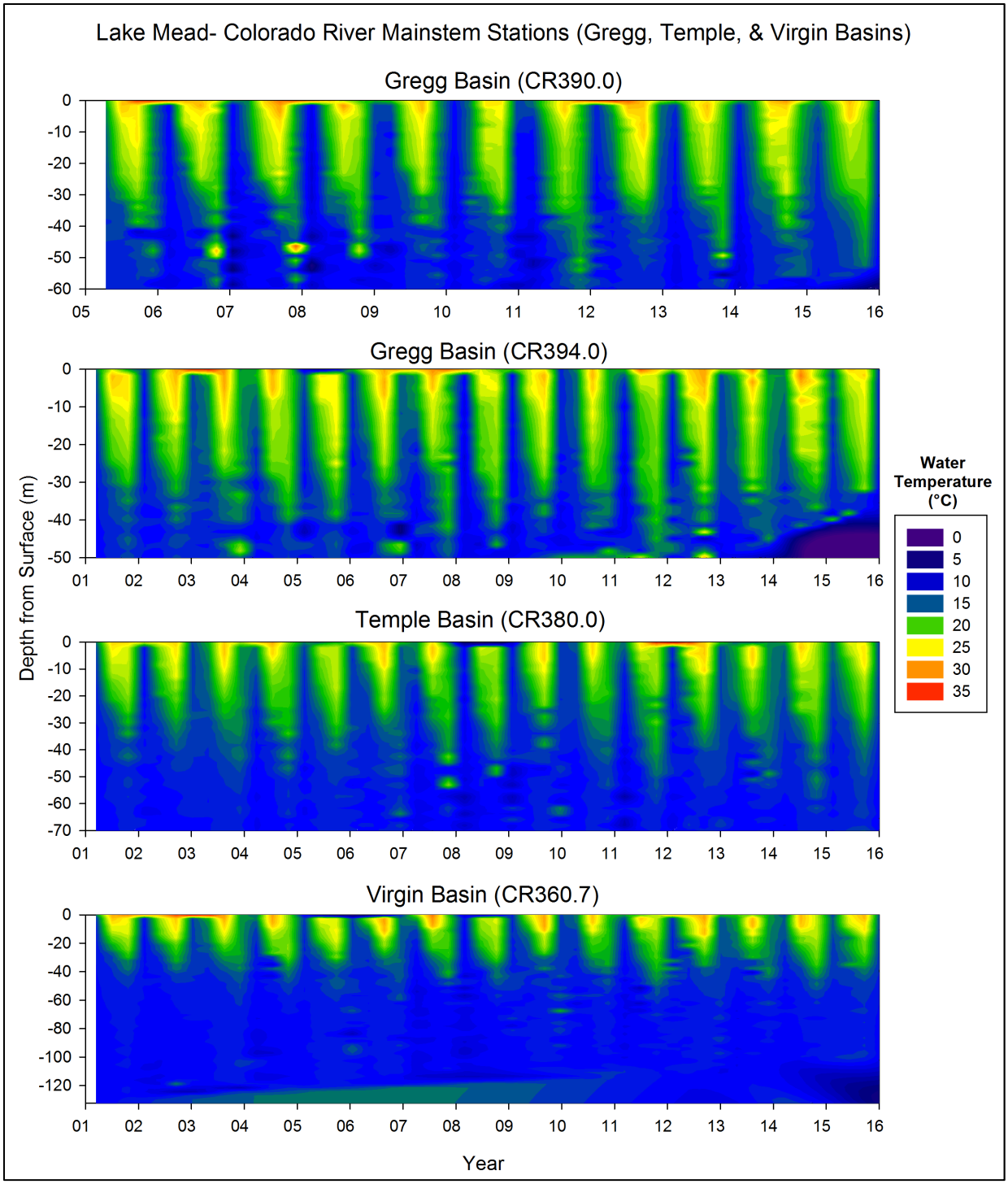


Figure 4.1.2-5. Time series of water column temperature profile data collected from Colorado River mainstem stations: Gregg Basin (CR390.0: 2005–2015 & CR394.0: 2001–2015), Temple Basin (CR380.0: 2001–2015), and Virgin Basin (CR360.7; 2001–2015). Profile data were collected monthly. See Figure B-3 for station locations and Table B-1 for station descriptions.

Table 4.1.2-3. Reference conditions for Hydrologic function used to determine the condition status and trend.

Measurement(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Turnover rate; water column temperature (whole lake), retention time and thermal stratification	Reduced turnover rate with increased strength and length of thermal stratification from historical observations.	Trending toward reduced turnover rate with increased strength and length of thermal stratification from historical observations.	Turnover (mixing) rate and stratification strength and length follow the typical pattern observed historically at Lake Mead.

Lake Mead departs slightly from the warm monomictic pattern; on average of 1 out of every 2 years, extensive but incomplete mixing has occurred in Lake Mead. This pattern can be observed in the open waters of Boulder Basin, especially in recent years (Figure 4.1.3-4). Veley and Moran (2011) found little development of a thermocline at the Las Vegas Bay (site # 3, LVB3) station. When lake elevation was greater than 340 m above sea level (masl), a decrease in temperature of about 5°C between the surface water and the deepest measurement at around 20m was observed in the summer months. However, as lake elevation dropped below 340 masl, temperatures were nearly constant at all depths at LVB3 (Veley & Moran, 2011). Thus, lake level influences the development of a thermocline and stratification. A similar pattern was observed at Overton Arm station where the development of a seasonal thermocline was absent (Figure 4.1.2-6). At the Sentinel Island station in Boulder Basin, the Virgin Basin station, and the Temple Basin station, a seasonal thermocline began forming in May and reached peak development in August (Veley & Moran, 2011). At Sentinel Island station, the thermocline weakened from October to December and moved deeper in the water column. The epilimnion was about 12 meters thick at the height of thermocline development at this station. The metalimnion extended from about 12–35 meters in depth, and the hypolimnion extended from about 35 meters to the bottom of the lake (Table 4.1.2-4). The SNWA public-water-supply intakes (No. 1 and 2), situated at approximately 305 masl, were located near the base of the metalimnion from May through August and within the metalimnion from October through December. A new third intake (No. 3), situated at approximately 262 masl, would be located within the hypolimnion throughout the year (Veley & Moran, 2011). At Virgin Basin and Temple Basin stations, the thermoclines weakened and moved deeper in the water column from September through December. No significant thermoclines were observed from January through April at both stations. The epilimnion at both locations was about 7 m thick at the height of thermocline development, the metalimnion extended from about 7–35 meters in depth, and the hypolimnion extended from about 35 meters to the bottom of the lake (Table 4.1.2-4). On the contrary to LaBounty and Burns (2005) finding where certain areas of Lake Mead, primarily Boulder Basin do not always completely destratify in the winter, Veley and Moran (2011) found that all deep water stations (Sentinel Island, Virgin and Temple Basins) undergo thermal destratification in the winter.

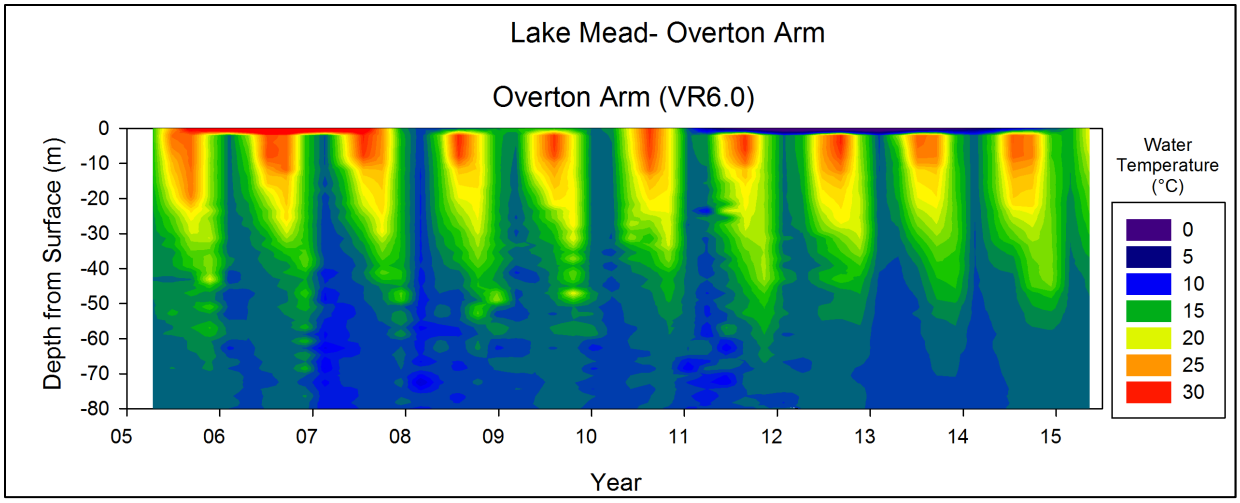


Figure 4.1.2-6. Time series of water column temperature profile data collected from Overton Arm (VR6.0). Profile data were collected quarterly. See Figure B-3 for station locations and Table B-1 for station descriptions.

Table 4.1.2-4. Approximate location of thermal layers in Lake Mead at USGS water quality stations where thermal stratification was present between 2005–2009. Modified from Veley and Moran, 2011.

	Depth (m)		
Station Name	**Epilimnion**	**Metalimnion**	**Hypolimnion**
Sentinel Island	0–12	12–35	35-bottom
Virgin Basin	0–7	7–35	35-bottom
Temple Basin	0–7	7–35	35-bottom

Water temperatures in Lake Mohave are generally isothermal (12–13 °C) during the winter. Thermal stratification begins to develop in May through October. Cold water releases establish and maintain stratification. This pattern is at risk with drought and climate change and would severly modify the stratification pattern of the lake and likely change the entire limnology of the system. The thermocline is located at 10 to 15 m in Cottonwood Basin and varies from 3 to 10 m in Eldorado Basin with varying Hoover Dam discharges in the summer (Paulson et al., 1980a). Willow Beach had the lowest average water column temperatures amongst the four Lake Mohave stations (Figure 4.1.2-4). Willow Beach is the first location receiving cold discharge from Hoover Dam, and it is also located at the riverine stretch of Lake Mohave.

No significant trend for average water column temperatures was found in lakes Mead and Mohave during the periods examined for all stations (Figure 4.1.2-1 to Figure 4.1.2-4). However, the recent trend of decreasing lake levels and changing climate condition with warming temperatures could have a significant effect on water column temperatures. While the epilimnion of lakes typically is the most important biologically and chemically, its spatial dominance is variable and repeatable year to year. Increase in air temperature as projected by climate change models will likely result in an increase in mean lake temperatures. Warming of surface waters will potentially increase the strength

and length of thermal stratification, which will lead to subsequent reduced mixing (Butcher et al., 2015). Longer periods of stratification can increase the risk of hypolimnetic anoxia, which could potentially facilitate regeneration of soluble phosphorus and metals from lake sediments and affect water quality (Butcher et al., 2015). As lake levels fall, the withdrawals have a disproportionate impact on the hypolimnion. Annual patterns of water column mixing and warming will, generally, produce an epilimnion of the same depth. The combination of these factors, stable epilimnetic formation and falling surface elevation combine could reduce the size of the hypolimnion. Any reduction in the size of the hypolimnion necessarily increases the proportion of the water column that is the epilimnion, and the importance of epilimnetic biological and chemical processes become more important overall. If surface water elevations continue to fall, many of the advantages conveyed by Lake Mead's depth will likely become reduced (SNWA, 2006).

The retention time of Lake Mead averages about 2.6 years and has been dependent on reservoir operations for Lakes Mead and Powell, as well as the reservoir volume at the time of releases (Table 4.1.2-5; Lara & Sanders, 1970; Ferrari, 2008; Holdren & Turner, 2010; Rosen et al., 2012). Surveys between 1963–64 and 2001 detected a slight increase in residence time. The water budget for Lake Mohave is highly regulated and depends primarily on downstream releases through Hoover Dam and Davis Dam. The retention time of Lake Mohave during the stratified period is far more complex. The cold hypolimnion carries Hoover dam releases through the system quickly while the surface waters are retained for a longer period. None the less, coarsly estimated, the retention time of Lake Mohave is short, approximately 60 days due to rapid flushing by the Colorado River (Paulson et al., 1980b) (Table 4.1.2-5).

Table 4.1.2-5. Retention time of lakes Mead and Mohave. Modified from Lake Mead NRA, 2010, Holdren & Turner, 2010, and Rosen et al., 2012. See "Units" for abbreviation definitions.

Lake	Source	Hydralogic Residence Time*
Lake Mead	Lara & Sanders, 1970	2.1 yr
	Ferrari, 2008; Holdren & Turner, 2010; Rosen et al., 2012	2.6 yr
Lake Mohave	Rosen et al., 2012	60 days

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

Assessment Confidence and Key Data Gaps

The overall assessment confidence for hydrologic function is moderate to low. While the given the amount and type of data available for Lake Mead is abundant there are no published studies completed for Lake Mohave regarding this indicator. There is need for more accurate volumetric data using improved bathyemtry to determine hydrologic flow through put conditions.

4.1.3. Trophic Level

A summary of the parameters used assess lake trophic level are shown in Table 4.1.3-1.

Table 4.1.3-1. Assessment outcome for Trophic level.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Trophic Level	Secchi depth		Secchi depth values greater than 1m (3 ft) is defined in the Lake Mead NRA Recreation Suitability Guidelines as an indication of clear water. Overall, Lake Mead has high water clarity, ranging from 6 m to 18 m Secchi depths measured at open water locations. Lake Mohave has good water clarity with Secchi depth measurements ranging from 3m to 20 m. Willow Beach, located closest to the Hoover Dam discharge has the lowest water clarity in Lake Mohave but water clarity improves with distance from the discharge. Based on the Burns et al. (1999) categorization for trophic status in relations to Secchi depth, the current status of lakes Mead and Mohave would be considered between oligotrophic and mesotrophic. This corresponds to historic classifications for Lake Mead as mildly mesotrophic based on several classification indices.
	Chlorophyll *a*		Peak concentrations of Chlorophyll *a* have been less than 25 µg/L in Las Vegas Bay and less than 5 µg/L in Boulder Basin in most years following the 2001 algal bloom. Overall, chlorophyll *a* concentrations measured from Lake Mead were within the NDEP water quality standard (≤ 5 µg/L) and the USEPA NLA “good” range (≤ 7.79 µg/L) for open water locations with concentrations ranging between 1µg/L and 5µg/L in most years, except during the 2001 algal bloom in Las Vegas Bay and Boulder Basin. Based on the Burns et al. (1999) categorization for trophic status in relations to chlorophyll *a*, the current status of Lake Mead would be considered between oligotrophic and mesotrophic. This corresponds to historic classifications for Lake Mead as mildly mesotrophic based on several classification indices. Very limited data were available from Lake Mohave to establish condition and trend.

Table 4.1.3-1 (continued). Assessment outcome for Trophic level.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Trophic Level (continued)	Trophic index (Burns Trophic Level Index, TLI)		The TLI trend in Boulder Basin has been downward from 2000 to 2010 and remained stable since then with oligotrophic character, indicating that water quality has improved.

Description

In aquatic ecosystems, primary productivity is the growth of new biomass by primary producers (phytoplankton; see section 4.2.3), which form the base of the food web. Through photosynthesis, phytoplankton convert dissolved inorganic carbon in the water into organic compounds. Trophic level depicts biological productivity in lakes (USEPA, 2009). In the large, deep lakes, productivity is generally quite low (**oligotrophic**). Nearer to inflowing rivers, productivity, in general, increases to mesotrophic levels due to the introduction of two components: nutrients (nitrogen and phosphorus; see section 4.1.1) 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 can degrade conditions for fish and other wildlife (Wetzel 2001).

Many states and lake associations use a variety of thresholds for nutrient (phosphorus or nitrogen), Secchi depth, or chlorophyll *a* to classify a lake's productivity and trophic level (USEPA, 2009). Productivity can be estimated using the Burns Trophic Level Index (TLI; LaBounty & Burns, 2005).

Secchi depth has been used as an inexpensive but effective method for measuring water clarity. Secchi depth is measured by lowering an eight-inch black and white colored disk into the water with multiple replicates per location. The depth at which the disk visually disappears and then reappears as the disk is raised is recorded. Secchi depth data taken over time can reflect changes in the concentration of suspended sediments or algal abundance. Secchi depths have been measured at various locations in Lake Mead for over 20 years (Rosen et al., 2012).

Chlorophyll *a* is one of the pigments involved in photosynthesis. It is commonly used as an indicator of water quality for measuring algal biomass in the water column. In Lake Mead, concentrations of chlorophyll *a* have usually been highest near tributaries confluences, which contribute nutrients to the lake (Rosen et al., 2012).

The index does not provide a quantitative measure of productivity. Instead, the index is used to classify trends towards improving or degrading water quality based on a lake's trophic state (Burns et al., 1999). TLI combines information on algal biomass (chlorophyll *a*) and water clarity (Secchi depth) presented in this section, as well as nutrients (nitrogen and phosphorus) and standard water-quality parameters examined in section 4.1.1 (Rosen et al., 2012).

Data and Methods

Table 4.1.3-2 shows the data and methods used to assess tropic level.

Table 4.1.3-2. Data and methods used to determine the condition status and trend of Tropic level.

Indicator(s)	Measurement(s)	Scale of Analysis
Trophic Level	• Secchi depth • Chlorophyll *a* • Trophic index (Burns Trophic Level Index)	Lake

Secchi depth and chlorophyll *a* concentrations have been taken as part of the interagency monitoring of lakes Mead and Mohave (See section 2.3.2 for detail description of interagency monitoring effort and Table 4.1.3-3 for stations examined for this assessment). Secchi depth and chlorophyll *a* concentrations have been sampled either monthly or quarterly at most stations examined (Table 4.1.3-3).

For Secchi depth, a black-and-white Secchi disk attached to a measured chain is used. Two readings, one with a Viewscope (which can reduce the influence of wind, wave action and variable light) and one without, were taken at each site. LaBounty (2008) found that readings taken in Boulder Basin with and without a Viewscope were similar when Secchi depths were less than 4m (13ft) with light wind. When Secchi depths were more than 4m (13ft), the Viewscope generally resulted in a greater Secchi depth measurement.

Table 4.1.3-3. List of Secchi depth and chlorophyll *a* monitoring sites in Lake Mead NRA examined showing period of record examined. For site coordinates and locations, see Figure B-3, Figure B-5, and Table B-1.

Lake	Location	Site ID	Secchi Depth		Chlorophyll *a*	
			First Record	Last Record	First Record	Last Record
Lake Mead	Las Vegas Bay	LVB4.15	11/14/2006	1/20/2016	1/11/2000	5/15/2015
		LVB4.95	7/9/2003	5/13/2015	1/11/2000	5/15/2015
	Boulder Basin	CR346.4	7/3/2003	1/20/2016	1/4/2000	5/11/2015
	Virgin Basin	CR360.7	11/14/2006	1/13/2016	3/14/2001	5/11/2015
	Overton Arm	VR6.0	11/14/2006	5/12/2015	4/12/2005	9/13/2011
		VR25.1	11/13/2006	11/8/2011	1/10/2000	6/15/2010
	Temple Basin	CR380.0	11/13/2006	1/13/2016	3/14/2001	5/11/2015
	Gregg Basin	CR390.0	11/13/2006	1/13/2016	4/13/2005	5/11/2015
		CR394.0	11/13/2006	1/13/2016	3/14/2001	5/11/2015
Lake Mohave	Willow Beach	CR329.7	5/16/2007	1/23/2013	01/2014–07/2014*	01/2014–07/2014*
	Placer Cove	CR316.34	5/16/2007	1/23/2013	01/2014–07/2014*	01/2014–07/2014*
	Cottonwood Cove	CR298.5W.5	5/15/2007	1/23/2013	01/2014–07/2014*	01/2014–07/2014*
	Katherine's Landing	CR278.0	5/15/2007	12/13/2011	01/2014–07/2014*	01/2014–07/2014*

* Quarterly samples taken

Composite (0–6 m) water samples for analyses of chlorophyll *a* were collected using a flexible hose. The pool hose was rinsed once before each sample collection.

In Rosen et al. (2012), the Trophic Level Index (TLI) score was calculated using the annual chlorophyll Trophic Level value, annual Secchi Trophic Level value, and annual total phosphorus Trophic Level value. Equations used to calculate the TLI values and variable Trophic Level values from the annual average values of Chlorophyll *a*, Secchi depth, and Total Phosphorus (Burns et al., 1999) are as follows:

$$TLc = 2.22 + 2.54 \log(\text{chlorophyll } a) \quad (1)$$

$$TLs = 5.10 + 2.60^{*} \log(1/\text{secchi disc} - 1/40) \quad (2)$$

$$TLp = 0.218 + 2.92 \log(\text{total phosphorus}) \quad (3)$$

*coefficient revised in 2000.

The equations above create normalized trophic level indices, enabling the average trophic level index to be calculated:

$$TLI = 1/3 \, (TL_C + TL_S + TL_P) \quad (4)$$

TLI calculations for Lake Mead did not include the nitrogen component. While nitrogen concentrations generally were high in Lake Mead, low phosphorus concentrations in the lake control primary production within this system (Paulson & Baker, 1983; LaBounty and Horn, 1997; LaBounty and Burns, 2005; LaBounty, 2008; Holdren and Turner, 2010). For the purposes of this assessment, a lower TLI value indicates higher water quality. Burns et al. (1999) provided a general categorization of seven trophic status evaluation levels and the boundaries for the three parameters (Table 4.1.3-4).

Table 4.1.3-4. Values of parameters that define boundaries for different Trophic Levels (Burns et al., 1999).

Lake Type	Chlorophyll a (µg/L)	Secchi Depth (m)	Total Phosphorus (mgP/m^3)	Trophic Level
Ultra-oligotrophic	0.13–0.33	33–25	0.84–1.8	0–1
Oligotrophic	0.33–0.82	25–15	1.8–4.1	1–2
Oligotrophic	0.82–2	15–7	4.1–9	2–3
Mesotrophic	2–5	7–2.8	9–20	3–4
Eutrophic	5–12	2.8–1.1	20–43	4–5
Supertrophic	12–31	1.1–0.4	43–96	5–6
Hypertrophic	>31	<0.4	>96	6–7

Reference Conditions

In 2007, USEPA conducted a baseline study of the condition of lakes in the United States, including Lake Mead. The National Lakes Assessment (NLA) categorized Lake Mead into the EPA level-III Xeric ecoregion (USEPA, 2009). Data for six parameters (concentrations of total nitrogen, total

phosphorus, chlorophyll *a*, dissolved oxygen, turbidity, and an aggregate measure of the lakes' suitability for recreation) from Lake Mead were compared to other lakes in the Xeric ecoregion to assess conditions (Rosen et al., 2012).

Chlorophyll *a* was rated using a good/fair/poor scale relative to conditions found in reference lakes (USEPA, 2009). A reference lake in NLA definition would be a lake, either natural or man-made, with attributes (e.g. water quality) that come as close as practical to those expected in a natural state. Target lakes with indicator values above 25% of the reference range values within the same ecoregion are considered "good"; below the 5% are considered "poor". The Nevada Department of Environmental Protection (NDEP) has also established regulatory water quality standards for chlorophyll *a* (Lake Mead NRA, 2015). The standards recognize that the values within the mixing zones of the tributary confluences will be higher than those of the open waters of the Lakes. Therefore, the standards are specifically for open water sites, including Boulder, Virgin, Gregg, Temple, and Pierce Basins. NDEP standards are defined as "The mean for chlorophyll *a* in the growing season (April 1-September 30) must not exceed 5 µg/l in the open water of Boulder Basin, Virgin Basin, Gregg Basin and Pierce Basin. The single value must not exceed 10 µg/l for more than 5 percent of the samples." (Lake Mead NRA, 2015). For this assessment, the established NLA scale and NDEP standards are used to evaluate current whole lake conditions of chlorophyll *a* (see table below). The Burns et al. (1999) categorization was also used as a reference for chlorophyll *a* assessment (Table 4.1.3-4).

For Secchi depth (for trophic level assessment) and TLI, the Burns et al. (1999) categorization was used as a reference for assessment (Table 4.1.3-3).

Condition and Trend

Secchi depth

Secchi depth values greater than 1m (3 ft) are defined in the Lake Mead NRA Recreation Suitability Guidelines as an indication of clear water (Rosen et al., 2012; Lake Mead NRA, 2015).

Water clarity is lower at stations that are closest to the tributaries, e.g. LVB4.15 and LVB4.19 in Las Vegas Bay, CR394.0 and CR390.0 in Gregg Basin, and VR25.1 in Overton Arm (Figure 4.1.3-1) with higher sediment and nutrient loading near these stations, resulting in higher turbidity and algal production and biomass, thus greater productivity and trophic levels compared to open water stations. The downward trend in water clarity (lower transparency) in Las Vegas Bay as measured by Secchi disc depth was statistically significant ($p < 0.05$) (Figure 4.1.3-1) and probably due to the influence of river inflows to this fixed station which has not changed as the lake level has dropped. Water clarity at open water stations was relatively higher. A slight increasing trend (greater transparency) was observed at the open water station in Overton Arm, although this trend was not statistically significant (Figure 4.1.3-1). Overall, Lake Mead has high water clarity, ranging from 6 m to 18 m Secchi depth as measured at open water locations (Figure B-5).

Lake Mohave also has good water clarity, with Secchi depth measurements ranging from 3 m to 20 m. Willow Beach, located closest to the Hoover Dam discharge had the lowest water clarity amongst

all sampled stations in Lake Mohave, though water clarity improved with distance from the discharge (Figure 4.1.3-2; Figure B-5).

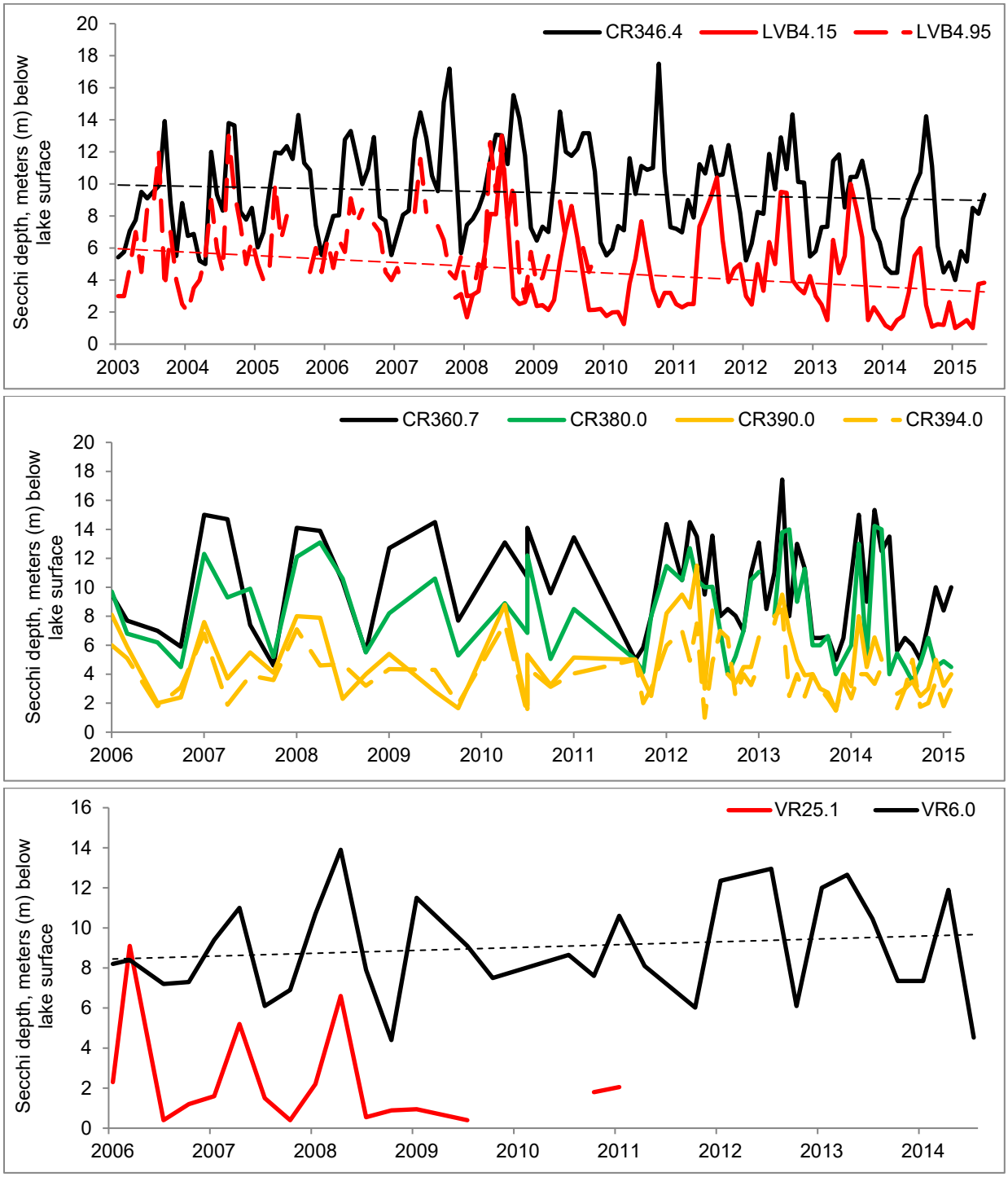


Figure 4.1.3-1. Time series (monthly averages, 2003–2015) of Secchi depth data collected at Lake Mead from Las Vegas Bay stations (LVB4.15 and LVB4.95), Boulder Basin station (CR346.4), Colorado River mainstem stations (Virgin Basin -CR360.7, Temple Basin -CR380.0, and Gregg Basin -CR390.0 and CR 394.0), and Overton Arm stations (VR25.1 and VR6.0). See Figure B-3 for locations of listed stations.

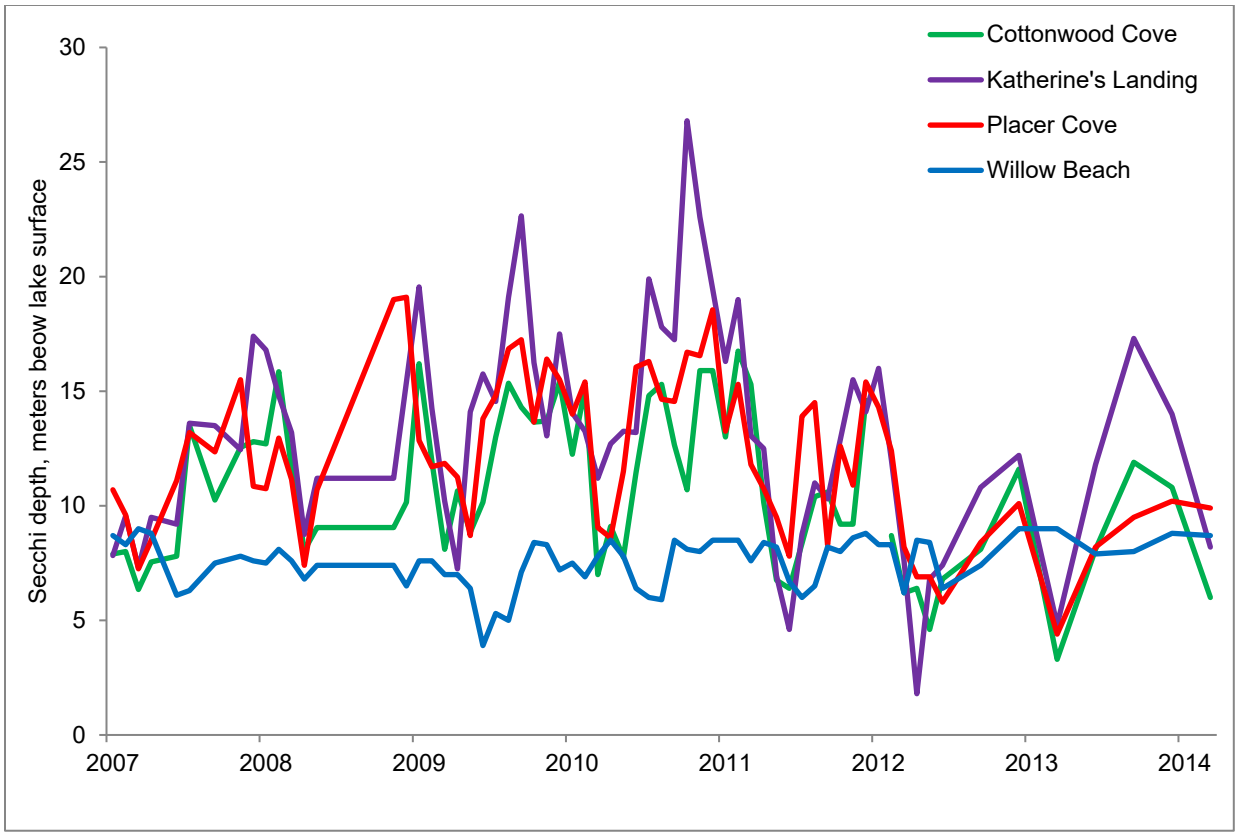


Figure 4.1.3-2. Time series (monthly averages, 2007–2014) of Secchi depth data collected at Lake Mohave from Willow Beach (CR329.7), Placer Cove (CR316.34), Cottonwood Cove (CR298.5W.5), and Katherine's Landing (CR278.0) monitoring stations. See Figure B-5 for locations of listed stations.

Based on the Burns et al. (1999) categorization for trophic status in relation to Secchi depth, the current status of lakes Mead and Mohave would be considered between oligotrophic and mesotrophic (Table 4.1.3-5). This corresponds to historic classifications for Lake Mead as mildly mesotrophic based on several classification indices (Vollenweider, 1970; Carlson, 1977).

Table 4.1.3-5. Reference conditions used to determine the status and trend of trophic level.

	Condition Status		
Parameter	**Significant Concern***	**Moderate Concern***	**Good***
Chlorophyll *a*	>29.5 µg/L	>5–29.5 µg/L	Growing season (April 1-September 30) averages ≤ 5 µg/L. No > 5% samples have single value > 10 µg/L (Open water locations, not including tributary confluences and Las Vegas Bay)

Chlorophyll a

Chlorophyll *a* concentrations were higher at the stations located closer to tributary confluences; in this system tributaries provide the main source of nutrients to Lake Mead (e.g. LVB4.15 and LVB4.19 in Las Vegas Bay, CR394.0 and CR390.0 in Gregg Basin, and VR25.1 in Overton Arm) (Figure 4.1.3-3 and Figure 4.1.3-4 and Figure 4.1.3-5). A spike in chlorophyll *a* concentration was recorded along the Colorado River main stem stations in August 2013, with peak concentrations at 20 µg/L in Gregg Basin (Figure 4.1.3-4). Chlorophyll *a* concentrations dropped off quickly with distance from the Colorado River confluence (Figure 4.1.3-4). A single sample collected in July 2008 from Overton Arm (VR6.0) station exceeded <5µg/L but not > 10 µg/L, thus remained within the NDEP open water standard for chlorophyll *a* (Figure 4.1.3-5).

In 2001, a major algal bloom occurred in Las Vegas Bay and Boulder Basin, resulting in significantly elevated chlorophyll *a* levels in individual samples collected from the Las Vegas Bay (>60 µg/L) and Boulder Basin (>500 µg/L) stations (Figure 4.1.3-3). The 2001 algal bloom in Lake Mead has been attributed to the effects of a combination of factors; lowering lake levels, exposed tributary delta areas, nutrient loading, the position of inflows in the water column due to warm spring rains, and construction activities in the Las Vegas Wash (LaBounty & Burns, 2005). In addition, Rosen et al. (2012) attributed the increased phosphorus concentrations at surface water during the spring warming of the lake to an important factor driving factor of the 2001 algal bloom.

Since the 2001 bloom, chlorophyll *a* has been decreasing in Lake Mead as a result of improved wastewater treatment processes for effluent streams entering the park (NPS, 2014). In response to the bloom, wastewater dischargers voluntarily agreed to remove phosphorus year-round through multiple treatment processes (Rosen et al., 2012). By 2005, the dischargers had optimized their treatment plants to reduce phosphorus loading significantly. Peak concentrations of chlorophyll *a* have been less than 25 µg/L in Las Vegas Bay and less than 5 µg/L in Boulder Basin in most years following the 2001 algal bloom (Figure 4.1.3-3). The wastewater treatment efforts have significantly improved the water quality and trophic status of Boulder Basin.

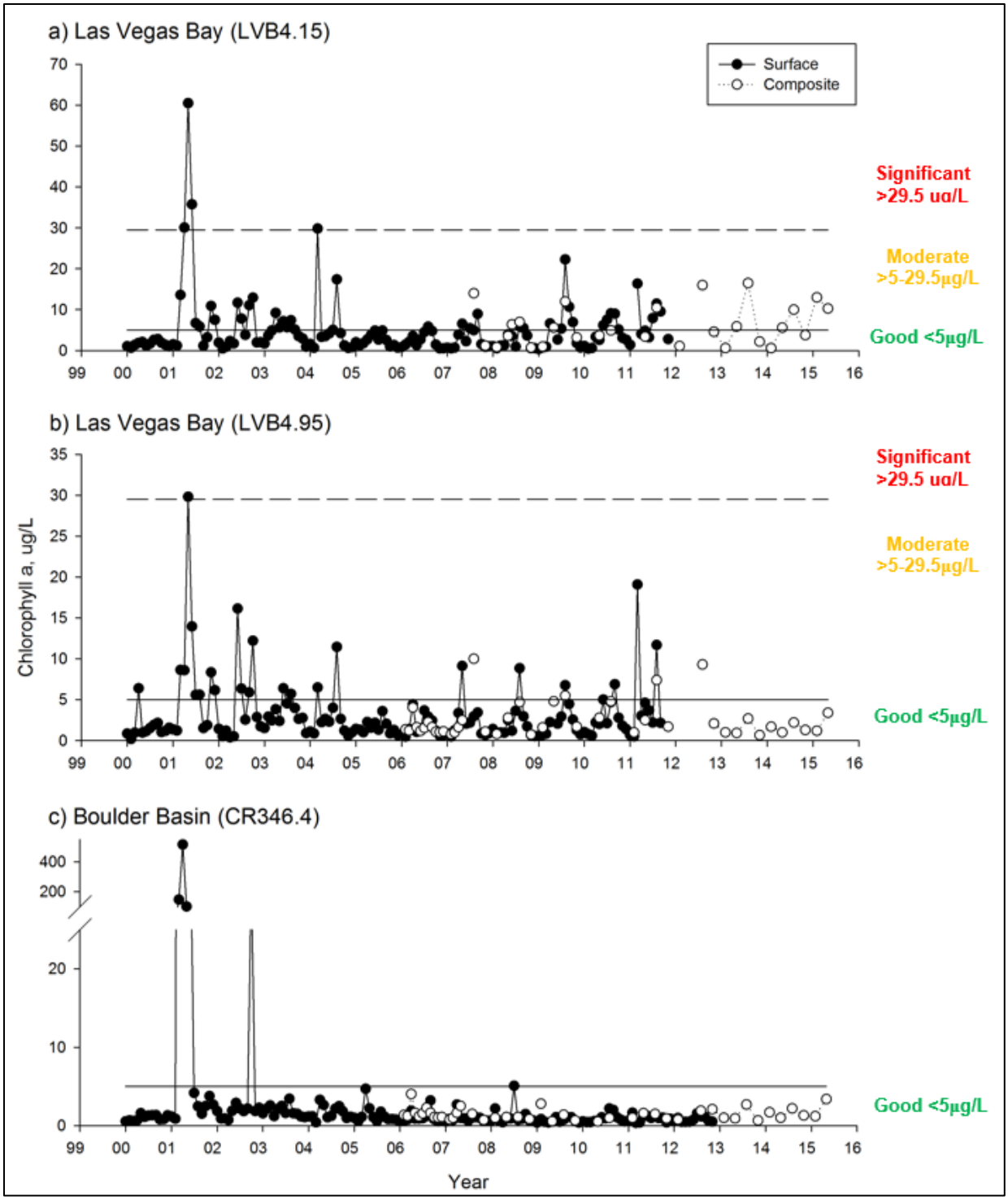


Figure 4.1.3-3. Monthly surface and composite chlorophyll *a* concentrations measured at Las Vegas Bay (LVB4.15 and LVB4.95) and Boulder Basin (CR346.4), 2000–2015. Stations ordered by distance from the Las Vegas Wash confluence.

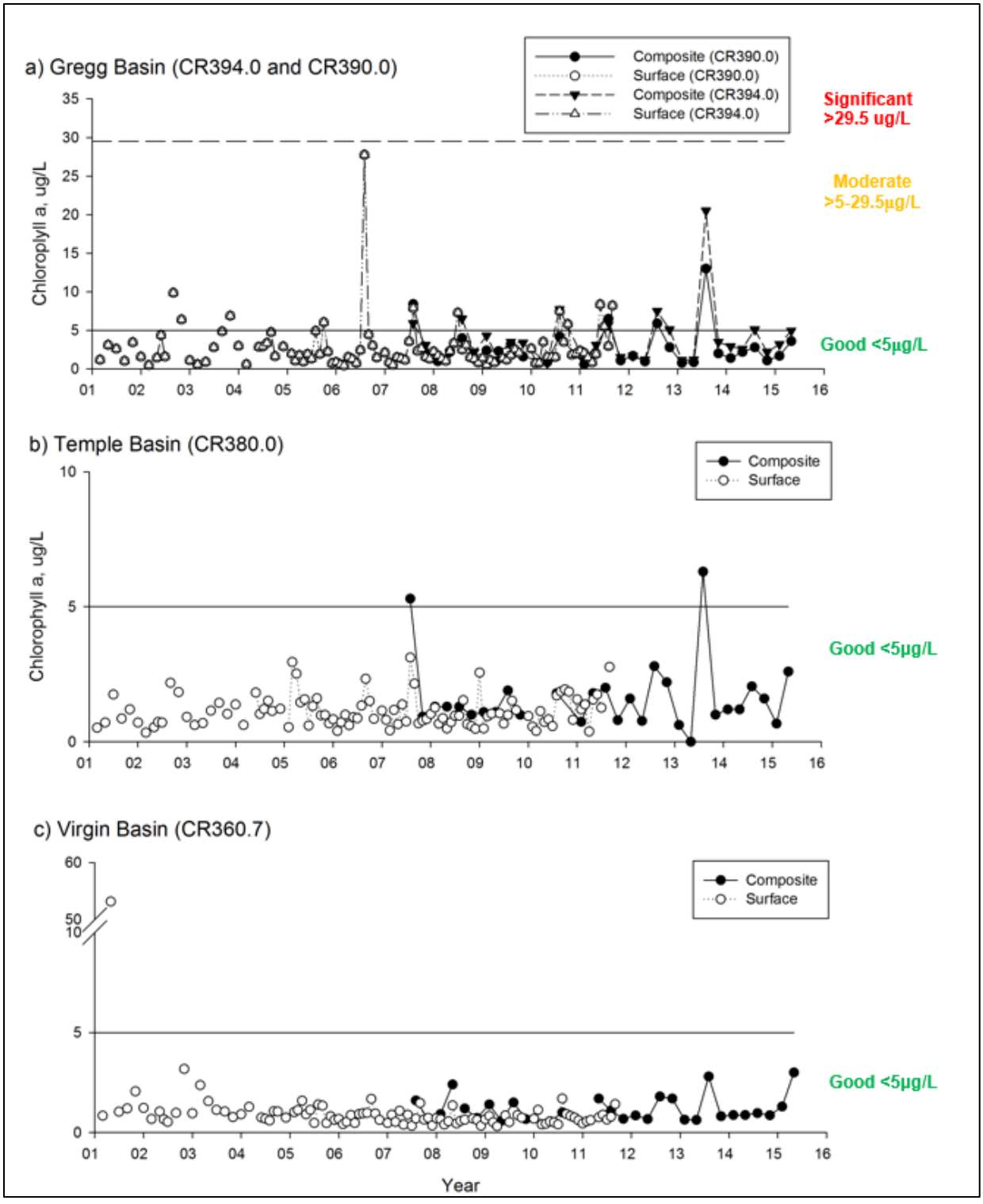


Figure 4.1.3-4. Monthly surface and composite chlorophyll *a* concentrations measured at Colorado River main stem stations, Gregg Basin (CR394.0 and CR390.0), Temple Basin (CR380.0), and Virgin Basin (CR360.7). Stations ordered by distance from Colorado River confluence.

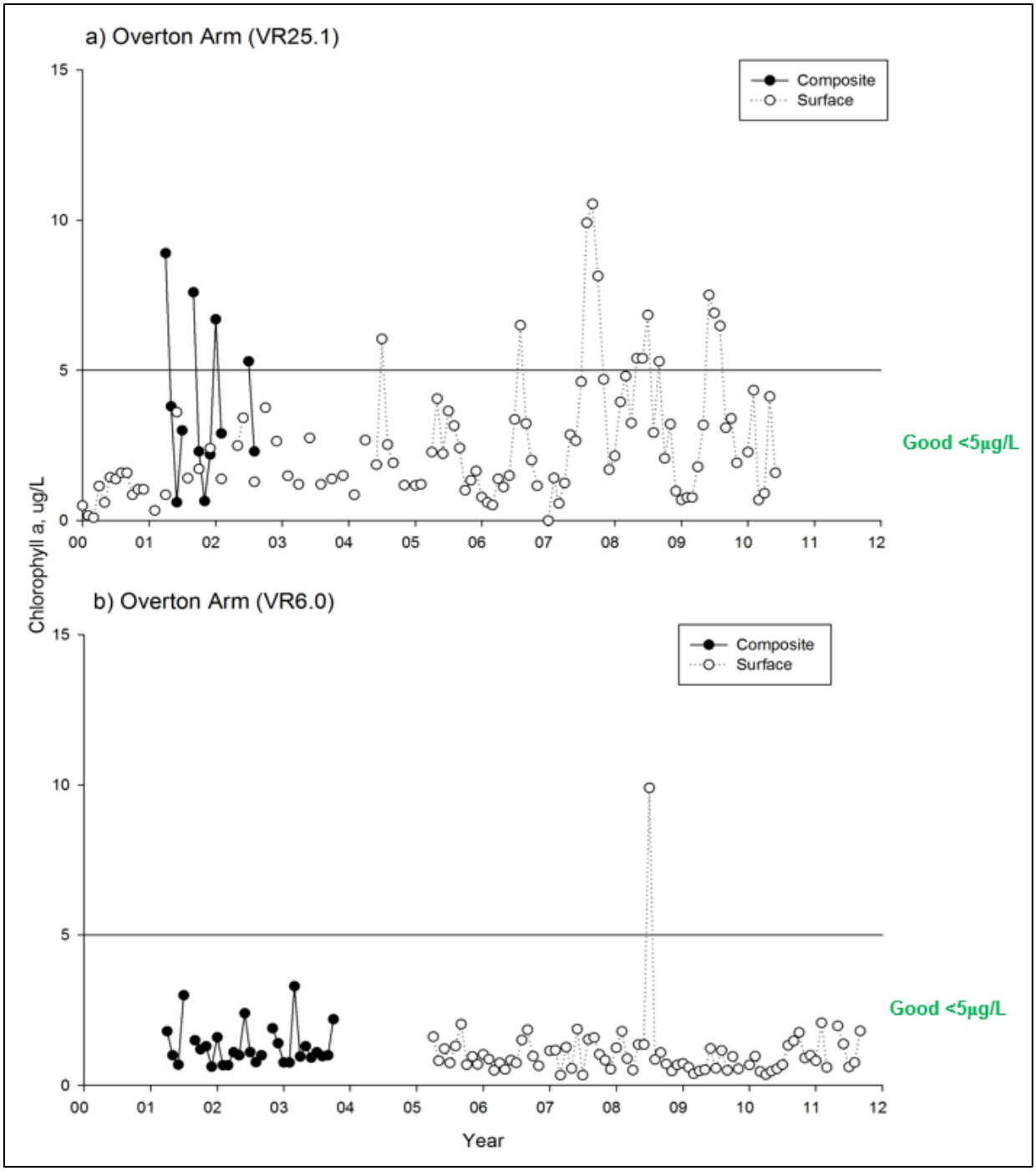


Figure 4.1.3-5. Monthly surface and composite chlorophyll *a* concentrations measured at two Overton Arm stations, VR25.1 (2000–2010) and VR6.0 (2001–2012). Stations ordered by distance from Virgin and Muddy confluences.

For Lake Mohave, chlorophyll *a* data is only available from January, May, and July 2014 and values ranged from 0.4 to 1.6 µg/L (Figure 4.1.3-6).

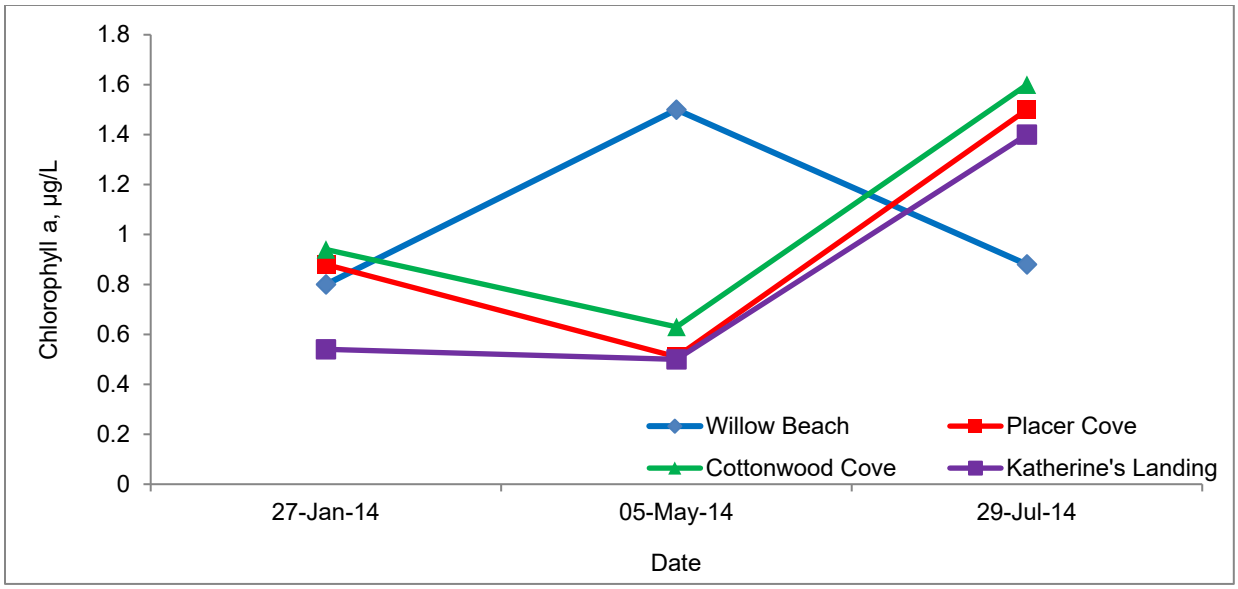


Figure 4.1.3-6. Chlorophyll *a* concentrations measured at Lake Mohave in 2014. Individual sample was collected at each location on listed dates (BOR data).

Overall chlorophyll *a* concentrations measured from Lake Mead were within the NDEP water quality standard (≤ 5 µg/L) and the USEPA NLA "good" range (≤ 7.79 µg/L) for open water locations with concentrations ranging from 1 to 5 µg/L in most years, except during the 2001 algal bloom in Las Vegas Bay and Boulder Basin (Figure 4.1.3-6). Based on the Burns et al. (1999) categorization for trophic status as a factor of chlorophyll *a* concentrations, the current status of Lake Mead would be considered between oligotrophic and mesotrophic (Table 4.1.3-7). This corresponds to historic classifications for Lake Mead as mildly mesotrophic based on several classification indices (Vollenweider, 1970; Carlson, 1977).

Table 4.1.3-7. A summary of basin-specific conditions and trends for Secchi depth and chlorophyll *a* measurements (See Figure B-3 for locations of listed sites).

Locations: Basins and Lakes	Measurements	
	Secchi depth	Chlorophyll a
Las Vegas Bay (LVB4.15/4.95)	↓	↔
Boulder Basin (CR346.4)	↔	↔
Virgin Basin (CR360.7/361.8)	↔	↔

Table 4.1.3-7 (continued). A summary of basin-specific conditions and trends for Secchi depth and chlorophyll *a* measurements (See Figure B-3 for locations of listed sites).

Locations: Basins and Lakes	Measurements	
	Secchi depth	Chlorophyll a
Temple Basin (CR380.0)		
Gregg Basin (CR394.0/390.0)		
Overton Arm (VR6.0/25.1)		
Lake Mead Overall Condition Status/Trend		
Lake Mohave (CR329.7/316.34/298.5W.5/278.0L)		

Trophic Index (Burns Trophic Level Index)

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 (Rosen et al., 2012).

As with other indicators of water quality, the Boulder Basin's TLI scores reflect efforts in wastewater treatment enhancement during the past decade. Basin-wide, the evaluation (Figure 4.1.3-7) showed that TLI scores have improved since 2001, 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) (Rosen et al., 2012). TLI indices computed for sampling locations near Las Vegas Wash inflow have reflected a eutrophic status (TLI values of 4.99–6.08 between 2000 and 2004) at some times of the year, but this level of productivity declined rapidly as the inflow is diluted by Boulder Basin (LaBounty & Burns, 2005).

TLI scores between 2005 and 2014 from CR346. 4 located in the outer Boulder Basin (see Figure B-3 for location map) showed that outer Boulder Basin has maintained oligotrophic status in the past 10 years from improvement in trophic status since 2004 (Figure 4.1.3-8).

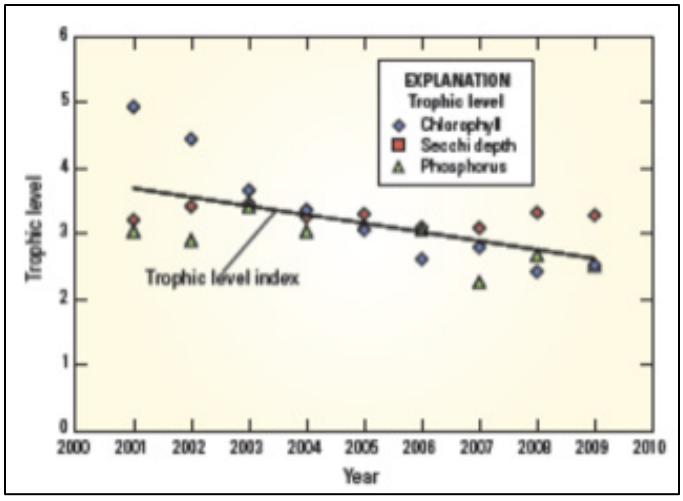


Figure 4.1.3-7. Burns Trophic Level Index (TLI) averaged scores for Lake Mead, 2000–2010, from three locations within Boulder Basin, including sampling sites LVB6.7, INTAKE (location before 2010), and CR346.4 (see Figure B-3 for location map). The TLI trend has been downward from 2000 to 2010, indicating that water quality is improving. Reprint from Rosen et al, 2012.

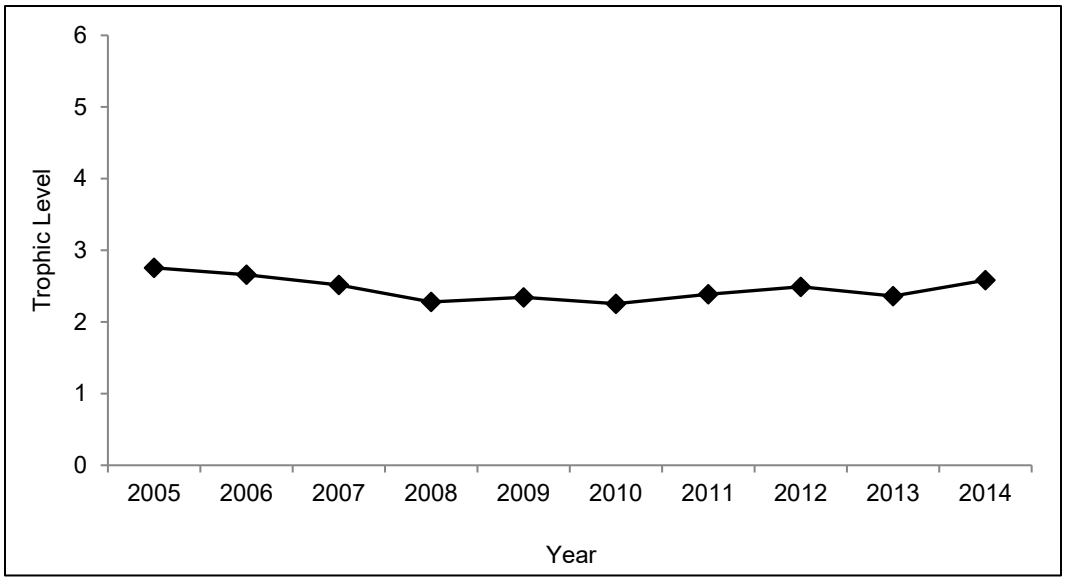


Figure 4.1.3-8. Burns Trophic Level Index scores from outer Boulder basin station CR346.4, 2005–2014 (see Figure B-3 for location map).

Assessment Confidence and Key Data Gaps

Assessment confidence for Secchi depth and chlorophyll *a* concentrations is high due to the following reasons: (1) there are regular and standardized sampling protocols established for both of these variables, (2) with long-term dataset that continue to be collected, and (3) reference conditions for these variables have long been established within the scientific literature.

Assessment confidence for the trophic index is moderate to low. The fixed sampling locations have changed since 2010 due to lake level changes. Thus, the historic TLI calculations may no longer

representative of the trophic level condition in Boulder Basin. For example, increased chlorophyll concentrations have been recorded at inner Boulder Basin in Las Vegas Bay. Evidence has suggested that these increases may be a result of a decline in water levels at Lake Mead, moving the confluence of Las Vegas Wash closer to some sampling stations instead of being indicative of broader trophic-level changes. See section 4.3.3 for discussion on alluvial delta changes. Furthermore, the INTAKE sampling station was relocated in early 2016 to reflect the relocation of a new drinking water intake in Lake Mead. Updated analysis using data collection from only the outer Boulder Basin station (CR346.4) was completed to show recent trend between 2005 and 2014. Completed annual chlorophyll *a* concentration data from 2015 and 2016 were not available at the time when this analysis was completed.

Key data gaps identified for these parameters include the need for increased monitoring in the Lake Mohave system.

4.1.4. Tributary Condition

A summary of the parameters used assess tributary condition are shown in Table 4.1.4-1.

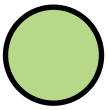
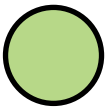
Table 4.1.4-1. Overall assessment (condition status and trend) of the indicator tributary condition.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Tributary Physical Characteristics	• Temperature • dissolved oxygen (DO) • pH • conductivity		Parameter values examined were within historical range of variability based on long-term annual means. No changes were detected for desirable parameters (e.g. DO).
Tributary Nutrient Load	• Total nitrogen (TN) • nitrate-nitrite as nitrogen (NO_3+NO_2-N) • ammonia as nitrogen (NH_3-N) • total phosphorus (TP); • dissolved orthophosphates (PO_4-P).		Downward trends were observed for nutrient concentrations suggesting improvement in condition of tributary nutrient load to Lake Mead.

Table 4.1.4-1 (continued). Overall assessment (condition status and trend) of the indicator tributary condition.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Tributary Inflows	Total annual inflow volume (million acre-feet, maf) to Lake Mead from the • Colorado River • Muddy Rier • Virgin River • Las Vegas Wash		Overall, Lake Mead has been experiencing a consistent downward trend of water level due to persistent drought and over-allocation of water on the Colorado River. These decreases are due to the lack of surplus inflow from Lake Powell through the Colorado River as a result of changing hydrologic regime in the Colorado River Basin and reduced inflows from the Virgin and Muddy Rivers. Increase in inflow volume from Las Vegas Wash is the result of increase return flow by SNWA and increase in effluent discharge and urban runoff from nearby municipalities. As return flow, Las Vegas Wash inflow has limited effect on Lake Mead's water level. Lake Mohave is operated as a regulated dam with discharge from Hoover Dam as its only significant inflow. Estimated inflow has been generally stable and unchanging across years, except during flood periods.
Tributary Contaminants	• Selenium (Se) • Perchlorate (ClO_4)		While Perchlorate entering the Las Vegas Wash remained above NDEP provisional action level for safe drinking water, concentrations have been reduced approximately 90% since 1997 with NDEP remediation efforts. Monthly measurements of total selenium concentration at the Las Vegas Wash inflow exceeded the USEPA criterion for protection of aquatic life in lotic water (3.1 µg/L) between June and August, 2016 but the exceedance was slight (7% exceedance in August) Measurements from the Colorado, Virgin, and Muddy Rivers were below the criterion in 2015 and 2016. Selenium concentrations at all locations show increasing trends between August 2015 and September 2016. No historical data were available for long-term trend assessment. No recent record for Se concentration at inflow to Lake Mohave.

Table 4.1.4-1 (continued). Overall assessment (condition status and trend) of the indicator tributary condition.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Sedimentation	• Suspended sediment discharge by tributaries • Nutrient loading associated with sediment (qualitative description if data not available) • Contaminant loading associated with sediment (qualitative description if data not available)		Since construction of Glen Canyon Dam, there has been an overall low sediment and nutrient load from tributaries into lakes Mead and Mohave. Reduced inflows also contributed to reduced sediment and nutrient loads.
Land Use within Watershed	• Developed and non-developed acres		Lake Mead NRA is largely surrounded by public lands. Most land ownership zoning types are compatible with park purposes. No comparable historical data available to justify a trend in the condition at this time.
	• Urbanized miles of tributaries		Mixed urbanized and non-urbanized tributaries miles along Las Vegas Wash and Muddy River. Virgin River within Halfway Wash Watershed and over 500 miles of Colorado River before entering Lake Mead are not urbanized. No quantitative data available for comparison to derive a trend.
Tributary Condition overall			–

Tributary Physical Characteristics and Nutrient Load

Table 4.1.4-2 shows the parameters used to assess tributary physical characteristics and nutrient load.

Table 4.1.4-2. Assessment outcome (condition status and trend) for Tributary physical characteristics and nutrient load.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Tributary Physical Characteristics	• Temperature • Dissolved oxygen (DO) • Conductivity • pH		Parameter values examined were within historical range of variability based on long-term annual means. No changes were detected for desirable parameters (e.g. DO).

Table 4.1.4-2 (continued). Assessment outcome (condition status and trend) for Tributary physical characteristics and nutrient load.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Tributary Nutrient Load	• Total nitrogen (TN) • Total phosphates (TP) • Orthophosphates (PO4-P) • Nitrate-nitrite as nitrogen (NO3+NO2-N) • Ammonium as nitrogen (NH3-N)		Downward trends were observed for nutrient concentrations suggesting improvement in condition of tributary nutrient load to Lake Mead.

Description

Streams and rivers transport energy and nutrients to lakes within a watershed, which in turn, support a variety of ecosystem processes and services. They are generally sensitive to stressors, both at the local and regional watershed levels. Therefore, streams and rivers are often monitored to determine long-term conditions and trends within a watershed. Lake Mead is fed by the Colorado River and three smaller tributaries: The Virgin and Muddy Rivers and Las Vegas Wash. Lake Mohave spans between Hoover and Davis Dam where outflow from Hoover Dam is the main water supply for Lake Mohave (Holdren & Turner, 2010). Urban stormwater and treated wastewater from increasing urbanization adjacent to park lands as well as agricultural run-off, aquatic invasive species, and altered riverine flow regimes in the Colorado River, Muddy River, and Virgin River are all potential sources for a wide range of pollutants, including endocrine disrupting compounds, pesticides, fertilizers, and hydrocarbons (NPS, 2014).

Physical characteristics and nutrient load measurements typically collected for water quality assessment are examined to assess the condition of these tributaries entering lakes Mead and Mohave. For detailed descriptions and background of the physical characteristics and nutrient load measurements examined in this section, see section 4.1.1.

Data and Methods

Table 4.1.4-3 shows the data and methods used to assess tributaries.

Table 4.1.4-3. Data methods to determine used in the assessment of Tributaries.

Indicator(s)	Measurement(s)	Scale of Analysis
Tributary Physical Characteristics	• Temperature • Dissolved oxygen (DO) • Conductivity pH	Tributary

Table 4.1.4-3 (continued). Data methods to determine used in the assessment of Tributaries.

Indicator(s)	Measurement(s)	Scale of Analysis
Tributary Nutrient Load	• Total nitrogen (TN) • Total phosphates (TP) • Orthophosphates (PO4-P) • Nitrate-nitrite as nitrogen (NO3+NO2-N) Ammonium as nitrogen (NH3-N)	Tributary

Average physical stream reach characteristics and nutrient concentrations measured directly at the inflows were derived from continuing studies conducted by the BOR's Technical Service Center's research program the inflows of the Colorado (CRLM_A and _B), Virgin (VRLM_B), and Muddy (MRLM_B) Rivers. SNWA Upper Lake Mead monitoring program collects physical and nutrient measurements from the Las Vegas Wash inflow (LWLVB), the Colorado, Virgin, and Muddy Rivers. Information on all stream/tributary stations used to elevate the stream reach conditions is presented in Table 4.1.4-4 and Figure B-3. The units used for measurements were dependent on parameters analyzed.

Table 4.1.4-4. Reference conditions used in the assessment of tributaries.

	Condition Status		
Measurement(s)	**Significant Concern***	**Moderate Concern***	**Good***
• Temperature • Dissolved oxygen (DO) • Conductivity • pH	Consistently beyond historical range of variability based on long-term annual means and/or upward trends for undesirable parameters (e.g. nutrients and temperature)	Occasionally beyond historical range of variability based on long-term annual means.	Within historic range of variability based on long-term annual means and/or upward trends for desirable parameters (e.g. DO) and downward trends for undesirable parameters (e.g. nutrients and temperature)

Condition and Trend

Tributary Physical Characteristics

Temperature

The Colorado River is the coldest tributary entering Lake Mead with water temperature averages at approximately 15°C between 2001 and 2009 (Figure 4.1.4-1). Since cold water is denser than warm water, the Colorado River water typically flows along the lake bottom into Gregg Basin, which has limited nutrient availability and algal productivity in the upper levels of the water column. Las Vegas Wash enters Lake Mead with the warmest water (Figure 4.1.4-1). Relative to lake temperatures, Las Vegas Wash temperatures vary throughout the year and therefore have entered the lake either as an overflow, interflow, or underflow depending on the season (Rosen et al., 2012). All recent water temperatures (2010–2015) recorded at the four tributaries were within historical range of variability based on 10-year average (2001–2009). No significant trend was observed.

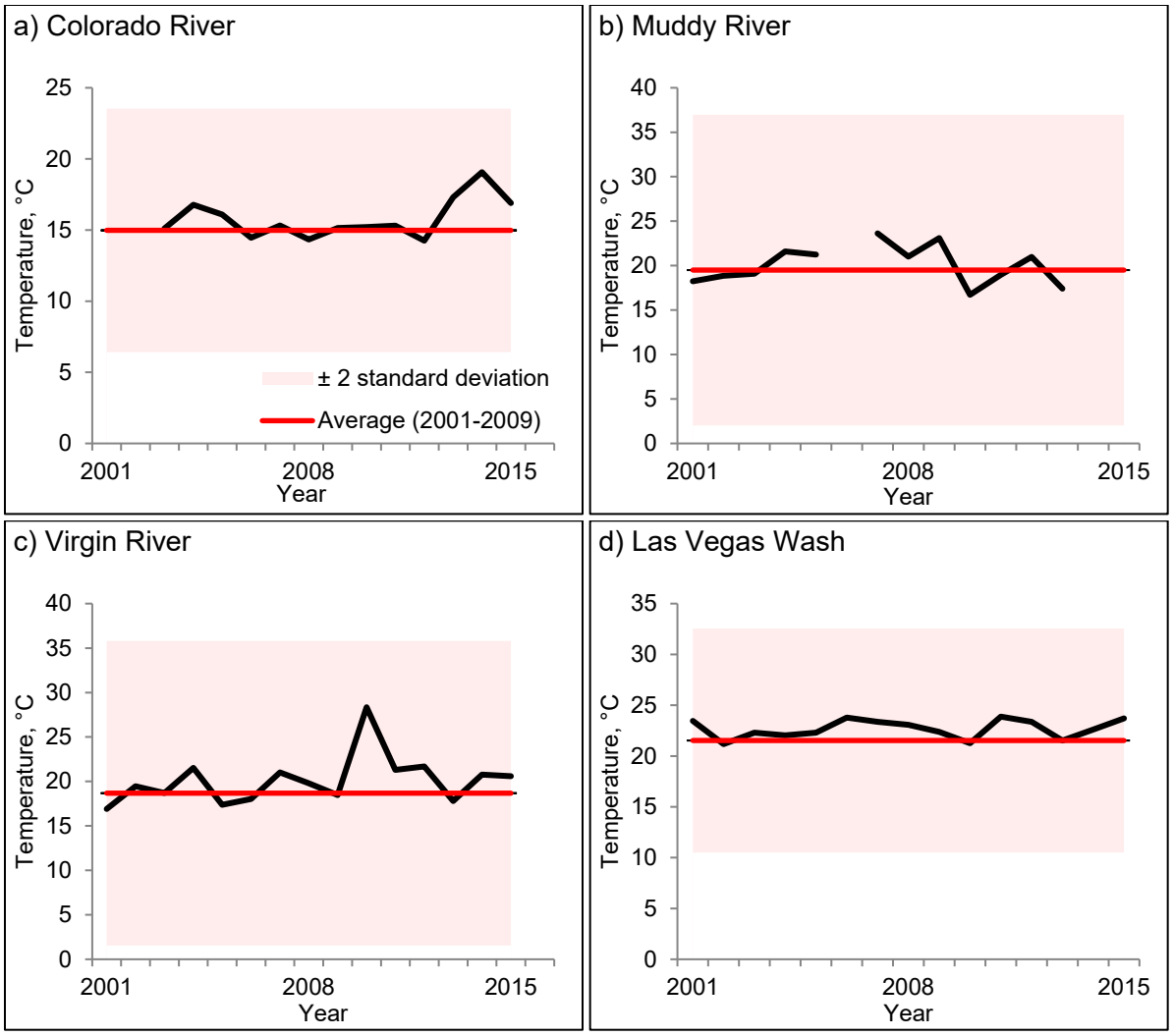


Figure 4.1.4-1. Comparison of 2001–2015 water temperature (Black line: yearly average pooled from all depths) measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average.

Dissolved oxygen (DO)

Dissolved oxygen concentration in lake water is subject to fluctuations caused by variation in temperature, photosynthetic activity, and stream flow (Holdren et al., 2008). Short term spikes in DO concentrations were recorded at Colorado and Virgins Rivers in 2013 (Figure 4.1.4-2). Recent DO concentrations measured at the four tributaries were within historic range of variability calculated based on the long-term annual mean (2001–2009) in most years. No significant trend is observed.

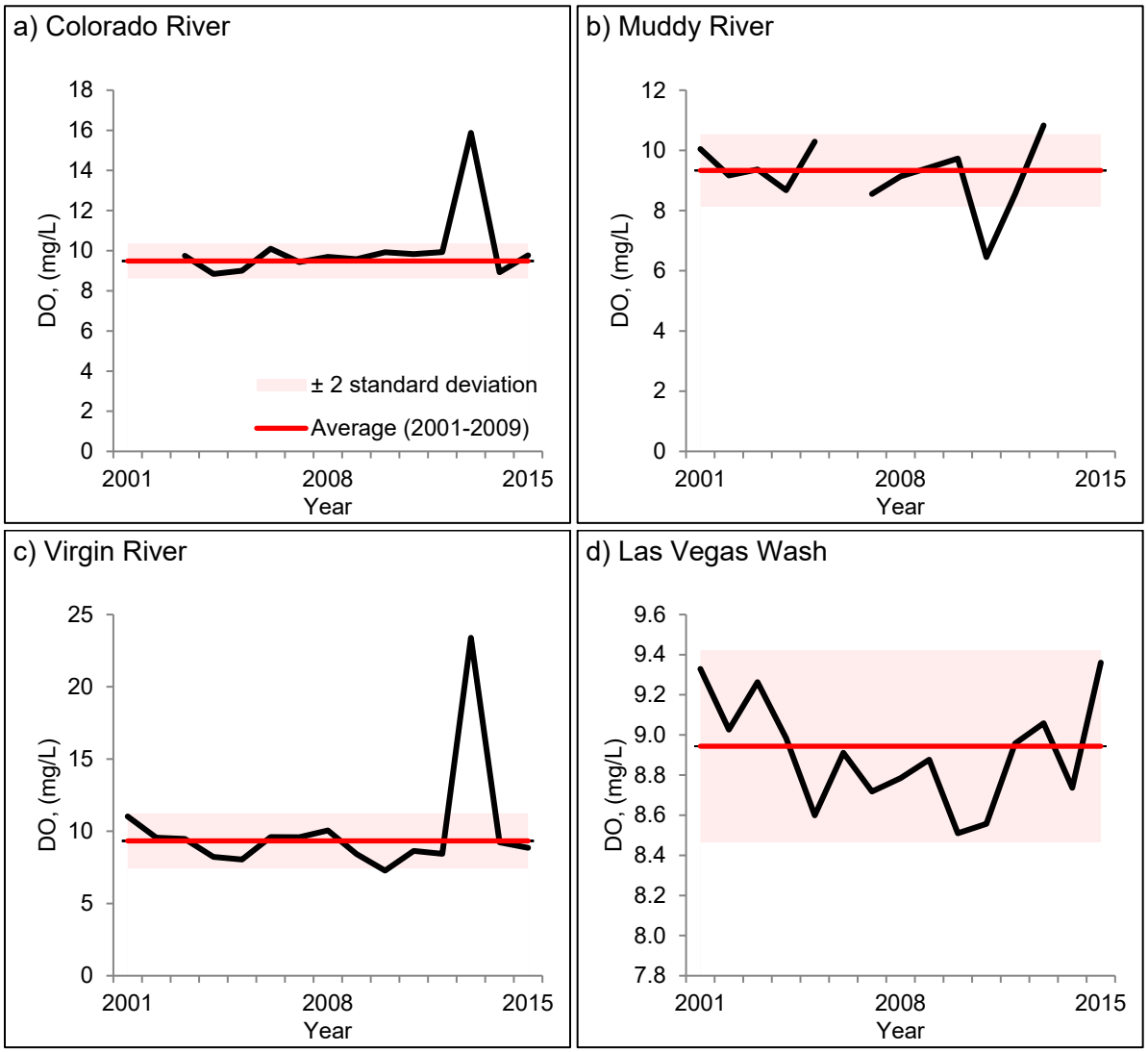


Figure 4.1.4-2. Comparison of 2001–2015 dissolved oxygen (DO; Black line: yearly average pooled from all depths) measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average.

Conductivity

Conductivity measures the ability of water to conduct electrical current and provides an estimate of the concentration of total dissolved solids present in water (see section 4.1.1.1). Conductivity is also a traceable feature useful in tracking the path of one water source flowing into another. The Colorado

River inflow has had significantly lower conductivity than the other three tributaries (Figure 4.1.4-3). Low conductivity water from the Colorado River has often been detected at the Hoover Dam, more than 60 miles downstream (Rosen et al., 2012). Highest overall conductivity was measured in the Virgin River but has shown a decreasing trend since 2009 with recent levels significantly below the 2001–2009 average (Figure 4.1.4-3).



Figure 4.1.4-3. Comparison of 2001–2015 conductivity (Black line: yearly average pooled from all depths) measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average.

pH

pH can affect chemical and biological reactions in lake and river systems. The recommended water quality criterion of pH for the protection of aquatic life is between 6.5 and 9 (USEPA, 2016a). All pH measurements between 2001 and 2015 from all locations fell within the recommended range (Figure 4.1.4-4). Recent pH levels measured at the four tributaries were in general within historical range of variability calculated based on the 2001–2009 annual mean. pH levels in the water from the Colorado and Virgin rivers have been increasing since 2001 (Figure 4.1.4-4).

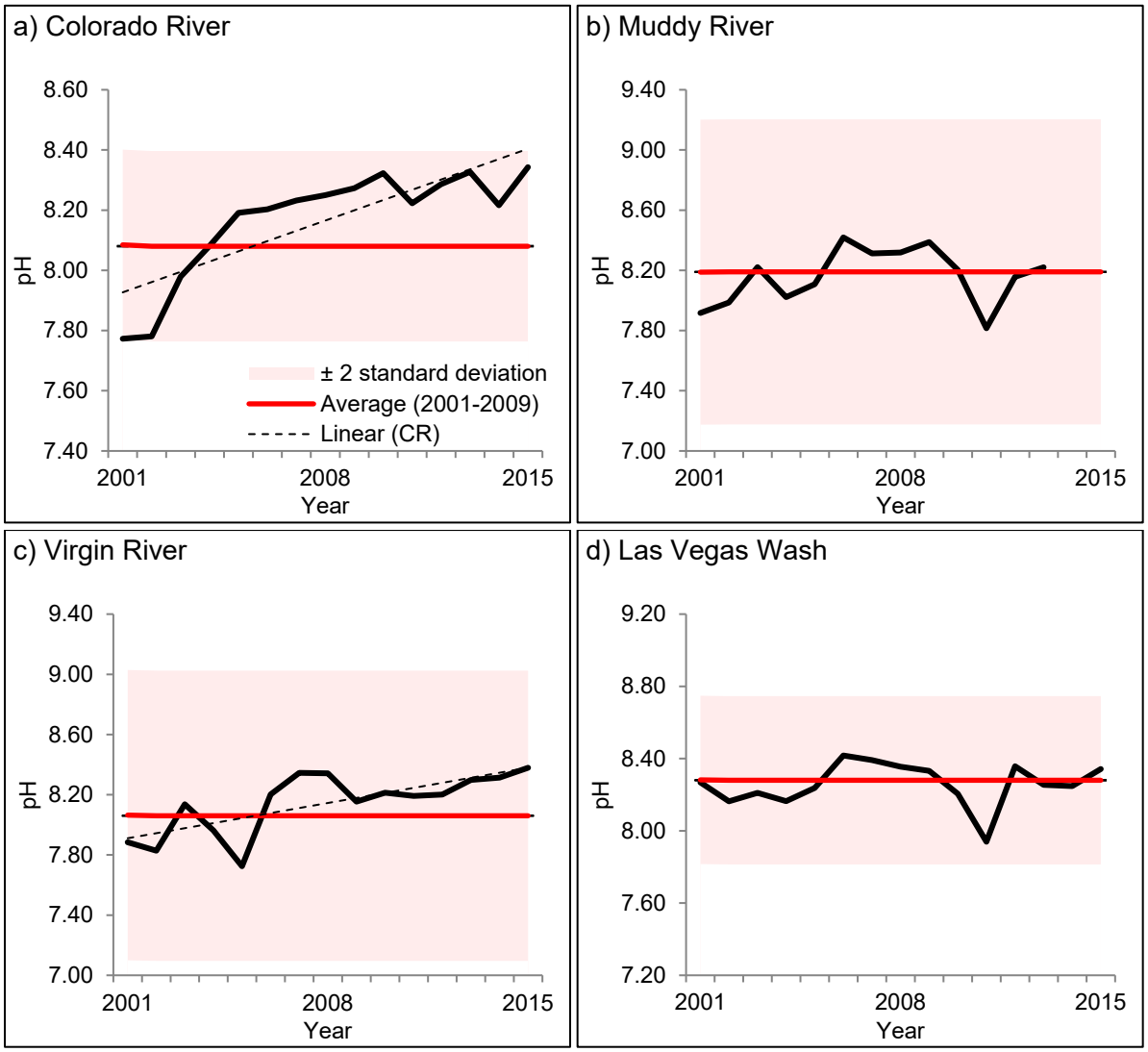


Figure 4.1.4-4. Comparison of 2001–2015 pH (Black line: yearly average pooled from all depths) measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2001–2009 average.

Tributary Nutrient Load

Tributary inflows are the main nutrient sources for Lake Mead. Higher nutrient concentrations have often been detected at areas near the inflows. Tributary inflows enter Lake Mead's water column at the level at which their density, determined by water temperature and conductivity, is equal to the

density of the receiving water. All tributaries entering Lake Mead have higher nutrient concentrations than the receiving water of the Lake Mead. The level at which the inflows enter Lake Mead would determine nutrient availability and algal productivity (Holdren & Turner, 2010; Rosen et al., 2012).

Nitrogen

Nitrogen can exist in oxidized forms, such as nitrate (NO_3-N) or nitrite (NO_2-N), or in reduced forms, such as ammonia (NH_3-N) and organic nitrogen. The most common form of nitrogen in surface waters is NO_3-N, while as ammonia is predominantly found in low oxygen environments (Holdren et al., 2008).

The Las Vegas Wash inflow has had significantly higher NO_3+NO_2-N concentrations than any other inflows (Figure 4.1.4-5). Limited data were available from the SNWA database for the Las Vegas Wash inflow station. However, by comparing recent concentrations (2011–2015) with the historical average (2001–2009) and the annual average from 2005 (17.4 mg/L), a significant decline in NO_3+NO_2-N concentrations has occurred (Figure 4.1.4-5). Decreasing trends are also observed at the Colorado and Virgin rivers inflows. Low NO_3+NO_2-N concentrations (< 0.052 mg/L) were recorded at Muddy River inflow.

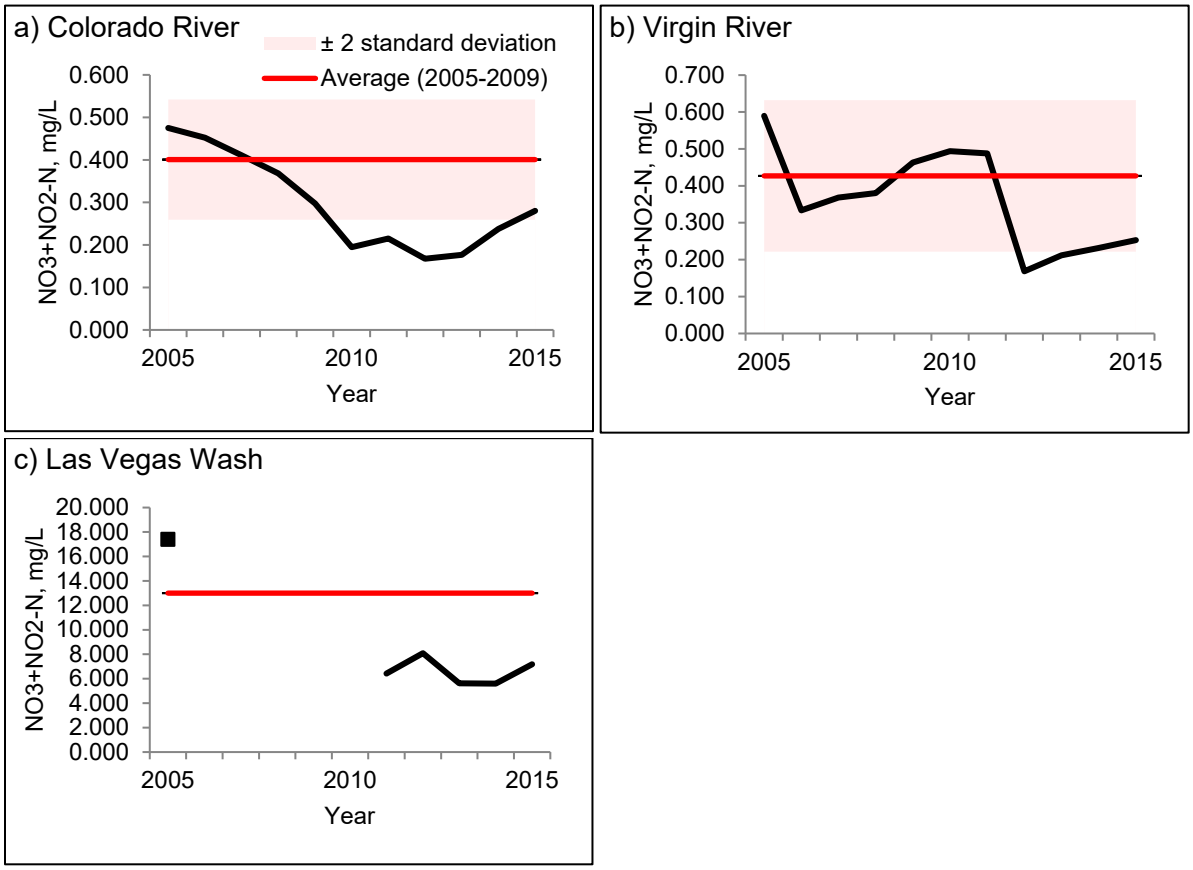


Figure 4.1.4-5. Comparison of 2005-2015 nitrite and nitrate as nitrogen concentrations (NO_3+NO_2-N; Black line: yearly average from surface) measured in the Colorado and Virgin rivers and Las Vegas Wash to 2001–2009 average. The black square (c) represents a onetime measurement collected in 2005 at Las Vegas Wash.

NH_3-N concentrations in the Colorado inflow were less than 0.1 mg/L and have decreased in recent years (Figure 4.1.4-6). NH_3-N concentrations in recent years from Muddy and Virgin rivers and Las Vegas Wash have also decreased (Figure 4.1.4-6).

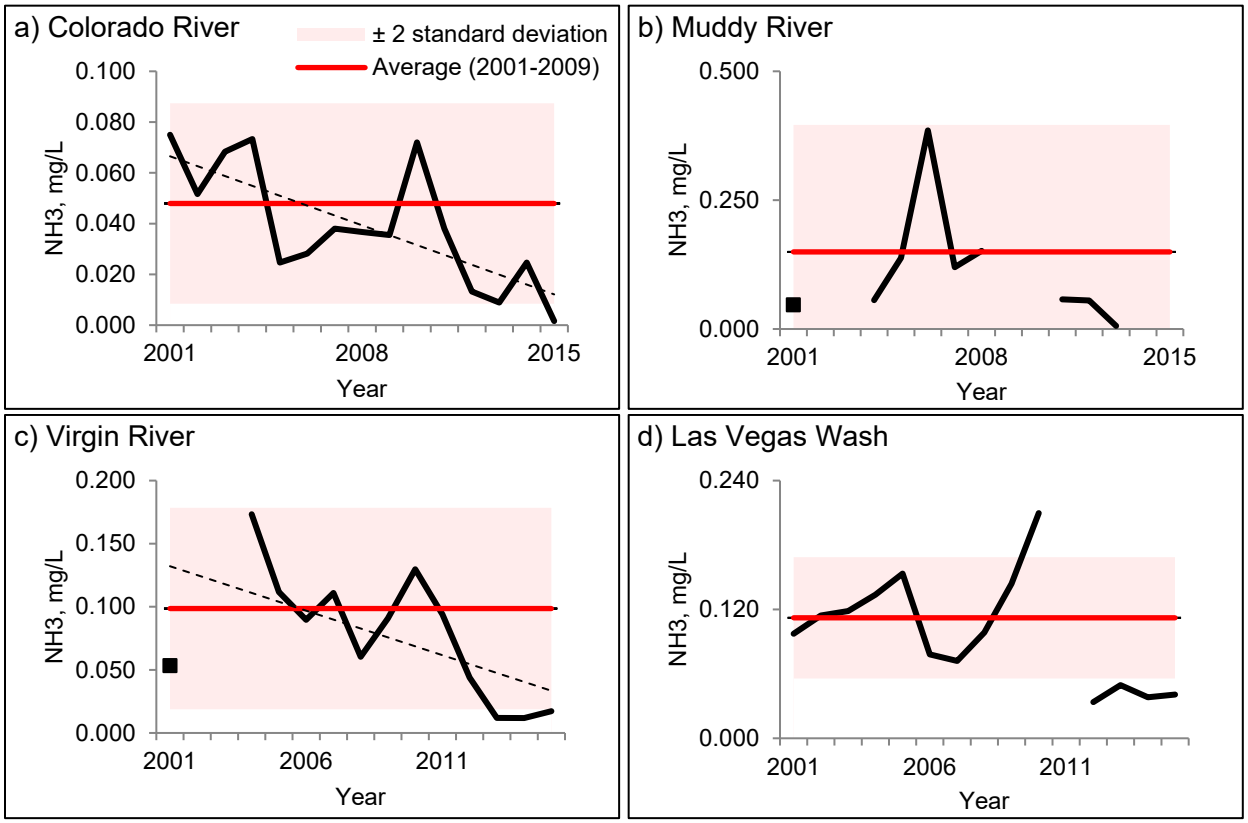


Figure 4.1.4-6. Comparison of 2001-2015 ammonia nitrogen concentrations (NH_3-N, yearly average from surface) measured in the Colorado, Muddy, and Virgin Rivers and Las Vegas Wash to 2001–2009 average. The black squares (b and c) represent onetime measurements.

Total nitrogen (TN) concentrations at Colorado, Virgin, and Muddy rivers inflows generally ranged from less than 0.5 mg/L to 0.8 mg/L, with higher concentrations measured at Muddy and Virgin River inflows. Total nitrogen (TN) concentrations at Colorado and Virgin rivers between 2010 and 2015 were lower than the 2001–2009 average (Holdren & Turner, 2010). Las Vegas Wash had significantly higher TN concentrations relative to other tributaries. TN concentrations at Las Vegas Wash have decreased in recent years (Figure 4.1.4-7).

The USEPA eutrophic criteria for protection against the adverse effects of nutrient over-enrichment in rivers and streams for TN at the Xeric West Ecoregion where Lake Mead is located were between 0.22 to 0.90 mg/L (USEPA, 2015a). Colorado and Virgin River inflows of TN concentrations as measured in 2015 were both within the criteria range. No TN measurements were taken at the Muddy River inflow in 2015. In 2015, Las Vegas Wash TN was significantly higher than the criteria.

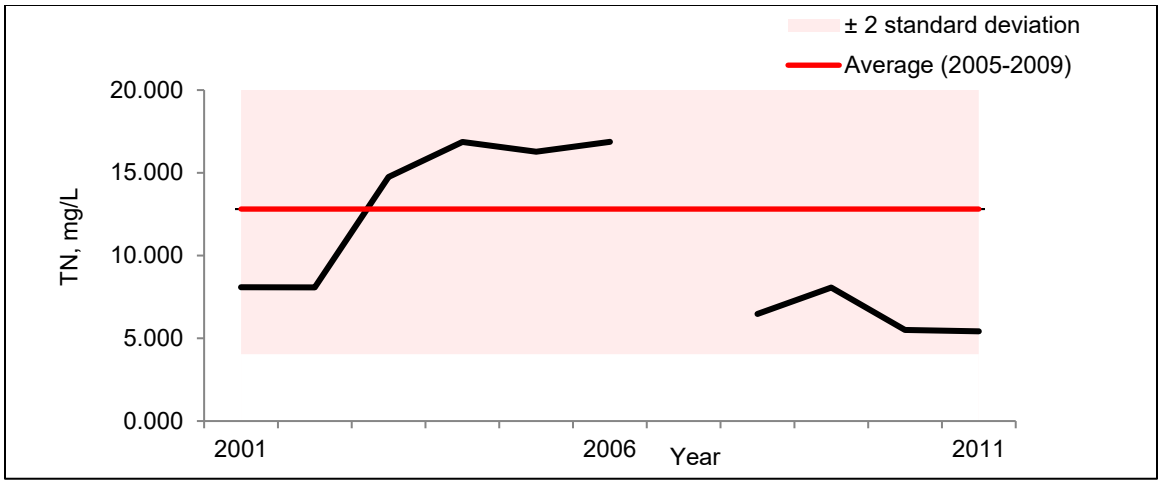


Figure 4.1.4-7. Comparison of 2001–2015 total nitrogen concentrations (TN; Black line: yearly average from surface) measured in Las Vegas Wash inflow to 2001–2009 average.

Phosphorus

Lake Mead has been and continues to be strongly phosphorus limited. Dissolved orthophosphate (PO_4-P) is a phosphorus form that is readily available for algal uptake. TP levels in Lake Mead are affected by daily phosphorus load brought in by tributary inflows. The concentration of PO_4-P, on the other hand, is affected by algal consumption during the growing season (Holdren et al., 2008). Total phosphorus (TP) represents the sum of all phosphorus forms described here.

Overall, phosphorus concentrations (TP and PO_4-P), and particularly PO_4-P concentrations in the Colorado River, Virgin River, and Las Vegas Wash have been decreasing (Figure 4.1.4-8 and Figure 4.1.4-9). Average concentrations detected in recent years (2010–2015) were significantly lower relative to the 2002–2009 average at all inflows (Figure 4.1.4-8 and Figure 4.1.4-9). Phosphorus declines in Las Vegas Wash are likely the result of voluntary phosphorus removal efforts by Lake Mead's wastewater dischargers (Figure 4.1.4-8 and Figure 4.1.4-9; Rosen et al., 2012).

The USEPA eutrophic criteria for TP in rivers and streams at the Xeric West Ecoregion is between 0.01 to 0.055 mg/L (USEPA, 2015a). Rivers and streams with TP concentrations below 0.01 mg/L are generally considered unproductive and if TP concentrations are higher than 0.055 mg/L, nuisance algal blooms and/or aquatic weed growth may be expected (USEPA, 2015a). Both the Colorado River and Virgin River inflow TP concentrations in 2015 were within the criteria levels that protect against the adverse effects of nutrient over-enrichment. However, Las Vegas Wash TP concentration in 2015 exceeded those criteria (Figure 4.1.4-9).

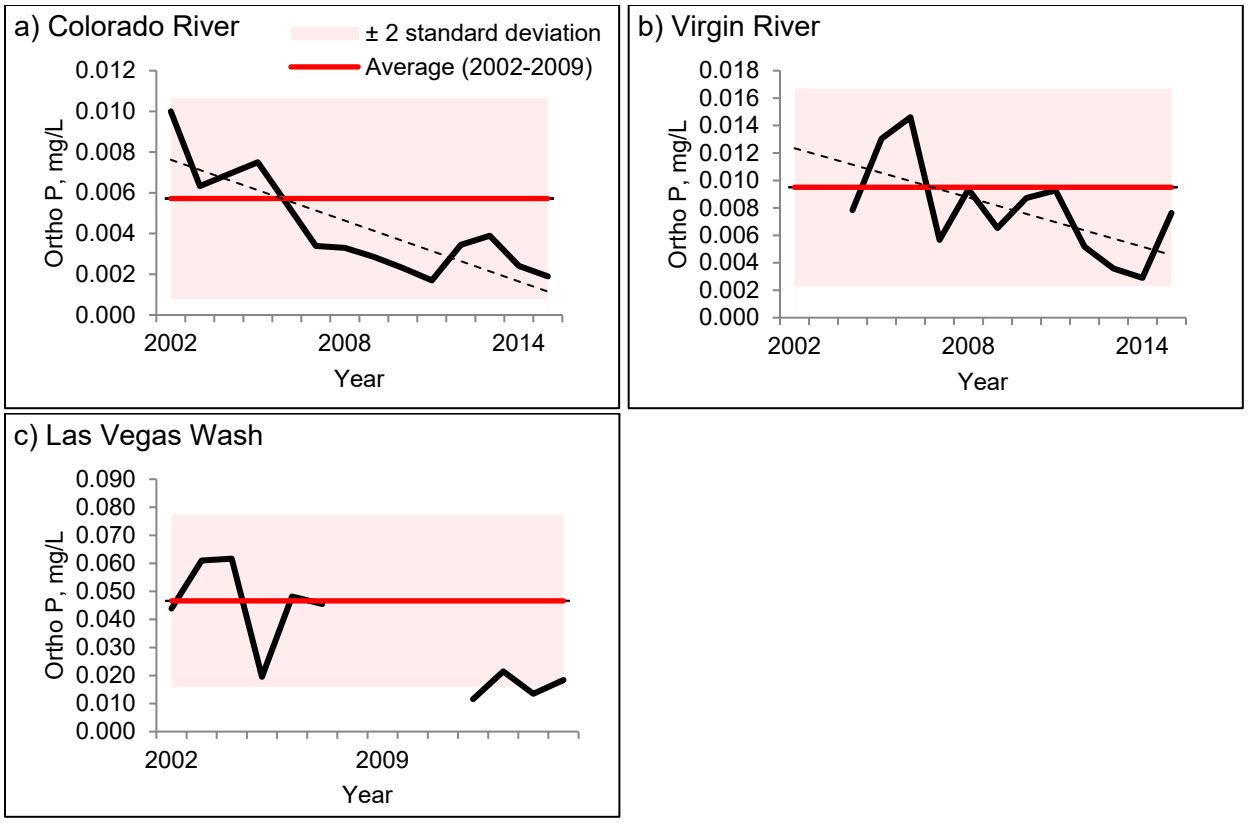


Figure 4.1.4-8. Comparison of 2001-2015 dissolved orthophosphate concentrations (PO_4-P; Black line: yearly average from surface) measured in the Colorado, and Virgin Rivers and Las Vegas Wash to 2002–2009 average.

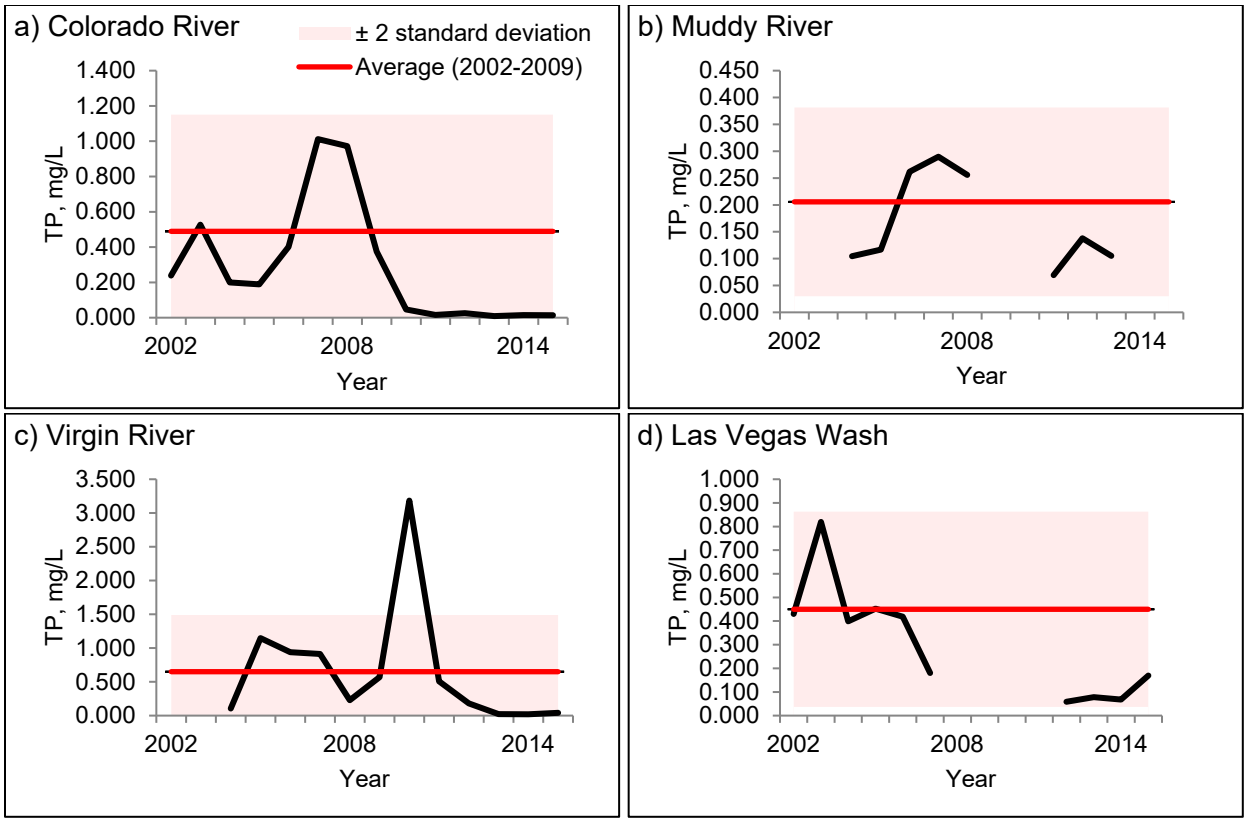


Figure 4.1.4-9. Comparison of 2001-2015 total phosphorus concentrations (TP; Black line: yearly average from surface) measured in the Colorado, Muddy, and Virgin rivers and Las Vegas Wash to 2002–2009 average.

Assessment Confidence and Key Data Gaps

The overall assessment confidence for physical characteristics and nutrient loads from tributaries to Lake Mead is moderate. The analytical capabilities and detection limits for some of the measurements have shifted throughout the years, particularly for nutrient concentrations measurements. This limitation presents some level of uncertainty for across-year comparisons.

Ongoing long-term monitoring of tributary water quality condition is essential to assess potential resource changes such as increasing urbanization along tributaries or effects of climate change to the flow regime and respective loading impacts. Standardized sampling and analytical methods should be established to ensure comparability.

4.1.5. Tributary Inflows

A summary of the parameters used assess tributary inflows are shown in Table 4.1.5-1.

Table 4.1.5-1. Assessment outcome for the indicator tributary inflows.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Tributary Inflows	Total annual inflow volume (million acre-feet, maf) to Lake Mead from the Colorado, Virgin and Muddy Rivers, and Las Vegas Wash		Overall, Lake Mead has been experiencing a consistent downward trend of water level due to persistent drought and over-allocation of water on the Colorado River. These decreases are due to the lack of surplus inflow from Lake Powell through the Colorado River as a result of changing hydrologic regime in the Colorado River Basin and reduced inflows from the Virgin and Muddy Rivers. Increased inflow volume from Las Vegas Wash is the result of increased return flow by SNWA and increases in effluent discharge and urban runoff from nearby municipalities. As return flow, Las Vegas Wash inflow has limited effect on Lake Mead's water level. Lake Mohave is operated as a regulated dam with discharge from Hoover Dam as its only significant inflow. Estimated inflow has been generally stable and unchanging across years, except during flood periods.

Description

Lake Mead is mainly fed by the Colorado River and three smaller tributaries: the Virgin and Muddy Rivers and Las Vegas Wash. The Colorado River inflow to Lake Mead is dependent on upstream releases from Lake Powell through the Glen Canyon Dam and is highly regulated via various laws, operating plans, agreements and regulations collectively known as the "Law of the River". The Las Vegas Wash inflow is dominated by releases of tertiary-treated sewage effluent, urban stormwater runoff, and shallow groundwater discharge from Las Vegas Valley. Muddy River inflow originates as spring discharge from the terminus of the White River Flow System. The spring discharge is mostly composed of ground water discharge and small amounts of snow melt from the Sheep Range and other mountains of Nevada. The Virgin River originates from the mountains of southern Utah near Zion National Park (Rosen & Van Metre, 2010). Nearly all water entering Lake Mohave comes through releases of Lake Mead through the Hoover Dam (Rosen et al., 2012).

Lake Mead stores water that supplies three western states (California, Arizona, and Nevada) and Mexico. It supplies drinking water for approximately 25 million people, agricultural irrigation, habitat for numerous fish and other wildlife species, world-class recreational opportunities, and hydropower generation (NPS, 2014). Lake Mohave re-regulates releases from the Hoover Dam to provide for required downstream deliveries to Mexico. Since lakes Mead and Mohave depend heavily on tributary inflows to maintain their water balance, understanding of the flow changes of these tributaries over time is essential for long-term reservoir management and planning.

Data and Methods

Table 4.1.5-2 shows the data and methods used to assess tributary inflows.

Table 4.1.5-2. Data and methods in the assessment of tributary inflows.

Indicator(s)	Measurement(s)	Scale of Analysis
Tributary Inflows	Total annual inflow volume (million acre-feet, maf) to Lake Mead from the Colorado, Virgin and Muddy Rivers, and Las Vegas Wash	Tributary

The USGS operates and maintains flow gauges at the tributaries of Lake Mead. Gauges are either flow- or continuous-type based on the flow types (e.g., flood flow or base flow). Gauges are maintained every 6 to 8 weeks with base flow measurements verified on site (Shanahan & Zhou, 2011). Runoff/flow data from the four major tributaries were collected from the following USGS gauging stations: Virgin River at Littlefield, AZ (USGS gauging station #09415000), located 36 miles upstream from Lake Mead; Muddy River near Glendale, NV (USGS gauging station #09419000), located 16 miles upstream from Lake Mead; Colorado River above Diamond Creek near Peach Springs, AZ (USGS gauging station #09404200), located 130 miles upstream from Hoover Dam; and Las Vegas Wash below Lake Las Vegas near Boulder City, NV (USGS gauging station #09419800), located approximately 0.55 miles upstream of the high water line for Lake Mead (Holdren and Turner 2010e). Additional stations, Virgin River near Overton, NV (#09415250), located 0.25 miles upstream from Lake Mead and Muddy River at Lewis Avenue at Overton, NV (#09419507), located 1.5 miles upstream from Lake Mead were used to provide supplemental information for Virgin and Muddy rivers inflow.

For Lake Mohave, flow data from USGS gauging station Colorado River below Hoover Dam, AZ-NV (#09421500), located several thousand feet downstream of the dam is used.

Discharge data for these sites were downloaded from the USGS National Water Information System (http://waterdata.usgs.gov/nwis/inventory). Information on all gauging stations was used to elevate the hydrologic regime condition is presented in Table B-1 and Figure B-3.

Estimated annual inflow volume is calculated from mean annual discharge by water year (October 1st to September 30th of the next year) in cubic feet per second (cfs). Mean annual discharge values were converted to acre-ft by multiplying the cfs values with a conversion factor of 723.97 acre-ft and consolidated into an annual estimate of inflow volume in million acre-ft (maf).

Reference Conditions

Table 4.1.5-3 reference conditions used to assess tributary inflows.

Table 4.1.5-3. Reference conditions for tributary inflows used in the assessment.

Measurement(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Tributary Inflows	Significant reduction in overall inflow volume, resulting in significant decline in lake elevation, affecting the usability of existing shoreline facilities	Overall inflow volume is slightly reduced with limited decline in lake elevation and effects on the usability of existing shoreline facilities.	Adequate or above flow, thus lake elevation to maintain reservoir operation and usability of existing shoreline facilities.

Temporal trends of Colorado River and other tributaries (Muddy and Virgin River, Las Vegas Wash) inflows into Lake Mead and Black Canyon in Lake Mohave were examined for this assessment. Long-term averages are computed for trend comparison where applicable. The long-term average is calculated where each subsequent year is being averaged to the previous years.

Condition and Trend

Lake Mead:

In water year 2015, the Colorado River was contributing about 96.9% of the flow to Lake Mead. Inflows to Lake Mead from the Colorado River are regulated releases from Lake Powell through the Glen Canyon Dam, as determined by annual operating plans and guidelines to meet operational requirements established as the "Law of the River." In 2007 the U.S. Department of the Interior and the seven basin states developed the Colorado River Interim Guidelines providing guidance for operations during periods 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. The criteria of the Interim Guidelines are driven by hydrologic conditions on Lake Powell and Lake Mead, with protection of certain water levels on each lake (Rosen et al., 2012).

The Colorado River Basin has experienced consistent drought through the late 1980s and then again in the 2000s (See section 2.3.1 for discussion on the hydrologic condition of the Colorado River Basin). Concern over the drought and water-level declines within Lakes Mead and Powell led the BOR to coordinate river operations among the seven basin States in 2007. The Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead was developed. An operational model is developed by BOR and is strictly followed to meet legal requirements and contractual demands for drinking, municipal, industrial, and irrigation water. 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. 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.

Key operational criteria for both Lake Powell and Lake Mead were established within the 2007 Interim Guidelines. The approximate annual minimum release, referred to operationally as Minimum Objective Release (MOR) from Lake Powell through Glen Canyon Dam to Lake Mead since 1980 is 8.23 maf (Rosen et al., 2012). 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. In any year when Lake Mead receives only the minimum objective release, the overall average yearly Lake Mead water budget would operate at a 1.2 maf deficit, which is equal to approximately a decrease in 12 ft of lake elevation. Therefore, 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 from the previous year's high water level (Rosen et al., 2012). Significant increases in the water level of Lake Mead generally requires either several years of above-average snowpack and precipitation within the watershed where above MOR volume is released from Lake Powell. Lake Mead elevations could also rise in response to lower consumptive use by Basin states, but significantly lower uses than currently anticipated would be needed.

Total annual releases from Lake Powell to Lake Mead through the Colorado River have averaged about 10.9 maf (13.4 billion m^3/yr) between 1935 and 2001 (Ferrari, 2008; Figure 4.1.5-1). A smaller percentage of water comes from tributaries and washes along the river between Glen Canyon Dam and Lake Mead (Rosen et al., 2012). Lake Mead has been operating mostly at a deficit in the past decade and as a result, continuous decline in lake elevation.

As the only major drainage for the Las Vegas Valley including the Las Vegas metropolitan area, Las Vegas Wash provides the second largest inflow into Lake Mead. Almost all of Las Vegas Wash inflows are return flows by treatment facilties to offset direct withdrawal from Lake Mead for municipal water supply. Flows from Las Vegas Wash have increased significantly in recent years (2003–2015) (Figure 4.1.5-2). Average annual inflow volume between 2003 and 2015 was 0.21 maf, which is about 350% over the average annual flow between 1970 and 1983 (0.06 maf) (Figure 4.1.5-2). The significant increase in inflow from Las Vegas Wash was likely a result of recent urbanization and rapid population growth in the Las Vegas Valley and correlates with increased effluent and urban runoff contributions. The return flow credits are part of the total Southern Nevada community needs and are required to enable the additional withdrawals beyond its allocation (Rosen et al., 2012). Las Vegas Wash contributed about 2.2% of the annual inflow to Lake Mead in 2015. However, as return flow, it has little to no net effect on lake elevation.

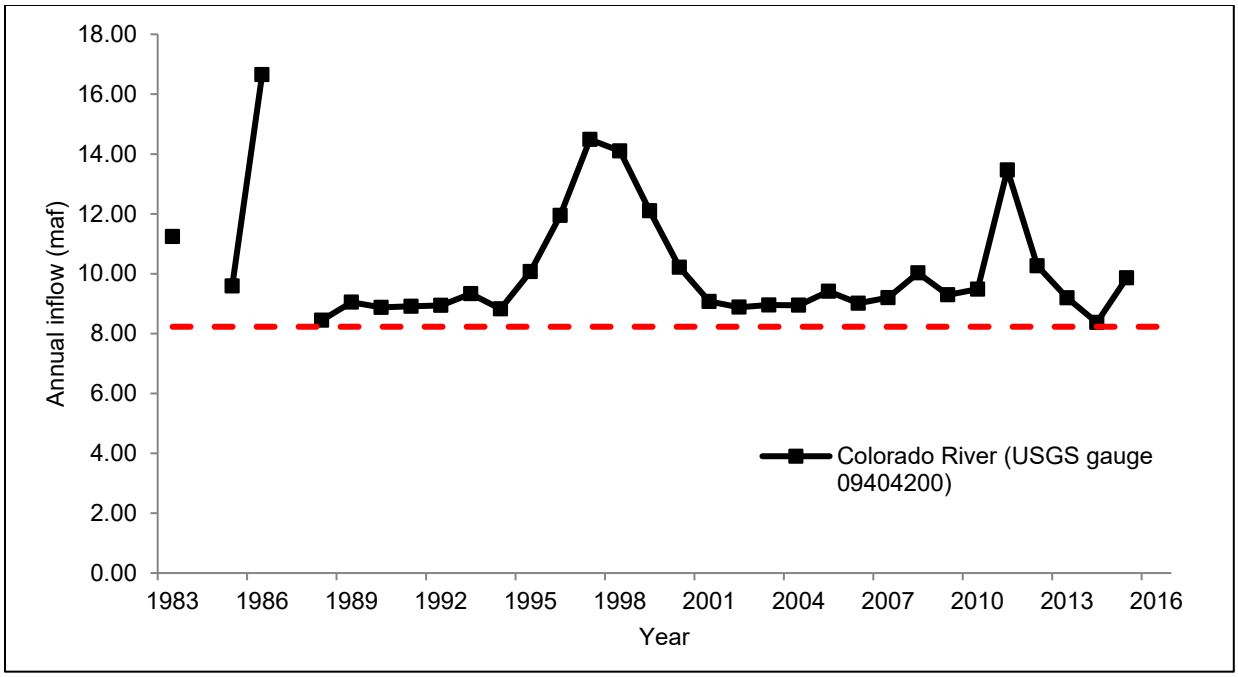


Figure 4.1.5-1. Estimated annual inflows (in maf) from regulated releases by Lake Powell to Lake Mead via the Colorado River. Discharge data collected by USGS automated flow gauge at Colorado River above Diamond Creek near Peach Springs, AZ (USGS gauging station #09404200) were used to produce the estimates. The red line (at 8.23 maf) represents the approximate annual minimum release, referred to operationally as Minimum Objective Release from Lake Powell through Glen Canyon Dam to Lake Mead. Meeting this minimum release objective is critical for providing a sufficient inflow to Lake Mead to meet downstream water needs.

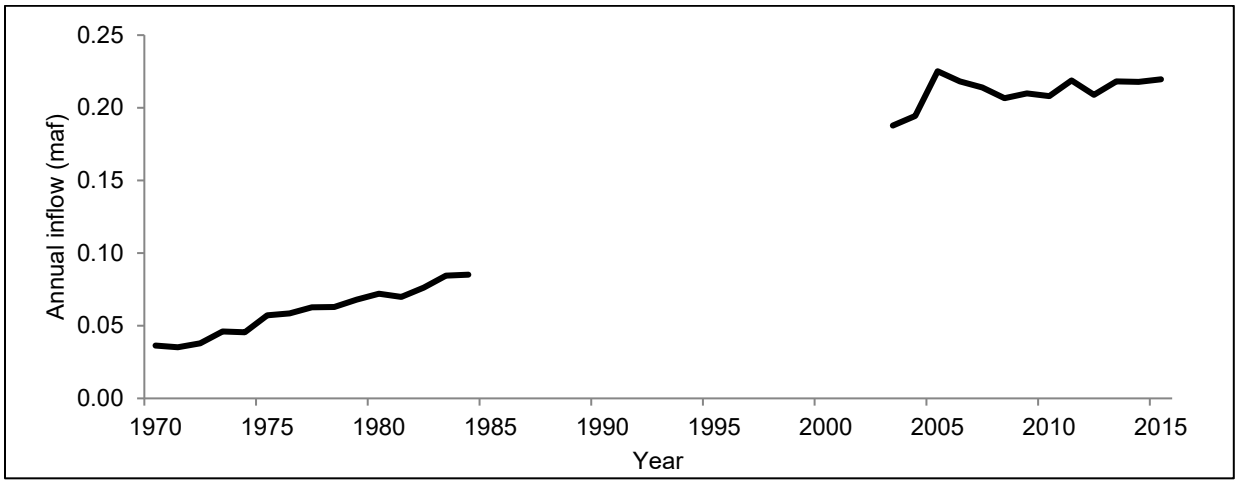


Figure 4.1.5-2. Estimated annual inflow (in maf) from Las Vegas Wash to Lake Mead. Discharge data collected by USGS automated flow gauge at Las Vegas Wash below Lake Las Vegas near Boulder City, NV (USGS gauging station #09419800) were used to produce the estimates.

Due to falling water levels, the Virgin and Muddy Rivers have been entering Lake Mead as a combined inflow since July 2009 (Holdren & Turner, 2010). The longest term flow records from the

Virgin and Muddy Rivers near Lake Mead come from the USGS stations at the Virgin River at Littlefield and Muddy River near Glendale. However, both of these stations overestimate inflow to Lake Mead as major agricultural diversions happen between these stations and the Lake Mead NRA before the water enter Lake Mead. During the summer months, almost the entirety of the flow of both rivers is diverted (Holdren et al., 2008). When comparing the flows measured at these upper gauging stations with two newer gauging stations, Virgin River near Overton, NV, and Muddy River at Lewis Avenue at Overton, NV, that are located downstream and are closer to Lake Mead, the flow volume decreased significantly reflecting flow losses by diversions. The Virgin River near Overton, NV site, operated since 2006 averaged about 73% of the flow measured at the upstream Littlefield, AZ site (Figure 4.1.5-3). Flow at the downstream Lewis Avenue site on the Muddy River averaged only about 52% of the upstream Glendale site on an annual basis between 1997 and 2015 (Figure 4.1.5-4). A downward trend in inflow volume by the Virgin River is observed since 1983 (Figure 4.1.5-3). The Virgin and Muddy Rivers are estimated to contribute about 0.7% and 0.2%, respectively, of the annual inflow to Lake Mead in 2015. The Virgin River contributes more inflow to Lake Mead than Muddy River (Figure 4.1.5-3 and Figure 4.1.5-4).

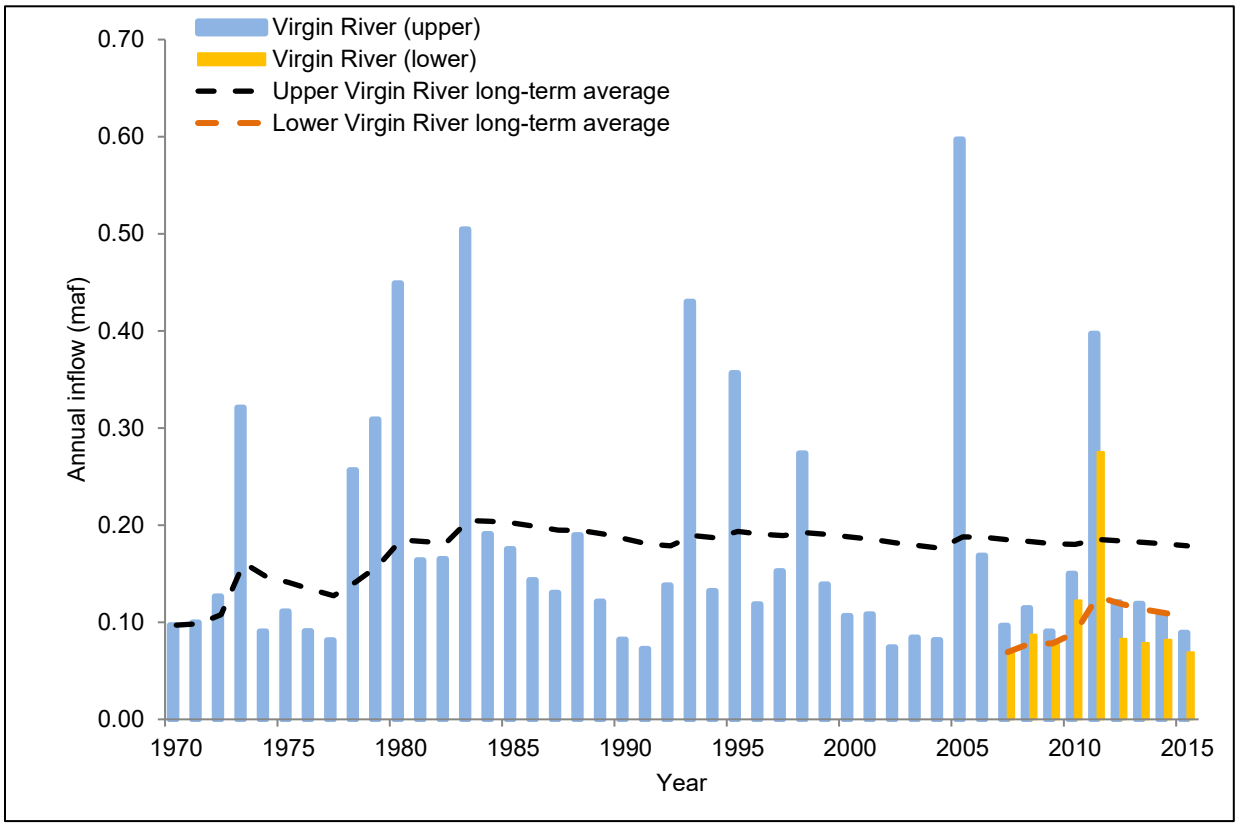


Figure 4.1.5-3. Estimated annual inflow from the Virgin River. Discharge data collected by USGS automated flow gauge at Upper Virgin River at Littlefield, AZ (USGS gauging station #09415000) and lower Virgin River near Overton, NV (#09415250) were used to produce the estimates.

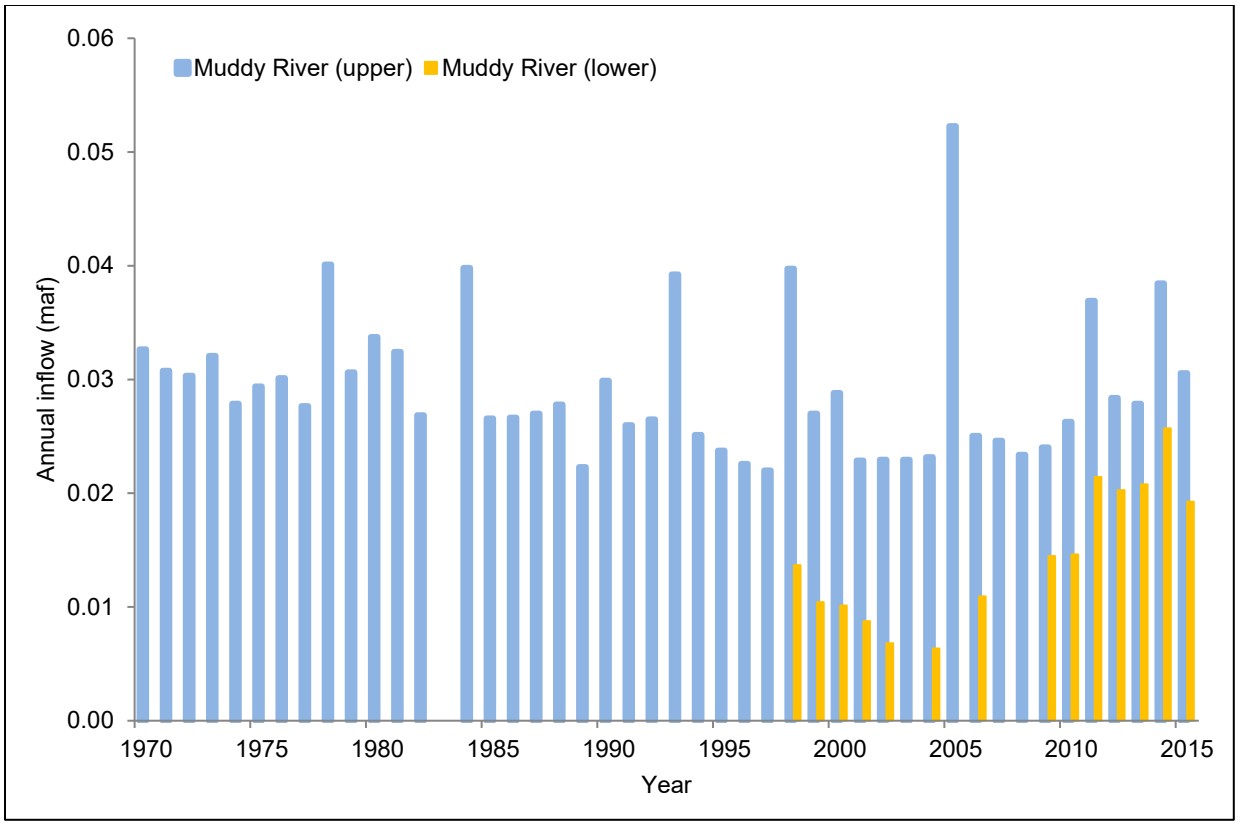


Figure 4.1.5-4. Estimated annual inflow from the Muddy River. Discharge data collected by USGS automated flow gauge at upper Muddy River near Glendale, NV (USGS gauging station #09419000) and lower Muddy River at Lewis Avenue at Overton, NV (#09419507) were used to produce the estimates.

Overall, Lake Mead has been experiencing a consistent downward trend of water level due to persistent drought and over-allocation of water on the Colorado River. These decreases are due to the lack of surplus inflow from Lake Powell through the Colorado River as a result of changing hydrologic regime in the Colorado River Basin and reduced inflows from Lake Mead's other tributaries (see section 4.3.2 for discussion on the hydrologic condition of the Colorado River Basin).

Lake Mohave:

Lake Mohave is operated as a regulated dam with discharge from Hoover Dam as its only significant inflow. Water is released as needed to meet water delivery requisites to Arizona, California, Nevada, and Mexico as prescribed by the Law of the River. Average annual inflow to Lake Mohave is about 9.6 maf. Estimated inflow from station below Hoover Dam has been generally stable and unchanging across years, except during flood periods, e.g. 1983–1986 and 1997–1999 (Figure 4.1.5-5).

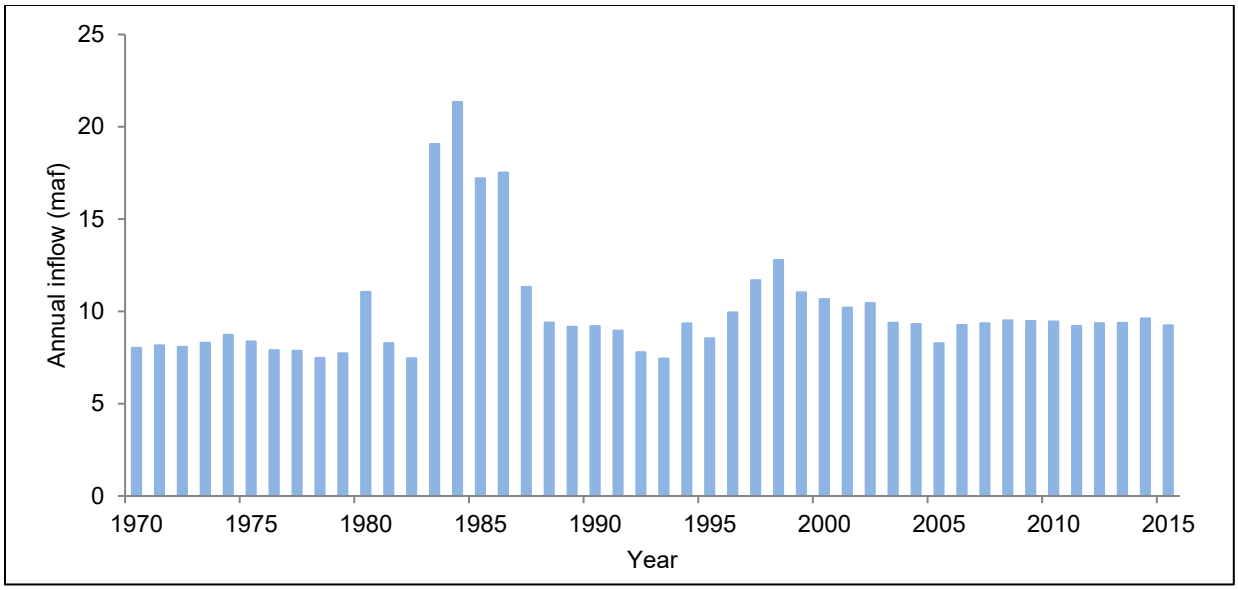


Figure 4.1.5-5. Estimated annual inflow to Lake Mohave from Hoover Dam. Discharge data collected by USGS automated flow gauge at Colorado River below Hoover Dam, AZ-NV (#09421500) was used to produce the estimates.

Assessment Confidence/Key Data Gaps/Stressors

The assessment confidence for inflows to lakes Mead and Mohave is generally high. Releases along the Colorado River system are highly regulated; the timing and nature of these releases are generally well understood.

Based on observed trends over the last few decades and forecasts of drought conditions and reduced precipitation from regional climate models, water volume and availability are likely to continue to be the key stressor impacting the Lake Mead system moving forward. Particularly as extreme storm events and associated hydrologic pulses are expected to increase, the nature and impact of inflow dynamics are also expected to increase. See section 4.3.2 for discussion on the hydrologic condition of the Colorado River Basin.

4.1.6. Tributary Contaminants

A summary of the parameters used assess tributary contaminants are shown in Table 4.1.6-1.

Table 4.1.6-1. Assessment outcome for tributary contaminants.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Tributary Contaminants	• Selenium (Se) • Perchlorate (ClO_4)		While Perchlorate entering the Las Vegas Wash remained above NDEP provisional action level for safe drinking water, concentrations have been reduced approximately 90% since 1997 with NDEP remediation efforts. Monthly measurements of total selenium concentration at the Las Vegas Wash inflow exceeded the USEPA criterion for protection of aquatic life in lotic water (3.1 µg/L) between June and August, 2016, but the exceedance was slight (7% exceedance in August). Measurements from the Colorado, Virgin, and Muddy Rivers were below the USEPA criterion in 2015 and 2016. Selenium concentrations at all locations show increasing trends between August 2015 and September 2016. No historical data were available for long-term trend assessment. No recent record for Se concentration at inflow to Lake Mohave.

Description

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. However, at elevated concentrations, it is toxic and the threshold between providing a benefit and toxicity is narrow (National Research Council Committee on Minerals and Toxic Substances in Diets and Water for Animals, 2005). Selenium bioaccumulates, and in aquatic environments, the risks from this metalloid primarily stem from aquatic life consuming food that is contaminated with selenium rather than direct exposure. Selenium can affect the growth and survival of juvenile fish and reproductive health of aquatic biota. Excessive selenium can also cause skeletal deformities in birds (USEPA, 2016b). Soils in Las Vegas Valley are naturally rich in selenium due to their marine sediment origin. Monitoring selenium concentrations in Las Vegas Wash is important because soils in up-gradient areas in Las Vegas Valley contain selenium, which may leach into the shallow groundwater that enters the Wash or through irrigation or stormwater runoff into Lake Mead (Zhou et al., 2004).

Perchlorate (ClO_4) is a naturally occurring and manufactured oxidizer derived from inorganic salts. Perchlorate 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 (e.g. BMI Complex in Henderson, NV) near and up-gradient of the Las Vegas Wash. Leakage and transport of perchlorate to Las Vegas Wash through shallow aquifers has occurred from two manufacturing plants that operated until the late 1990s . Efforts to remove the perchlorate from groundwater and surface water have been underway for many years (Urbansky, 1998; Boralessa, 2001). Perchlorate can act as an endocrine disruptor which can impair the ability of the thyroid gland to produce hormones needed for normal growth and development (USEPA, 2015b).

For this indicator, the contribution of selenium and perchlorate from tributaries to lakes Mead and Mohave, in particular from Las Vegas Wash was examined (Table 4.1.6.2 and Table 4.1.6-3). For assessment of concentrations of these contaminants within the open waters of lakes Mead and Mohave, see section 4.5.1 Contaminants.

Table 4.1.6-2. Data and methods used in the assessment of tributary contaminants.

Indicator(s)	Measurement(s)	Scale of Analysis
Tributary Contaminants	• Selenium (Se) • Perchlorate (ClO_4)	Tributary

Table 4.1.6-3. Reference conditions for tributary contaminants used in the assessment.

	Condition Status		
Measurement(s)	**Significant Concern***	**Moderate Concern***	**Good***
• Selenium (Se) • Perchlorate (ClO_4)	Chronic exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life and the safety of drinking water.	Slight or occasional exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life the safety of drinking water.	Rare or no exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life the safety of drinking water.

For an assessment on other organic pollutants from runoff and endocrine disrupting contaminants (EDCs), including pharmaceutical compounds (PPCPs) from effluents, see section 4.5.1 Contaminants.

Primary data presented for Se and ClO_4 were downloaded from the SNWA database. Sampling locations used for this assessment were selected based on locations and data availability. Stations selected were from the inflows of the Colorado (CRLM, _A, and _B), Virgin (VRLM_B), and Muddy (MRLM_B) Rivers, and the Las Vegas Wash (LWLVB). A station located immediately below the Hoover Dam (CR342.0) was selected to represent Lake Mohave's main inflow from the Hoover Dam. See Table B-1 and Figure B-3 for monitoring locations and descriptions.

The USEPA has implemented a revision to the chronic aquatic life criterion for selenium in freshwater which defines the concentration of selenium in water and fish tissue that is considered safe for aquatic life (USEPA, 2016c). For this assessment, the maximum allowable contaminant level (MCL) for Se for lotic systems was used as the reference condition threshold (Table 4.1.6-4).

Table 4.1.6-4. USEPA and NDEP standards and recommendations for contaminant levels in drinking water and aquatic life ambient water quality.

Contaminants	USEPA Maximum Allowable Contaminant Level (MCL, µg/L or ppb)
Selenium Aquatic life (30-day average) – Lotic	3.1 [1]
Perchlorate (ClO_4)	≤ 18 µg/L [2] Provisional action level for safe drinking water

[1] USEPA, Final Aquatic Life Ambient Water Quality Criterion for Selenium (Freshwater) 2016

[2] NDEP, Defining a Perchlorate Drinking Water Standard, 2015

In 2011, the USEPA determined that perchlorate meets the criteria for regulation under the Safe Drinking Water Act. Since then, USEPA has initiated the process to develop and establish a national primary drinking water regulation, which is a legally enforceable standard that applies to public drinking water supplies. An Interim Lifetime Drinking Water Health Advisory has been issued while the enforceable standard is in development. NDEP has issued a provisional drinking water standard for perchlorate based upon USEPA guidance (NDEP, 2015; Table 4.1.6-4).

Condition and Trend

See section 4.5.1 for discussion on contaminants measured at open water locations in lakes Mead and Mohave.

Selenium (Se)

Typical concentrations of selenium in the upper Las Vegas Wash exceed the USEPA criterion for protection of aquatic life in lotic water (3.1 µg/L) (USEPA, 2016c); however, the increased water volumes provided by the wastewater reclamation plants along Las Vegas Wash dilute these concentrations (Rosen et al., 2012). 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 (LW0.8) to be 3.3 µg/L in 2007 which is slightly above the revised USEPA selenium criterion for aquatic life in lotic systems published in 2016.

Total selenium concentration (µg/L) data collected monthly at Colorado River inflow (CRLM_A: 2015–2016) and Virgin and Muddy Rivers combined inflow (VRLM_B: 2015–2016), and collected biweekly from Las Vegas Wash inflow (LWLVB_B) between August 2015 and August 2016 were available at the time of analysis. Monthly measurements of total selenium concentration at the Las Vegas Wash inflow exceeded the USEPA criterion for protection of aquatic life in lotic water (3.1 µg/L) between June and August 2016 but the exceedance was slight (7% exceedance in August)

(Figure 4.1.6-1). Measurements from the Colorado (average: 2.17 µg/L), Virgin, and Muddy (average: 2.41 µg/L) Rivers were below the USEPA criterion (Figure 4.1.6-1). While selenium concentrations at all locations show increasing trends within the one year of record examined, historical data were not available for long-term trend assessment.

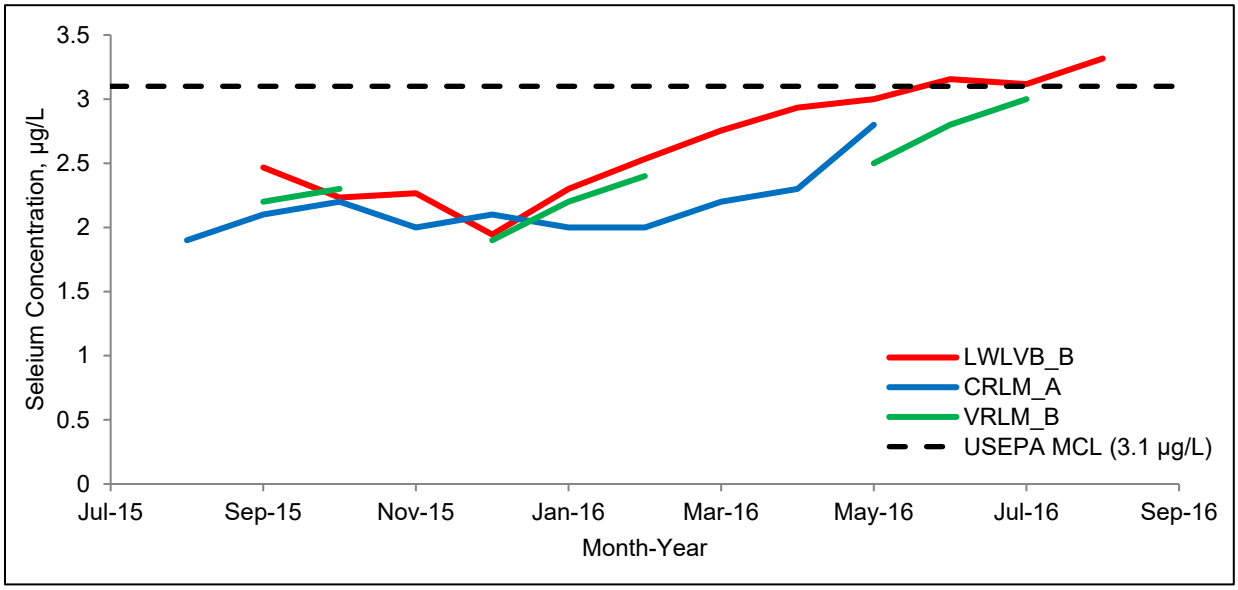


Figure 4.1.6-1. Selenium (Se) concentrations measured at three tributary inflow stations (Las Vegas Wash: LWLVB_B; Colorado River: CRLM_A; and Virgin and Muddy Rivers combined inflow: VRLM_B) at Lake Mead, August 2015–August 2016. The black dotted line (short dash) represents the USEPA selenium criterion for protection of aquatic life in lotic waters (3.1µg/L).

No recent record of total selenium concentration was available from the sampling station below Hoover Dam (CR342.0). The most recent record was collected in May, 2010 and the concentration was measured at 1.9 µg/L which is below the USEPA criterion.

Perchlorate (ClO_4)

From 1945 through 1988, ammonium perchlorate, a component of rocket fuel, was manufactured in Henderson, Nevada. Sodium, potassium, and magnesium perchlorate were also manufactured at two other facilities during that period. Production of perchlorate compounds stopped after one of the manufacturing plants exploded in 1988 (Holdren et al., 2008). Perchlorate was first detected in Southern California Water supplies in July 1997 and the source was traced upstream to Lake Mead and the Las Vegas Wash. The Las Vegas Wash is the drainage point for the Las Vegas valley and contains the shallow groundwater flows from the valley. The shallow groundwater system became contaminated with perchlorate due to the disposal practices of the perchlorate manufactures in the valley. By December 1998, cleanup operations at the two manufacturing sites were initiated due to health concerns by NDEP. Since then, NDEP has continued to monitor perchlorate levels at Lake Mead and in the Lower Colorado River (NDEP, 2015). In January 2015, the USEPA and the U.S. Department of Justice announced a settlement reached with the previous operators of the

manufacturing facilities where a trust will be set up for the cleaning up of the manufacturing facilities that led to perchlorate contamination in Lake Mead (USEPA, 2015d).

Perchlorate concentration (µg/L) data collected monthly at Las Vegas Wash inflow (LWLVB_B) between 1995 and 2012 and at sampling station below Hoover Dam (CR342.0) between 2003 and 2016 were available at the time of analysis. Remediation efforts undertaken since 1998 have significantly reduced perchlorate loading from Las Vegas Wash to Lake Mead, Lake Mohave, and downstream into the Lower Colorado River (Figure 4.1.6-2a). Perchlorate entering the Las Vegas Wash peaked in the spring and summer months and lowered in the winter (Figure 4.1.6-2a). Perchlorate loading has been reduced by approximately 90% since 1997 and as of August 2008, approximately 2,638 tons of perchlorate have been removed from the environment (NDEP, 2015).

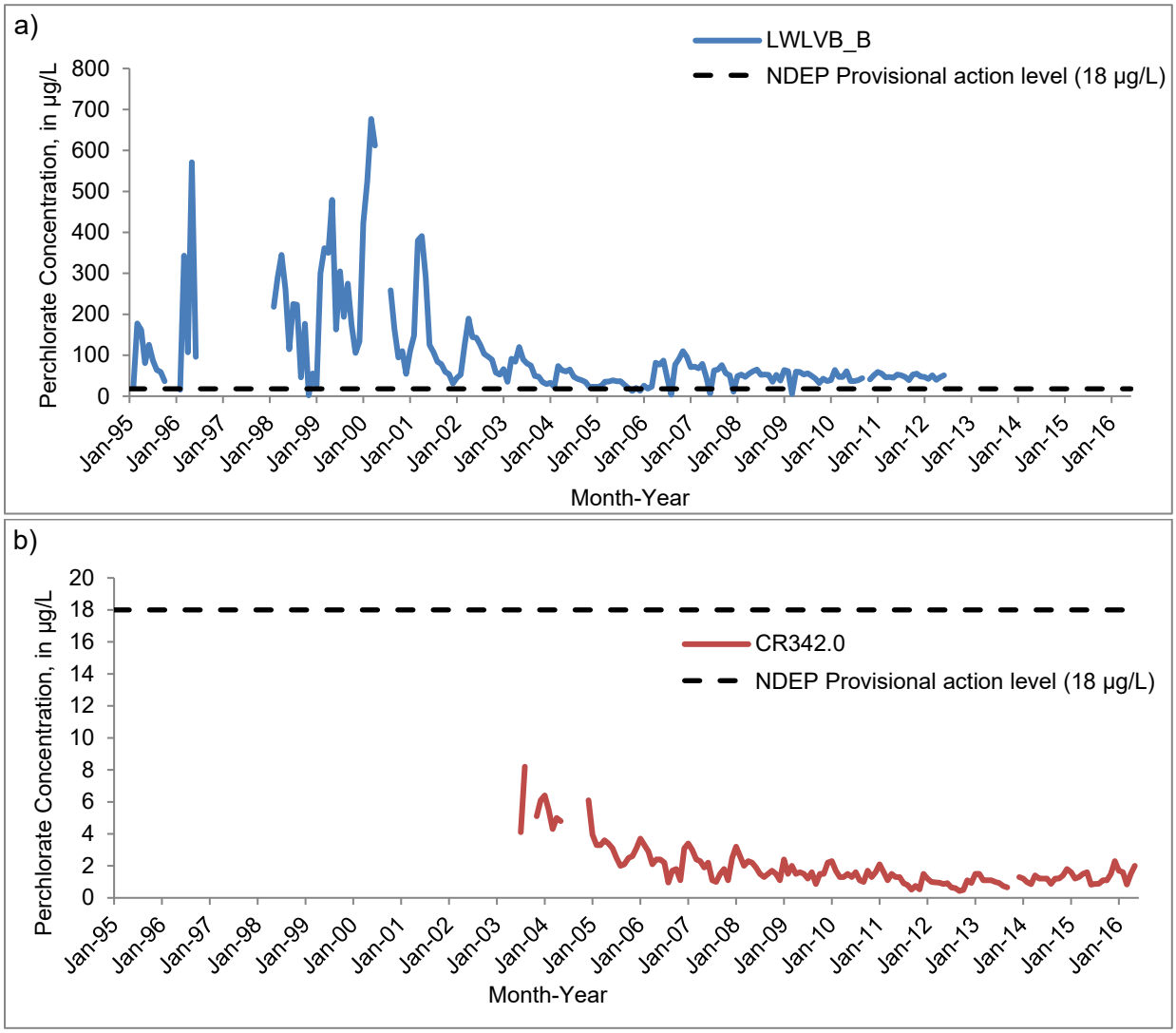


Figure 4.1.6-2. Perchlorate (ClO_4) concentrations measured at a) Las Vegas Wash: LWLVB_B and b) inflow to Lake Mohave (CR342.0) below Hoover Dam. The black dotted line (short dash) represents NDEP's provisional drinking water standard for perchlorate based upon USEPA guidance (18µg/L).

Downstream of the LWLVB_B Las Vegas Wash station, perchlorate concentrations measured at the inflow of Lake Mohave below Hoover Dam were significantly lower than concentrations at Las Vegas Wash inflow (Figure 4.1.6-2b). Perchlorate concentrations were also well below the NDEP provisional drinking water standard for perchlorate based upon USEPA guidance (18µg/L). NDEP continues to monitor perchlorate levels reported in the Lower Colorado River, which is below the safety limit set by EPA in February 2005 (NDEP, 2015).

Assessment Confidence and Key Data Gaps

Assessment confidence for tributary contaminants is moderate. While recent selenium concentration data were available for assessment, no historical data were available for long-term trend assessment. Selenium concentration data were not available for inflow to Lake Mohave at the time of the analysis. See section 4.5.1 for discussion on contaminants measured at open water locations in lakes Mead and Mohave.

4.1.7. Sedimentation

A summary of the parameters used assess sedimentation are shown in Table 4.1.7-1.

Table 4.1.7-1. Assessment outcome for sedimentation.

Indicator(s)	Measurement	Condition Status/Trend	Rationale
Sedimentation	• Suspended sediment discharge (tons per day) by tributaries • Nutrient loading associated with sediment (qualitative description if data not available) • Contaminant loading associated with sediment (qualitative description if data not available)		Since construction of Glen Canyon Dam, overall low sediment and nutrient load from tributaries into lakes Mead and Mohave. Reduced inflows also contribute to reduced sediment and nutrient loads.

Description

Sediment can harbor nutrients (e.g. phosphorus) and contaminants, entering lakes Mead and Mohave through their inflows. The concentration of suspended sediment can be affected by natural conditions such as soil erosion and sediment resuspension. It can also be affected by human activities, such as development, agricultural practices, and hydraulic alteration. Therefore, monitoring of sediment transport is important for identifying the current condition of the reservoirs to inform upstream land management and current reservoir operation practices.

With the completion of Glen Canyon Dam, many nutrients that used to enter the Lake Mead by way of the Colorado River are now trapped in the sediments of Lake Powell. A large fraction of Lake Mead's nutrient loading is now brought in through the treated sewage effluent discharge from Las Vegas Wash and is mainly confined to Boulder Basin. Sediment found deposited in Lake Mead may

act as a sink for low concentrations of legacy pesticides and other organic compounds, trapping the contaminants, so they do not reach overlying lake water (Lake Mead NRA, 2010).

The aggregate measure of tributary sediment contribution assessment takes into account three measurements: suspended sediment discharge which measures the volume of sediments delivered from tributaries in tons per day, and nutrient and contaminant loading associated with sediment transported to lakes Mead and Mohave.

Data and Methods

Table 4.1.7-2 shows the data and methods used to assess sedementation.

Table 4.1.7-2. Data and methods for the assessment of sedimentation.

Indicator(s)	Measurement(s)	Scale of Analysis
Sedimentation	• Suspended sediment discharge by tributaries • Nutrient loading associated with sediment (qualitative description if data not available) • Contaminant loading associated with sediment (qualitative description if data not available)	Tributary

Sediment load refers to the fate and transport of sediment and constituents bound to sediments. Total suspended solids (TSS) measures the amount of particulate organic and inorganic matter (e.g. sediment) that are suspended in or are carried by water in a water body and can be used to monitor sediment and associated nutrient load (USEPA, 2003). TSS data analyzed in this assessment were downloaded from the SNWA member database and were extracted from a subset of stations to represent the different Lake Mead basins and tributary inflows (Table 4.1.7.3, Figure B-3). Two stations were selected for Las Vegas Bay because LVB1.85M was no longer in service after 2004 due to declines in water volume.

Table 4.1.7-3. Reference conditions of sedimentation used in the assessment.

	Condition Status		
Measurement(s)	Significant Concern*	Moderate Concern*	Good*
• Suspended sediment discharge (tons per day) by tributaries • Nutrient and contaminant loading associated with sediment (qualitative description if data not available)	Increased sediment and associated nutrient and contaminant load.	Slightly elevated sediment, and associated nutrient and contaminant load.	Low or reduced sediment, and associated nutrient and contaminant load.

Additional information was gathered from a series of sedimentation studies: Lara and Sanders (1970), Bevans et al. (1996), Foster et al (2004), Ferrari (2008), Holdren and Turner (2010), Lake Mead NRA documentation (2010), Rosen & Van Metre (2010, and Rosen et al. (2012).

Data and detailed discussion of nutrient concentration found at lakes Mead and Mohave tributary inflows are presented in section 4.1. Data and detailed discussion of contaminants found in lakes Mead and Mohave are presented in section 4.5.1.

Condition and Trend

Suspended Sediment Discharge (Tons per Day) by Tributaries

Lake Mead

All tributaries to Lake Mead carry sediment. The various inflow sources are colder (Colorado River), saltier (Las Vegas Wash), or both (Virgin and Muddy Rivers) than the receiving waters of Lake Mead. This affects the flow regime and tends to limit mixing and nutrient loading as the majority of nutrients enter Lake Mead at the hypolimnion or lower part of the epilimnion, making them unavailable to support algal growth.

A 2001 sedimentation study (Ferrari, 2008) calculated an average annual sediment inflow rate of 36,024 acre-ft to Lake Mead reservoir since the closure of Glen Canyon Dam compared to the 1963 computed average annual rate (Lara & Sanders, 1970) of 88,280 acre-ft for the first 29.7 years of reservoir operation. An estimated 7,200 acre-ft of annual sediment delta growth in the upper delta portion of the reservoir on the Colorado River has been recorded since 1963 (Ferrari, 2008).

Samples for TSS were collected at variable depths at each station examined except Overton Arm where only surface TSS levels were collected. Average TSS concentrations across all depths at Virgin Basin and Boulder Basin were generally below the detection limit (5 mg/L) from 2007 to 2009 and from 2002 to 2013. Overton Arm's surface TSS concentrations averaged 9 mg/L between 2007 and 2009, except a spike of 40 mg/L occurred in May and June of 2009. This peak may have been due to higher inflow during an above-average water year at that time. Las Vegas Bay consistently has had higher TSS concentrations than all other locations (Figure 4.1.7-1). As treated sewage effluent discharge from Las Vegas Wash enters Lake Mead through Las Vegas Bay, it is expected that Las Vegas Bay would have higher TSS concentrations as a result. From 2008 to 2013, TSS in Las Vegas Bay have been consistently measured at an average concentration of approximately 5mg/L with most months at less than 5 mg/L. Since 2007 average TSS concentrations in Las Vegas Bay have decreased (Figure 4.1.7-1).

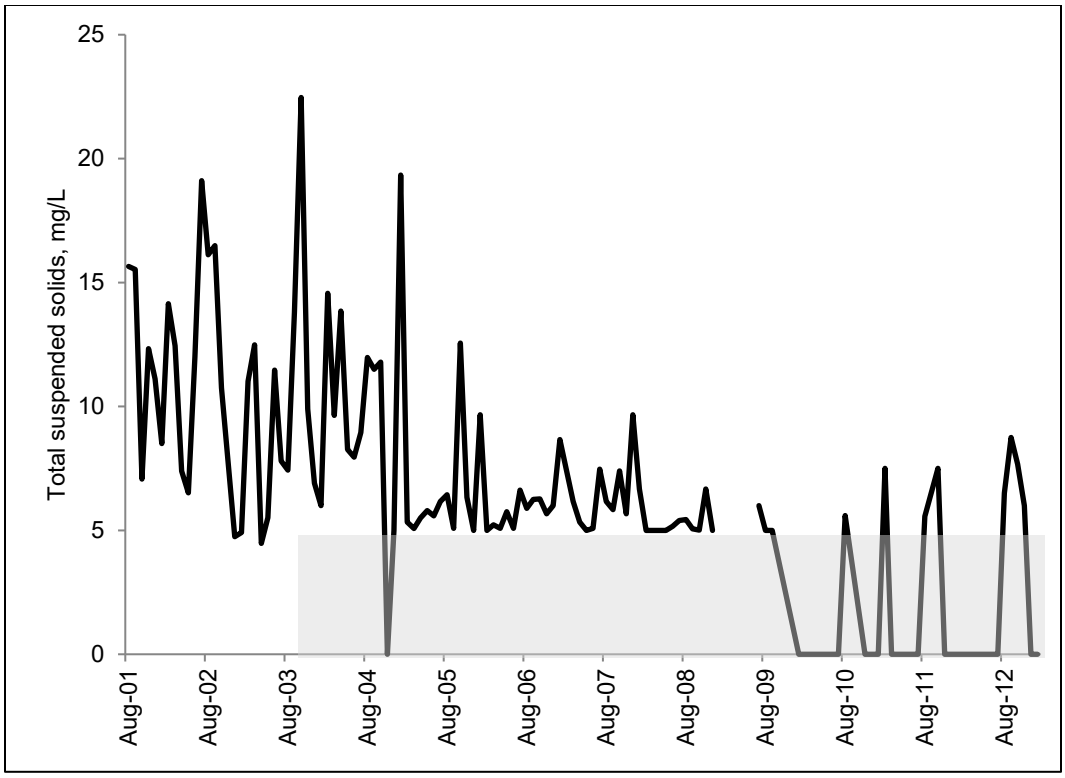


Figure 4.1.7-1. Time series depicting total suspended solids (mg/L) at Las Vegas Bay (LVB1.85M and LWLVB). Since late 2003, detection limit of TSS has increased to 5 mg/L. The grey shaded area shows detection of TSS concentration less than the detection limit of 5 mg/L.

Lake Mohave

Little sediment has accumulated in Lake Mohave since its impoundment in 1951 by closure of the Davis Dam (Foster et al., 2004) as the sediment load from Hoover Dam discharge is minimal. Post-impoundment deposition is mainly comprised of fine-grained sediment and tends to accumulate in the deepest parts of the Lake Mead NRA within sheltered areas along the edges of the Colorado River Channel (NPS, 2010).

Nutrient Loading Associated with Sediment

Lake Mead

Suspended sediment loading into Lake Mead from the Colorado River has decreased significantly after Lake Powell was formed in 1963. Lake Mead nutrient loading associated with sedimentation was estimated to be 1320 (nitrogen) and 623 (phosphorus) metric tons per year after 1963 as compared to 8420 (nitrogen) and 5200 (phosphorus) metric ton per year between 1955 and 1962. The closure of Glen Canyon Dam and the formation of Lake Powell significantly reduced the nutrient load by sediment to the upper basin of Lake Mead (Prentki et al., 1981).

Ding et al. (2014) determined that most of the phosphorus entering the lake is bound to sediment particles from the Colorado River, accounting for 98% of total external loading. As this phosphorus quickly settles to the lake bottom, most of the nutrient load is unavailable for use by algae in downgradient areas of the lake. Soluble and bioavailable orthophosphate only account for less than

2% of the TP loading from the Colorado River (Ding et al., 2014). The combined contribution of total phosphorus load from the Muddy and Virgin Rivers was estimated to be 220 lbs/d (99.7 kg/d) (Rosen et al., 2012). Las Vegas Wash was the largest phosphorus contributor to the Boulder BAsin area of Lake Mead in 2007 and 2008 (Ding et al. 2014). Retention basins and erosion control is occuring in the Las Vegas Valley which is intended to reduce loading.

Contaminant Loading Associated with Sediment

In addition to conventional contaminants monitored in the Lake Mead (see section 4.5.1), contaminants of emerging concern (CECs) such as pharmaceuticals and personal care products (PPCPs), plasticizers, and other compounds disposed of into the environment by households and industries are of recent concern to Lake Mead NRA managers. As populations of nearby cities continue to grow, both increases in water demand and additional effluent inputs will results in additional impacts to the Lake Mead NRA (Rosen et al., 2012).

Studies on the fate and transport of CECs at Lake Mead began in 1996. Bevans et al. (1996) reported 1992 surveys conducted by Nevada Basin and Range study unit (NVBR) where bottom-sediment samples from Las Vegas Wash and Las Vegas Bay were used to determine that synthetic organic contaminants were present and persistent within these two sites.

Rosen & Van Metre (2010) examined cores of Lake Mead bottom sediments collected in 1998 from Las Vegas Bay, Overton Arm, and Virgin Basin to delineate input sources of trace metals and organic contaminants in Lake Mead. This study found that concentrations of organic contaminants measured were highest in Las Vegas Bay. However, only the concentrations of two individual organic contaminants (dichlorodiphenyldichloroethane, DDD, and dichlorodiphenyldichloroethylene, DDE) exceeded the sediment quality guideline termed the “probable effect concentration (PEC)” value (MacDonald et al., 2000). The PEC defines concentration above which adverse biological effects are expected based on toxicity to benthic organisms (Rosen & Van Metre, 2010). Trace metal concentrations were higher in Las Vegas Bay relative to Overton Arm and Virgin Basin.

Increased concentrations of mercury (Hg) were detected in Las Vegas Bay from 1985 to 1998 and this accumulation was likely the result of urban growth. Overton Arm was the least affected by anthropogenic contaminant inputs. Trace elements detected and measured in the Virgin Basin were found to be influenced by the Colorado River, and showed major shifts in the early 1960s. By the 1980’s and 1990’s trace metal concentrations in the Virgin Basin gradually returned to concentrations typical of pre-1960 conditions (Rosen & Van Metre, 2010).

Assessment Confidence and Key Data Gaps

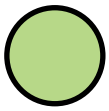
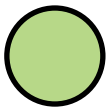
The assessment confidence for sediment, nutrient, and contaminant loading is moderate because of the lack of availability of recent data. Quantitative sediment, nutrient, and contaminant load data were only available from historical time periods. TSS monitoring at most Lake Mead basins and inflows were over relatively short time periods, with the exception of samples collected in Las Vegas Bay. While these data provide a valuable baseline for future assessments, there is a need for increased spatial and temporal resolution for this dataset. As regional population growth continues to occur, particularly under the pressures from climate change and persistent drought, the contribution

and impact of sediment nutrient and contamination loading to ecosystem and public health concerns will become increasingly important. Specifically, characterization of the transport of sediments and potential re-suspension of contaminants related to the lowering of lake levels is needed to better understand the relationship of nutrients and contaminant in sediments to food web dynamics and water quality. Monitoring of sediment transport in response to lowering lake levels can provide insight to Lake Mead's changing hydrology.

4.1.8. Land Use within Watershed

A summary of the parameters used assess land use within the watershed are shown in Table 4.1.8-1.

Table 4.1.8-1. Assessment outcome for the indicator land use within watershed.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Land Use within Watershed	Developed and non-developed acres		Lake Mead NRA is largely surrounded by public lands. Most land ownership zoning types are compatible with park purposes. No comparable historic data available to justify a trend in the condition at this time.
	Urbanized miles of tributaries		Mixed urbanized and non-urbanized tributary miles along Las Vegas Wash and Muddy River. Virgin River within Halfway Wash Watershed and over 500 miles of Colorado River before entering Lake Mead are not urbanized. No quantitative data available to derive a trend.

Description

Lake Mead NRA is located within the sub-basin Lake Mead Basin (USGS HUC 1501) in the lower Colorado River Basin (Batker et al., 2014; Figure 2.2.1-1). The park contains vast backcountry and wilderness lands, including nine designated wilderness areas that cover more than 185,000 acres and several other proposed, eligible, or potential wilderness lands that encompass an additional 373,000 acres. These lands preserve ecological resources and processes, and provide exemplary opportunities for primitive recreation and desert solitude (NPS, 2014). The park is managed within a broader context of connectivity to adjacent conservation lands managed by other federal and state agencies. These include wilderness areas, BLM "Areas of Critical Environmental Concern", critical habitat for listed species, wildlife management areas, and regional parks and trails (NPS, 2014).

There are several major cities located near Lake Mead NRA including Las Vegas and Henderson, Nevada, and St. George, Utah (Batker, et al., 2014). Lake Mead provides municipal water for Las Vegas and Henderson and treated effluent from these cities is returned to Lake Mead via Las Vegas Wash in Las Vegas Valley, and from urban corridors along Moapa Valley and Virgin River (Holdren & Turner, 2010; Lake Mead NRA, 2010).

There are four water reclamation districts that discharge treated wastewater effluent to Lake Mead through Las Vegas Wash. These districts monitor their discharge to comply with their National Pollutant Discharge Elimination System (NPDES) discharge permits, which are issued by the Nevada Division of Environmental Protection (NDEP) (Lake Mead NRA, 2010). With increasing population growth in the Las Vegas Valley, there has been a growing concern with the potential impacts of associated increases in effluent volume on Lake Mead and Mohave's water quality. Since the mid-1990s, the water reclamation districts that discharge treated wastewater effluent into Las Vegas Wash have undergone a series of planning initiatives to address these concerns.

For the indicator of Land Use within Watershed, two measurements were used to assess condition and trend (Table 4.1.8-2): A measure of developed and non-developed acres was used to identify these types of areas surrounding Lake Mead NRA, and a measure of urbanized tributary miles was used to characterize the number of tributary miles that contribute to Lake Mead which are surrounded by urbanized, developed area.

Table 4.1.8-2. Data and methods used in the assessment of land use within the watershed.

Indicator(s)	Measurement(s)	Scale of Analysis
Land Use within Watershed	• Developed and non-developed acres • Urbanized tributaries miles vs. non-urbanized miles	Watershed (Based on USGS HU, except for Colorado River); Tributary

Geographic Information System (GIS) data from Homer et al. (2015) was used to assess the acreage of developed and non-developed within the study region. Lake Mead NRA staff adapted cover classes from USGS 2011 National Land Cover Database (Homer et al., 2015) to characterize watersheds and basins within the study area. Sub-watershed units examined were selected by Lake Mead NRA staff to cover a range of adjacent lands along tributaries entering Lake Mead. Sub-watershed examined include Duck Creek-Las Vegas Wash watershed (HUC: 1501001507) which covers most of Las Vegas Wash; Halfway Wash-Virgin River watershed (HUC: 1501001007) which covers part of the Virgin River; and, Lower Muddy River watershed (HUC: 1501001209) that encompasses part of the Muddy River (Figure B-2). A unique HUC (hydrologic unit code) is assigned by USGS to each hydrologic unit. USGS has divided and sub-divided the United States into successively smaller hydrologic units which are classified into four levels: regions, sub-regions, accounting units, and cataloging unit (USGS, 2015). Acreages were assigned as conservation, developed (open space, low intensity, medium intensity, high intensity) and undeveloped area based on these cover classes. Supplemental data presented in the Lake Mead NRA Resource Stewardship Strategy (NPS, 2014) document was also used for this assessment (Table 4.1.8-3).

Estimates of urbanized vs. non-urbanized miles of tributaries were determined using ESRI world imagery basemap (ESRI, 2016) and the USGS National Land Cover Database 2011 (Homer, et al., 2015). Aerial images from the two sources were reviewed and urbanized miles of tributaries by Lake

Mead NRA staff. Hydrolines for Virgin River, Muddy River, and Las Vegas Wash were derived from the 24K National Hydrology Dataset (http://nhd.usgs.gov/).

Table 4.1.8-3. Reference conditions for land use within the watershed used in the assessment.

Measurement(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Developed and non-developed acres	Lands adjacent to park boundary and tributaries are incompatible with park purposes (e.g. developed)	Lands adjacent to park boundary and tributaries support resource conservation but may change	Lands adjacent to park boundary and tributaries supports resource conservation (e.g. Conservation assignment, undeveloped)
Urbanized miles of tributaries	Majority of the tributaries are adjacent to urbanized area	Mixed urbanized and non-urbanized tributary miles.	No or little urbanized tributary miles.

Condition and Trend

Developed and Non-Developed Acres

Lake Mead NRA is largely surrounded by public land managed by federal, state and local agencies. The park boundary includes a mix of adjacent land uses with a majority (75%) that are compatible with the park's general purposes of conservation and recreation (Table 4.1.8-4, NPS, 2014 and NPS, 2015). In addition, the remaining 25% of the park perimeter that is classified as urban is mainly comprised of undeveloped areas of municipalities along the park boundary.

Table 4.1.8-4. Land uses along the boundary of Lake Mead NRA (NPS, 2014).

Land uses	Perimeter (miles)	Percentage of total perimeter (%)
Conservation	174	43
Developed (Urban or industrial purposes)	103	25
Undeveloped	129	32
Total	**406**	**100**

The eastern end of the park along the Colorado River adjoins Grand Canyon – Parashant National Monument (co-managed by the National Park Service and the Bureau of Land Management), Grand Canyon National Park, and the Hualapai Reservation (Figure B-2, NPS, 2014). These areas mainly serve conservation and primitive recreation purposes. Developed areas near park boundaries are mainly concentrated in the three sub-watersheds along other tributaries that enter Lake Mead: Duck Creek-Las Vegas Wash watershed (HUC: 1501001507) which covers the city of Henderson and most of Las Vegas Wash; Halfway Wash-Virgin River watershed (HUC: 1501001007) which covers part of the Virgin River and north of the city of Mesquite, Nevada; and, Lower Muddy River watershed (HUC: 1501001209) that encompasses part of the Muddy River, and the cities of Glendale, Overton,

and Logandale, Nevada (Figure B-2). Land cover assignments within these sub-watersheds are listed in Table 4.1.8-4 and Table 4.1.8-5. While Duck Creek-Las Vegas Wash watershed has the highest intensity of development, most lands within these three sub-watersheds are undeveloped. Land cover types are not expected to change significantly in the future with majority of adjacent lands being publicly owned.

Table 4.1.8-5. Land cover types and acreages covered in the three sub-watersheds, Duck Creek-Las Vegas Wash, Halfway Wash-Virgin River, and Lower Muddy River adjacent to Lake Mead NRA (See Figure B-2 for locations of sub-watersheds).

	Land Cover (acres)				
Watershed	Developed (Open Space)	Developed (Low intensity)	Developed (Medium intensity)	Developed (High intensity)	Undeveloped
Duck Creek – Las Vegas Wash	8669.8	20355.9	34898.5	11246.2	170161.9
Halfway Wash – Virgin River	877.9	163.3	5.3	0.2	172716.2
Lower Muddy River	1537.3	1133.9	129.0	10.0	160524.3

Urbanized Miles of Tributaries

The Colorado River flows through over 500 miles of lands managed by the NPS or tribal lands prior to entering Lake Mead; therefore, urban development near that section of the Colorado River is minimal.

Drainage entering Lake Mead via the Las Vegas Wash includes both non-point source urban runoff and permitted discharges from four municipal wastewater treatment plants (Holdren & Turner, 2010). Majority of Las Vegas Wash within Duck Creek watershed is urbanized (Table 4.1.8-6). Muddy River within the Lower Muddy River watershed is about 65% urbanized while all tributary miles of the Virgin River within Halfway Wash watershed is not urbanized (Table 4.1.8-6).

Table 4.1.8-6. Number of miles of tributaries (Virgin, Muddy, and Las Vegas Wash) that are urbanized and non-urbanized in the three sub-watersheds, Duck Creek-Las Vegas Wash, Halfway Wash-Virgin River, and Lower Muddy River adjacent to Lake Mead NRA.

	Tributaries (Miles)	
Watershed	Urbanized	Non-urbanized
Las Vegas Wash within Duck Creek Watershed	10.93	0.58
Virgin River within Halfway Wash Watershed	0	20.03
Muddy River within Lower Muddy River Watershed	9.78	5.19

Assessment Confidence and Key Data Gaps

Lake Mead NRA staff provided assistance and conducted land use and urbanized tributary miles analyses using the most recent land cover data and aerial imagery available (e.g. Homer et al., 2015 and ESRI, 2016). Land cover data were collected in 2011 and no significant changes in land use have been documented within or adjacent to Lake Mead NRA. Therefore, the results accurately reflected the current condition for these measurements. No comparable historic data were available within the scope of this study to justify a trend in the condition at this time. However, historic imagery dating back to the 1964 establishment of Lake Mead NRA was available to consider future analyses for land development trends.

Future increases in population in nearby municipalities may result in changes of land use within the watershed with increase development (see section 4.5.3). Therefore, periodic evaluation to determine change in compatible and incompatible land use adjacent to the park boundary and tributaries entering Lake Mead is important to maintain up-to-date knowledge of park surroundings.

4.1.9. Literature Cited

ADEQ. (2010, April 13). Title 18: Environmental Quality, Chapter 11: Department of Environmental Quality, Article 1: Water Quality Standards. Retrieved from EPA Water Quality Standards Regulations-Arizona: https://www.epa.gov/sites/production/files/2014-12/documents/az-chapter11.pdf

Batker, D., Christian, Z., Cooley, C., Graf, W., Jones, K., Loomis, J., & Pittman, J. (2014). Nature's Value in the Colorado River Basin. Earth Economics, 104p.

Bevans, H., Goodbred, S., Miesner, J., Watkins, S., Gross, T., Denslow, N., & Schoeb, T. (1996). Synthetic Organic Compounds and Carp Endocrinology and Histology in Las Vegas Wash, and LAs Vegas and Callville Bays of Lake Mead, Nevada, 1992 and 1995. U.S. Geological Survey Water-Resources Investigations Report 96-4266. Retrieved from http://pubs.er.usgs.gov/publication/wri964266

Boralessa, M. (2001). Transport of Perchlorate in the Las Vegas Wash and Lake Mead. Las Vegas, NV: University of Nevada Las Vegas, M.S. Thesis.

Burns, N., Rutherford, J., & Clayton, J. (1999). A Monitoring and Classification System for New Zealand Lakes and Reservoirs. Lake and Reservoir Management, 15: 255–271.

Butcher, J., Nover, D., Johnson, T., & Clark, C. (2015). Sensitivity of Lake Thermal and Mixing Dynamics to Climate Change. Climatic Change, 129:295–305.

Carlson, R. (1977). A Trophic Status Index for Lakes. Limnology and Oceanography, 22:361–369.

Colorado River Basin Salinity Control Forum. (2011). 2011 Review: Water Quality Standards for Salinity, Colorado River System. Colorado River Basin Salinity Control Forum.

Ding, L. H., List, E., & Tietjen, T. (2014). Development of a Phosphorus Budget for Lake Mead. Lake and Reservoir Management, 30:143–156.

ESRI. (2016, February 5). World Imagery. Retrieved from ArcGIS: https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

Ferrari, R. (2008). 2001 Lake Mead Sedimentation Survey. Denver, CO: Bureau of Reclamation, Technical Service Center.

Foster, D., Capone, M., Parolski, K., Twichell, D., & Rudin, M. (2004). Surficial Geology and Analysis of Post-Impoundment Sediment of Lake Mohave – Interpretation of Sidescan Sonar and Seismic-reflection Data. U.S. Geological Survey Open-File Report 2004-1256. Retrieved from http://pubs.usgs.gov/of/2004/1256/index.html

Holdren, G., & Turner, K. (2010). Characteristics of Lake Mead, Arizona-Nevada. Lake Mead NRA and Reservoir management, 26 (4): 230–239.

Holdren, G., Horn, M., & Lieberman, D. (2008). The Limnology of Lake Mead, Arizona-Nevada, 2006 Report of Findings. Denver, CO: Bureau of Reclamation, Technical Service Center.

Homer, C., Dewitz, J., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K. (2015). Completion of the 2011 National Land Cover Database for the Conterminous United States – Representing a Decade of Land Cover Change Information. Photogrammetric Engineering and Remote Sensing, 81:345–354.

LaBounty, J. (2005). Limnological Status of Boulder Basin, Lake Mead, Nevada-Arizon: 2000–2004. Las Vegas, NV: Southern Nevada Water Authority Technical Report.

LaBounty, J. (2008). Secchi Transparency of Boulder Basin, Lake Mead, Arizona-Nevada 1990–2007. Lake and Reservoir Management, 24:277–307.

LaBounty, J., & Burns, N. (2005). Characterization of Boulder Basin, Lake Mead, Nevada-Arizona, USA-Based on analysis of 34 Limnological Parameters. Lake and Reservoir Management, 21:277–307.

LaBounty, J., & Horn, M. (1997). The Influence of Drainage form the Las Vegas Valley on the Limnology of Boulder Basin, Lake Mead, Arizona-Nevada. Lake and Reservoir Management, 13:95–108.

Lake Mead NRA. (2010). Long-term Limnology and Aquatic Resources Monitoring and Research Plan for lakes Mead and Mohave: Boulder City, NV. Lake Mead National Recreation Area and University of Nevada, Las Vegas. Retrieved from http://www.nps.gov/Lake Mead NRA/learn/nature/upload/Eco_Monitoring_Plan_for_Lakes_Mead_and_Mohave_4-27_update.pdf

Lara, J., & Sanders, J. (1970). The 1963–64 Lake Mead Study. Bureau of Reclamation Report No. REC-OCE-70-21. U.S. Department of the Interior.

Lee, C., & Gazafy, S. (1979). Lake Mead and Lake Mead NRA Powell Salinity Reports. Retrieved from http://digitalscholarship.unlv.edu/water_pubs/12

LVVWD. (2016). Water Quality Reports. Retrieved from Las Vegas Valley Water District: https://www.lvvwd.com/wq/reports.html

MacDonald, D., Ingersoll, C., & Berger, T. (2000). Development and Evaluation of Consensus-based Quality Guidelines for Freshwater Ecosystems. *Archives of Environmental Contamination and Toxicology*, 39:20–31.

National Research Council Committee on Minerals and Toxic Substances in Diets and Water for Animals. (2005). Mineral Tolerance of Animals (2nd revised ed.). Washington, D.C.: National Academies Press.

NDEP. (2004, August 1). Rationale for Proposed Revisions to the Nevada Water Pollution Control Regulations NAC 445A.195-NAC445A.197 Las Vegas Bay and Lake Mead. Retrieved from Nevada Division of Environmental Protection, Bureau of Water Quality Planning: https://ndep.nv.gov/docs_04/las_vegas_bay082404.pdf

NDEP. (2015, September 1). Defining a Perchlorate Drinking Water Standard. Retrieved from Nevada Division of Environmental Protection, Bureau of Corrective Actions: http://ndep.nv.gov/bca/perchlorate02_05.htm

NPS. (2006). Management Policies 2006 – The Guide to Managing the National Park System. Washington, D.C.

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region.

NPS. (2015). Foundation Document. Lake Mead National Recreation Area, Arizona and Nevada: National Park Service, U.S. Department of the Interior.

Paulson, L. J., Baker, J. R., & U.S. Water and Power Resources Service (1980a). Evaluation of Impacts Associated with Reregulation of Water Levels in Lake Mohave. Lake Mead Limnological Research Center: Technical Report Series, 4. Retrieved from http://digitalscholarship.unlv.edu/water_pubs/67

Paulson, L. J., Baker, J. R., Deacon, J. E., & U.S. Water and Power Resources Service (1980b). The Limnological Status of Lake Mead and Lake Mohave under Present and Future Powerplant Operations of Hoover Dam. Lake Mead Limnological Research Center: Technical Report Series, 1. Retrieved from: http://digitalscholarship.unlv.edu/water_pubs/64

Paulson, L., & Baker, J. (1983). Limnology in Reservoirs on the Colorado River. Technical Report No. 11. Las Vegas, NV: UNLV Lake Mead Limnology Research Center, University of Nevada, Las Vegas.

Prentki, R., Paulson, L., & Baker, J. (1981). Chemical and Biological Structure of Lake Mead Sediments. Technical Report Series 6: Lake Mead Limnological Research Center.

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

Rosen, M., & Van Metre, P. (2010). Assessment of Multiple Sources of Anthropogenic and Natural Chemical Inputs to a Morphologically Complex Basin, Lake Mead, USA. Paleogeography, Paleoclimatology, Paleoecology.

Ryan, R., & Zhou, X. (2010). TDS and Selenium Projections for the Las Vegas Wash, Post Completion of the Systems Conveyance and Operations Program (SCOP). Lake and Reservoir Management, 26:249–257.

SNWA. (2010). Limnological Status of Boulder Basin, Lake Mead, Nevada-Arizona 2004–2009. Southern Nevada Water Authority.

Urbansky, E. (1998). Perchlorate Chemistry – Implications for Analysis and Remediation. Bioremediation Journal, 2:81–95.

USEPA. (1986). Quality Criteria for Water 1986. Washington, DC: United States Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyNET.exe/00001MGA.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1986+Thru+1990&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&

USEPA. (2003). Draft: Developing Water Quality Criteria for Suspended and Bedded Sediments (SABS) – Potential Approaches. USEPA, Office of Water, Office of Science and Technology. Retrieved from http://www.epa.gov/sites/production/files/2015-10/documents/sediment-report.pdf

USEPA. (2009). National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. Washington, D.C.: U.S. Environmental Protection Agency, Office of Water and Office of Research and Development.

USEPA. (2013). Aquatic Life Ambient Water Quality Criteria for Ammonia-Freshwater. Washington, D.C.: United States Environmental Protection Agency.

USEPA. (2015, November 15). Basic Information about Your Drinking Water. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/your-drinking-water/basic-information-about-your-drinking-water

USEPA. (2015a, December 31). Ecoregional Nutrient Criteria Documents for Rivers and Streams. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/nutrient-policy-data/ecoregional-nutrient-criteria-documents-rivers-streams

USEPA. (2015b, November 23). Perchlorate. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/dwstandardsregulations/perchlorate

USEPA. (2015d, January 23). $2 Billion in Funds Headed for Cleanups in Nevada and on the Navajo Nation from Historic Anadarko Settlement with U.S. EPA, States. Retrieved from USEPA Newsroom: https://yosemite.epa.gov/opa/admpress.nsf/0/2E47E97C62ACF44385257DD6007428C5

USEPA. (2016, January 6). Secondary Drinking Water Standards: Guidance for Nuisance Chemicals. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals

USEPA. (2016a, January 25). National Recommended Water Quality Criteria-Aquatic Life Criteria Table. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

USEPA. (2016b, January 15). Aquatic Life Criterion-Selenium. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/wqc/aquatic-life-criterion-selenium

USEPA. (2016c, June). Fact Sheet – Final Aquatic Life Ambient Water Quality Criterion for Selenium (Freshwater) 2016. Retrieved from Aquatic Life Criterion – Selenium Documents: https://www.epa.gov/sites/production/files/2016-06/documents/se_2016_fact_sheet_final.pdf

USGS. (2015, September 2). Hydrologic Unit Maps. Retrieved June 23, 2016, from Water Resources of the United States: http://water.usgs.gov/GIS/huc.html

Veley, R.J. and Moran, M.J., 2011, Evaluating lake stratification and temporal trends by using near-continuous water-quality data from automated profiling systems for water years 2005–09, Lake Mead, Arizona and Nevada: U.S. Geological Survey Scientific Investigation Report 2012–5080, 25 p. Available at *http://pubs.usgs.gov/sir/2012/5080/*.

Vollenweider, R. (1970). Scientific Fundamentals of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Report DAS/CSL/6827. Organization for Economic Co-operation and Development.

Wetzel, R.G. (2001). Limnology: Lake and River Ecosystems. Third Edition. Academic Press, New York, NY. 1006 pp.

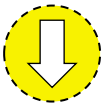
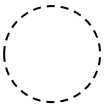
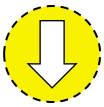
Zhou, X., Roefer, P., Zikmund, K., & LaBounty, J. (2004). Selenium Concentrations in the Las Vegas Wash and its Tributary Waters. Proceedings of the American Water Works Association 2004 Water Resources Conference and Exposition, (pp. 1–13). Austin, TX.

4.2. Biotic Condition

4.2.1. Benthic Macroinvertebrates

A summary of the parameters used assess benthic macroinvertebrates are shown in Table 4.2.1-1.

Table 4.2.1-1. Overall Assessment outcome for condition status and trend for Benthic Macroinvertebrates.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Population Trend by Key Taxonomic Benthic Groups	Benthic macroinverte-brates density	Mead		The presence and absence of non-native benthic macroinvertebrates account for the majority of the dissimilarity between historic and contemporary invertebrate assemblages in Lake Mead. Invertebrate assemblages shifted from a mostly native oligochaeate-chironomid assemblage to a non-native quagga mussel-mudsnail-oligochaeate assemblage dominated by non-native invertebrates.
	Benthic macroinverte-brates density	Mohave		No qualitative benthic macroinvertebrate data or monitoring program exists for Lake Mohave.
Benthic Macroinvertebrates overall				–

Description

Benthic macroinvertebrate species assemblage and density are known to be useful predictors of water quality impairment and are commonly used for assessment of biological integrity of freshwater ecosystems. Benthic macroinvertebrates are a major food source for fish in lakes Mead and Mohave. Analyses of fish stomach contents have indicated that sport and forage fish rely to some degree on benthic macroinvertebrates seasonally or year round. The feeding behavior of benthic macroinvertebrates also play an important functional role in the lake's ecosystems (Umek et al., 2010, Rosen et al. 2012) where some invertebrates may consumer organic matter, relase nutrients for algal growth, and serve as food for fish as indicated previously. While benthic macroinvertebrate species live on the bottom habitat of lakes Mead and Mohave, the distributions of these invertebrates change with depth, substrate, food availability, temperature, and predation by fish. In addition, some of the benthic invertebrates may have a part of their life history that has an open water, pelagic phase in their life cycle like quagga mussels and Asian clams.

Data and Methods

Table 4.2.1-2 shows the data and methods used to assess benthic macroinvertebrates.

Table 4.2.1-2. Data and methods used in the assessment of Benthic macroinvertebrates.

Indicator(s)	Measurement(s)	Scale of Analysis
Population Trend by Key Taxonomic Benthic Groups	Benthic macroinvertebrates density	Lake

This assessment is based on benthic macroinvertebrate studies conducted in Lake Mead between 2007 and 2009 (Umek et al. 2010, Wittmann et al. 2010), and unpublished data collected by the University of Nevada Reno Aquatic Ecosystems Analysis Laboratory in 2010 and 2011 (Davis et al., 2014 and Caldwell et al., 2015). Between the four studies, three basins of Lake Mead were sampled: Las Vegas Bay, Overton Arm, and Boulder Basin. Benthic macroinvertebrate samples were collected in the spring and fall with predefined transacts from soft sediments. A petite PONAR grab sampler was used to collect 3–5 sediment grabs per depth. Samples were retained on a 500µm mesh screen and preserved in 70% ethanol until identification. Preserved invertebrates were identified to the lowest taxonomic level possible. Detailed sampling protocols can be found in Umek et al (2010), Wittmann et al. (2010), and Caldwell et al. (2015).

No published benthic macroinvertebrate distribution data were available from Lake Mohave.

Reference Conditions

Benthic macroinvertebrate density data collected from pre and post quagga mussel invasion were compared. Pre-quagga mussel invasion data were from a benthic macroinvertebrate survey conducted in 1986 by Peck et al. (1987) and post invasion data were collected by Umek et al (2010), Wittmann et al. (2010), and Davis et al. (2014). As indicated above, no formal benthic macroinvertebrate surveys have been conducted in Lake Mohave.

Condition and Trend

Since the 1980s, the benthic macroinvertebrate community of Lake Mead has been a mixture of native and non-native species with variable community composition. Observed densities have generally been highest in deltas receiving inflows from Lake Mead's tributaries (Peck et al., 1987).

Oligochaetes and chironomids dominated the soft sediment benthic assemblage at Las Vegas Bay and Overton Arm in 2007 and spring of 2008. Quagga mussels (*Dreissena bugensis*, see section 4.5.2) were discovered in Lake Mead in 2007, but no quagga mussel individuals were found in Umek et al. (2010) benthic collections in 2007.

Wittmann et al. (2010) found that the composition and abundance of macroinvertebrate taxa observed in October 2008 and March 2009 was consistent between Las Vegas Bay, Boulder Basin, and Overton Arm, with most of the population abundance variability associated with depth and with the presence of quagga mussels. Taxa collected included quagga mussels, Asian clams (*Corbicula fluminea*), various gastropoda (*Physidae* spp., *Planorbidae* spp., *Hydrobiidae* spp.) including New Zealand mudsnail (*Potamopyrgus antipodarium*), Oligochaeta, Chironomidae at various stages (adult, pupae and larvae) and others (Ceratopogonidae, Ostracoda, Gammaridae, Odonata) (Wittmann, et al., 2010). Comparing data from 1986 and 2008, abundances of Asian clam and

chironomids have generally decreased, Oligochaeta densities have not changed significantly, and the average density of other taxa have increased (Figure 4.2.1-1). First discovered in Lake Mead in 2008, the New Zealand mudsnail (see section 4.5.2) was frequently detected in the fall 2008 and spring 2009 surveys (Wittmann, et al., 2010).

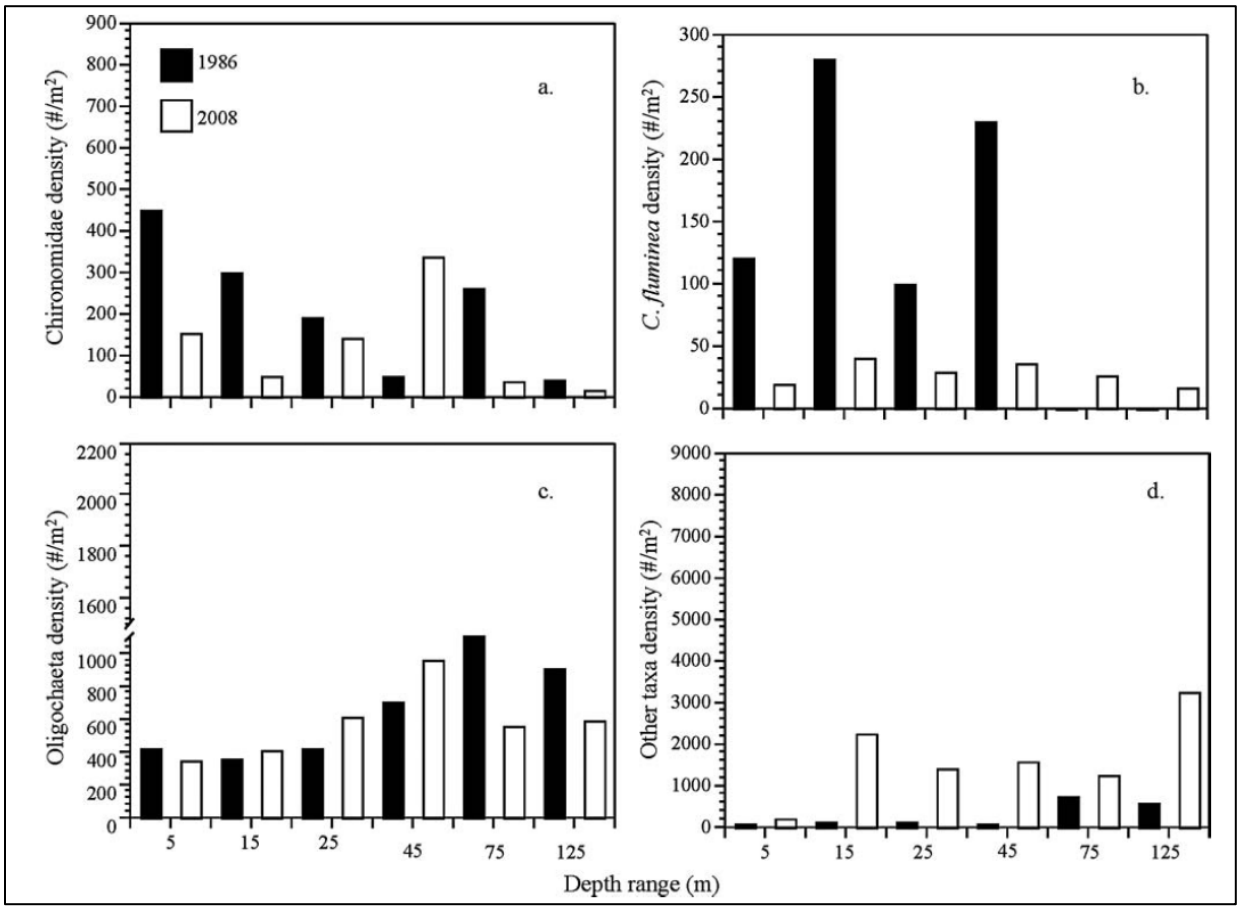


Figure 4.2.1-1. Changes in overall Lake Mead macroinvertebrate abundance between 1986 and 2008. Relative temporal comparison of densities by depth distribution of a) Chironomidae; b) *Corbicula fluminea*; c) Oligocheatae; and d) other taxa. Excerpted from Wittmann, et al., 2010.

Davis et al. (2014) collected additional macroinvertebrate data in the fall of 2010 and 2011. In 1986, native benthic macroinvertebrates dominated Lake Mead's benthic community at all depth ranges, with only Asian clam contributing to a minor portion of non-native species abundance. By fall 2011, non-native invertebrates, such as quagga mussels and New Zealand mudsnails became the majority at all depth ranges (Davis et al., 2014). Changes in quagga mussels and New Zealand mudsnail densities are discussed in section 4.5.2.

The total density of benthic macroinvertebrates inhabiting soft-sediment substrates in Lake Mead shows basin-specific spatial and temporal pattern (Figure 4.2.1-2). Since the 1980's, macroinvertebrate density in Boulder Basin has increased substantially in the littoral and sublittoral zones. Overton Arm sublittoral and **profundal zones** also had large increases in benthic

macroinvertebrate density in 2011(Figure 4.2.1-2). Increased overall densities observed in Boulder Basin and Overton Arm were largely driven by quagga mussel populations, as quagga mussels comprised the bulk of the macroinvertebrate community in these locations after its establishment. In contrast, Las Vegas Bay, which has very few quagga mussel populations, has relatively stable invertebrate densities through time (Figure 4.2.1-2).

Compared to 1986, chironomid densities have significantly decreased at all depth ranges in Boulder Basin and Overton Arm (Figure 4.2.1-3). Chironomids were absent in fall 2009 and recovered in fall 2011 in some basins' littoral (Las Vegas Bay), sublittoral (Boulder Basin and Overton Arm), and profundal zones (Boulder Basin and Overton Arm) (Figure 4.2.1-3). Overall, Oligochaeta densities were temporally stable across all depths at all three basins (Figure 4.2.1-5). Oligochaete densities in Boulder Basin, however, have had recent declines in the profundal zone. Densities of native gastropods have increased relative to1986 surveys, when they were typically absent from Lake Mead (Figure 4.2.1-4). The largest increases for native gastropods occurred in the sublittoral and profundal zones of Boulder Basin and Overton Arm (Figure 4.2.1-4). Asian clam densities were highly variable, though primarily have declined from 1986 to 2000s in the three basins (Figure 4.2.1-6).

The presence and absence of non-native benthic macroinvertebrates account for the majority of the dissimilarity between historic and contemporary invertebrate assemblages in Lake Mead, from a mostly native oligochaeate-chironomid assemblage to a mostly non-native quagga mussel-mudsnail-oligochaeate assemblage.

No benthic macroinvertebrate density data exist for Lake Mohave.

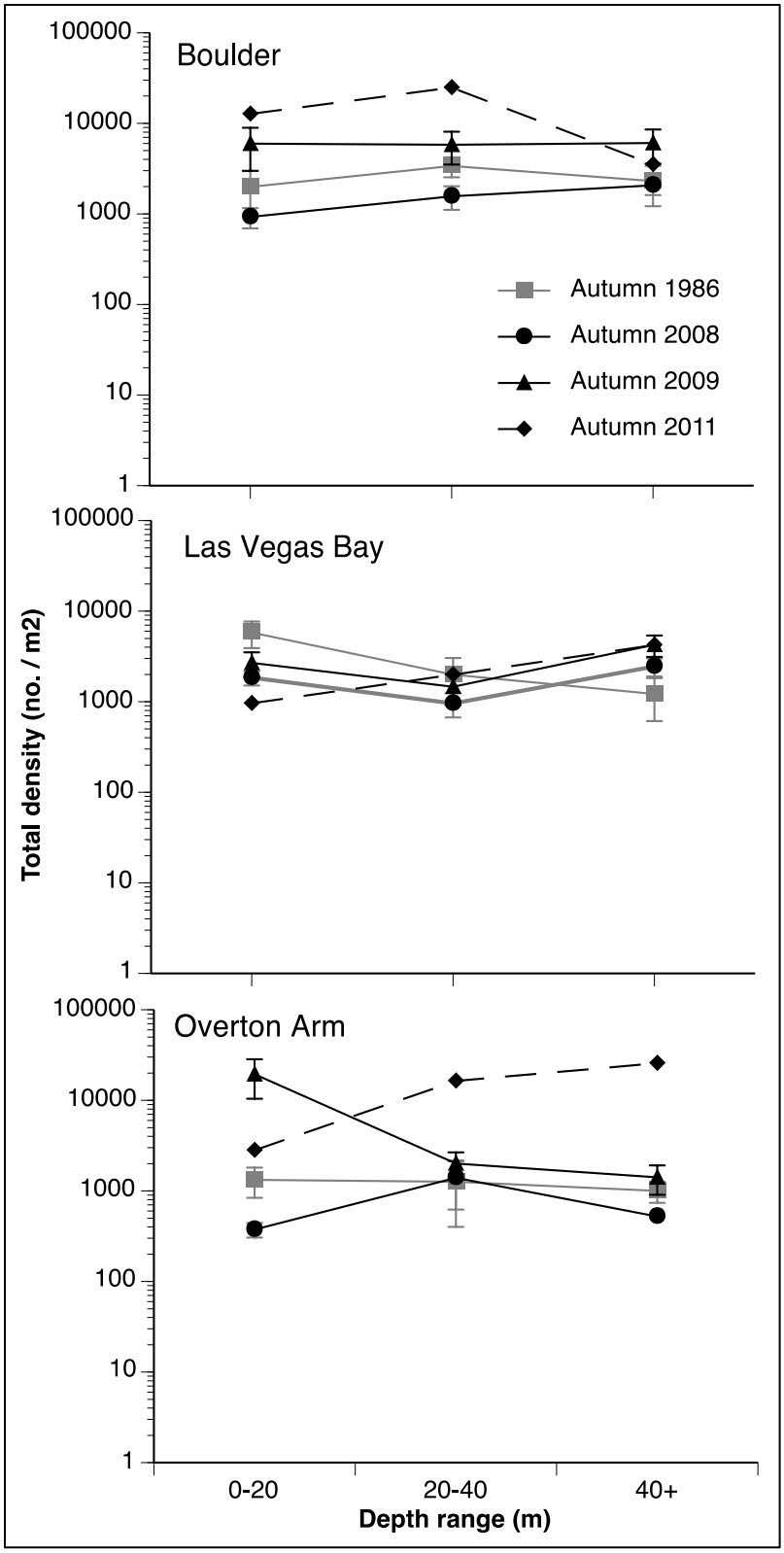


Figure 4.2.1-2. Total invertebrate density by depth (0–20m, 20–40m, and 40+ m) comparison in soft sediments for 1986 (grey) and 2008, 2009, 2011 (black) within three basins of Lake Mead. Note log scale in panels (mean +/- standard error). Data provided by Davis et al., 2014.

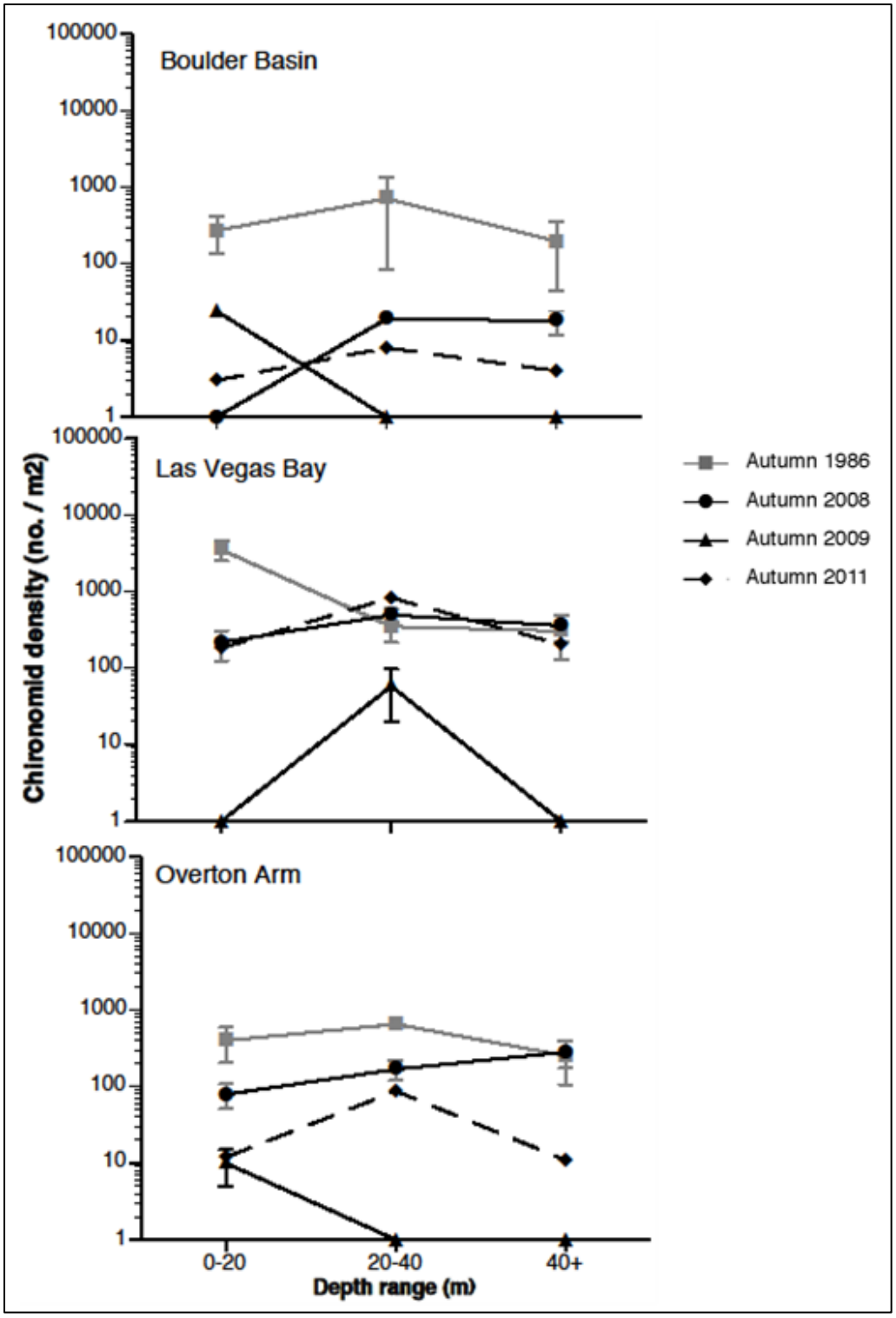


Figure 4.2.1-3. Chironomidae density by depth (0–20m, 20–40m, and 40+ m) comparison in soft sediments for 1986 (grey) and 2008, 2009, 2011 (black) within three basins of Lake Mead. Note log scale in panels (mean +/- standard error). Data provided by Davis et al., 2014.

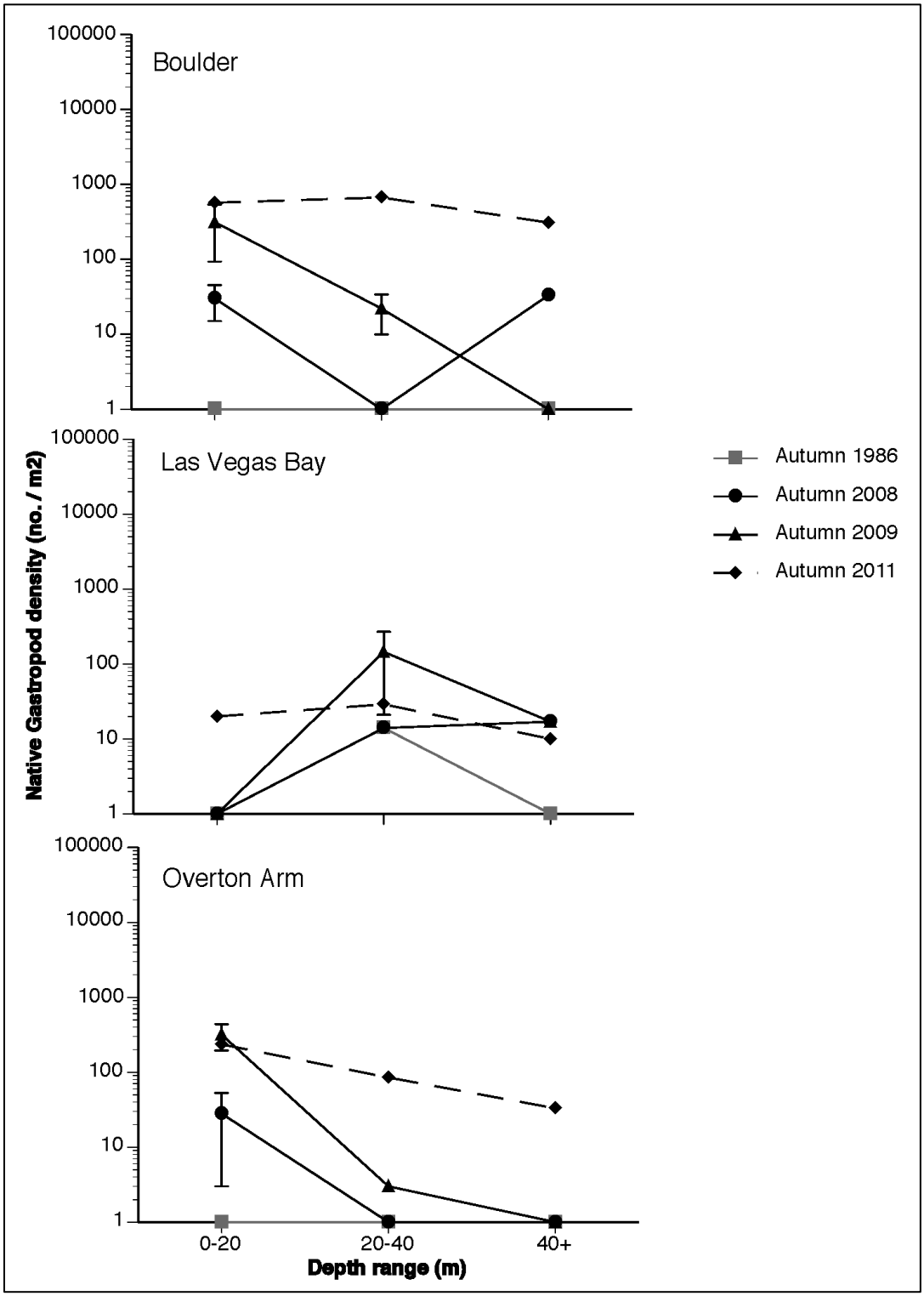


Figure 4.2.1-4. Native gastropod density by depth (0–20m, 20–40m, and 40+ m) comparison in soft sediments for 1986 (grey) and 2008, 2009, 2011 (black) within three basins of Lake Mead. Note log scale in panels (mean +/- standard error). Data provided by Davis et al., 2014.

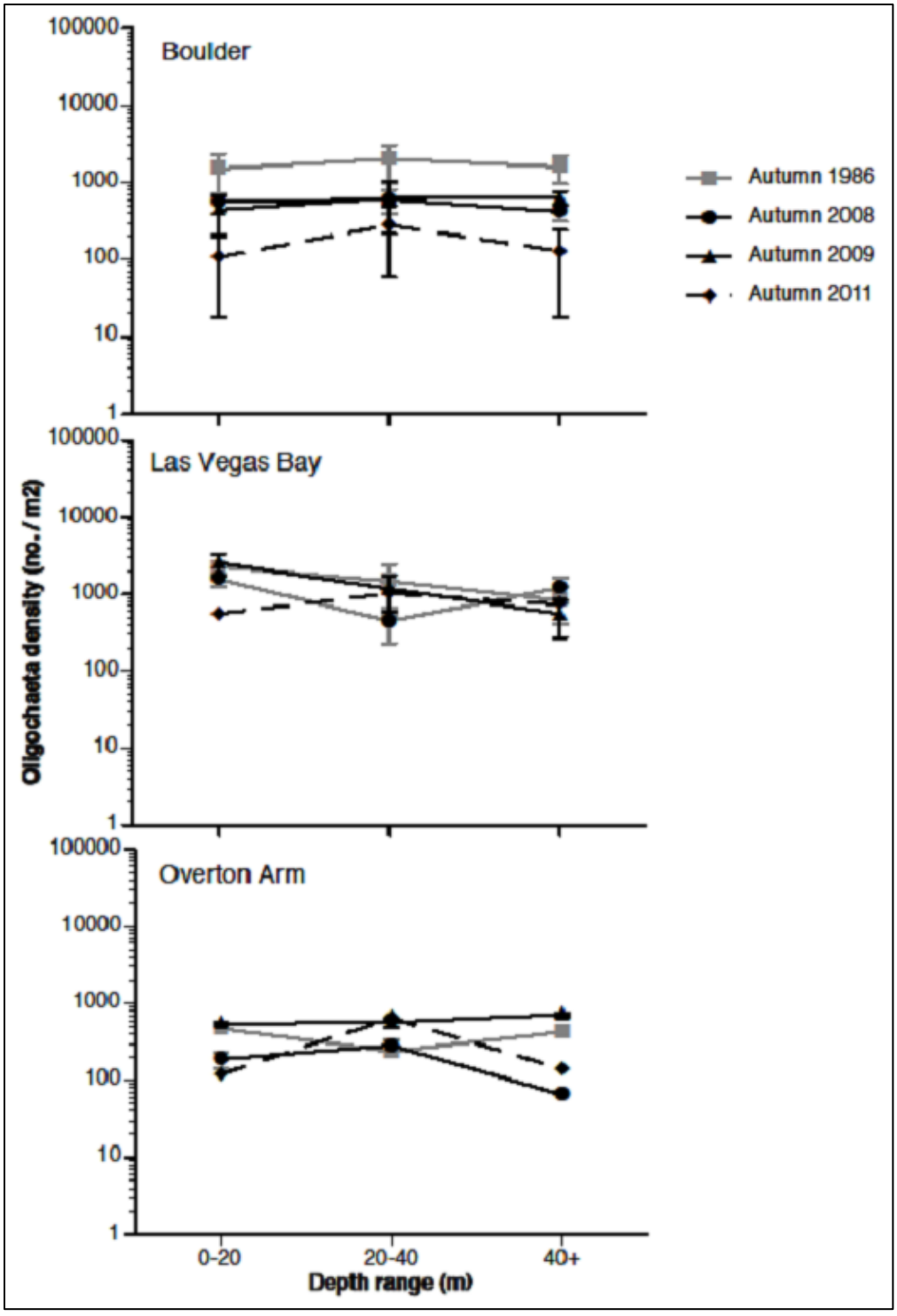


Figure 4.2.1-5. Oligocheatae density by depth (0–20m, 20–40m, and 40+ m) comparison in soft sediments for 1986 (grey) and 2008, 2009, 2011 (black) within three basins of Lake Mead. Note log scale in panels (mean +/- standard error). Data provided by Davis et al., 2014.

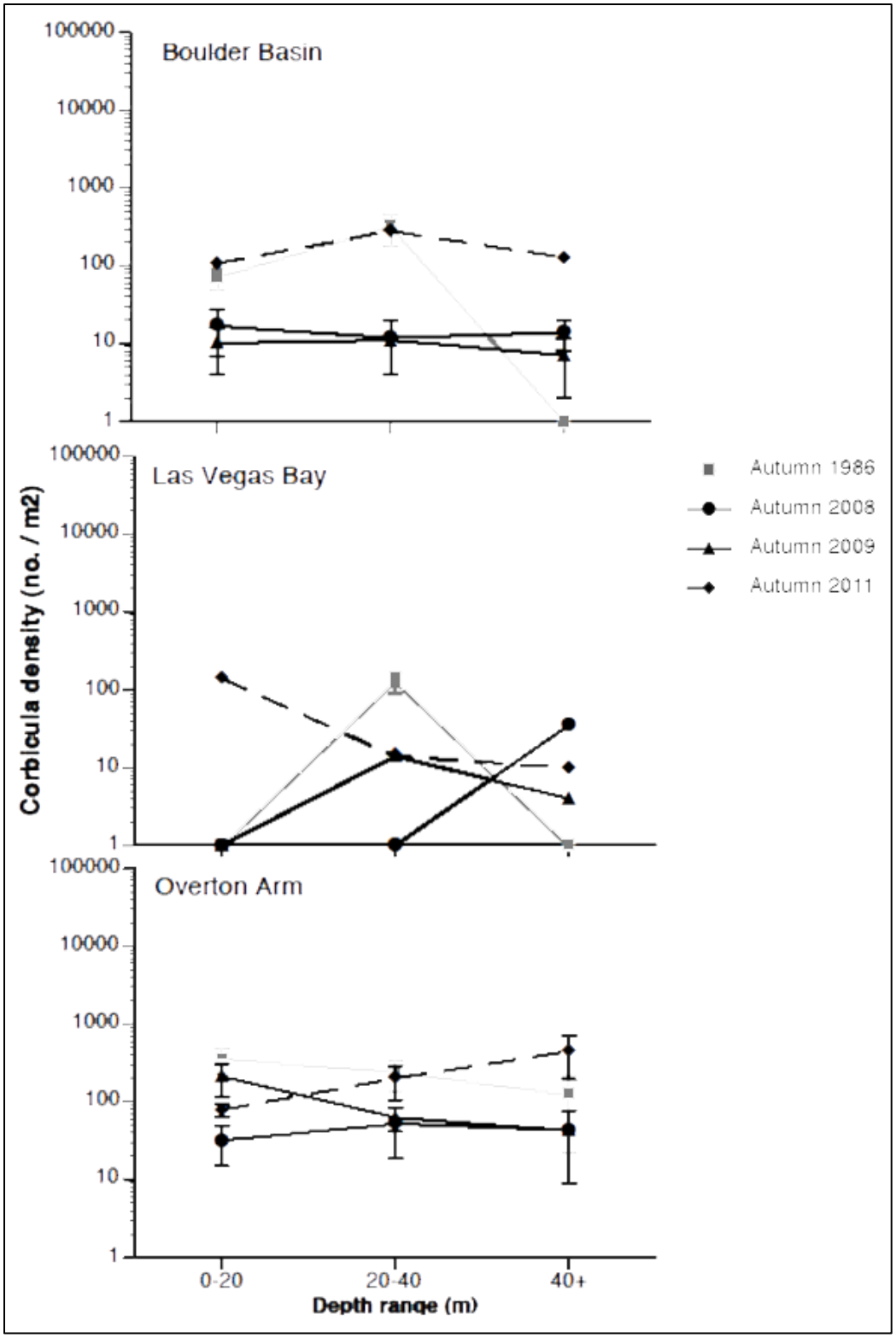


Figure 4.2.1-6. *Corbicula fluminea* density by depth (0–20m, 20–40m, and 40+ m) comparison in soft sediments for 1986 (grey) and 2008, 2009, 2011 (black) within three basins of Lake Mead. Note log scale in panels (mean +/- standard error). Data provided by Davis et al., 2014.

Assessment Confidence/Key Data Gaps/Stressors

Assessment confidence for current benthic macroinvertebrate condition status in Lake Mead is moderate due to the lack of contemporary benthic macroinvertebrate composition and density information. In addition, no data were available for Lake Mohave. Similar to monitoring zooplankton, benthic invertebrates should be incorprated into a regular monitoring program. Regular seasonal monitoring of benthic macroinvertebrate populations is highly recommended to link changes from water quality, invasive of mussels, and potential changes to the fish community since the food web relies storngly on benthic processes. Changes in the soft sediment and hard rock community may indicated different changes to the lake ecosystem. Quagga mussel do utilize both habitats but likely prefer hard substrate where as native and soft bodies invertebrates may use soft sediments.

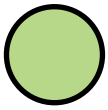
See section 4.5 Stressors and Disturbance Regimes for further discussion regarding the impact and potential threat of aquatic invasive species and other stressors on the benthic macroinvertebrate communities in lakes Mead and Mohave.

4.2.2. Zooplankton

Assessment Outcome

A summary of the parameters used assess zooplankton are shown in Table 4.2.2-1.

Table 4.2.2-1. Assessment outcome for the overall condition status and trend for Zooplankton.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Population Trend by Key Taxonomic Groups	Density	Mead		Zooplankton diversity and density are highly variable but similar to historical conditions even with quagga mussel invasive veligers compromising part of the planktonic community and drought issues.
	Density	Mohave		In sufficient data over time to detect trend and status.

Description

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. 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 sportfish in Lakes Mead and Mohave, such as largemouth bass and striped bass. Nearshore zooplankton are likely important food resources for young of year and early age class nongame and game fishes. Thus, monitoring zooplankton abundance is critical to the sport fishery on both lakes (Rosen, Turner, Goodbred, & Miller, 2012).

Free-swimming zooplankton community types can be classified by where they reside in a lake. 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. The density of aquatic vegetation is one of the major influences on the diversity and abundance of littoral zooplankton (Rosen, Turner, Goodbred, & Miller, 2012). Lakes Mead and Mohave generally lack abundant aquatic vegetation, thus is dominated by limnetic zooplankton.

Key zooplankton groups found in Lakes Mead and Mohave are copepods, cladocerans, rotifers, ostracods, and quagga mussel veligers (Rosen, Turner, Goodbred, & Miller, 2012). In Lake Mead, zooplankton abundance and species composition appear to be largely controlled by fish abundance and predation (Sollberger & and Paulson, 1992).

Data and Methods

Table 4.2.2-2 shows the data and methods used to assess zooplankton.

Table 4.2.2-2. Data and used in the assessment of zooplankton.

Indicator(s)	Measurement(s)	Scale of Analysis
Population trend by key taxonomic groups	Density, individual/L	Lake

Zooplankton density data have been collected by several different monitoring programs in Lakes Mead and snap shots studies from Mohave.

Between 1990 and 2006, while monitoring water quality of the source water in Lake Mead for drinking water safety, Southern Nevada Water Authority (SNWA) also collected total zooplankton abundance data. Reclamation surface monitoring conducted by BOR LCR region in Lakes Mead and Mohave collected zooplankton densities data on a monthly basis from 1990 to 2009 and on a quarterly interval from 2010 to present. Early sampling effort was primarily focused in Boulder Basin, particularly in the Las Vegas Bay area. In 2000, the monitoring program was expanded to the other 4 basins in Lake Mead. Between 1990 and 1998, zooplankton samples were collected with a Wisconsin-style plankton net with 80 µm mesh towed from 5–6m below the surface to the top of the water column (LaBounty, Holdren, & Horn, 2004). From 2002, zooplankton samples were collected with a Wisconsin-style plankton net with 64 µm mesh and 15 cm diameter towed from the bottom or from a depth of 30 m to the surface through the water column. The tow depth modification was a result of findings from Mueller and Horn (1999) showing significant zooplankton concentrations in deeper water in Lake Mead. Zooplankton density data collected by these monitoring programs were used in this assessment. Data (2000–2015) for Lake Mead were downloaded from the SNWA database (http://snwaexapps.lvvwd.com/WaterQuality/wqv3/WQSearch.aspx?action=&uuid=). Locations were selected were to capture conditions in different basins within Lake Mead. Data were included from representative monitoring stations in Boulder, Virgin, Temple, and Gregg basins, Overton Arm, and Las Vegas Bay based on sites analyzed in LaBounty et al. (2004), Holdren et al.

(2008). Zooplankton monitoring data from Lake Mohave were provided by BOR LCR and include data collected in 2013 and 2014.

Values used for each site for comparison were computed as monthly averages of values for all samples (including those at all sample depths, where appropriate, unless specified) collected from each year examined. Additional information from published literature was also used. Sources include: (Sollberger & and Paulson, 1992; Mueller & Horn, 1999; LaBounty & Burns, 2005; Rosen, Turner, Goodbred, & Miller, 2012).

Reference Conditions

Table 4.2.2-3 shows the reference conditions used to assess zooplankton.

Table 4.2.2-3. Reference conditions for zooplankton used in the assessement.

Measurement(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Density	Significant density reduction from periods of pre-quagga invasion where populations are no longer sufficient for forage fish species to support sport fishery	Slight reduction in population density compared to densities recorded before quagga invasion.	No change or increase in population density and composition during post quagga invasion period compared to before quagga invasion. Populations remain sufficient for forage fish species to support sport fishery.

Condition and Trend

Lake Mead

Overall, a diverse zooplankton community exists in Lake Mead. 27 limnetic and 15 littoral species of zooplankton were present in surveys conducted in 1984–1985 at Las Vegas Bay in Boulder Basin. Limnetic species were found to dominate both littoral and limnetic zooplankton communities. Littoral species rarely exceeded 2% of total zooplankton densities. Most common zooplankton groups were copepods, cladocerans, and rotifers, with peak densities observed in the fall and late winter (Sollberger & and Paulson, 1992). Similar species were found in 1996–1997 collections with densities of rotifers and copepods peaking in spring and late fall (Mueller & Horn 1999).

Between 1990 and 1998, BOR LCR region collected zooplankton samples in Boulder Basin. Zooplankton samples were collected from the top 5 m of the water column. Since zooplankton migrate within the water column on a diurnal basis, this study would not have captured zooplankton found below the 5 m depth sampled. LaBounty et al. (2004) shows that zooplankton density changed from within inner Las Vegas Bay to the outer bay, and again in open Boulder Basin to Hoover Dam. They also found that overall zooplankton densities were higher in 1990–1995 than 1996–1998 which correspond with the drought years of 1990–1995 and the wet years of 1996–1998 (LaBounty, Holdren, & Horn, 2004).

In zooplankton surveys made from 2000 to 2004 by SNWA and BOR (LaBounty & Burns 2005), more than 70 species were identified in Boulder Basin indicating that species diversity in Lake Mead is higher than previously implied. Zooplankton abundance increased from 2000 to 2004 in Boulder Basin, with a large spike in population in 2003 (LaBounty & Burns 2005). Increases such as these may provide greater forage for sportfish. However, when populations of zooplankton-eating fish exceed the zooplankton supply, zooplankton abundance can crash. This, which is part of a natural cycle in Lake Mead, occurred at the end of 2003 (LaBounty and Burns, 2005).

Between 2000 and 2006, zooplankton composition was relatively stable across monitoring locations. Cladocerans, copepods, and rotifers represent 10–20%, 40–80%, and 10–30% of total, respectively. However, since invasive quagga mussels were first detected in Lake Mead in 2007, quagga mussel veligers, the temporary planktonic phase of quagga mussels, have at times become a dominant zooplankton species (up to 80%) in Lake Mead (Figure 4.2.2-1 – Figure 4.2.2-6). Much of the offset in percent composition by veligers were from the copepods. While the densities of veligers represent a significant fraction of the zooplankton community in Lake Mead, biomass of individual veligers is much lower than copepods and cladocerans, thus total biomass of veligers is expected to be lower than other zooplankton.

Zooplankton densities are the highest in Las Vegas Bay compared to other monitoring locations. This may be the result of increased food availability from Las Vegas Wash waters and associated nutrients (Figure 4.2.2-1). Copepods and rotifers dominated the community in Las Vegas Bay. Veligers reached peak densities in fall 2010 and spring 2011 (15–20 individuals/L) and have since existed much lower densities (< 5 individuals/L) (Figure 4.2.2-1). Rotifer and copepod densities also bloom during the same period. Average zooplankton densities of all key zooplankton groups have increased post-quagga mussel invasion (2007–2015) in Las Vegas Bay. In particular, a significant increase in rotifer densities was observed during the post-invasion period (pre: averaged 4 individuals/L to post: averaged 15 individuals/L). Rotifers tend to occur in higher densities in eutrophic and shallow waters. An increase in rotifer densities may imply increased eutrophication (Holdren, Horn, & Lieberman, 2008).

Zooplankton densities are the lowest in Boulder Basin compared to other monitoring locations (Figure 4.2.2-2). Veligers dominated the community in Boulder Basin after quagga mussel invasion, making up 20 to 80% of total and peaked in 2008 with 35 individuals/L. However, the overall abundance of veligers was similar to that seen in other basins. Similar to Las Vegas Bay, Boulder Basin also saw a zooplankton bloom during fall 2010 and spring 2011 with copepods and veligers contributing to the majority of the bloom in total densities (Figure 4.2.2-2). Average zooplankton densities of all key zooplankton groups have remained unchanged post-quagga mussel invasion (2007–2015) in Boulder Basin. In a comprehensive spatial assessment of Boulder Basin in relation to drought dynamics, Beaver et al. (2010) suggest, average *Daphnia* abundance since the beginning of drought conditions and the establishment of quagga mussels is lower in Boulder Basin. However, the pattern in time and space are more comparable to predrought conditions in Boulder Basin and other basins.

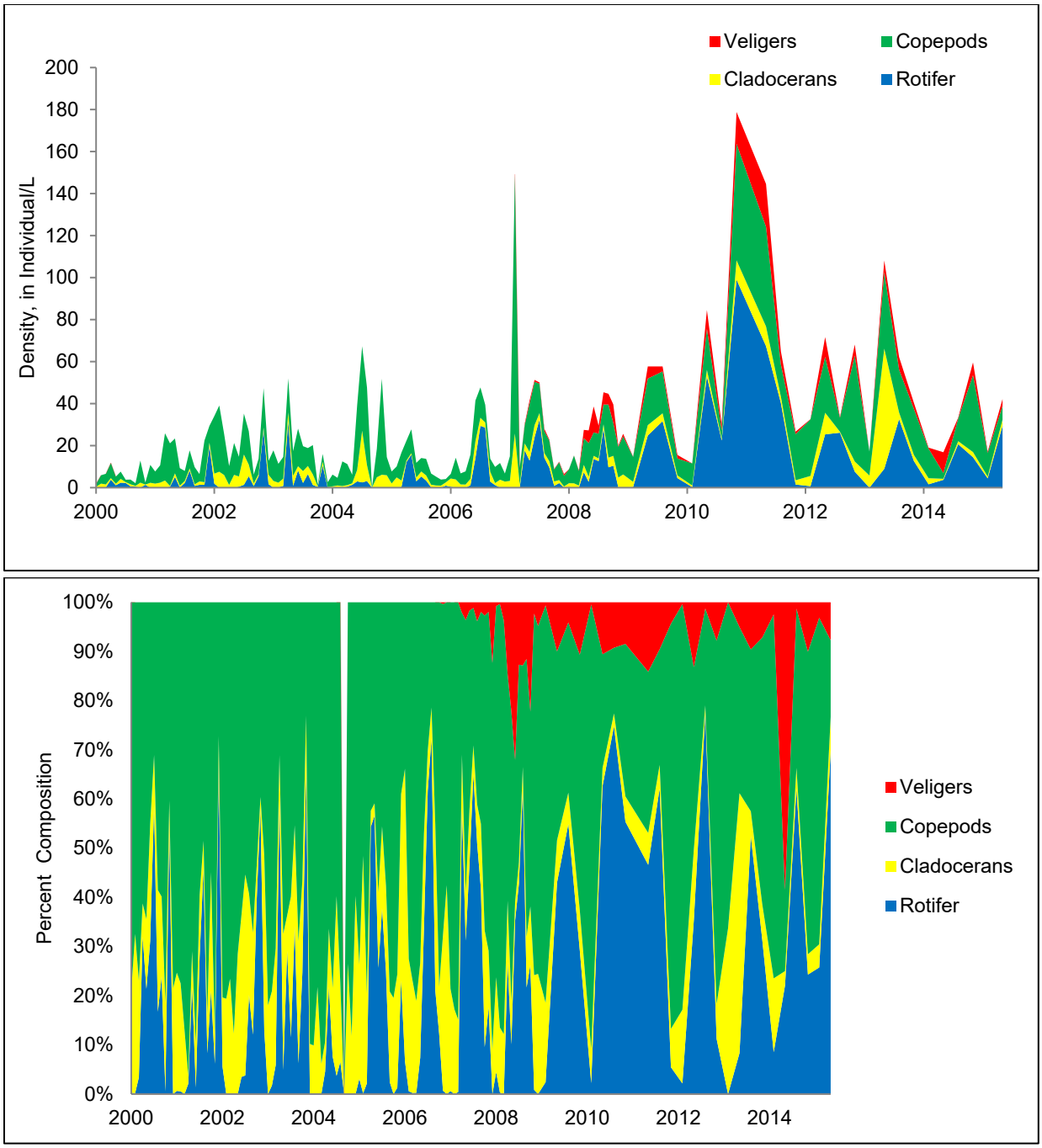


Figure 4.2.2-1. Zooplankton density (top) and proportional representation (bottom) for Las Vegas Bay (LVB4.15 and 4.95).

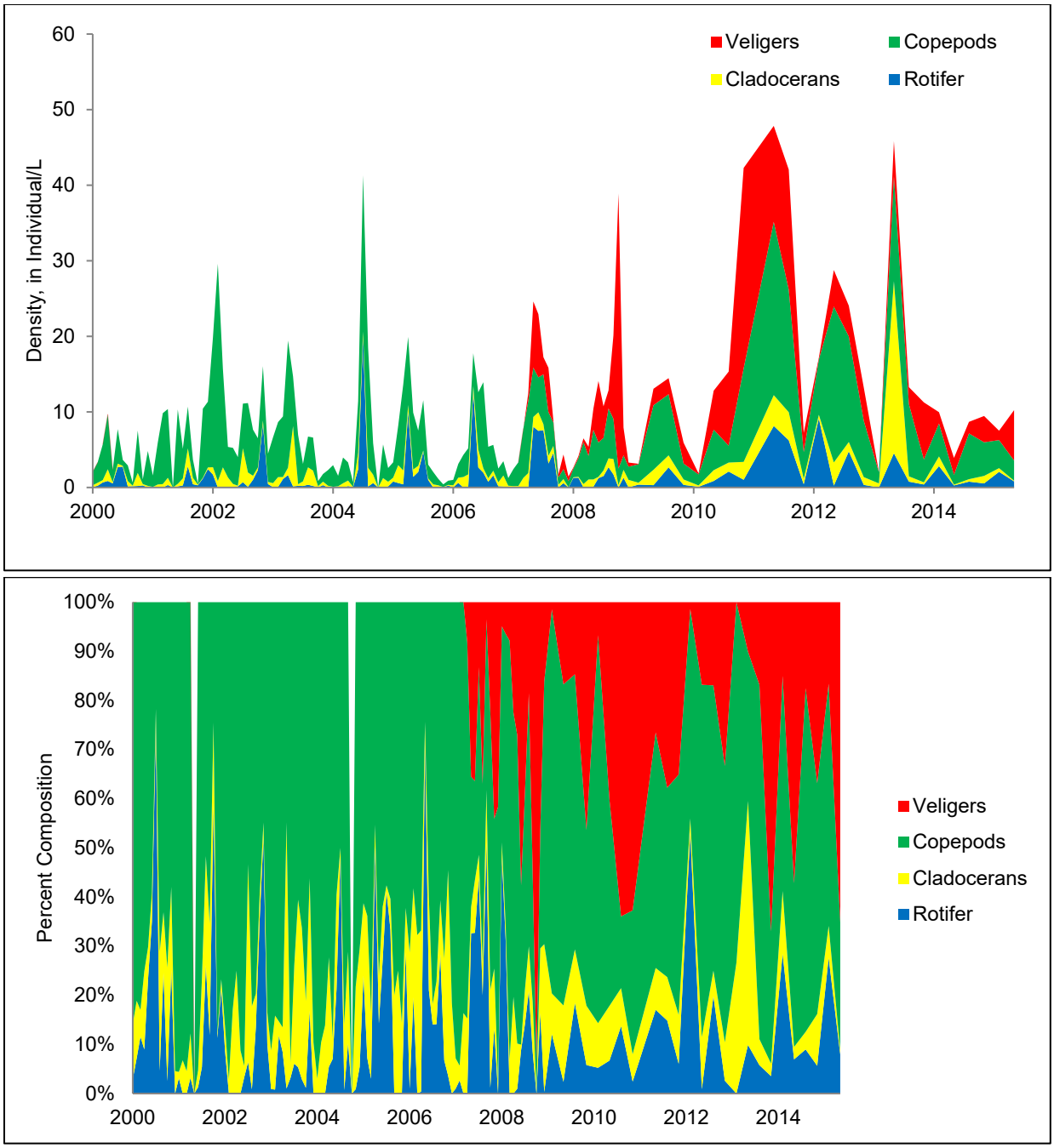


Figure 4.2.2-2. Zooplankton density (top) and proportional representation (bottom) for Boulder Basin (CR346.4).

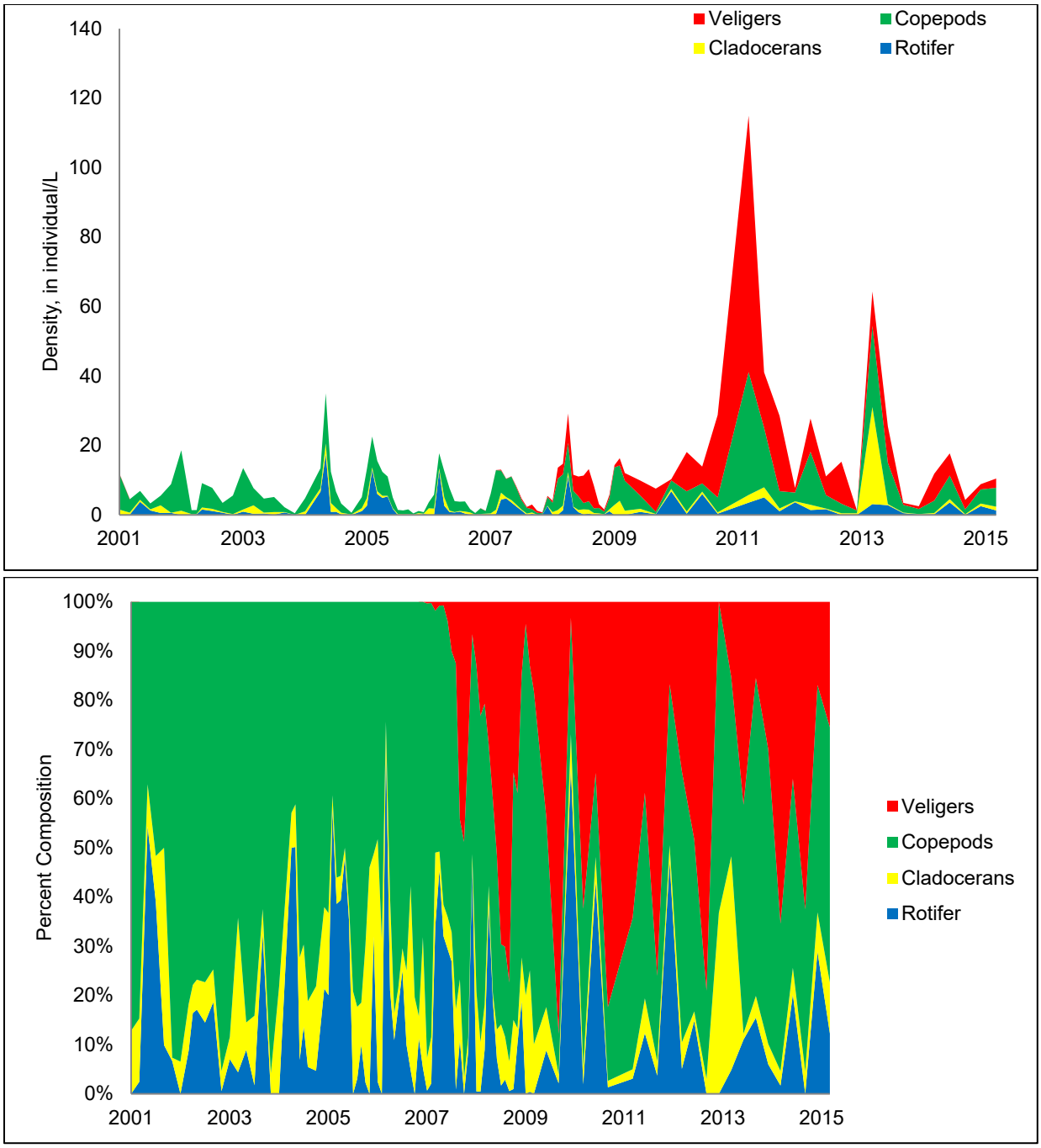


Figure 4.2.2-3. Zooplankton density (top) and proportional representation (bottom) for Virgin Basin (CR360.7).

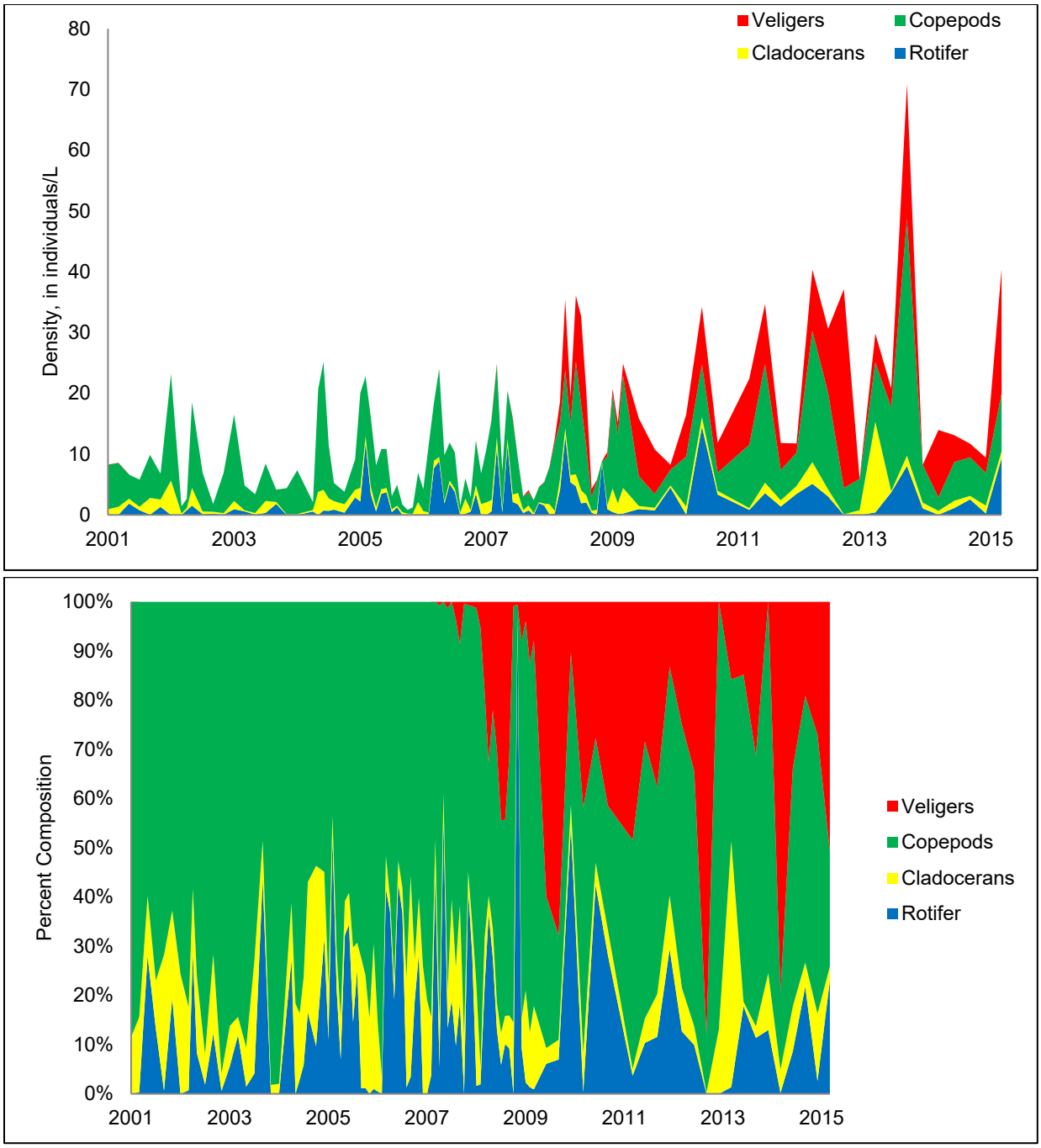


Figure 4.2.2-4. Zooplankton density (top) and proportional representation (bottom) for Temple Basin (CR380.0).

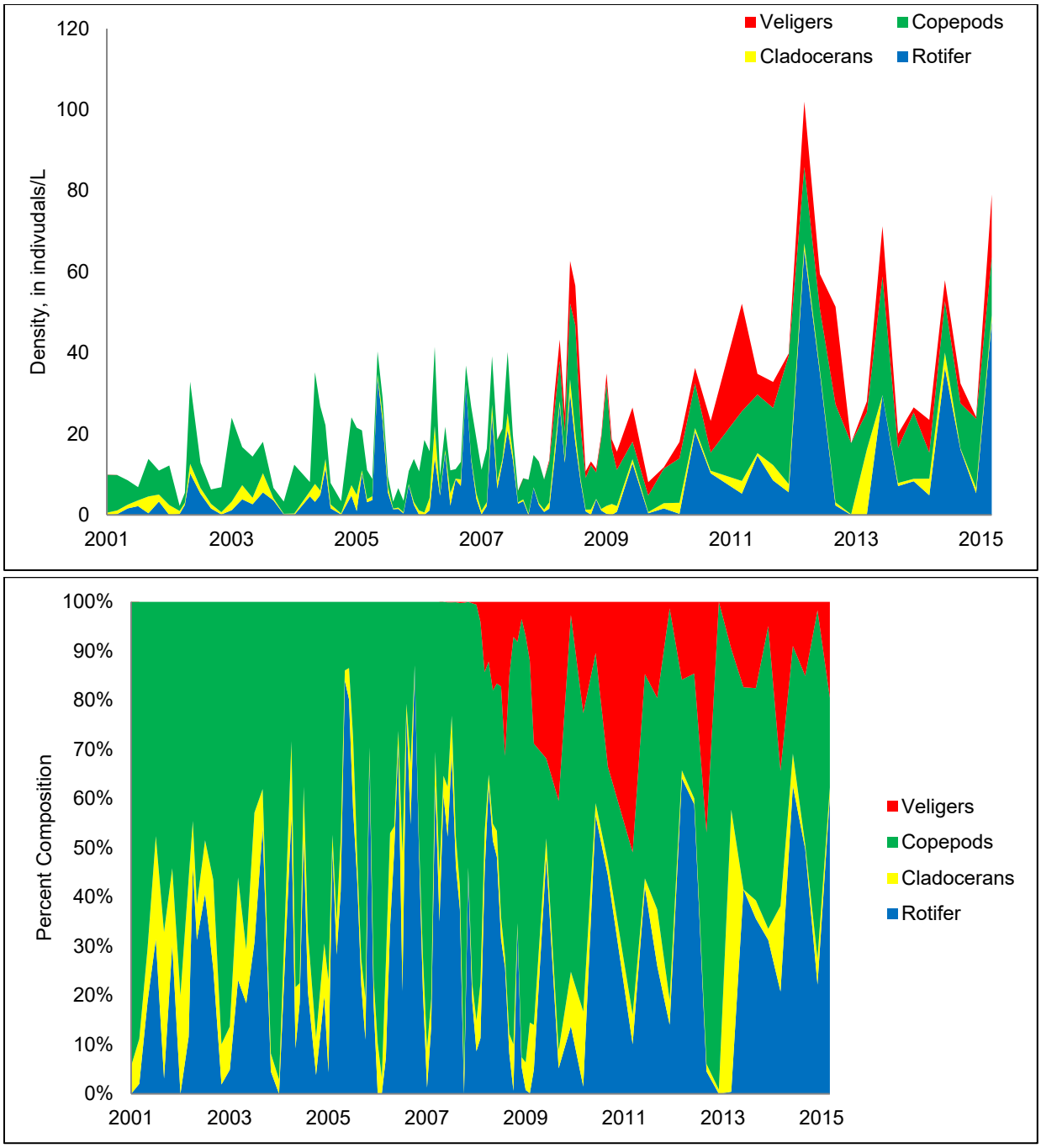


Figure 4.2.2-5. Zooplankton density (top) and proportional representation (bottom) for Gregg Basin (CR390.0 and CR394.0).

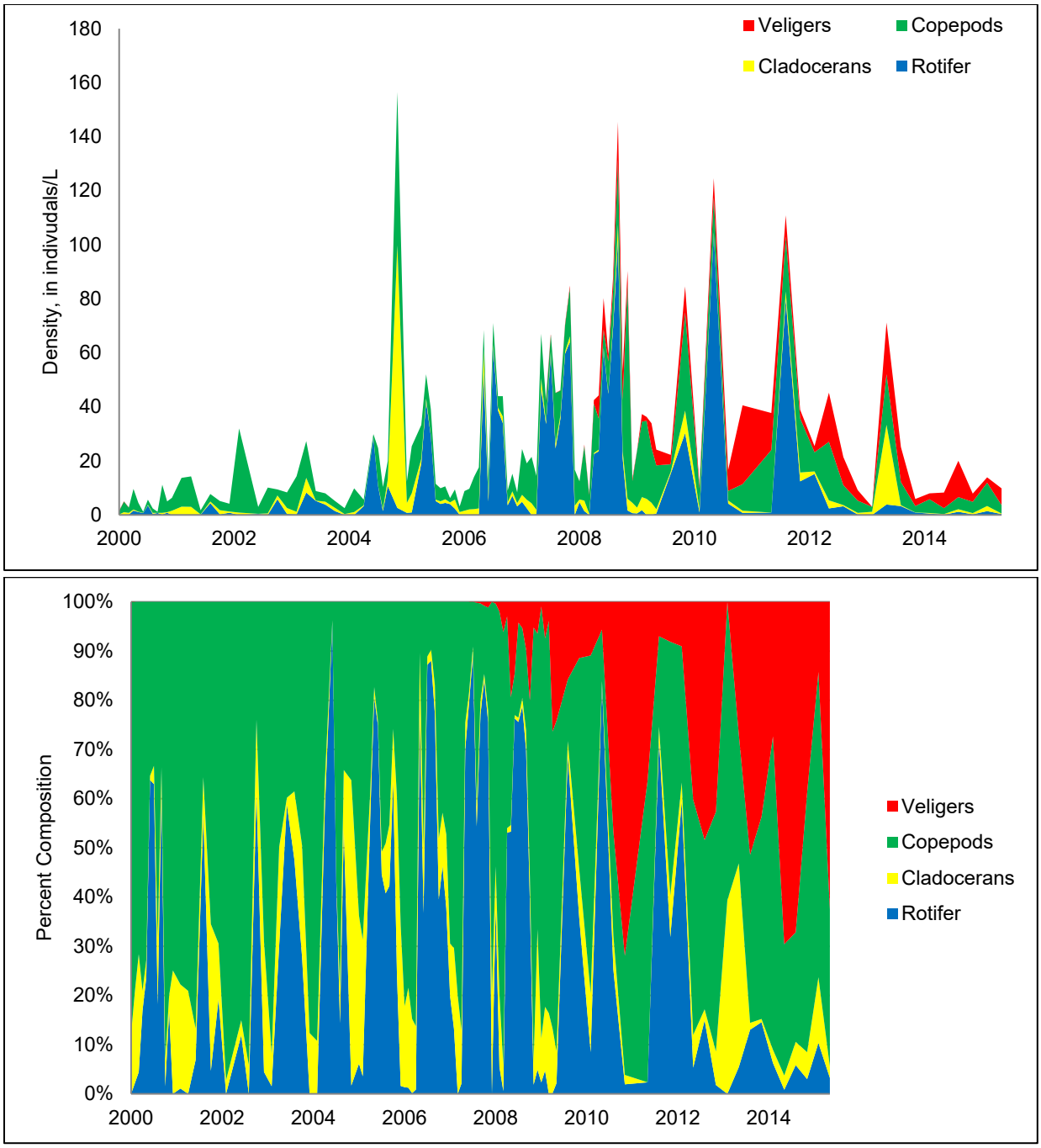


Figure 4.2.2-6. Zooplankton density (top) and proportional representation (bottom) for Overton Arm (VR6.0 and VR25.1).

Similar total zooplankton densities were observed among Virgin (Figure 4.2.2-3), Temple (Figure 4.2.2-4), and Gregg (Figure 4.2.2-5) basins. Copepods dominated the zooplankton communities in all three basins. Veligers densities were similar among the three basins (averaged 6 individuals/L between 2007 and 2015). Average zooplankton densities of all key zooplankton groups in Virgin

Basin and Temple Basin remained unchanged after quagga mussel invasion. Rotifer densities have increased in Gregg Basin since the invasion of quagga mussels (Figure 4.2.2-5).

In Overton Arm, there was a spike in rotifer densities between 2005 and 2011 with peaks at about 100 individuals/L. Densities have since reduced to less than 3 individuals/L. Veligers have dominated the zooplankton community in recent years (2012–2015) with a decrease in densities observed with other zooplankton groups.

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 (2007–2015) for Lakes Mead and Mohave indicate that although quagga mussel veligers can periodically be a dominant species of zooplankton, the overall composition and densities of other zooplankton remain unchanged or increased in recent years (at Colorado main stem stations, e.g. Gregg, Temple, and Virgin basins) which correspond to the persistent drought experienced by the Colorado River Basin and the lake in the past decade (Figure 4.2.2-1–Figure 4.2.2-6).

Lake Mohave

Zooplankton density data were only available from three sampling events conducted in 2013 and 2014. Placer Cove has the lowest overall zooplankton densities at all seasons. Veliger densities dominated zooplankton composition mostly in spring. Summer veliger densities were generally low in the summer except at Katherine's Landing. No consistent patterns were observed with densities of other zooplankton groups (Figure 4.2.2-7).

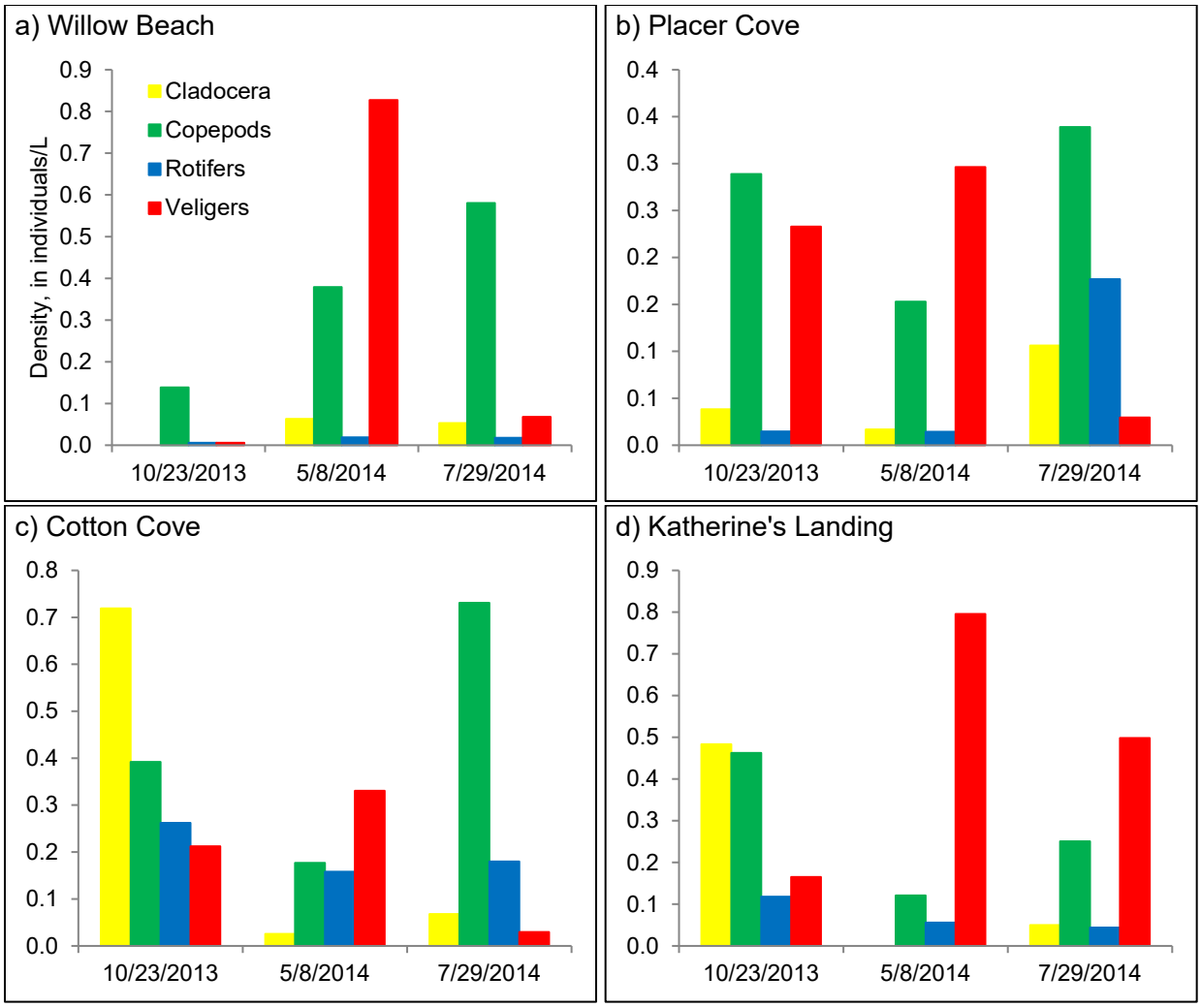


Figure 4.2.2-7. Zooplankton densities measured at various monitoring stations in Lake Mohave, a) Willow Beach, b) Placer Cove, c) Cottonwood Cove, and d) Katherine's Landing.

Assessment Confidence/Key Data Gaps/Threats

The confidence around zooplankton trend and status is high in Lake Mead. Trend data suggest highly variable but zooplankton composition and densities have not changed after invasion by mussels and during drought. Research from other large lakes suggests the biomass of zooplankton may decrease if there is competition between veligers and zooplankton and structural changes in microzooplankton may occur if there is increased predation from veligers. In order to assess the confidence of the trend and mechanistic role of plankton in the system, select experiments are recommended to evaluate the influence of invasive veligers to zooplankton biodiversity, growth, and reproduction

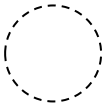
There is little data from the lake to assess the status and trend of the zooplankton community for Lake Mohave. Initiating and maintaining a monitoring program to detect trends in densities and mechanistic experiments to quantify the influence of veligers to zooplankton growth and reproduction are needed. Veliger densities can be higher than other zooplankton densities during certain seasons.

4.2.3. Phytoplankton

Assessment Outcome

A summary of the parameters used assess phytoplankton are shown in Table 4.2.3-1.

Table 4.2.3-1. Overall assessment outcome for the assessment of phytoplankton.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Population Trend by Key Taxonomic Groups	Density	Mead		Increase in cyanobacterial cells post quagga detection in Boulder Basin.
	Density	Mohave		In sufficient data to quantify changes before/ after mussel invasion.

Description

Phytoplankton are microscopic plants that form the base of the aquatic food web. Free-floating phytoplankton in the water column are an important source of food (energy) for zooplankton, some fish, and aquatic birds in Lakes Mead and Mohave. Freshwater phytoplankton can be categorized into different groups such as green algae (Chlorophyta), cyanobacteria that also are known as blue-green algae (Cyanophyta), diatoms (Bacillariophyceae), golden-brown algae (Chrysophyta), and dinoflagellates (Pyrrhophyta). Many environmental and chemical factors control phytoplankton population in a lake. Phytoplankton require light, carbon dioxide, and nutrients such as nitrogen and phosphorus to grow. Nitrogen and phosphorus must be present at a certain ratio (the Redfield ratio; (Redfield, 1934)) for optimal algae growth; therefore, if either or both of these nutrients are absent or in low supply, algal growth will be limited. A healthy lake system should support a diverse phytoplankton assemblage. Excessive growth of phytoplankton can lead to algal blooms and if there are taxa which can fix nitrogen can results in an influx of nutrients into the lake system (Holdren, Horn, & Lieberman, 2008). Algal blooms can cause unsightly conditions that affect recreation and visual enjoyment of the lake, reduced light penetration into the lake, and after settling to the lake bottome and consumed by bacteria can lead to the reduction of dissolved oxygen, killing invertebrate and fish species. Thus, monitoring phytoplankton composition and abundance can provide insight to the condition and health of a lake ecosystem.

Data and Methods

Table 4.2.3-2 shows the data and methods used to assess phytoplankton.

Table 4.2.3-2. Measurements and metrics used in the assessment of phytoplankton.

Measurement	Metric	Scale of Analysis
Population trend by key taxonomic groups	Density and biovolume	Lake

Phytoplankton samples from open water sites were collected from the same composite sampler used for chlorophyll *a* collections with ongoing monitoring programs conducted by BOR and SNWA since 1994. Phytoplankton composition and count are aggregated into the following taxonomic groups:

- Diatoms (Bacillariophyceae)
- Green algae (Chlorophyta)
- Cryptomonads (Cryptophyta)
- Cyanobacteria/blue-green algae (Cyanophyta), including Microcystis sp. (Microcystis aeruginosa) – See section 4.4
- Golden-brown algae (Chrysophyta)
- Euglenoids (Euglenophyta)
- Dinoflagellates/red algae (Pyrrhophyta)
- Total includes all groups above and miscellaneous algae (microflagellates, unidentifiable cysts, and Gonyostomum semen, which is in the division Chloromonadophyta)

Phytoplankton data are reported as total phytoplankton densities (cells/ml) and/or densities by taxonomic groups (natural units/ml), and total biovolume or biovolume by taxonomic groups (μm^3/mL) at all monitoring stations examined here. Density, frequently used when examining algal production, describes the number of cells found in a given volume but do not account for cell size. The measure of biovolume, on the other hand, accounts for the variation in cell size among algal species. Biovolume is estimated by assigning each algal cell to the nearest geometrical shape and may give a better indication of blooms of nuisance species (Holdren, Horn, & Lieberman, 2008). Cyanobacteria (Cyanophyta) and Microcystis sp. (Microcystis aeruginosa) are evaluated under the Recreation Suitability Indicator-Harmful Algal Bloom/Toxin parameter (See section 4.4).

Data were included from representative monitoring stations in Boulder, Virgin, Temple, and Gregg basins, Overton Arm, and Las Vegas Bay based on sites analyzed in LaBounty et al. (2004), Holdren et al. (2008). Data for Lake Mead were downloaded from the SNWA database (http://snwaexapps.lvvwd.com/WaterQuality/wqv3/WQSearch.aspx?action=&uuid=). The following data were evaluated for this assessment:

- Quarterly (February, May, August, and November) biovolume by taxonomic groups from all selected stations (2006, 2008–2015; Las Vegas Bay and Boulder Basin have data from 2007)
- Quarterly densities by taxonomic groups from all selected stations (2012–2015)
- Monthly total phytoplankton densities and biovolume from Boulder Basin (2000–2015)

Lake Mead: Boulder Basin Case Study. Please note, phytoplankton samples were counted by different agencies and phytoplankton experts over time. Using different phytoplankton experts yields different results in identification and counting. In order to develop a consistency with counts, we reached out to Ann St Armand, a phycologist expert who counted over 1421 algal samples from Boulder Basin in 2002–2013 were analyzed to the genus level with numeric counts (Natural

Units/mL, cells/mL and biovolume as um^3/mL) using Multi-Dimensional Scaling (MDS) in Primer-E, v6. In this analysis, all algal samples were processed at one laboratory with a single expert taxonomist, avoiding the pitfalls of misidentification of algal taxa and including similar sizes of taxa. Algal samples were taken at multiple stations, including the inflow, Las Vegas Wash, and the Hoover Dam. Zooplankton data, water chemistry, elevation, and discharge total phosphorus data were from the aforementioned SNWA and BOR databases.

Lake Mohave. Phytoplankton monitoring data from Lake Mohave were provided by BOR LCR and include data collected in May and August 2014.

Reference Conditions

Table 4.2.3-3 shows the reference conditions used to assess phytoplankton.

Table 4.2.3-3. Reference conditions of phytoplankton used in the assessment.

	Condition Status		
Measurment(s)	**Significant Concern***	**Moderate Concern***	**Good***
Density cell or biovolume concentration	Significant change in taxa over time before and after mussel invasion.	Slight reduction or increase in algal densities and composition shifts before and after mussel invasion; increase in cyanobacteria.	No change in density of algae or composition before and after mussel invasion.

Condition and Trend

There are unique patterns in phytoplankton dynamics over time depending on the basin which is reflective of the inputs and limnological dynamics in each basin. Strong seasonal influences are apparent in each basin with peaks corresponding with spring inflows and physical turnover (Figures 4.2.3-1 to 4.2.3-2). Overall phytoplankton biomass is highest in Las Vegas Bay compared to other parts of Lake Mead. Phytoplankton cell counts remain relatively consistent over time except in Spring 2013 (Figure 4.2.3-3). All basins exhibit a dramatic increase in phytoplankton in this season. Las Vegas Bay phytoplankton is comprised of taxa that are indicative of more mesotrophic to eutrophic conditions (Figure 4.2.3-4). Boulder Basin has a higher diversity of algae proportionally. The phytoplankton group that dominated by biovolume can be different than the phytoplankton group that dominated by density.

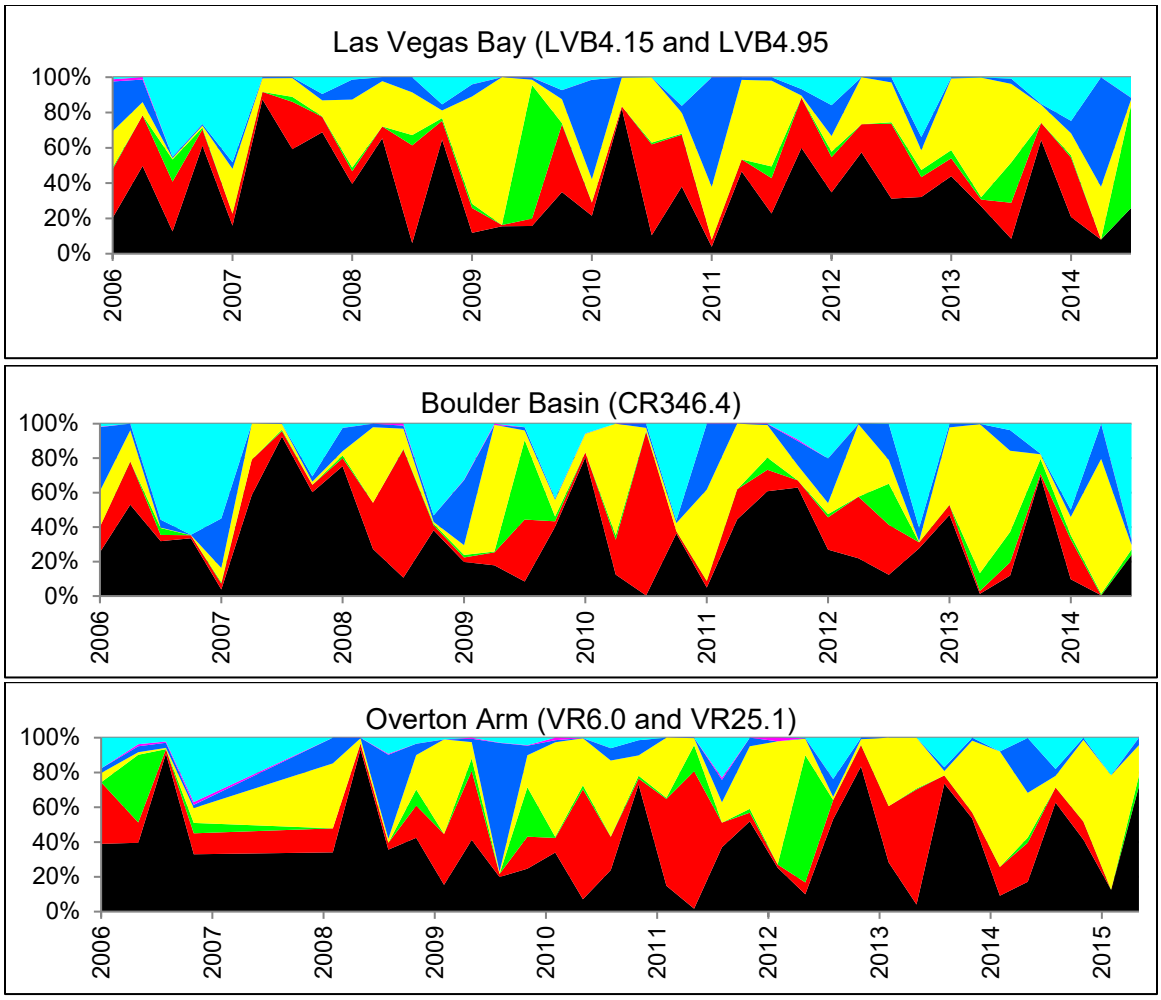


Figure 4.2.3-1. Quarterly measures of phytoplankton group biovolume and proportional representation from 2006 to 2015 for Las Vegas Bay (LV4.15 and 4.95), Boulder Basin (CR346.4), and Overton Arm (VR6.0 and VR25.1).

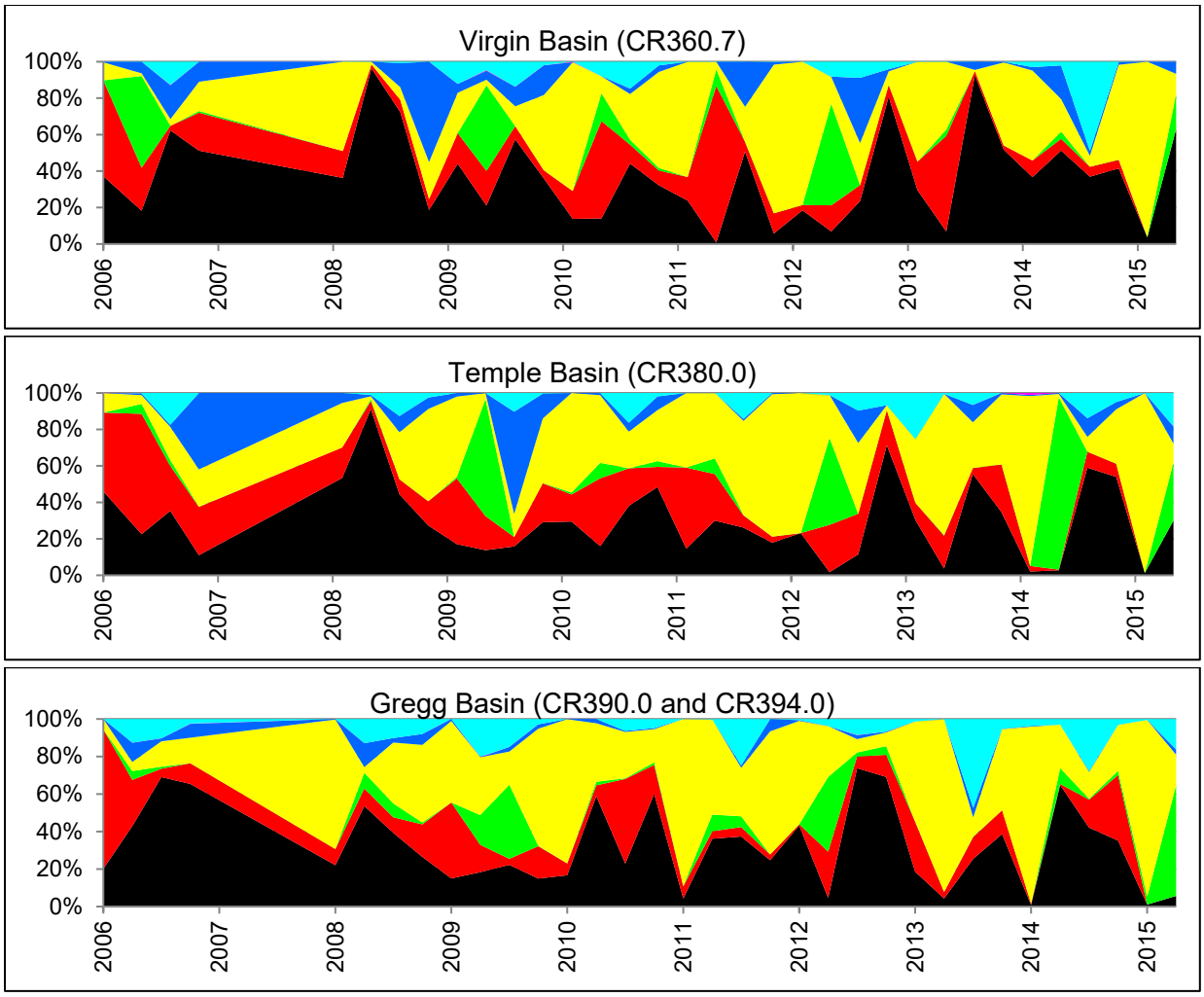


Figure 4.2.3-2. Quarterly measures of phytoplankton group biovolume and proportional representation from 2006 to 2015 for Colorado River mainstem monitoring stations, Virgin Basin (CR360.7), Temple Basin (CR380.0), and Gregg Basin (CR 390.0 and CR394.0).

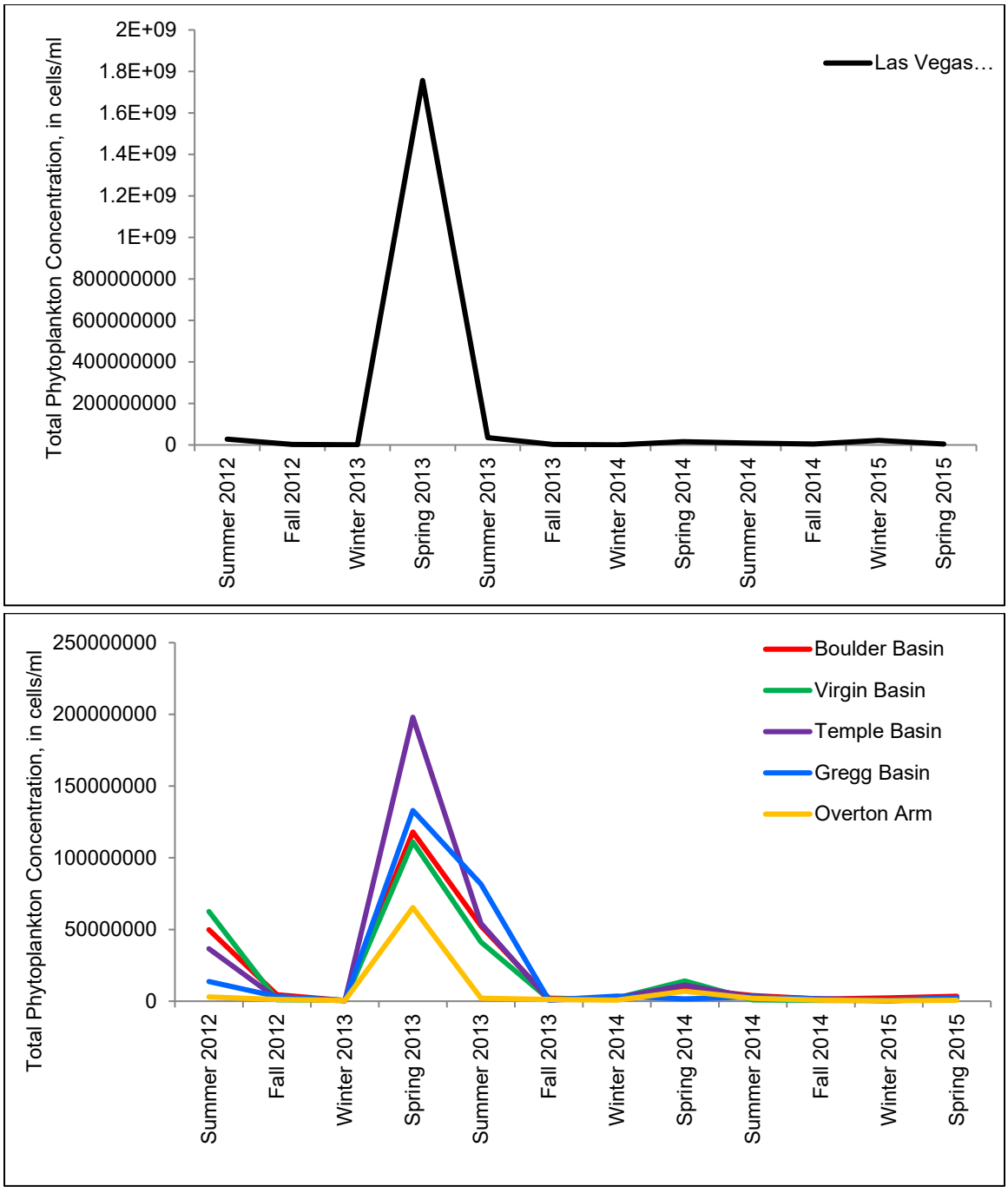


Figure 4.2.3-3. Total phytoplankton concentrations (cells/ml) (measured quarterly, 2012–2015) for all monitoring stations.

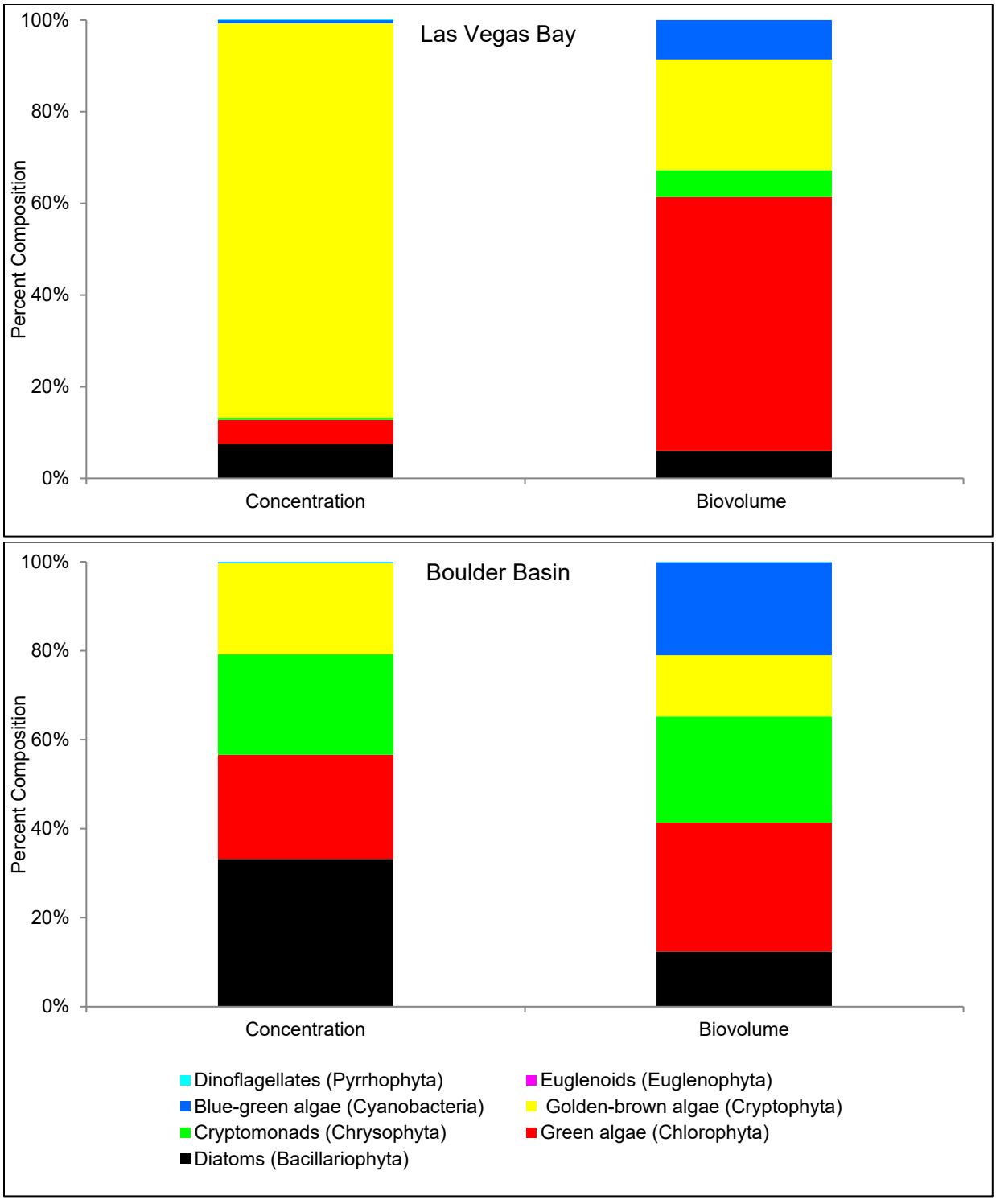


Figure 4.2.3-4. Relative percentages of major phytoplankton groups by concentration and biovolume in May 2013 for Las Vegas Bay (LVB4.15 and LVB4.95) and Boulder Basin (CR346.4) monitoring stations.

Assessment Confidence/Key Data Gaps/Threats

Lake Mead

Confidence is high for understanding phytoplankton dynamics of Lake Mead. The increase in Microcystis blooms and whether or not it produces detectable toxins may be a future issue to monitor. The inherent complexity for quantifying phytoplankton community dynamics should be evaluated by mesocosm experiments in which factors (e.g. veligers, nutrients, zooplankton) are facilitating phytoplankton changes.

Source of Expertise

Dr. Ann St Amand, phycologist and expert in Lake Mead phytoplankton is a major contributor to the Boulder Basin analysis.

Case Study: Boulder Basin 2002–2013 (expert remarks courtesty of Dr. Anne St. Amand)

Over the course of the study period, nutrient discharge and elevation has trended downward with slight increases in 2005–2006 and 2011–2012. Growing season for algae was determined by Multi-Dimensional Scaling (MDS) to occur from April through October. Boulder Basin was stratified into an Inner and an Outer Basin, each with unique algal dynamics. The Inner Boulder Basin is more productive and more likely to be dominated by toxin-producing Cyanophyta (Blue-green algae). All of the analyses were then based on analyzing the basins individually. Algal biovolume was the most sensitive response variable.

When the total biovolume was analyzed, without looking at individual taxa contributions, there was not a statistically significant trend among years in the Inner Basin, while the Outer Basin indicated a slight, but statistically insignificant, decrease following the 2007 detection of quagga mussels. However, when MDS was used to analyze the algal assemblage data with individual taxa included, 3 distinct, statistically significant year clusters appeared in both basins.

In the Inner Basin, the clusters were 2002–2003, 2004–2007 and 2008–2013 while in the Outer Basin, the clusters were 2002–2003, 2004–2009, and 2010–2013. Temperature was slightly lower in the Outer Basin than the Inner Basin, with distinct trends per basin. Secchi depth was much lower in the Inner Basin (indicating potentially higher algall mass and higher turbidity), and conductivity was considerably higher and more variable in the Inner Basin than in the Outer Basin (lower conductivity of the incoming Colorado River in the Outer Basin versus the higher conductivity Wash influence in the Inner Basin). Conductivity correlates with both the Inner and Outer Basin Year Clusters by algal assemblage.

Total zooplankton also aligned well with the year clusters in both basins, with rotifer biomass aligning particularly well in the Inner Basin, but not as well in the Outer Basin. Quagga mussel veliger densities also correlate well with Inner Basin year clusters, but not as well in the Outer Basin. It is not clear if veligers in the inner basin may be influencing dynamics in space in Boulder Basin. Cladocerans were reasonably well aligned with the Year Clusters in both Basins.

Relative *Microcystis* cell concentration generally increased following Quagga detection in 2007 in both basins as well.

Several algal groups and taxa were important within the Inner/ Outer Basin Year Clusters, including Microcystis, Cylindrospermopsis and Cyclotella (< 8 um). Random forest regression analysis was used to analyze the relationship between physical factors/water chemistry parameters and Microcystis, Cyclotella and quagga veliger response.

Of the important factors (analysis is still being completed by Dr. Ann St. Amand, phycology expert), elevation, temperature, Secchi disc depth and conductivity always ranked in the top 5 factors, indicating the overall importance of the physical stresses on these biotic communities. Total zooplankton, percent veligers, and percent rotifers were generally in the top 10 factors as being important for predicting algal community/taxa composition. This highlights the complex interactions that may be moderating and facilitating the phytoplankton composition over time and within Boulder Basin.

Boulder Basin is very complicated morphometrically, with physical factors like elevation and water chemistry setting the limit on which algal taxa dominate in what season and year, and then the zooplankton community, including the quagga mussel veligers, becomes important as a forcing factor along with interactions among the algal genera. The most sensitive response variable continues to be the cumulative algal assemblage as analyzed by MDS, making full phytoplankton counts with biovolume a crucial water quality indicator for the reservoir.

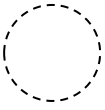
Microcystis produced detectable microcystin for the first time in 2015, at what seemed to be a period of lower conductivity in the Inner Basin. The mechanisms responsible for when and how Microcystis blooms and whether or not it produces detectable toxin are not clear

4.2.4. Food Web Dynamics

Assessment Outcome

A summary of the parameters used assess food web dynamics are shown in Table 4.2.4-1.

Table 4.2.4-1. Overall assessment outcome for condition status and trend of food web dynamics.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Changes in Food Web Structure	Trophic status	Mead		Food web structure does not appear to change dramatically in space or time.
	Trophic status	Mohave		No data available.

Description

Understanding the connection within food webs, the feeding and strength of connection of one organism to another, is important for understanding ecosystem function including the fate of contaminants and production of fishes. For example, longer food chains within a food web may result in greater contaminant concentrations in top predator fish that humans consumer for food. With changing ecosystems charactertistics over time, the food web connections may change. For example, variability in the strength of food web connections may occur depending on natural variations in biological populations over time; ecosystems with impacts from cultural eutrophication or invasive species may result in more pronounced permanent influences to food web structure and flows of energy across habitats (e.g. pelagic and benthic) (Young et al. 2015, Chandra et al. 2005). There may also be different food webs in large lakes and reservoirs depending on the specific location when there are differences in ecosystem characteristics. Since Lake Mead is large in size with varying degree of water quality in some basins (e.g. Overton is more oligotrophic than Las Vegas Bay which is more eutrophic), you may expect sources of energy at the base of the food web or the structure of the food webs in each location to be dissimilar. In this section, we think about sources of energy coming from the bottom (benthic) versus pelagic habitat in the food web as well as trophic positons, or how high in the food web chain an organism is feeding as an indicator.

Data and Methods

There have been limited collections of fish diets across species from Lakes Mead over time to understand changes in the food web. However, there have been recent collections of diets and measurements of natural tracers used in food web ecology to recreate the architecture of food webs in different locations. We utilized previously published information (Umek et al. 2010) and information collected by the authors (Chandra) to evaluate the food web structure of Lake Mead. Stable isotopes (carbon and nitrogen) were used to determine the food web structure for 2 general periods (2007/08 and 2013/14) from different areas of the lake (Table 4.2.4-2). Unlike traditional gut content information which can be used to identify the selection of diet for a moment of time, isotopes are useful tools for measuring integrated forms of energy into body tissue over time (e.g. 4–6 months of energy use). Isotopic $\delta^{13}C$ can be used to determine the flow of organic matter through food webs (Gu et al. 1994; Vander Zanden et al. 1999). The minimal enrichment (±.47 ‰) from lower to high trophic levels allowed for the differentiation of littoral and pelagic primary production sources (Hecky and Hesslein 1995; Vander Zanden and Rasmussen 2001). With predictable enrichment (between 3–4 ‰) biotic trophic position can be inferred by using isotopic $\delta^{15}N$ (Minagawa and Wada 1984; Vander Zanden and Rasmussen 2001).

Table 4.2.4-2. Indicators and measurements used in the assessment of food web dynamics.

Indicator(s)	Measurement(s)	Scale of Analysis
Significant changes in food web structure	• Trophic status • Significant shift in habitat use of carbon from benthic to pelagic for select fishes, including game fish and forage fish	Lake

There is no food web structure information for Lake Mohave.

Reference Conditions

Table 4.2.4-3 shows the reference conditions used to assess food web dynamics.

Table 4.2.4-3. Reference conditions for food web dynamics used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
• Energy used by the fishery • Trophic position of top predators	Significant change in the use of habitats (benthic or pelagic) in the fishery and drop in trophic position for top predators	Moderate change in the use of habitats (benthic or pelagic) in the fishery or drop in trophic position for top predators	No change in the use of habitats (benthic or pelagic) in the fishery or drop in trophic position for top predators

Condition and Trend

Las Vegas Bay

Littoral-benthic resources contribute to food web structure and fisheries in Las Vegas Bay (Figure 4.2.4-1). Threadfin shad, an important forage fish, more in the benthic environment along with the top predator large and smallmouth bass that obtain their energy from the littoral benthic zone. In general, the contribution from benthic resource contributions decreases from 2008 to 2013 with exceptions (e.g. largemouth bass, 83% to 84%; bluegill, 85 to 74%; carp, 76 to 68%; threadfin shad, 40 to 41%). Introduced gizzard shad become an important part of the food web receiving 69% energy from littoral benthic resources, likely supporting top predators.

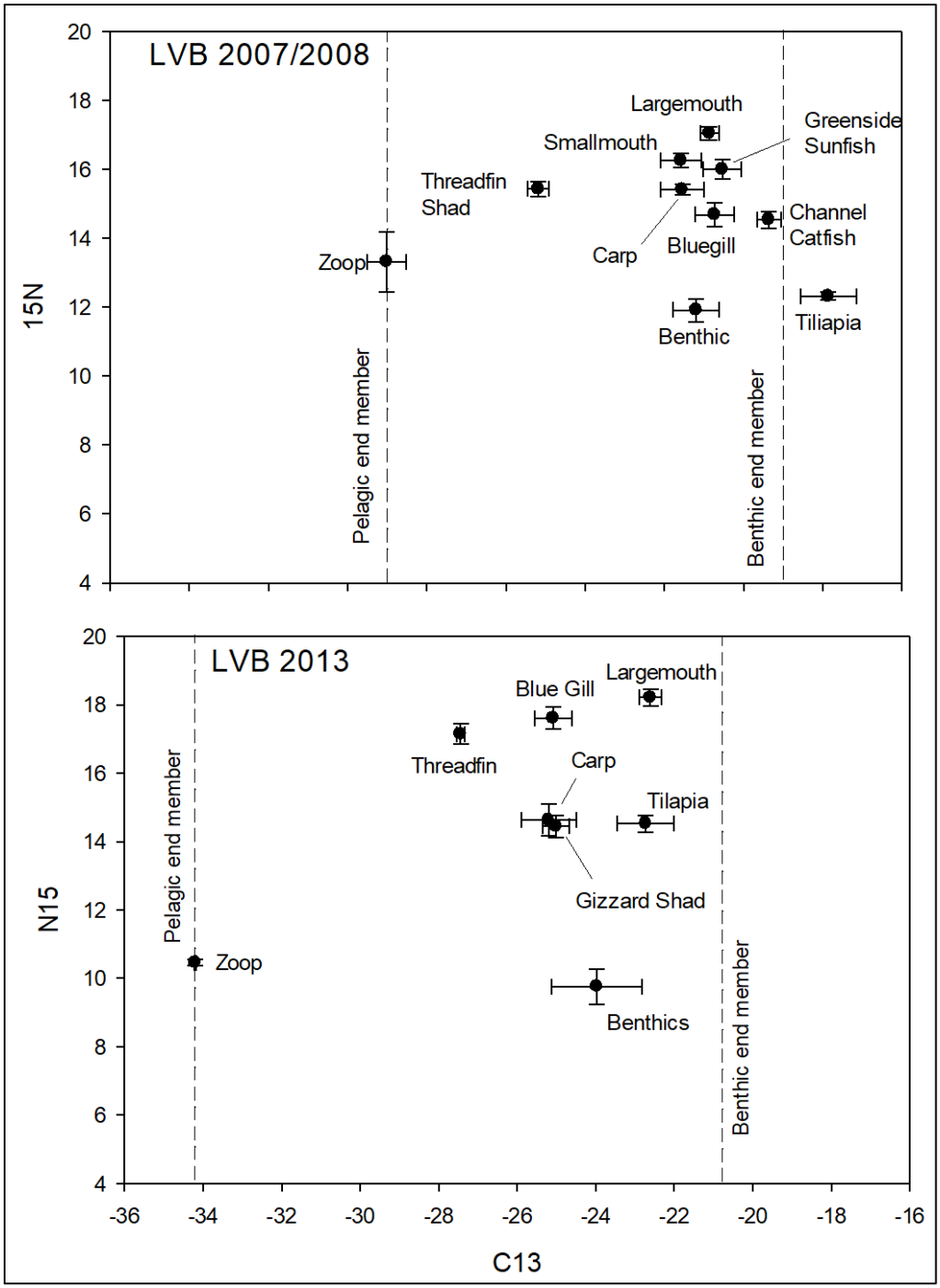


Figure 4.2.4-1. Food web structure comparison over time of Las Vegas Bay (LVB), Lake Mead. The benthic end member is the signal of the littoral bottom carbon source to the food web where as the pelagic end member is the open water phytoplankton signal. The y axis is delta nitrogen where the higher the number indicates a higher trophic position in the food web.

Overton Arm

Littoral-benthic resources also contribute to food web structure and fishery in Overton Arm (Figure 4.2.4-2). Threadfish shad utilized a slightly greater benthic contribution (48 to 50%) than Las Vegas

Bay. There is more variable resource feeding in the fishery over time. Striped bass, large- and smallmouth bass are the top predators in Overton Arm.

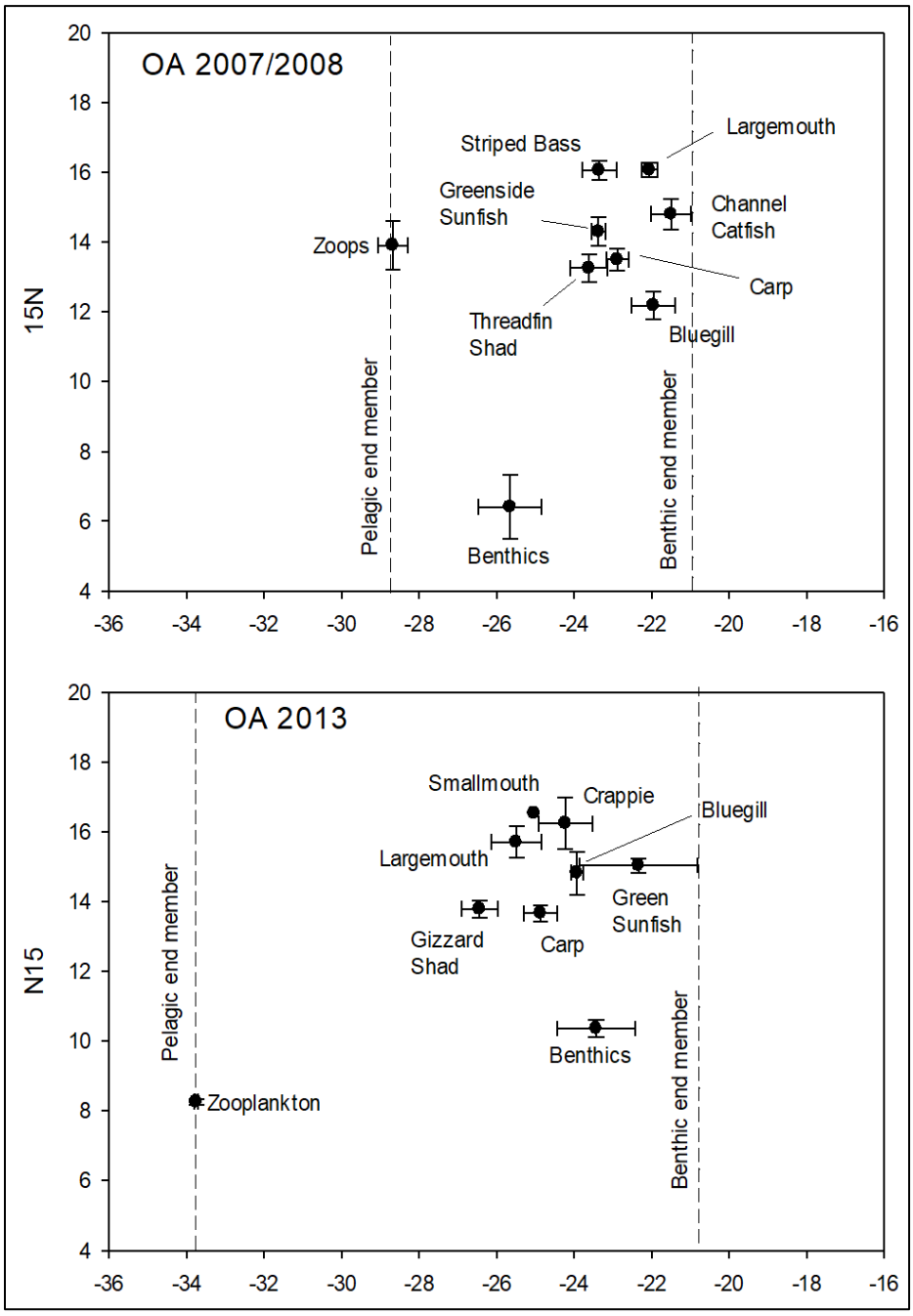


Figure 4.2.4-2. Food web structure comparison over time of Overton Arm (OA), Lake Mead. The benthic end member is the signal of the littoral bottom carbon source to the food web where as the pelagic end member is the open water phytoplankton signal. The y axis is delta nitrogen where the higher the number indicates a higher trophic position in the food web.

Comparison of Basins

Contemporary comparison of bays and basins across Lake Mead indicated variable trophic (how high in the food web an organism is feeding) structure across Lake Mead (Figure 4.2.4-3). There is also variable resource utilization across basins. Overall the littoral-benthic habitat supports the Lake Mead fishery. Gizzard shad, an invasive introduced fish in the last decade, utilize benthic resources (66–70%) across the bays and likely transfer energy to top predators. Carp and bluegill can be variable in utilizing benthic resources. In Boulder Basin, for example, they use more pelagic resources compared to the other basins. Despite the establishment of gizzard shad there does not appear to be a change in trophic position of top predator like bass in the basins or significant change in the littoral benthic energy utilized by fishes.

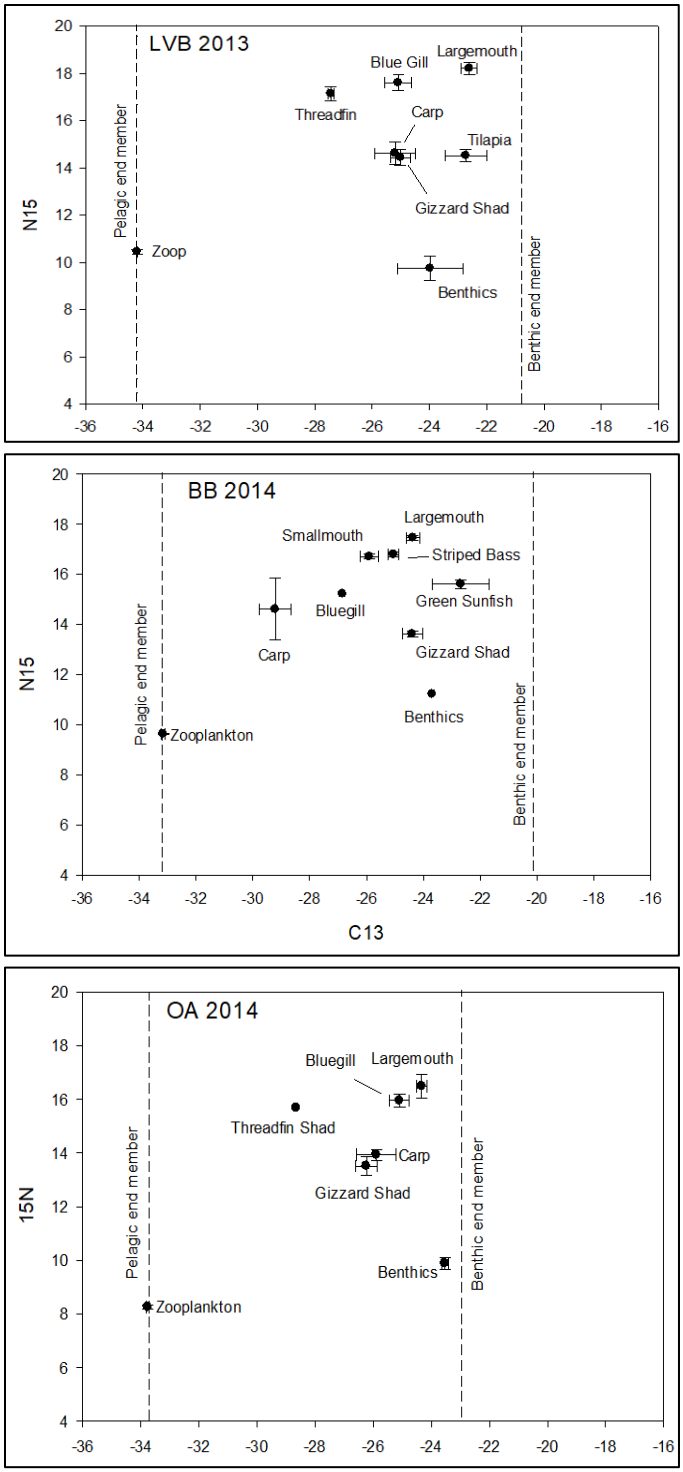


Figure 4.2.4-3. Contemporary (2013–14) food web structure comparison of 3 basins (LVB – Las Vegas Bay, BB – Boulder Basin, OA – Overton Arm) in Lake Mead. The benthic end member is the signal of the littoral bottom carbon source to the food web where as the pelagic end member is the open water phytoplankton signal. The y axis is delta nitrogen where the higher the number indicates a higher trophic position in the food web.

Lake Mohave

There is not food web structure data for Lake Mohave.

Assessment Confidence and Key Data Gaps

Lake Mead

There are only two general time periods, approximately 5–6 years apart, where food web structure has been measured at Lake Mead. Even without a strong time series data, confidence is high for this analysis where we have used the earlier period as a reference for the measurement 5–6 years later in time. There are no large changes in carbon sources from the littoral habitat to the food web. The food web structure appears to be relatively stable, with littoral-benthic resources supporting the fishery and bass spp., remaining as the top predator with the highest trophic position. Despite the establishment of gizzard shad there does not appear to be a change in trophic position of top predator like bass in the basins or significant change in the littoral benthic energy utilized by fishes.

Lake Mohave

Confidence is low since no data exists documenting the food web structure of the lake.

4.2.5. Native Fish

Assessment Outcome

A summary of the parameters used assess native fish are shown in Table 4.2.5-1.

Table 4.2.5-1. Overall assessment outcome of the condition status and trend for native fish.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Population Trend by Species	• Species abundance • Population abundance	Mead		In the 1980s, Razorback sucker populations were believed to be extirpated from Lake Mead. Monitoring since the 1990s has found an estimated 370 to 808 individuals currently in the lake. Additional spawning locations have been documented since the first one found in Las Vegas Bay. This population is unique along the Colorado River in documented as natural recruitment. Long-term viability of Razorback sucker is uncertain. Bonytail chub, Colorado pikeminnow, woundfin, Sonoran topminnow, desert pupfish are not currently present in Lake Mead. Flannelmouth suckers are rarely found in Lake Mead. Humpback chub was recently documented in upper Lake Mead.

Table 4.2.5-1 (continued). Overall assessment outcome of the condition status and trend for native fish.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Population Trend by Species (continued)	• Species abundance • Population abundance	Mohave		Significant decline in number of razorback suckers with recent estimates of less than 5000 fish as compared to 60,000 in the late 1980s. The larger population cohort of 60,000 was considered remnants from populations prior to construction of Davis Dam. The current population is the result of aggressive rearing program since the early 1990s. Lake Mohave population has the greatest genetic diversity of all Razorback populations on the Colorado River. The USFWS recovery goals for razorback sucker are to maintain a refuge of genetically diverse fish within Lake Mohave, with managed and sustained populations greater than 5800 individuals. Bonytail chub has poor post-stocking survival rate. Population is maintained by stocking activities.
Native Fish overall				–

Description

The Lake Mead NRA is located within the sub-basin Lake Mead Basin (HUC 1501) in the lower Colorado River Basin (Batker, et al., 2014). Nine fish species were native to the pre-impounded lower mainstem of the Colorado River (Table B-4). Native fish generally require high water quality, food resource availability, and suitable habitat to maintain healthy and sustainable populations. The completion of Hoover Dam and Davis Dam, and subsequent formation of lakes Mead and Mohave have altered native fish habitat along the Colorado River and significant reductions in fish populations have been observed (Rosen et al., 2012). Anthropogenic habitat alterations (e.g. dam constructions) and non-native fish introductions have provided the greatest impact to native fish habitat and survival, and seven out of nine Colorado mainstem native fish are now federally protected as endangered under the Federal Endangered Species Act of 1973 (Table B-4) (Mueller & Marsh, 2002). Lakes Mead and Mohave are considered critical habitat for some of these species. For example, lakes Mead and Mohave are designated critical habitat for the federally listed endangered razorback sucker and Lake Mohave is designated critical habitat for the federally listed endangered bonytail chub (Lake Mead NRA, 2010). Monitoring the condition and status of these endangered native fish populations is important for ensuring the integrity of native fishery and that their viability in these currently designated habitats is sustained.

Data and Methods

Table 4.2.5-2 shows the data and methods used to assess native fish.

Table 4.2.5-2. Indicators and measurements used in the assessment of population trends.

Indicator(s)	Measurement(s)	Scale of Analysis
Population trend by species	• Species abundance • Population estimate	Lake

Native fish population abundance estimates for lakes Mead and Mohave were derived using information compiled from the Lower Colorado River Multi-Species Conservation Program (LCRMSCP) with data provided by LCRMSCP contractors, Marsh & Associates and BIO-West, in cooperation with NDOW and SNWA (Albrecht et al., 2013). In 1996, SNWA, NDOW, and the Colorado River Commission of Nevada initiated a study to collect and develop information about the Lake Mead razorback sucker population and BIO-WEST designed and conducted the study. Subsequently, BOR and LCRMSCP provided funding to continue the long-term monitoring efforts. Population estimates for razorback sucker in Lake Mead were calculated from mark-recapture data. Stocked fish were not used in population estimates unless they had survived a minimum of 1 year in Lake Mead (i.e. time between initial capture and recapture) (Albrecht et al., 2013).

Mueller & Marsh (2002) provided the most comprehensive review of historic lower Colorado River native fish information. Additional information was supplemented from the Nevada Department of Wildlife (NDOW) annual lake-wide fish population inventory assessment in lakes Mead and Mohave, and Rosen et al. 2012.

Reference Conditions

Table 4.2.5-3 shows the reference conditions used to assess native fish.

Table 4.2.5-3. Reference conditions for native fish used in the assessment.

	Condition Status		
Measurment(s)	**Significant Concern***	**Moderate Concern***	**Good***
• Species abundance • Population estimate	Significant reduction in abundance or extirpation of population.	Slight reduction of native fish abundance.	Consistently stable or increasing population abundance or viability.

Condition and Trend

Razorback Sucker

Lake Mead

Lake Mead Razorback populations experienced significant declines in the 1970s, and from 1980 through 1989, NDOW and AZGFD did not detect any individuals in Lake Mead (Sjoberg, 1995). Surveys in the early 1990s found low numbers of fish and one spawning bed in the Las Vegas Bay. The Lake Mead razorback sucker population at that time was considered to be low and in danger of extirpation (Brandon et al., 2013).

Increased surveys since 2000, however, have found additional spawning locations and increased abundances for this species. Adults 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 areas of Gregg Basin where the Colorado River enters Lake Mead from the Grand Canyon (Figure 2.1.2-1) (Rosen et al., 2012). It is unclear why razorback suckers can successfully survive to adulthood in Lake Mead; that is the subject of ongoing research. The Lake Mead population is estimated to be approximately several hundred individuals. Razorback suckers are unique in Lake Mead in that along the Colorado River, observations of consistent natural **recruitment** (without management augmentation) from larval fish to adulthood has been recorded (Rosen et al., 2012; Albrecht et al., 2013).

Gillnet surveys conducted by NDOW in 2014 found the highest CPUE of Razorbacks recorded since fall gillnetting surveys have been initiated (Figure 4.2.5-1). Using mark-recapture data, the estimated lake-wide average population estimate, which included data from all long-term monitoring study areas and Colorado River Inflow area, was from 541–741 individuals in 2008–2010, and 597 individual (range: 474–776) during 2011–2013, and 589 individual (range: 370 -808 fish) during 2012–2014 (Albrecht et al., 2010; Albrecht et al., 2013; Albrecht et al., 2014). Recent studies tracking tagged fish have found Lake Mead razorback suckers also utilizing areas of the lower Grand Canyon. Additional research is planned to determine which conditions facilitate natural recruitment, why the population is increasing, and the long-term status and management implications for the overall recovery efforts (Brandon et al., 2013).

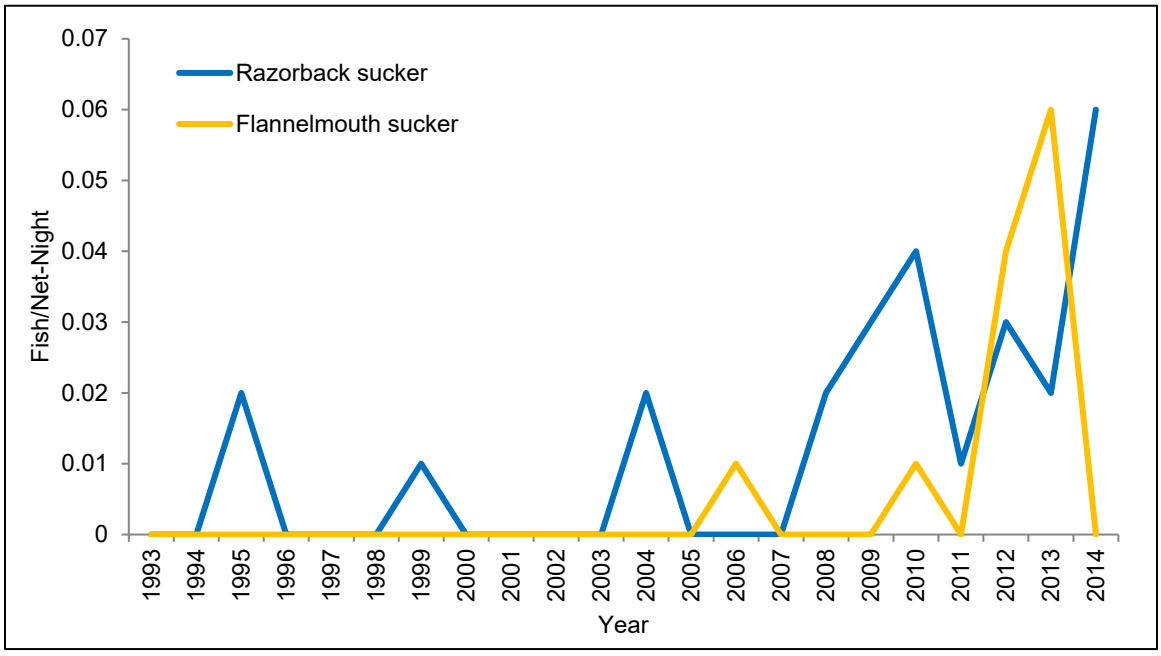


Figure 4.2.5-1. Gillnet survey native fish catch rates in Lake Mead, 1993–2014 (NDOW data).

Lake Mohave

Adult razorback suckers are present throughout Lake Mohave (Minckley, 1983; Rosen et al., 2012). However, natural recruitment and survival of wild fish to adulthood has not been documented in Lake Mohave for many years (Rosen et al., 2012). The interagency Native Fish Work Group was formed in 1989 in an attempt to restore the remnant razorback sucker population in Lake Mohave. Stocking augmentation programs have been implemented by stocking larger fish grown from wild-caught larvae to maintain adult populations and preserve the genetic integrity of the remaining small wild population (Mueller & Marsh, 2002; Rosen et al., 2012)

The razorback sucker population has most recently been estimated at less than 5,000 fish, which is a significant decline from previous estimates of 60,000 in the late 1980s (NDOW, 2015). During the 1990s the interagency Native Fish Work Group anticipated the impending loss of the population of adult fish that recruited prior to the development of the Davis Dam. While the early 1990s population was large in number, it consisted primarily of large, old adults because of predation on their larvae by non-native sportfish (Marsh et al., 2003). The Native Fish Work Group initiated active management in the early 1990s to capture larvae from these remaining adults and grow them in rearing ponds and facilities for repatriation to the lake. Wild and repatriated razorback sucker population estimates have dropped from 3954 and 4523 individuals in 2001 to 2015 individuals in 2015, respectively (Figure 4.2.5-2). Catch rates of razorback suckers by gillnet averaged 0.24 fish/net-night in 2015, which was below the long-term mean of 0.32 fish/net-night (Figure 4.2.5-3). No wild adult razorback suckers were captured in the 2015 roundup survey (Marsh & Associates LLC, 2015).

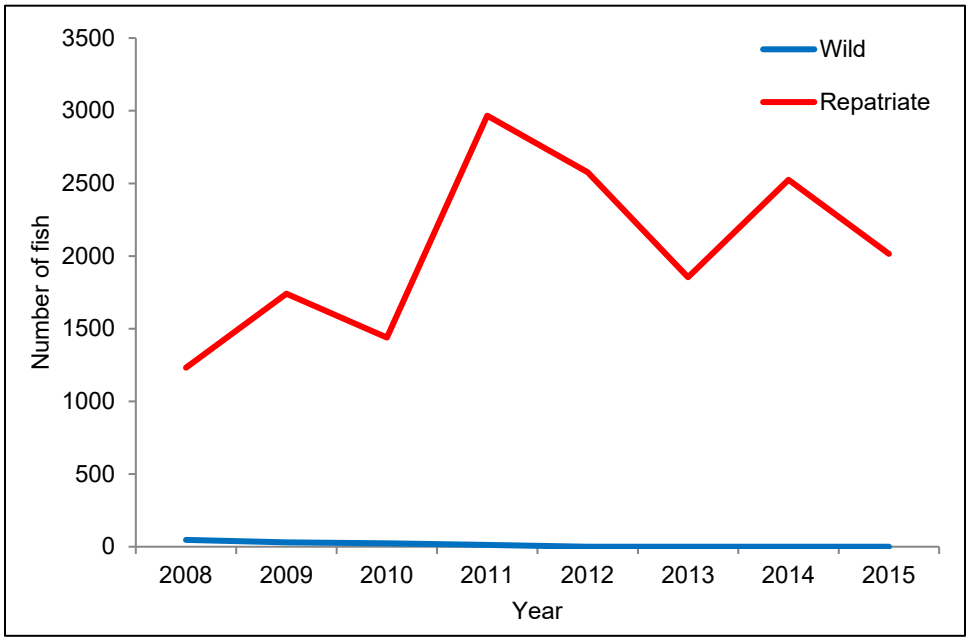


Figure 4.2.5-2. Wild and repatriate razorback sucker population estimates in Lake Mohave based on field data collected in March between 2008 and 2015 by Marsh &Associates (2015).

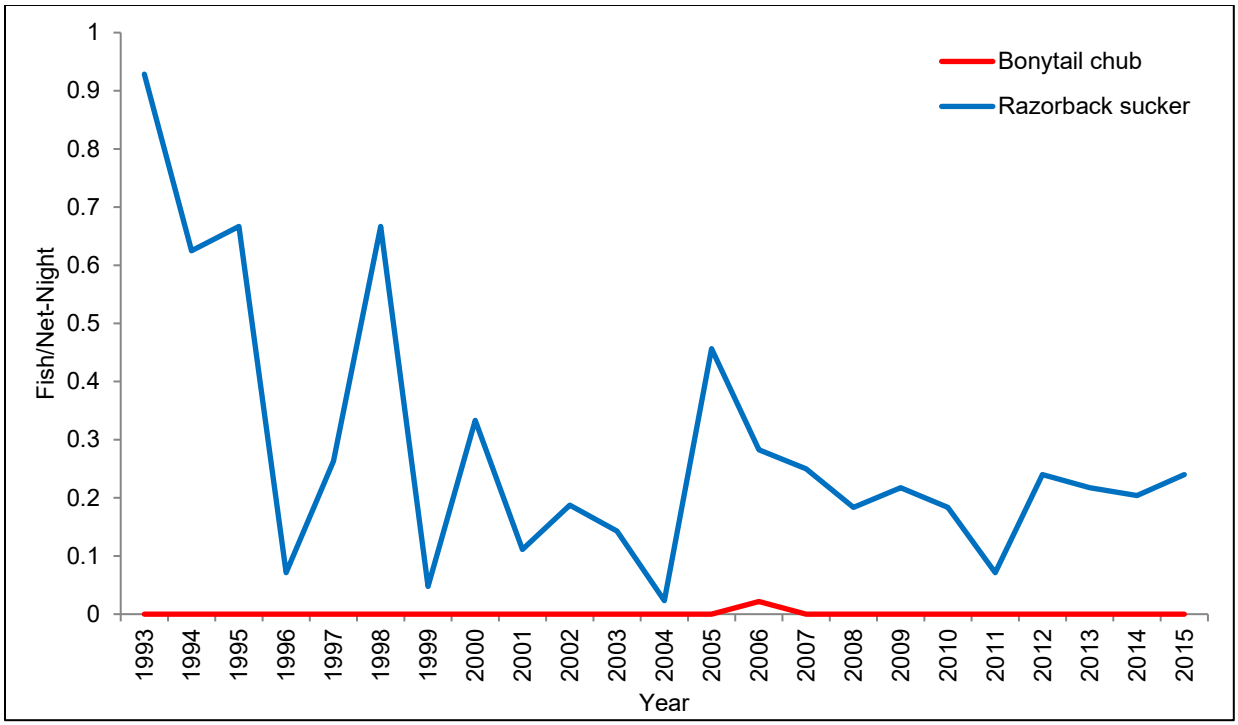


Figure 4.2.5-3. Gillnet survey catch rates by native fish species in Lake Mohave, 1993–2015 (NDOW data).

Despite the decline, Lake Mohave contains the largest remaining population of razorback suckers in the Colorado River Basin (NDOW, 2015). The Mohave population also contains the greatest genetic diversity in the Colorado River Basin--the USFWS recovery goals for this species include maintaining a genetic refuge in Lake Mohave (USFWS, 2002). The population is not thought to be self-sustaining, however, and is believed to be maintained by the stocking of large fish grown from wild-caught larvae. Predation by non-native fish in Lake Mohave appears to be the main reason for the lack of razorback sucker recruitment (Albrecht et al., 2013). In addition to maintaining Lake Mohave as a genetic refuge, USFWS recovery goals for Lake Mohave are to achieve a mean estimated recruitment of age-3 (300 – 399 mm total length) naturally produced fish that equals or exceeds mean annual adult mortality with the population exceeding 5,800 adults (USFWS, 2002).

Flannelmouth sucker

Lake Mead

The flannelmouth sucker is rarely found in Lake Mead. They were historically found below Davis Dam were historically exterpated but were re-established by the Arizona Fish and Game Department in the 1980s (Best & Lantow, 2010).This species prefers flowing waters and are common in upstream habitats within the Grand Canyon and ocassionally in the Muddy River which is a soure to Overton Arm of Lake Mead. Monitoring surveys conducted in 2009–2010 captured 52 flannelmouth suckers in the Colorado River inflow area, and five were captured in the vicinity of the Virgin and Muddy River inflow areas (Rosen et al., 2012). flannelmouth suckers were also captured in the 2012 and 2013 lake-wide gillnetting surveys conducted by NDOW (Figure 4.2.5-1).

Lake Mohave

Historically, flannelmouth suckers were not commonly found in Lake Mohave and downstream reaches of the lower Colorado River. However, a small population has been observed to persist downstream of Lake Mohave (Best & Lantow, 2010).

Bonytail Chub

Lake Mead

Bonytail chub is not currently present in Lake Mead.

Lake Mohave

Bonytail chub, a federally listed endangered species, is found in low numbers in Lake Mohave. Data collected by the Native Fish Work Group (NFWG) indicated that bonytail chub have been captured in low numbers of most years between 1983 and 2007 (Pacey & Marsh, 2008). Gillnet surveys conducted in Lake Mohave by NDOW, AZGFD, and BOR detected 0.02 fish/net-night of stocked bonytail chub in 2006 (Figure 4.2.5-3).

Wild bonytail chub have not been detected in Lake Mead or Mohave since 2005 and it is unknown if a wild population persists or reproduces. The U.S. Fish and Wildlife Services (USFWS) Willow Beach Fish Hatchery on Lake Mohave (Figure B-1) rears bonytail chub and releases larger sized individuals into park waters to maintain the Lake Mohave population (Mueller & Marsh, 2002). Releases have occurred in Lake Mohave backwaters such as Davis Cove (NPS, 2014).

Genetic studies on present population reveal that most fish currently found in Lake Mohave are descendants of a small founder population. Stocking of hatchery-reared fishes has maintained the persistence of bonytail chub. Post-stocking survival has been poor (Pacey & Marsh, 2008).

Humpback Chub

Historically, Minckley (1983) reposted that humpback chub were found downstream as far as Eldorado Canyon, which is now part of Lake Mohave. However, it was never considered common in the lower Colorado River Basin (Mueller & Marsh, 2002).

Between 2014 and 2017, the federally listed humpback chub, previously known to exist upstream in the Grand Canyon, has been documented in upper Lake Mead (BIO-WEST, 2017).

Colorado Pikeminnow

Endemic to Colorado River Basin, Colorado pikeminnow are federally listed as endangered. Their usual habitat is the backwaters of the turbulent and turbid streams in the Colorado River system. Natural populations survive only in the Upper Basin (Rosen et al., 2012). Once common in the lower Colorado River, Colorado pikeminnow were likley common during the filling of the lakes. They are believed to be extirpated from the river's lower basin and are not currently found in Lake Mead NRA (Rosen et al., 2012). The last record of a pikeminnow in Lake Mohave was 1962 from near Willow Beach (Mueller and Marsh 2002).

Woundfin

Once widely distributed from the Virgin through the Salt and Gila Rivers, it is now only found in a small part of the Virgin River (Mueller & Marsh, 2002). It is not currently found in lakes Mead and Mohave.

Assessment Confidence and Key Data Gaps

Assessment confidence is high because native fish species have been monitored for an extended period using standardized sampling protocols and consistent population estimation methods (NDOW, 2015). Data used in this assessment were provided by the monitoring agencies.

Annual census of razorback sucker for movement, population size, and recruitment, and opportunistic sampling of bonytail chub and other native fish species are critical for supporting regional efforts to recover, maintain, and manage threatened and endangered native fish species in lakes Mead and Mohave. The fact that other native species (e.g. pike minnow) continue to be absent from the lakes, continues to be problematic considering these species are native to the Colorado River ecosystem.

A number of environmental conditions that can adversely affect fish health and survival should be monitored to protect native fish population. These conditions include habitat loss from lake level changes, alterations to food resources resulting from ecological stressors such as invasive species such as quagga mussels, predation by non-native fish, and contaminant loading to Lake Mead from Las Vegas Wash and other tributaries influenced by human activities (Mickley, 1983; Mueller & Marsh, 2002; Rosen et al., 2012). For example, the habitat for razorback suckers may be degraded by the presence of mussel beds in areas previously used for spawning (Wong et al., 2011).

4.2.6. Sportfish

Assessment Outcome

A summary of the parameters used assess sportfish are shown in Table 4.2.6-1.

Table 4.2.6-1. Overall assessment outcome for the condition status and trend of sportfish.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Population Trend by Species	• Population estimate • Angler catch rates	Mead		Overall stable population abundance and stable angler catch rates.
	• Population estimate • Angler catch rates	Mohave		Total sportfish catch rates by gillnetting have generally trended upward toward historical averages since 2006 with the highest catch rate recorded in 2015 suggesting a stabilizing sport fishery in Lake Mohave.
Sportfish overall				–

Description

The sport fisheries in lakes Mead and Mohave are comprised entirely of non-native species (Table B-4). Fish stocking and regulation of anglers is managed by the Nevada Division of Wildlife (NDOW) and the Arizona Game and Fish Department (AZGFD) (NPS, 2014). Many of the non-native species also provide an important food resource for aquatic birds (Rosen et al., 2012). Recreational sport fishing contributes significantly to local economy with an average of 205,164 and 45,106 annual angler use days at lakes Mead and Mohave, respectively (Lake Mead NRA, 2010). Recreational fishing is one of the recognized, directed activities within the enabling legislation for Lake Mead NRA. Using angler expenditure per fishing day values for Nevada from the 2011 National Survey of Fishing, Hunting and Wildlife-associated Recreation Survey (USDOI 2011) the total angler days equal an economic value of approximately $24,670,000 (250,270 angler days x $98.57/day). Therefore, maintenance of sportfish condition and numbers within historic ranges and in accordance with recent catch rates is important for the management of lakes Mead and Mohave. It should be noted however that the introduced sportfish do have a negative impact on state and federally listed native fishes (e.g. Razoback sucker) through predation and competition.

Lake Mead

Historically, largemouth bass was the main focus of Lake Mead sport fishery. Degraded population estimates for largemouth bass were reported in the early 1940s and continued into the 1950s. It was then determined that a new forage species (threadfin shad, see 4.2.7) should be introduced to provide a reliable food source for largemouth bass and other species (Rosen et al., 2012). Construction of upstream reservoirs also contributed to largemouth bass declines in mid-1960s. In recent years, largemouth bass populations have remained stable, providing a good recreational and tournament

fishery. Smallmouth bass, first observed in 1999 in Lake Mead, also comprises a substantial portion of tournament catch (NDOW, 2010 and 2015a).

To create a sustainable alternative fishery, striped bass, a cool water fish and several coldwater salmonid species, e.g. rainbow trout, Brown Trout (*Salmo trutta*), and Coho Salmon (*Oncorhynchus kistutch*) were introduced in 1969. Striped bass, originally thought unable to reproduce in Lake Mead, became the dominant fish in the system. The proliferation of striped bass has negatively impacted salmonid populations in the lake and has also has contributed to significant declines of black Crappie (NDOW, 2010). Currently, there is an unlimited take of striped bass under 20 inches and a 20 fish limit on individuals over 20 inches to encourage angler harvest of this species (NDOW, 2010).

Salmonid stocking was discontinued in 1983 and reestablished in 1991. Salmonid stocking from Lake Mead Hatchery was suspended again in 2003 for reconstruction but stocking was continued using contracted fish through spring 2006. Stocking from hatchery was again done from fall 2006 through spring 2007 when the hatchery was closed due to quagga mussels which was the last salmonid stocking into Lake Mead. None the less, the salmonid stocking program had previously created a successful put-and-take winter season fishery in Boulder Basin in Lake Mead prior to program suspension (NDOW, 2015a).

Lake Mohave

Impoundment by Hoover and Davis Dams permit the upper regions of Lake Mohave to be managed as a year-round coldwater fishery. The upper regions of Lake Mohave along Black Canyon were stocked year-round with catchable rainbow trout until suspension of the program in 2013 due to hatchery production issues (NDOW, 2015b) and resumed again in 2016. After closure of the Lake Mead Hatchery in 2007 NDOW continued trout production and stocking for Lake Mohave using net pens at Willow Beach. The NDOW program ended in 2011. Introduction of striped bass has also negatively impacted the stocked rainbow trout fishery.

Striped bass, first identified in Lake Mohave in the early 1980s, are the major component of the sport fishery. Striped bass have been observed to reproduce in the seasonally warm reaches in Lake Mohave and move into the cold-water areas as they became larger when they eventually prey on stocked rainbow trout and other fishes. Largemouth and smallmouth bass, channel catfish, and Sunfish support the remaining portion of Lake Mohave's sport fishery.

Data and Methods

Table 4.2.6-2 shows the data and methods used to assess sportfish.

Table 4.2.6-2. Indicators and measurements used in the assessment of sportfish.

Indicator(s)	Measurement(s)	Scale of Analysis
Population trend by species	• Population estimates • Angler catch rates	Lake

Population estimates derived from species-specific catch rates for lakes Mead and Mohave were derived from catch data provided by the NDOW. Lake-wide fish population inventory and assessment has been conducted annually through joint effort by NDOW, AZGFD, and BOR. Methods used include fall and spring overnight gillnet surveys and nearshore electrofishing to supplement gillnetting for littoral species (NDOW, 2015a and 2015b).

In Lake Mead, overnight gillnet and electrofishing surveys were conducted annually during the fall (NDOW, 2015a). The Lake Mead gillnet surveys were modified to a randomized design developed by AZGFD which includes up to 100 net sites over the entire lake (NDOW data). Electrofishing surveys were done during the evening hours using a boat equipped with a Coffelt shocking apparatus and VVP-15B electrical box (NDOW, 2015a). Angler catch rates were calculated using data collected from creel surveys conducted by NDOW at Lake Mead (NDOW data). Opportunistic creel surveys were conducted from March through December at four angler access points on Boulder Basin (Boulder Harbor, Callville Bay, and Hemenway) and Overton Arm (Echo Bay) (Figure B-1) (NDOW, 2015a). Surveys were conducted for a continuous period of time and information such as total catch, effort, bait type used, species caught, angler origin, species preference, and presence of tags or marks on fish was collected. In addition, a subsample of harvested fish were weighed and measured to obtain length and weight data (NDOW, 2015a).

In Lake Mohave, electrofishing surveys were conducted in the spring from 2004 to 2007 and 2012 to 2014 and in the fall from 1998 to 2002 and from 2009 to 2011 using a randomized sampling design developed by AZGFD. Fish captured were identified to species, counted, measured, weighed, and then released back to the lake. Overnight gillnet surveys were conducted in April of each year, utilizing the AZGFD gillnet protocol where 50 randomly selected netting sites between Hoover Dam and Davis Dam were sampled (NDOW, 2015b). Lake Mohave is typically divided into 3 sections, with 20 sites on the lower section (Davis Dam to Clam Cove), 20 sites on the middle section (Clam Cove to Twin Cove), and 10 sites on the upper section (Twin Cove to Hoover Dam) (Cummins, 2016).

Reference Conditions

Table 4.2.6-3 shows the reference conditions used to assess sportfish.

Table 4.2.6-3. Reference conditions for sportfish, used in the assessment.

	Condition Status		
Measurement(s)	**Significant Concern***	**Moderate Concern***	**Good***
• Population estimates • Angler catch rates	Significant reduction in abundance and populations can no longer sustain recreational harvest, or extirpation of population.	Reduction of some key species of sportfish abundance, which others remain stable or are increasing in abundance.	Consistently stable or increasing population abundance or viability.

Sportfish condition was assessed by comparing catch rates of key sportfish species over time.

Condition and Trend

Lake Mead

Total sportfish catch rates by gillnetting have trended slightly downward since 2010 but have remained higher than the historical (1993–2002) catch rate range (Figure 4.2.6-1). In contrast, total sportfish catch rates by electrofishing have been trending upward since 2012 (Figure 4.2.6-2).

Striped bass were stocked between 1969 and 1972 when they were found naturally reproducing in Lake Mead and stocking was discontinued. The establishment of striped bass was negatively impacting the concurrently established salmonid fishery and led to a significant decline of the long-established black crappie fishery. As a result, in 2007 the management strategy for striped bass was altered to encourage anglers to harvest the smaller sizes (12 to 15 in/ 305–381mm), or the one- and two-year-old fish that were abundant by increasing angler possession limits (NDOW, 2015a). A policy of unlimited take of striped bass under 20 inches and a 20 fish limit on striped bass over 20 inches was implemented and expanded to Lakes Powell and Mohave to encourage angler harvest (NDOW, 2010). However, despite these changes, angling interest has declined, as well as catch rate (CPUE) and percent of overall harvest in the creel surveys. Striped bass was the most abundant sportfish species captured in 2014 despite decrease in CPUE by gillnetting suggesting a potential decline in population size (Figure 4.2.6-3 and Figure 4.2.6-2). Harvested striped bass sampled during creel surveys were smaller in 2014 than 2013, but in better body condition. This was also observed from striped bass collected by gillnet (NDOW, 2015a). By basin, striped bass in Boulder Basin showed the best condition, followed by Virgin Basin, Overton Arm, and Gregg Basin (NDOW, 2015a).

Gillnet and electrofishing surveys indicated increased smallmouth bass abundance and decreased largemouth bass abundance. In 2014, smallmouth bass young of year (YOY) observation nearly tripled from 2013, while largemouth bass YOY observations remained unchanged from 2013 (NDOW, 2015a). Overall, Black Bass abundance remained stable (Figure 4.2.6-2 and Figure 4.2.6-3).

In 2014, angler catch rate was comparable with recent angler catch rates and recent angler catch rates were higher than historical catch rates. This suggests that recreational harvesting is stable and sustained by current sportfish population (Figure 4.2.6-4).

In addition, an increase in number of sport fishing tournaments have been held at Lake Mead in recent years suggesting increase in sport fishing interest in the area as well as increase in sport fish catch rate (T. Thom, personal communication 2016; Table 4.2.6-1).

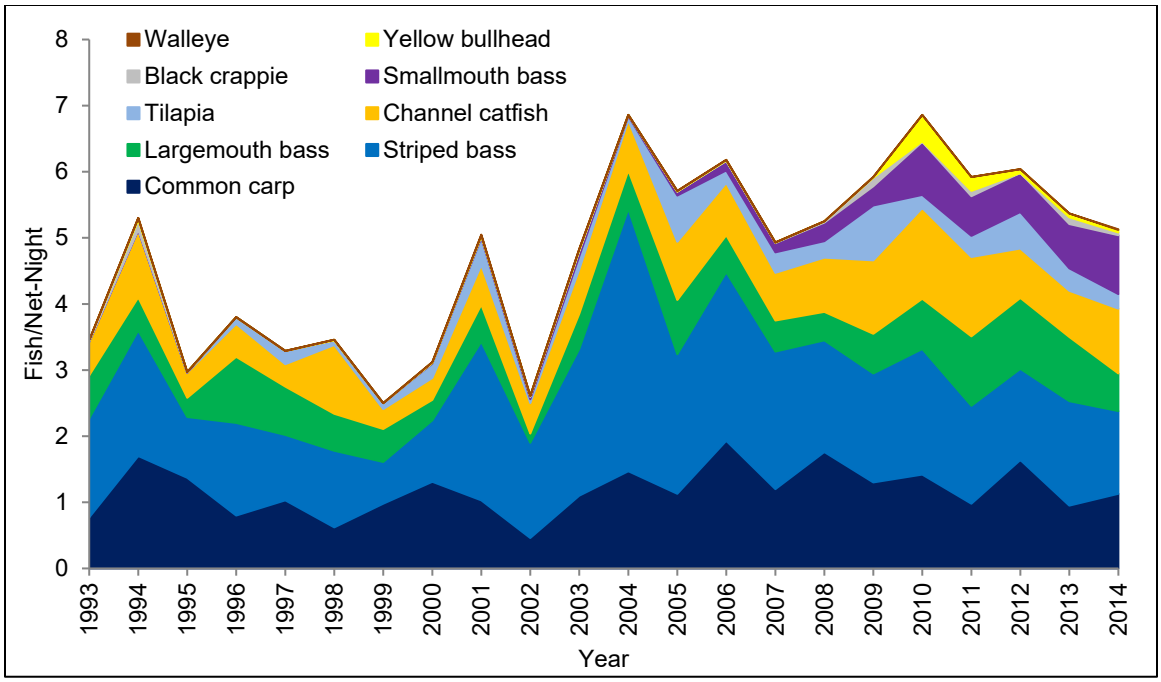


Figure 4.2.6-1. Cumulative gillnetting catch rates of sportfish species in Lake Mead, 1993–2014 (NDOW data).

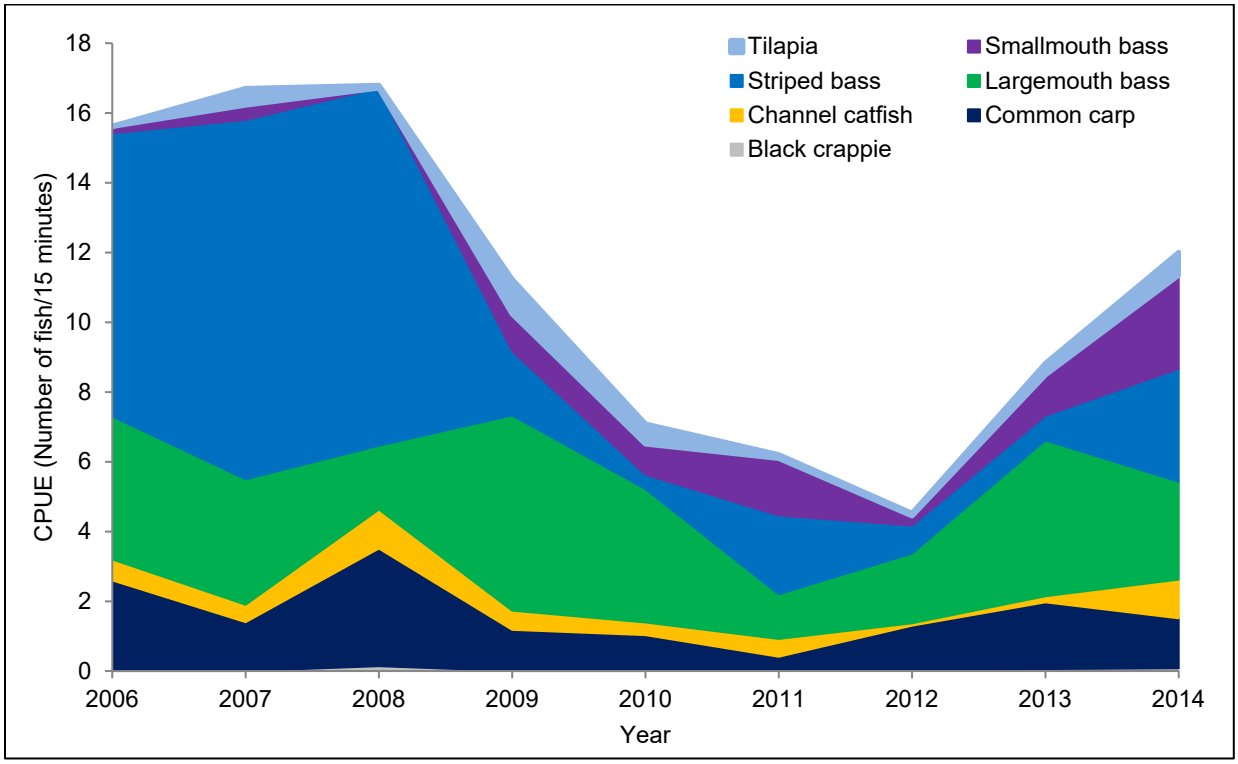


Figure 4.2.6-2. Cumulative electrofishing catch rates of sportfish species in Lake Mead, 2006–2014 (NDOW data).

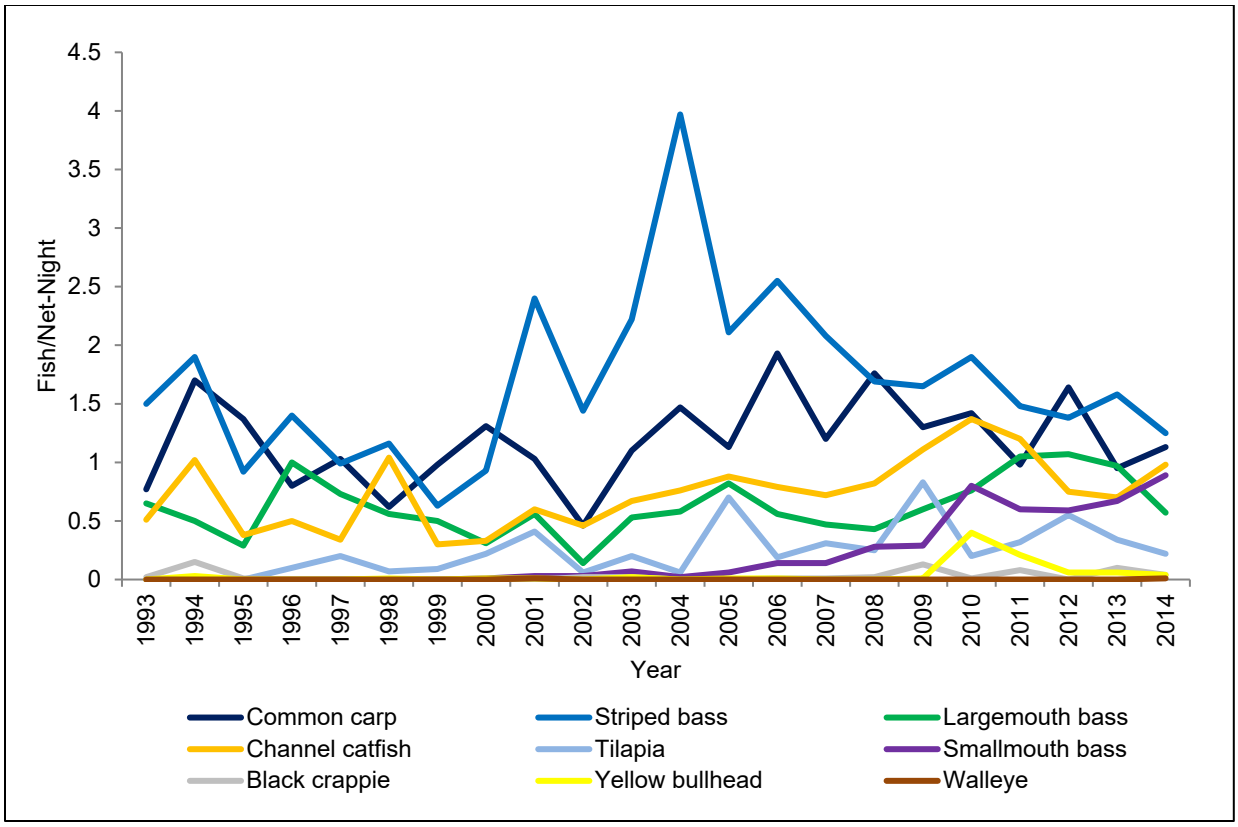


Figure 4.2.6-3. Gillnet survey catch rates by sportfish species in Lake Mead, 1993–2014 (NDOW data).

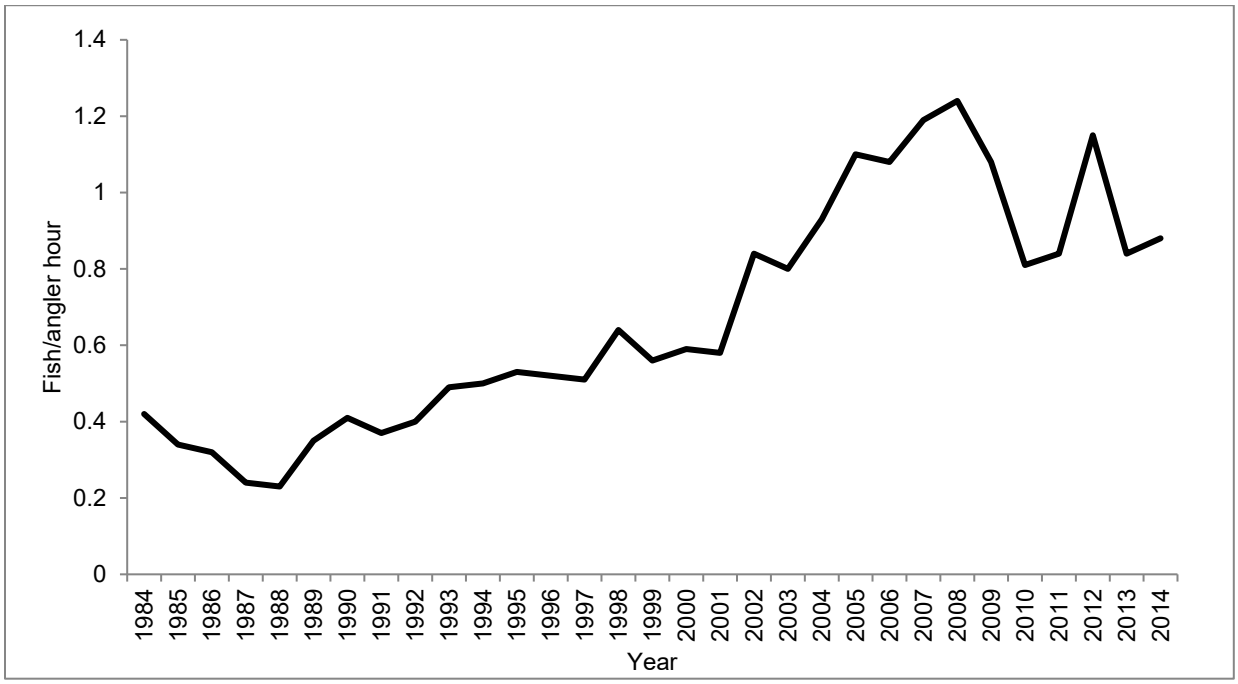


Figure 4.2.6-4. Angler catch rates in Lake Mead collected from creel surveys, 1984–2014.

Table 4.2.6-4. Summary statistics on the number of fishing tournaments held in Lake Mead (T. Thom, personal communication, December 2016).

Year	Number of Fishing Tournament
2005	42
2006	66
2007	72
2008	53
2009	44
2010	63
2011	70
2012	90
2013	95
2014	95
2015	93
2016	109

Lake Mohave

The Lake Mohave sport fishery is supported by striped bass, stocked rainbow trout, largemouth bass, smallmouth bass, bluegill, green sunfish, channel catfish, and yellow bullhead (NDOW, 2015b). Total sportfish catch rates by gillnetting have generally trended upward since 2006 with the highest catch rate recorded in 2015. Despite seasonal annual variabilities in these populations, the upward trend suggests a stabilizing sport fishery in Lake Mohave (Figure 4.2.6-5). Trends of gillnet catch rates for individual species has varied. While overall Black Bass (Largemouth and smallmouth bass) catch rates had increased in 2015, catch rates for largemouth bass decreased slightly relative to previous years and smallmouth bass catch rates have steadily increased since its first detection in Lake Mohave in 2010 (Figure 4.2.6-6). In 2015, striped bass catch rates increased significantly compared to 2014 with 2.24 fish/net-night. This catch rate was well above the 10-year average catch rate of 1.22 fish/net-night. However, the 2015 catch rate for striped bass remained well below historical maxima (Figure 4.2.6-6). In 2015, channel catfish and common carp catch rates increased relative to 2014 catch rates. In 2015, the channel catfish catch rate of 1.98 fish/net-night was above the long-term (1990–2014) average of 0.79 fish/net-night (Figure 4.2.6-6). common carp catch rates have been reported to be highly variable, with a cyclical boom-bust pattern every few years since the decline in striped bass abundance (NDOW, 2015b). The 2015 common carp catch rate was a peak year for this species with 3.76 fish/net-night compared to 0.49 fish/net-night in 2014 (Figure 4.2.6-6).

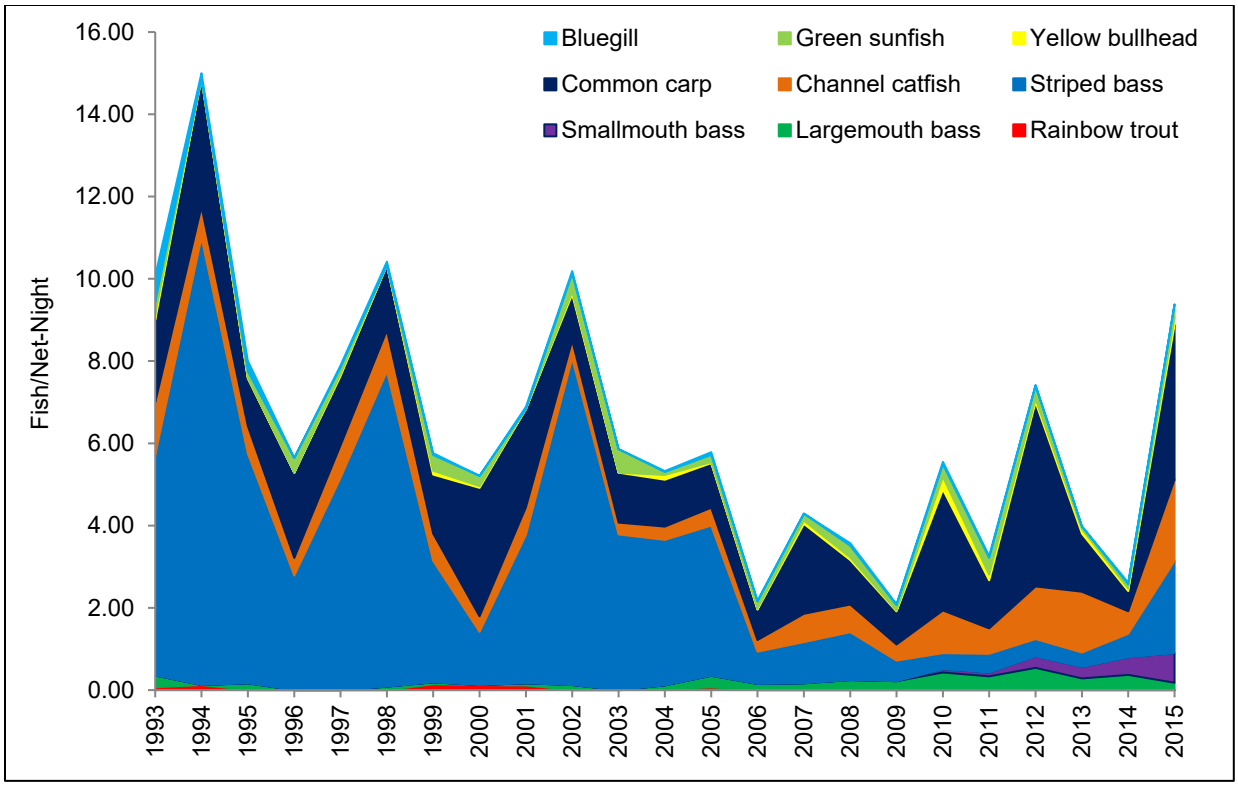


Figure 4.2.6-5. Cumulative gillnetting catch rates of sportfish species in Lake Mohave, 1993–2015 (NDOW data).

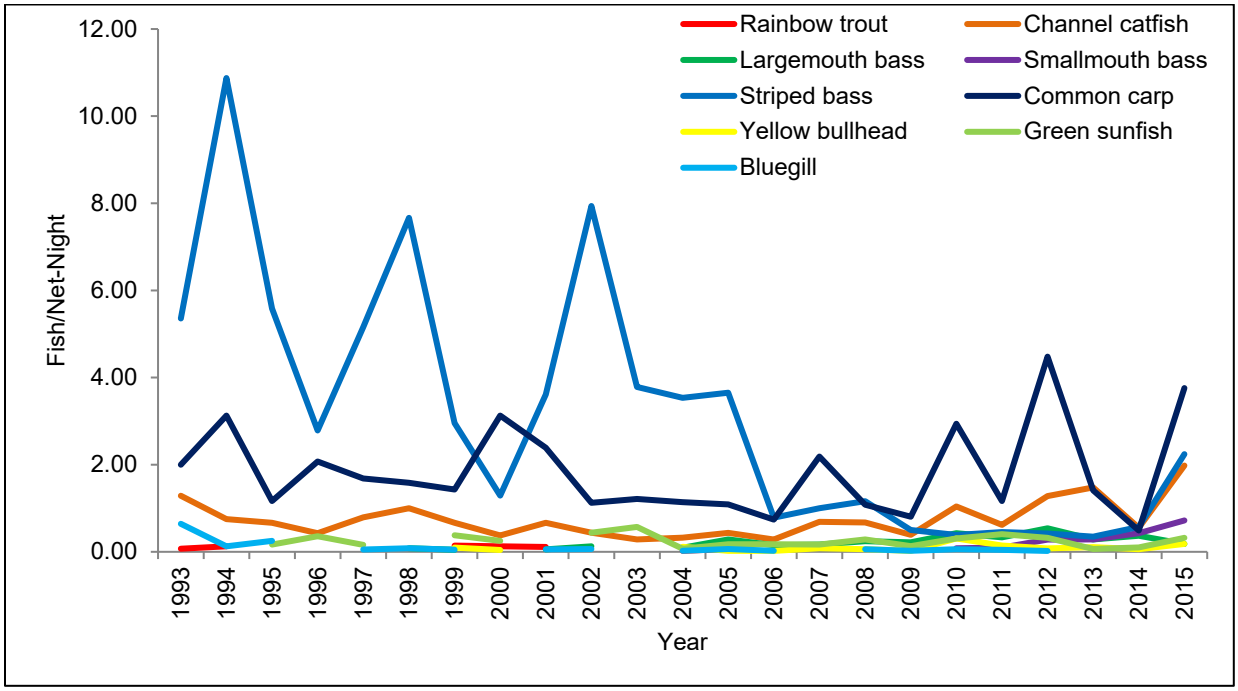


Figure 4.2.6-6. Gillnet survey catch rates by sportfish species in Lake Mohave, 1993–2015 (NDOW data).

Electrofishing surveys were conducted in the spring between 2004 to 2007 and 2012 to 2015. For all other years, surveys were conducted in the fall. No electrofishing surveys were conducted in 1996, 2001, 2003, and 2008. The 2015 total sportfish species catch rate estimated by electrofishing was up slightly from 2014 but remained similar to other spring sampling years (Figure 4.2.6-7). The 2015 largemouth bass catch rate remained stable compared to previous spring sampling years while smallmouth bass catch increased relative to 2014. No striped bass has been captured by electrofishing surveys since 2012 (Figure 4.2.6-7). Sunfish (green sunfish and bluegill) is the dominant species found in the nearshore of Lake Mohave. Sunfish abundance has increased from a low population abundance estimate recorded in 2012 and has fluctuated over the years (Figure 4.2.6-7).

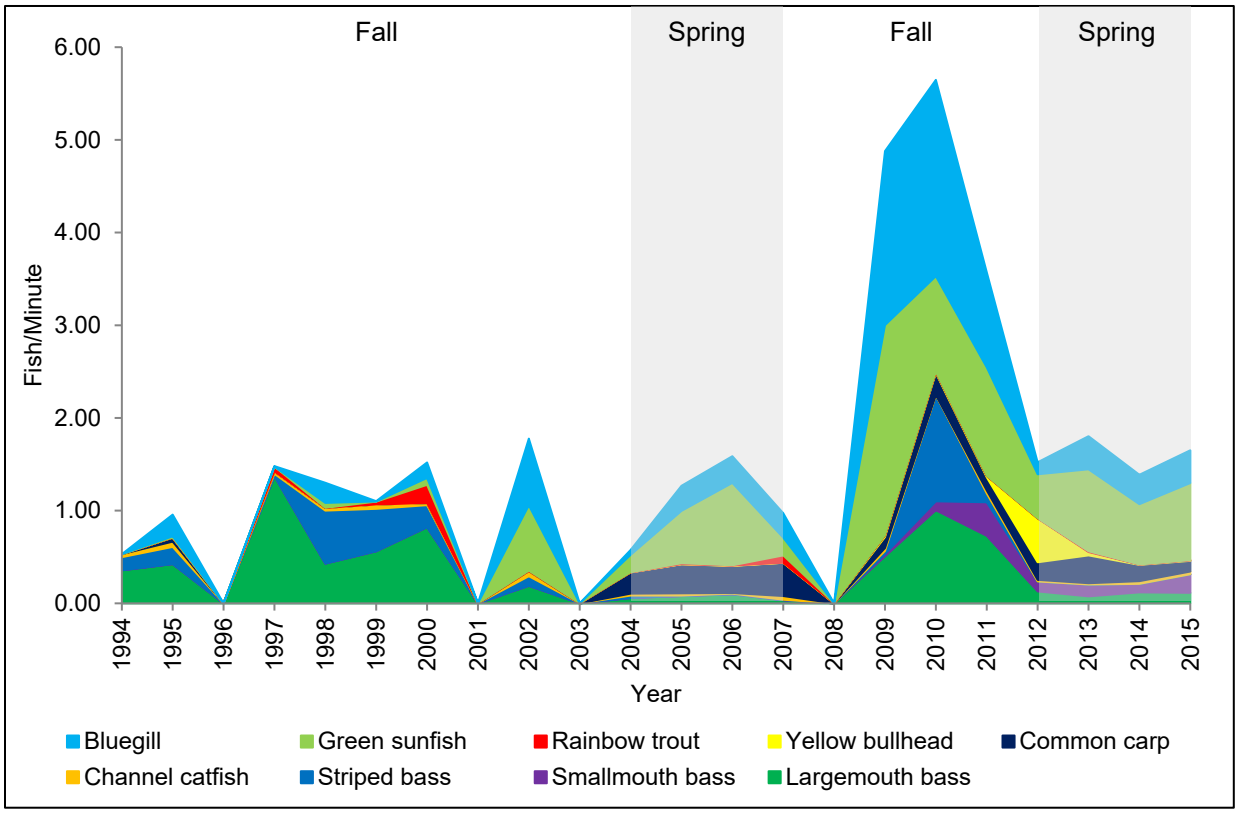


Figure 4.2.6-7. Cumulative electrofishing catch rates of sportfish species in Lake Mohave, 1994–2015 (NDOW data). Electrofishing surveys were conducted in the spring for 2004 to 2007 and 2012 to 2015. For all other years, surveys were conducted in the fall. No electrofishing surveys were conducted in 1996, 2001, 2003, and 2008.

Assessment Confidence and Key Data Gaps

Confidence in the existing data from lakes Mead and Mohave used for sportfish condition assessment is high due to the availability of long-term survey records collected with a consistent and standardized sampling and analysis protocol. However, significant inter-annual variability of catch rates observed from the long-term record could affect the certainty of the trend analysis; therefore a medium certainty rating is assigned.

There is concern that the sport fishery may be in decline following the introduction of several aquatic invasive species, including quagga mussels and gizzard shad (NPS, 2014; NDOW, 2015a). However, the impact of these species on the Lake Mead fishery is largely unknown at this time; therefore continued monitoring is essential toward meeting fishery management objectives to sustain a healthy sportfish population. More information is also needed concerning the potential impact of contaminants to sportfish within the system given the potential increase in urban populations and associated increases in wastewater effluent and urban runoff from nearby urban area to the park.

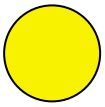
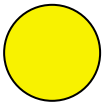
In addition, Lake Mead NRA water elevation is forecasted to continue to decline in future years, resulting in loss of shoreline cover which may compromise vital suitable habitat for littoral fish species and contribute to further population declines. Research and monitoring to understand nearshore processes is recommended.

4.2.7. Forage Fish

Assessment Outcome

A summary of the parameters used assess forage fish are shown in Table 4.2.7-1.

Table 4.2.7-1. Overall assessment outcome of the condition status and trend for forage fish.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Population Trend by Species	• Species abundance • Catch rates	Mead		Above average threadfin shad production recorded in 2015. Effects of high abundance of gizzard shad to forage and sportfish population remain unknown.
	• Species abundance • Catch rates	Mohave		Generally stable forage fish population with changing species composition. Populations of sunfish species have remained fairly abundant and gizzard shad started to appear in gillnets in 2015. Sharp increase in total forage fish catch rate in 2015 was a result of detection of gizzard shad. Since gizzard shad has only been recently detected in Lake Mohave, the long-term effect of its introduction remains unknown, thus no trend was identified.
Forage Fish overall				–

Description

In lakes Mead and Mohave forage fish serve as an important link between lower and higher trophic levels. A robust forage fish population is critical for supporting a healthy sport fishery. Several species of forage fish are found in lakes Mead and Mohave and larger sportfish in the lakes should rely on forage fish as their main food source.

The threadfin shad was first introduced into Lake Mead in 1955 as a food resource for game fish (Rosen et al., 2012). Initially, improvement in sportfish condition was observed, but the effect was short-lived. By the 1970s, the threadfin shad population had become an overabundant component of pelagic biomass, which is mostly unavailable to littoral predators, such as largemouth bass (NDOW, 2015a). Subsequent introduction and establishment of striped bass significantly reduced the pelagic threadfin shad population (Rosen et al., 2012). Another forage fish, gizzard shad was first detected in Lake Mead in 2007 and has become well established in Lake Mead (NPS, 2014). Although young gizzard shad have been found to increase forage availability for sportfish species, particularly for striped bass, adult shad generally become too large for most striped bass to consume. Currently, the major forage species present in Lake Mead are threadfin shad, bluegill, and green sunfish (Table B-4).

Lake Mohave also hosts several species of forage fish (Table B-4). Sportfish in Lake Mohave, such as largemouth bass and striped bass also rely on these forage species as their main food source. Populations of forage fish have remained fairly abundant in Lake Mohave with the exception of threadfin shad. Predation by striped bass, among other factors, has reduced threadfin shad abundance which has increased detection difficultly during standard surveys (NDOW, 2015b).

Data and Methods

Table 4.2.7-2 shows the data and methods used to assess forage fish.

Table 4.2.7-3. Indicators and measurements used in the assessment of forage fish.

Indicator(s)	Measurement(s)	Scale of Analysis
Population trend by species	• Species abundance • Catch rates	Lake

Since 1988, threadfin shad production has been monitored by weekly meter net trawls for one month during the spring and/or summer seasons in two basins of Lake Mead: Overton Arm and Boulder Basin (including Las Vegas Bay). The protocols and established transects were set in accordance with a 1988 nutrient study; these protocols are described in detail in Federal Aid Job Progress Reports for the Statewide Sportfish Restoration Program (NDOW, 2015a). The sampling technique used is efficient for small fish up to 0.8 in (20 mm) as larger fish tend to avoid the net, therefore results collected are an estimate of reproductive success but not a true recruitment value. Larval shad abundance was represented as fish/100m^3 and was calculated as peak abundance based on an average of the highest four or five weeks of shad production (NDOW, 2015a). Shad collected by trawl consisted of both large and small sizes of both Threadfin and Gizzard shad. Typically, larval shad collected were too small to be identified to species without the use of a microscope.

In Lake Mohave, lake-wide sportfish population inventory and assessment has been conducted annually through a joint effort by NDOW, AZGFD, and BOR. This assessment also included forage fish capture records. Population estimates through catch rates by species for Lake Mohave were derived from catch data provided by NDOW. Overnight gillnet surveys were generally conducted in

the spring. In addition, electrofishing surveys were conducted in the spring from 2004 to 2007 and 2012 to 2014 and in the fall from 1998 to 2002 and from 2009 to 2011. All Lake Mead surveys were conducted in the fall (NDOW, 2015).

Reference Conditions

Table 4.2.7-3 shows the reference conditions used to assess forage fish.

Table 4.2.7-3. Reference conditions of forage fish, used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
• Species abundance • Catch rates	Significant reduction in overall abundance and populations can no longer sustain sportfish population.	Evidences of changing forage species composition but populations remain stable providing sufficient forage base for sportfish.	Consistently stable population abundance providing a robust forage base for sportfish.

Condition and Trend

Lake Mead

The current condition is evaluated after 2008, post establishment of gizzard shad. Threadfin shad and sunfish abundance were low when compared to gizzard shad abundance in Lake Mead (Figure 4.2.7-1and Figure 4.2.7-2). Sunfish CPUE was generally higher with electrofishing as they are littoral species and easier to capture using this method (Figure 4.2.7-3). Threadfin shad have a higher CPUE by electrofishing than gizzard shad (Figure 4.2.7-3).

Threadfin shad populations generally exhibited a cyclical population pattern with two to three years of poor production followed by a peak year in production (NDOW, 2015a). The lowest average abundance occurred in 1989 at 2.78 fish/100m^3, and the highest was observed in 2007 at 446 fish/100m^3 in Las Vegas Bay. In Overton Arm, threadfin shad densities ranged from 2.7 fish/100m^3 in 2000 to 256 fish/100m^3 in 2007 (Lommis et al., 2011). Shad trawls conducted by NDOW at both Boulder Basin and Overton Arm showed increases in Shad production in 2009 following three consecutive years of decline (Figure 4.2.7-4). In 2014, lake-wide larval shad production was estimated at 93 fish/100m^3. Larvae collected from Las Vegas Bay consisted of both large and small sizes of both threadfin and gizzard shad. Fin rays were counted on some of the large shad to determine that both shad species were present (NDOW, 2015a). Samples from Overton Arm consisted of only small-sized larval shad. Larval shad are difficult to identify to species so trawl data typically represents a total estimate of all shad species.

In 2015 Shad production peaked in Overton Arm and but remained average in Boulder Basin. The 2015 Lake Mead NRA-wide larval shad production estimate (10-year average is 74 fish/100m^3) was above average at 84 fish/100m^3 (Figure 4.2.7-4). No information was available to determine whether samples consisted of only threadfin shad or both species of Shad.

Based on gillnetting data, gizzard shad became well established and reached a maximum CPUE of 11.6 fish/net-night in 2010. Since then, this species has maintained a relatively high abundance and has become the most numerous fish caught in gillnet surveys.

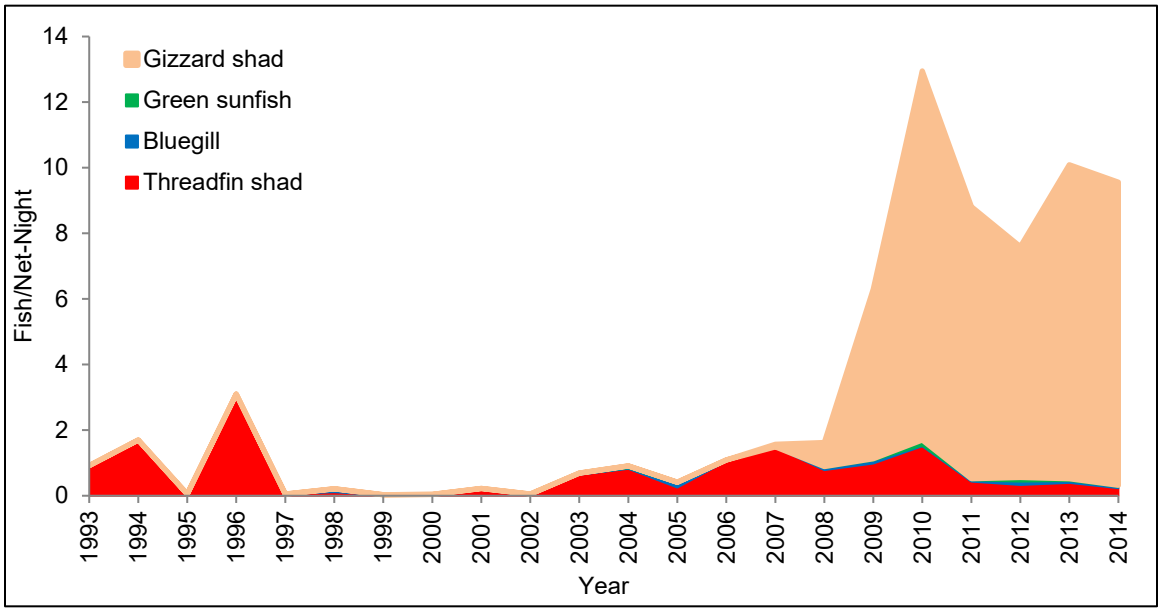


Figure 4.2.7-1. Cumulative gillnetting catch rates of forage fish species in Lake Mead, 1993–2015 (NDOW data).

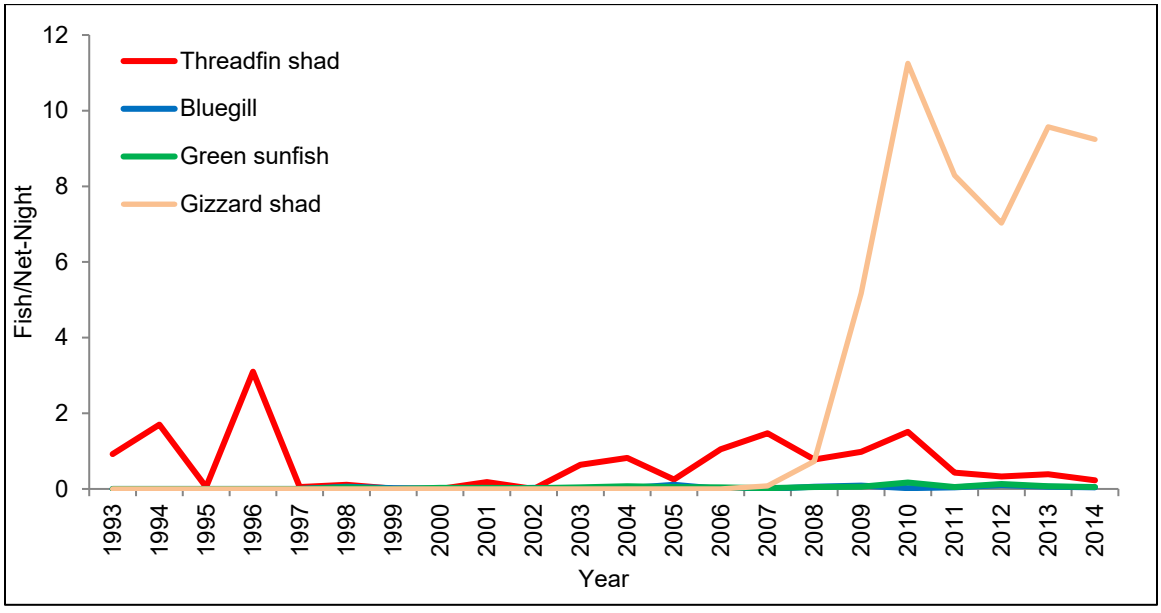


Figure 4.2.7-2. Gillnet survey catch rates by forage fish species in Lake Mead, 1993–2015 (NDOW data).

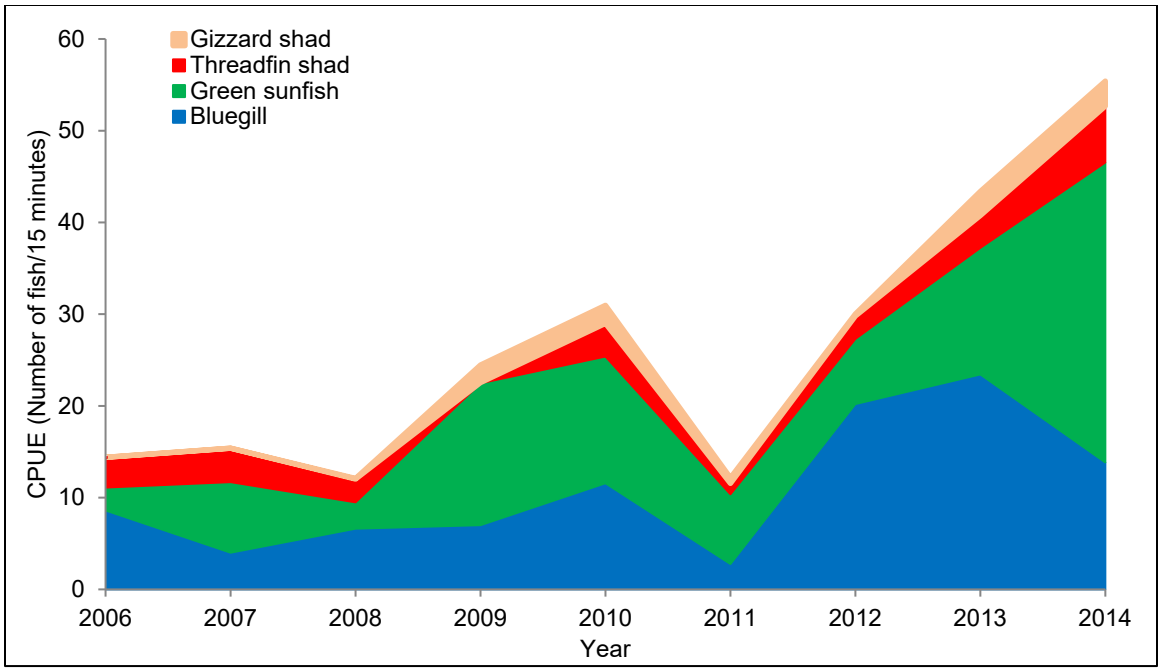


Figure 4.2.7-3. Cumulative electrofishing catch rates of forage fish species in Lake Mead, 2006–2014 (NDOW data).

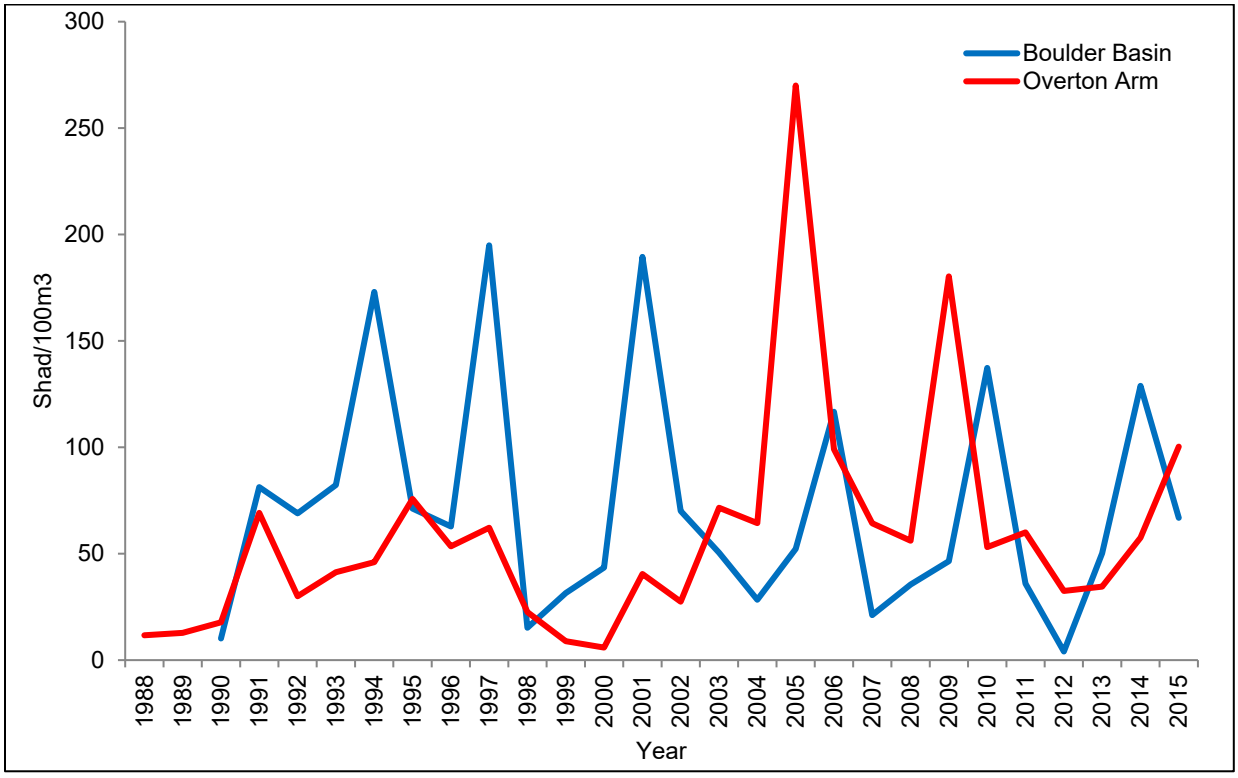


Figure 4.2.7-4. Lake Mead shad peak production densities (NDOW Data 1988–2015).

Lake Mohave

The major forage fish species in Lake Mohave are gizzard shad, bluegill, and green sunfish. Populations of sunfish species have remained fairly abundant however invasive gizzard shad appeared in gillnets in 2015 (Figure 4.2.7-5). No threadfin shad have been detected since 1998 through gillnet surveys; however, large schools of threadfin and gizzard shad were sight observed in 2013 and 2014 (NDOW, 2015b). In addition, gizzard shad were captured in the 2015 survey (Figure 4.2.7-6) and have become the dominant forage fish species over green sunfish in 2015 despite first year of detection (Figure 4.2.7-6).

The 2015 total forage fish catch rate by electrofishing increased slightly from 2014 but remained similar to other spring sampling years (Figure 4.2.7-7). No threadfin shad or gizzard shad were captured by electrofishing surveys (Figure 4.2.7-7), which is likely due to the pelagic nature of these species (Rosen et al., 2012).

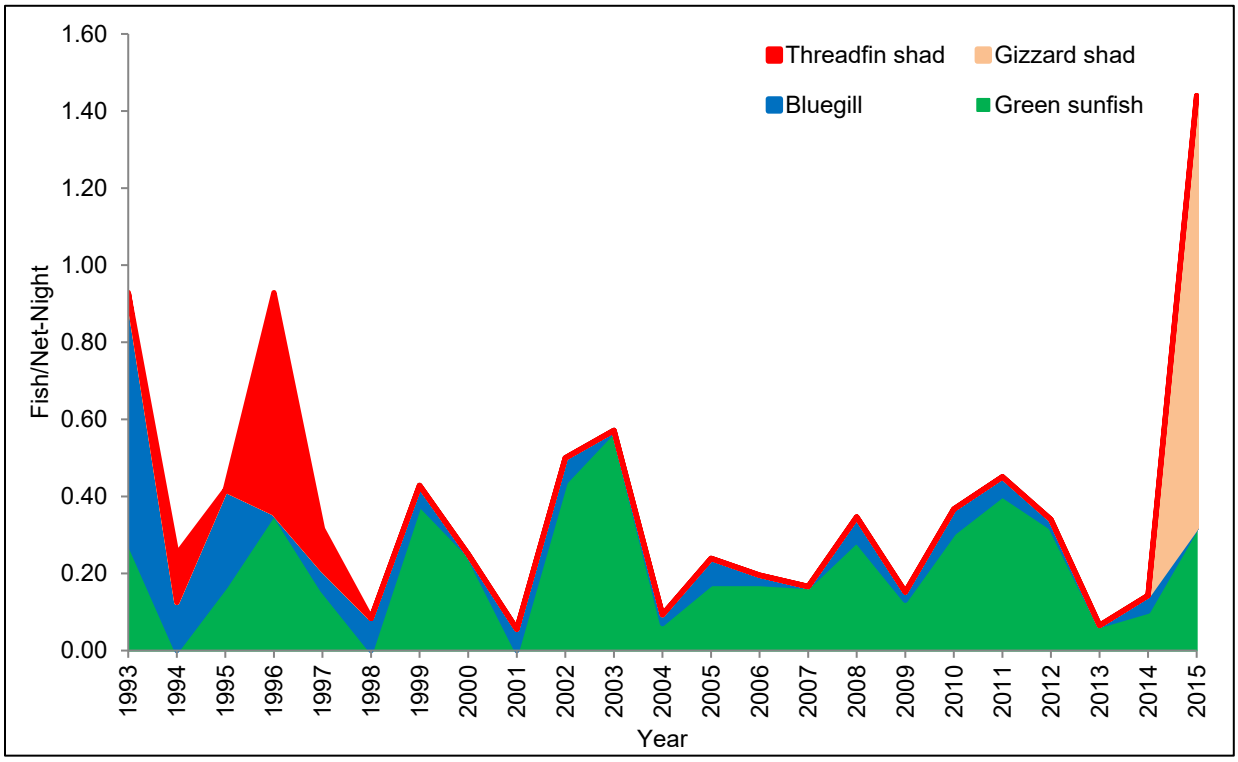


Figure 4.2.7-5. Cumulative gillnetting catch rates of forage fish species in Lake Mohave, 1993–2015 (NDOW data).

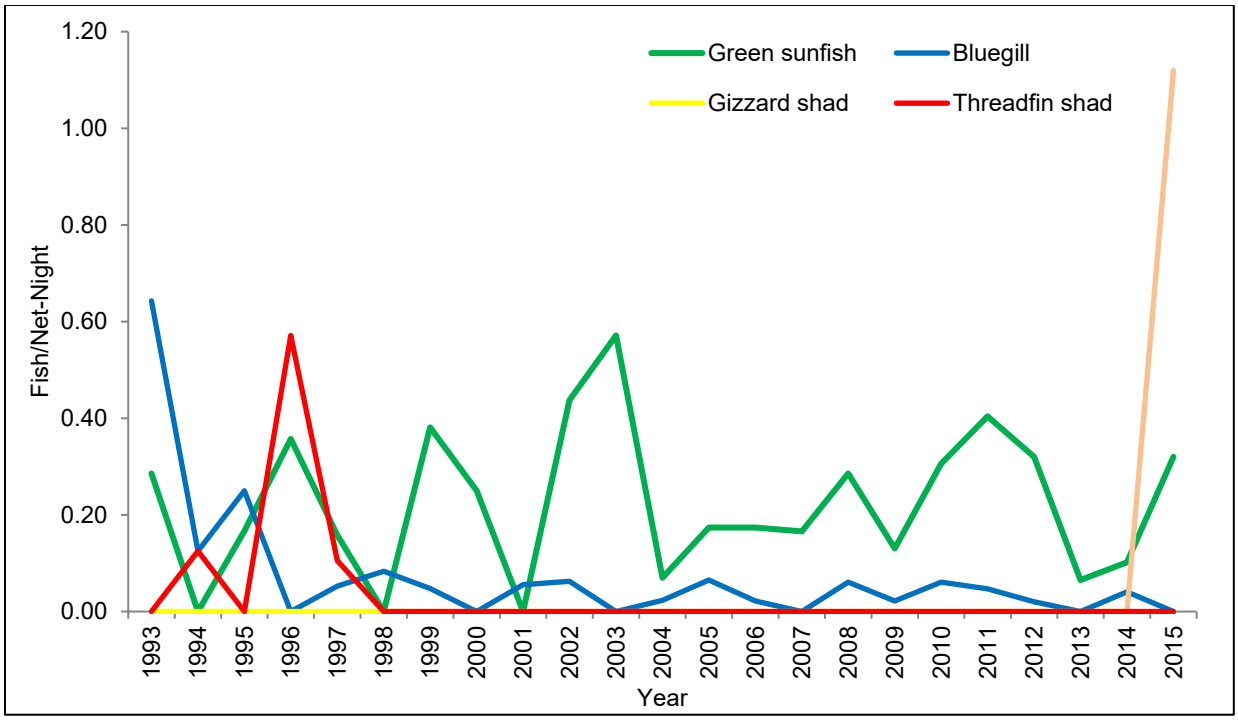


Figure 4.2.7-6. Gillnet survey catch rates by forage fish species in Lake Mohave, 1993–2015 (NDOW data).

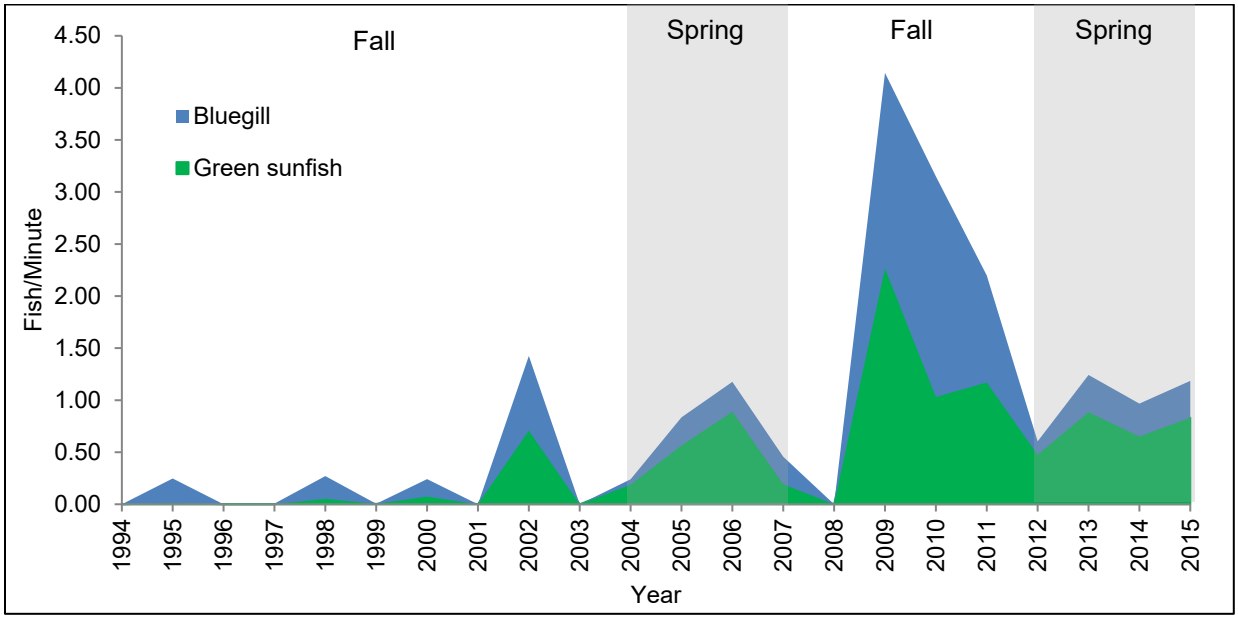


Figure 4.2.7-7. Cumulative electrofishing catch rates of forage fish species in Lake Mohave, 1994–2015 (NDOW data). Electrofishing surveys were conducted in the spring for 2004 to 2007 and 2012 to 2015. For all other years, surveys were conducted in the fall. No electrofishing surveys were conducted in 1996, 2001, 2003, or 2008.

Assessment Confidence and Key Data Gaps

Confidence in the existing data from lakes Mead and Mohave is high because of the long duration of surveillance records collected using consistent and standardized protocols for forage fish population estimation. However, the long-term effect of recently introduced gizzard shad on sportfish and other forage fish condition remains unknown, thus a medium certainty rating is assigned.

There is concern the sport fishery may be affected by the introduction of gizzard shad in the long-term because of its fast growth rate and ultimate size relative to threadfin shad, which may make them too large for sportfish to consume (Loomis et al., 2011; NPS, 2014). With increased densities of gizzard shad in Lake Mead, as well as its spread to Lake Mohave, studying the potential impact of this non-native fish to native, sport, and other forage fish are needed to maintain a sustainable sports fishery. Further, the establishment of nonindigenous species such as quagga mussels or New Zealand mudsnails may have significant impacts on the food availability or reproduction processes for forage fishes in the system. Understanding the impacts of these and other stressors to forage fish populations in the Lake Mead NRA is recommended.

4.2.8. Aquatic-dependent Birds

Assessment Outcome

A summary of the parameters used assess aquatic dependent birds are shown in Table 4.2.8-1.

Table 4.2.8-1. Overall assessment outcome of the condition status and trend of aquatic dependent birds.

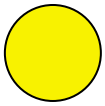
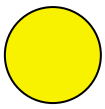
Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Population Trend by of Key Shorebird Species	• Species occurrence • Species abundance		The initial 5-year (2004–2009) shoreline and aquatic bird inventory provided useful baseline information regarding the current condition in lakes Mead and Mohave and for future assessments. A number of bird species of conservation interest use lakes Mead and Mohave year-round or seasonally. Therefore, Lake Mead NRA can play a critical role in the conservation of these species. However, availability of seasonal resources for these species is unstable due to fluctuating lake levels. Insufficient data to justify a trend in the condition.
Peregrine Falcon	• Annual estimate of nesting • Nesting success		Increased in numbers of nesting pairs and potentially nesting success.
Bald Eagle	• Wintering population census		Slight decrease in population census count.

Table 4.2.8-1 (continued). Overall assessment outcome of the condition status and trend of aquatic dependent birds.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Aquatic-dependent Birds overall			–

Description

Lake Mead NRA provides key habitats along the western flyway for shorebirds, waterfowl, and other aquatic dependent birds. These birds utilize the open water and vegetation in surrounding landscapes for cover, food, and nesting sites for breeding, as well as critical stopover for migratory birds (Lake Mead NRA, 2010). Nearly 370 species of migratory birds have been recorded within Lake Mead NRA. One hundred and nine species of aquatic and aquatic-dependent birds were documented at lakes Mead and Mohave during inventory and monitoring conducted between 2004 and 2009 (Barnes & Jaeger, 2011). Surveys recorded occurrence of several guilds of aquatic birds, including shorebirds and wading birds (sandpipers, plovers, ibis, herons, and egrets), marsh birds (soras, rails, and coots), and waterfowl and diving birds (ducks, geese, grebes, loons, and cormorants). The inventory also surveyed birds that are associated with open water, such as kingfishers, terns, and raptors that feed or nest near aquatic ecosystems (Lake Mead NRA, 2010).

Several species of shorebirds and aquatic-dependent birds found at lakes Mead and Mohave are federally listed as either threatened or endangered. Active monitoring and management are necessary to protect these species. Since site fidelity is common in birds, protection of critical breeding habits is essential for population recovery (Lake Mead NRA, 2010). Shorebirds and aquatic-dependent birds also have high aesthetic and recreational values. For example, bird watching and bird photography are popular recreational activities in Lake Mead NRA (Lake Mead NRA, 2010).

As top-predators in the food web, birds can consume macroinvertebrates, fish, and other birds thereby cycling organic matter and nutrients between aquatic and terrestrial environments. Changes in shorebird and aquatic-dependent bird populations may be indicators of changes in the biotic or abiotic components of the riparian and aquatic zones on which they depend.

Data and Methods

Table 4.2.8-2 shows the data and methods used to assess aquatic dependent birds.

Table 4.2.8-2. Indicators and measures used in the assessment of aquatic dependent birds.

Indicator(s)	Measurement(s)	Scale of Analysis
Population Trend by of Key Shorebird Species	• Species occurrence • Species abundance	Lake
Peregrine Falcon	• Annual estimate of nesting • Nesting success	Lake

Table 4.2.8-2 (continued). Indicators and measures used in the assessment of aquatic dependent birds.

Indicator(s)	Measurement(s)	Scale of Analysis
Bald Eagle	Wintering population census	Lake

Barnes and Jaeger (2011) reported the results from monthly surveys conducted on shoreline and aquatic bird species on lakes Mead and Mohave from March 2004 through July 2009. These surveys established species composition within Lake Mead NRA, seasonal migration and wintering pattern, general abundances, and variation by year. Bays, coves, and other sites known to attract aquatic birds were monitored on a monthly basis (Figure B-6). Incidental observations of rare or unusual species or of large congregations of aquatic birds during migrations were also recorded. Results from the surveys provide baseline information about the occurrence (presence/absence) and abundance of shoreline and aquatic birds in Lake Mead NRA, and are evaluated as part of this assessment.

Inventory information collected by Barnes and Jaeger (2011) between 2004 and 2009 is the most recent data available for a comprehensive survey of occurrence of shorebirds and aquatic-dependent birds at Lake Mead NRA. Species of conservation interest data collected by the LCRMSCP were also used as supporting information for this assessment. Assessments of the current status (occurrence) of aquatic-dependent bird species with conservation interest at Lake Mead NRA are also conducted using best available information in published literature. For example, bald eagle population census data collected annually in the winter by NPS staff and volunteers.

Reference Conditions

Table 4.2.8-3 shows the reference conditions used to assess aquatic dependent birds.

Table 4.2.8-3. Reference conditions of aquatic dependent birds used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
• Population trend by key shorebird species	Significant decline of general aquatic-dependent bird species or bird species of conservation interest occurrence and abundance.	Slightly decreasing trends of general aquatic-dependent bird species or bird species of conservation interest occurrence and abundance.	Stable or increasing trends of general aquatic-dependent bird species or bird species of conservation interest occurrence and abundance.
• Peregrine falcon annual estimate of nesting pairs • Nesting success	Significant decrease in annual estimate of nesting pairs and nesting success	Slightly decreasing trend in annual estimate of nesting pairs and nesting success	Stable or increasing trend in annual estimate of nesting pairs and nesting success
• Bald eagle wintering population census	Significant decrease in population size	Slightly decreasing trend in population size	Stable or increasing trend in population size

Results from the I&MP shoreline and aquatic bird report provide useful baseline information for the identification of general reference condition for future assessment.

Condition and Trend

Temporal and spatial changes in occurrence and abundance

Lake Mead has a greater diversity of aquatic bird species than Lake Mohave. Lake-wide aquatic bird surveys conducted between 2004 and 2009 resulted in the observation of 104 species at Lake Mead, of which 38 were unique to Lake Mead, and 71 species were observed at Lake Mohave, of which 5 were unique to Lake Mohave, and 4 of those were rare sightings (Table B-5). This increased species diversity measured at the lakes results primarily from the nutrient-rich and delta-forming inflows of the Muddy, Virgin, and Colorado Rivers, and Las Vegas Wash (Barnes & Jaeger, 2011). Barnes and Jaeger (2011) also found that the fluctuating water level of Lake Mead produced a diversity of dynamic habitats, including temporary mudflats and open beaches preferred by many shorebirds. These ephemeral habitats have attracted breeding by snowy plovers (*Charadrius nivosus*), a shorebird species considered threatened along the Pacific Coast. Conversely, Lake Mohave maintains a more regular surface-water level and has limited tributary inflow and nutrient input. The lesser diversity of avian habitats and tributary sources results in lower bird species diversity for Lake Mohave. Species evenness, which accounts for the relative abundance among species, was higher at Lake Mead for aquatic-dependent birds relative to Lake Mohave (Barnes & Jaeger, 2011). Virgin and Muddy river basins supported the highest observed numbers of waterfowl, diving ducks, and shorebirds (Barnes & Jaeger, 2011).

Overall, the American coot (*Fulica americana*), a migratory herbivore, and grebes have been the most abundant species regularly observed at Lake Mead, occurring in great numbers during winter months (Figure 4.2.8-1). The American coot is abundance at Lake Mohave. Occurrence and abundances of aquatic birds in lakes Mead and Mohave were highly seasonal (Figure 4.2.8-2). Overall seasonal abundance observed between 2004 and 2009 reflects predictable patterns associated with winter residency or migratory stopovers in spring and fall (Figure 4.2.8-2, and see Table B-5 for species list) (Barnes & Jaeger, 2011).

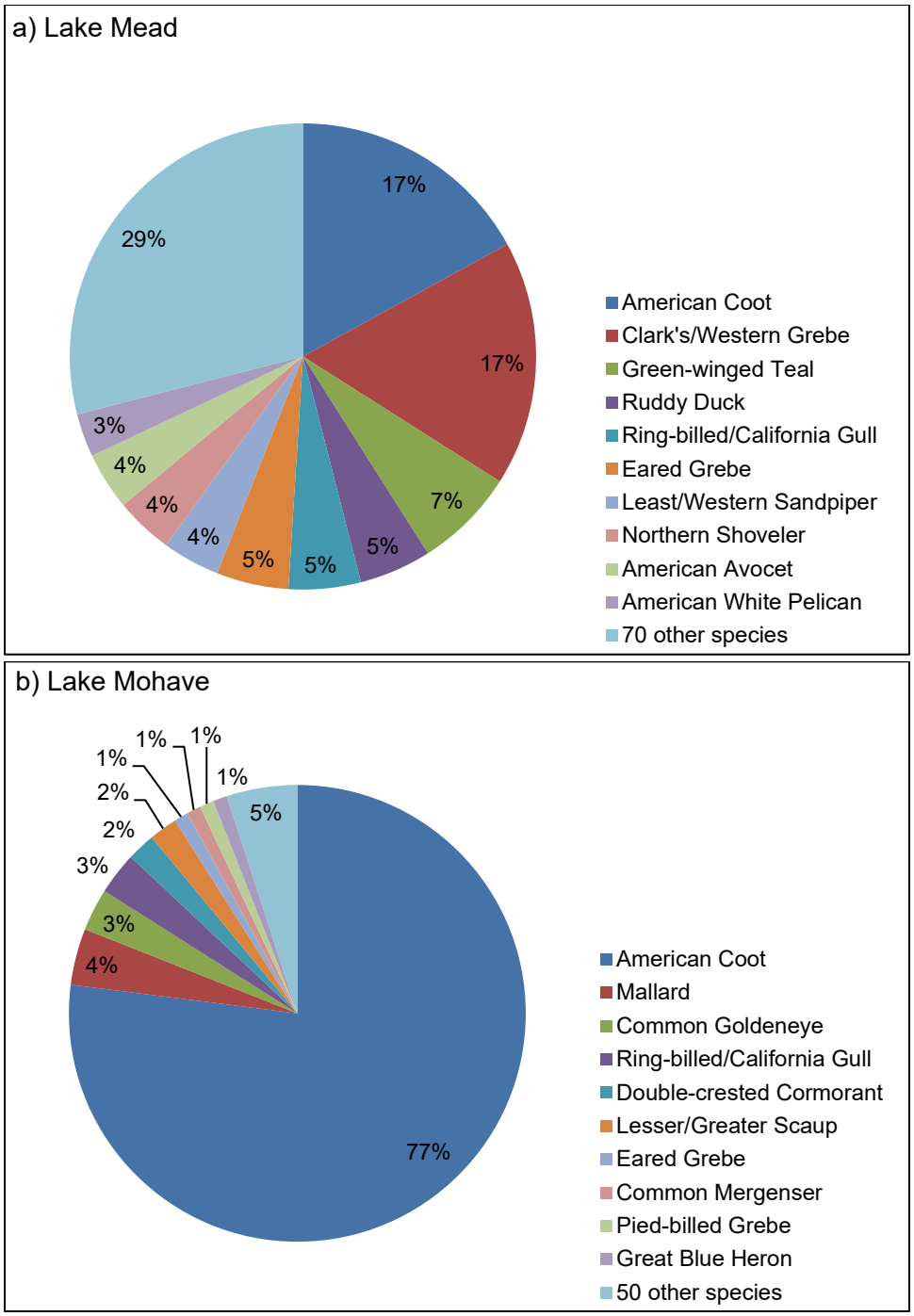


Figure 4.2.8-1. Percentages of the 10 most common species or species groups of aquatic birds in a) Lake Mead and b) Lake Mohave. Values derived from observation documented during monthly surveys from March 2004 through August 2009. Modified from Rosen et al., 2012.

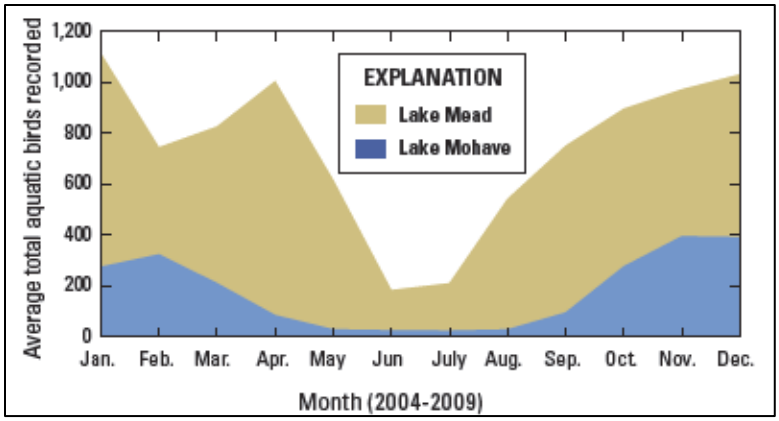


Figure 4.2.8-2. Monthly averages of total aquatic birds recorded per survey sites monitored during monthly surveys from March 2004 through August 2009. Data presented are the combined means of regularly monitored sites on Lake Mead and Lake Mohave. Excerpted from Rosen et al., 2012.

Yearly variation of aquatic bird abundance recorded at lakes Mead and Mohave may be due to the inherent tie of migratory birds to regional and continental climatic and environmental conditions located outside of Lake Mead NRA's boundary (Barnes & Jaeger, 2011). In 2005, the highest number of birds per survey was recorded at Lake Mead, whereas the lowest numbers of birds per survey were observed at Lake Mohave in the same year. Barnes and Jaeger (2011) suggested that the variability observed between the two lakes may be attributed to the different species composition observed at the lakes and the fluctuating conditions at Lake Mead as compared to the relative stability of Lake Mohave.

Lakes Mead and Mohave are also home to osprey (*Pandion haliaetus*), bald eagles (*Haliaeetus leucocephalus*), and peregrine falcons (*Falco peregrinus*) that prey primarily on fish and aquatic birds. Between 2004 and 2009, osprey and bald eagles were observed in all seasons, but use of the Lake Mead NRA by these species shifted seasonally, particularly for bald eagles, which typically were present in higher numbers during non-breeding winter months (Barnes & Jaeger, 2011).

Occurrence and status of species of conservation interest

Great blue herons (*Ardea herodias*): Great blue herons are year-round residents at Lake Mead NRA. Although fairly common, it is considered a sensitive species due to its habit of nesting in large groups or rookeries. Rookeries are present on both lakes Mead and Mohave (Lake Mead NRA, 2010).

Yellow-billed cuckoo (*Coccyzus americanus*): Yellow-billed cuckoo is a rare summer resident at Lake Mead NRA. The bird is considered a distinct population segment and listed as threatened in October 2014. This riparian-dependent species has experienced dramatic declines throughout its range. There are few recorded sightings at Lake Mead, although the species was recently documented in the Lower Virgin River (Rosen et al., 2012). The park largely lacks suitable mature riparian habitat for yellow-billed cuckoo (Lake Mead NRA, 2010).

Southwestern willow flycatcher (*Empidonax traillii extimus*): Southwestern willow flycatcher is a critically endangered (listed under the Endangered Species Act in 1995) riparian subspecies of the willow flycatcher. It is a summer resident that occupies riparian habitat characterized by dense growths of willows, *Baccharis* spp., tamarisk, arrowweed, and other riparian vegetation. The southwestern willow flycatcher has been observed at several locations on Lake Mohave, and breeding has been documented at sites in the Virgin River, Muddy River, and Lake Mead Deltas. The birds typically build their nests directly over or very near standing water, making them particularly susceptible to disturbance from boats or other water-based recreational activities (Rosen et al., 2012).

In 2004 and 2005, surveys conducted through the LCRMSCP found low numbers of migrating flycatchers along Lake Mohave, and none along Lake Mead (Fletcher & Barnes, 2005). Nesting habitat for southwestern willow flycatchers occurs along the Virgin River adjacent to Lake Mead, 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. A small number of southwestern willow flycatchers are also known to breed in Overton WMA along the lower Muddy River (surveyed by SWCA on contract with the Bureau of Reclamation) and farther upstream on the Muddy River in the Warm Springs Natural Area (surveyed by SWCA under contract with Southern NV Water Authority).

California condors (*Gymnogyps californianus*): California condors were reintroduced upstream of Lake Mead and are occasionally seen in the upper reaches of Lake Mead near the mouth of the Grand Canyon (NPS, 2014).

Yuma clapper rail (*Rallus longirostris yumanensis*): In the past decade, the Yuma clapper rail has been found in southern Nevada in areas on and adjacent to Lake Mead (Lake Mead, 2010). Yuma clapper rails occupy marshy areas with shallow water and dense vegetation including bulrush and cattails. Most of Lake Mead's shoreline habitat is unsuitable due to the fluctuations in water level, loss of riverine characteristics, and lack of marsh habitat. Potential habitat exists in discrete sections of shoreline where conditions intermittently support marsh establishment, though no rails have been documented within the park (NPS, 2014).

Snowy plover: Two breeding colonies with successful breeding of snowy plovers were discovered in 2007 and 2008 along the Overton Arm. These were the first observations of snowy plovers breeding on Lake Mead and represented a large range expansion (greater than 300 miles) from previously known breeding ranges (Barnes & Jaeger, 2011). Snowy plovers are listed as a Nevada Species of Concern and the Pacific Coast population is federally listed as threatened under the Endangered Species Act (ESA). The presence of snowy plover breeding colonies is believed to be the result of declined surface-water level at that time, which uncovered large areas of favorable habitat (Rosen et al., 2012).

Other aquatic-dependent birds of conservation concern utilize Lake Mead NRA year-round or seasonally. Table B-6 lists these species, along with their preferred habitat, conservation concerns, and management strategies based on the Great Basin Bird Observatory's Nevada Bird Conservation Plan (2010) and tailored to Lake Mead NRA.

Peregrine Falcons Annual Estimate of Nesting Pairs and Nesting Success

Peregrine falcons observed at lakes Mead and Mohave have been documented to prey on 29 species of aquatic birds. Peregrine falcons have been present year-round at Lake Mead NRA and nest on cliffs and canyon walls on both lakes Mead and Mohave (NPS, 2014). This species is most common at Lake Mead NRA from December to March.

Barnes et al. (2015) studied peregrine falcons breeding in Lake Mead NRA from 2006 to 2010. The number of known breeding territories at Lake Mead NRA increased from 16 in 2005 to 37 by 2010 (Figure 4.2.8-3). During the 5 year study period, breeding territory occupancy rate averaged 94%, annual breeding success averaged 72.4% ± 6.7 % (range: 64–82%), and reproductive output average 1.8 ± 0.3 young per nesting attempt. Because this was the first comprehensive peregrine survey conducted in Lake Mead NRA, it was not possible to definitively determine if the increase in territories reflected a population increase or was attributable, at least in part, to finding previously unknown territories. However, high occupancy and reproductive output likely represented an increasing population. The majority of eyries were located near lakeshores and along steep-walled canyons overlooking Lake Mead waters (Barnes, 2011). Peregrines also preferred north-facing eyries, likely as a response to the high-heat environment of the Mojave Desert (Barnes et al., 2015). Mild winters, prey availability, and results from non-breeding surveys and radio-tracking of peregrines in Black Canyon, suggest that breeding adults remain in the region year-round (Glinski & Garrison, 1992; Barnes & Jaeger, 2010; Barnes et al., 2015).

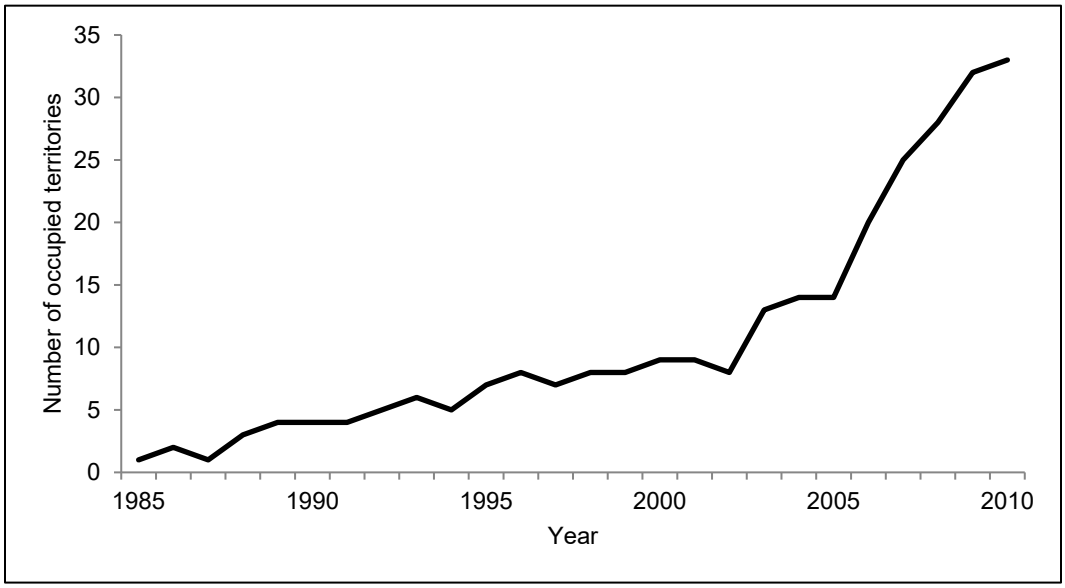


Figure 4.2.8-3. Number of known occupied peregrine falcon territories within Lake Mead NRA from 1985 through 2010. An occupied territory is defined as a site containing equal or more than one territorial peregrine present during a portion of the breeding season. Data from Barnes & Jaeger, 2010 and Barnes et al., 2015.

Bald Eagle Wintering Population Census

Delisted from USFWS endangered status in 2007, the bald eagle remained as a watch list species under Clark County Multiple Species Habitat Conservation Plan (MSHCP). Waterfowl and fish found at lakes Mead and Mohave are an important food source for bald eagles. Peak occurrence for bald eagles has typically been in November or early December, and they usually depart by late February or early March. Annual winter counts in early January by survey crews covering both lakes in a single day have been conducted at Lake Mead NRA since 1981. However, survey routes were not standardized until 2000. NPS formally established standard operating procedures for winter bald eagle count in 2007 (Fletcher & Jaeger, 2011). Data collected by the winter surveys between 2000 and 2011 suggest an upward trend in the number of bald eagles found at the lakes (Figure 4.2.8-4). Fletcher and Jaeger (2011) proposed that the trend observed may be the combined results of methodological change and increasing number of bald eagles using lakes Mead and Mohave. However, downward trends in the number of both immature and adult bald eagles have been observed since 2011 (Figure 4.2.8-4). It is not clear why these declines have occurred.

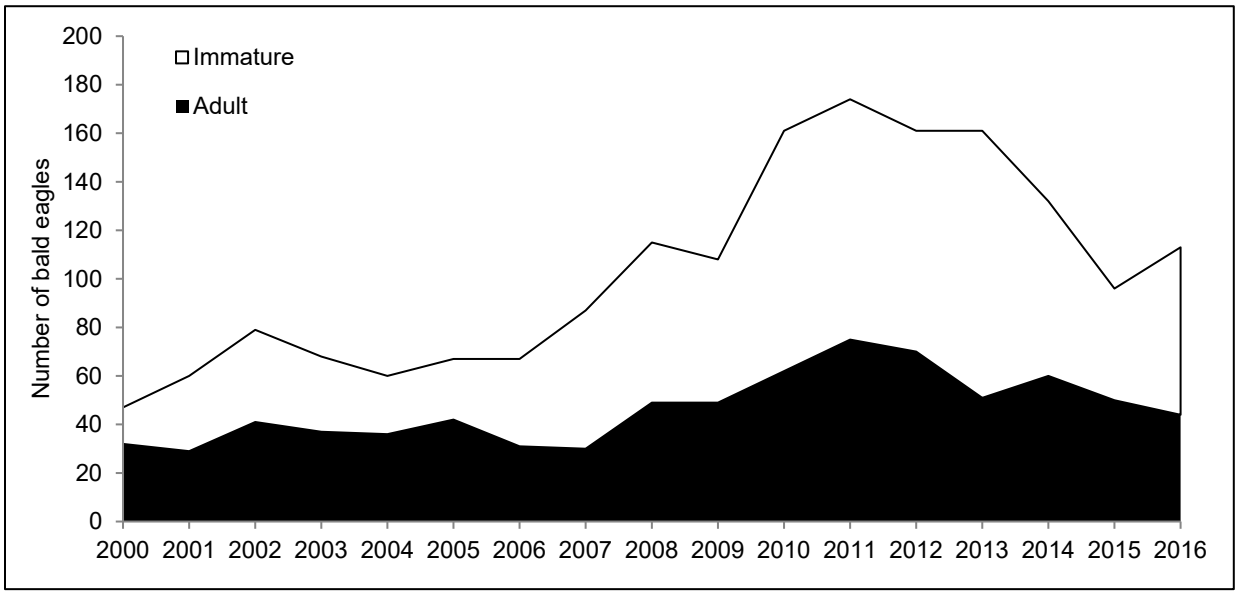


Figure 4.2.8-4. Number of bald eagles recorded from 2000 through 2016 during the winter counts at lakes Mead and Mohave. Note that methodologies have changed through time with standardized routes introduced in 2000, and standard operation procedures implemented in 2007. Data from Fletcher & Jaeger, 2011.

Overall

Changes in the surface-water level of Lake Mead significantly alter the availability and composition of habitats for aquatic birds (Barnes & Jaeger, 2011). The river mouths on Lake Mead and many of the coves and bays, unlike most areas around the lake, are shallow and have gradual slopes. Shifts in lake level expose or inundate large areas at these sites where some are covered by sediments. The fluctuations in lake level in recent years tended to create temporary mudflats and open beaches that, at times may favor shorebirds (for example, sandpipers, plovers) of which many are species of conservation interest (Rosen et al., 2012).

There is no current park-wide information available for examining trends in shoreline and aquatic bird population occurrence and abundance. Information presented in this section serves as a quantifiable baseline for future assessments.

Assessment Confidence and Key Data Gaps

Overall assessment confidence is moderate for the current condition of shoreline and aquatic-dependent birds. The initial 5-year (2004–2009) shoreline and aquatic bird inventory provided useful baseline information regarding the most recent condition assessment in lakes Mead and Mohave and would be useful for future assessment (Barnes & Jaeger, 2011). However, no comparable data were available beyond 2009. Inventory and monitoring data collected by Barnes and Jaeger (2011) between 2004 and 2009 were not suitable for justifying a trend in the condition due to methodical limitations (Barnes & Jaeger, 2011).

Continued monitoring is needed on the status and trends of species composition, occurrence and distribution, and abundance and fitness of shorebirds and aquatic-dependent birds. The report identified a number of bird species of conservation interest utilizing Lake Mead NRA year-round or seasonally. Therefore, NPS can play a critical role in the conservation of these species.

For the peregrine falcon, demographic measures such as mortality rate, immigration, and age at first breeding would help determine to what degree local reproduction is driving the observed population increase and whether peregrines at Lake Mead NRA represent a source or sink population (Barnes et al., 2015). Research is needed to better understand nesting success effects on population stability of peregrine falcons within the park.

In addition to the annual winter census for bald eagles, surveys of roosting and perch sites of bald eagles should be conducted to prevent impacts from visitor use and development within the park. Measurement of mercury from eagles is also recommended considering falcon concentrations were also elevated (see Contaminants section) (Barnes and Gerstenberger, 2015).

Migratory bird pathways tend to follow seasonally reliable resources (Shuford et al., 2002; Skagen, 2006); however, shoreline and shallow water habitats are an unstable seasonal resource for birds at Lake Mead due to high variation in water levels from year to year (Barnes & Jaeger, 2011). The impacts of resource changes on migrating and wintering bird populations at Lake Mead is unknown, and a comprehensive resource assessment of the entire river system would be worthwhile to better understand these impacts (Barnes & Jaeger, 2011).

Potential future climate effects on changes in habitat and food resources for aquatic birds in Lake Mead NRA should be evaluated. Continued monitoring of population dynamics and relationship to available habitats is needed to assess response to low water and evaluate bird responses to changes in Lake Mead NRA ecosystems. Aquatic bird species at lakes Mead and Mohave will be affected by anthropogenic-induced changes, particularly from non-native invasive species and contaminants contained in tributary inflow. Understanding pathways of contaminants within the food web and to bird reproduction is needed to assess risks to population health. Long-term monitoring of

anthropogenic activities in relation to the effect such activities have on aquatic birds is important for park managers, so they are better able to plan for protection of sensitive areas.

4.2.9. Riparian Vegetation

Assessment Outcome

A summary of the parameters used assess riparian vegetation are shown in Table 4.2.9-1.

Table 4.2.9-1. Overall assessment outcome for the condition status and trend of riparian vegetation.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Occurrence	Presence/ Absence	Mead		Composition of riparian vegetation remains unchanged, with a non-native species majority. Ongoing NPS riparian vegetation management has limited degradation and improved riparian habitat.
	Presence/ Absence	Mohave		Composition of riparian vegetation remains unchanged, with a non-native species majority. Ongoing NPS riparian vegetation management has limited degradation and improved riparian habitat.
Riparian Vegetation overall				–

Description

Riparian areas and associated vegetation serve many functions, including water purification, flood control, buffering riverbank erosion, and stream water temperature regulation. Riparian vegetation occurrence and composition can affect aquatic organisms by providing shade and nutrients to streams, impacting the physical and chemical dynamics of the system. Further, litter and debris from vegetation can support different aquatic invertebrate and fish assemblages and have effects on stream geomorphology (Lake Mead NRA, 2010). Riparian areas also provide breeding habitat for some birds. The composition and abundance of riparian vegetation result from a variety of factors such as geomorphology, shoreline sediment particle size, and lake and stream water levels (Rosen et al., 2012). Thus, riparian habitat integrity is a good indicator of landscape-level conditions as these habitats form a connection between both aquatic and upland systems (Gregory et al., 1991).

Riparian habitats associated with lakes Mead and Mohave support a number of water dependent plant species. These areas also provide critical habitat for several animal species protected under the MSHCP. Riparian vegetation in Lake Mead is mostly limited to tributary deltas and a few small areas containing shoreline springs. On the other hand, with predictable water level fluctuations, Lake Mohave is ringed with shoreline riparian habitats (Rosen et al., 2012). The 245 km of the Colorado River's former channel, 1718 km of lake shoreline, and the park's 89 desert springs provide

important preservation opportunities for one of the Southwest's most threatened habitats – the desert riparian community (NPS, 2014).

Data and Methods

Table 4.2.9-2 shows the data and methods used to assesss riparian vegetation.

Table 4.2.9-2. Indicators and measurements used in the assessment of riparian vegetation.

Indicator(s)	Measurement(s)	Scale of Analysis
Occurrence	Presence/Absence	Lake

Riparian vegetation was assessed by examining occurrence (presence/absence) and composition of vegetation in the riparian zone of lakes Mead and Mohave. Information and data from historical studies were used to identify reference condition for assessing status of riparian vegetation in lakes Mead and Mohave. A summary of the history of riparian vegetation mapping in the Lower Colorado River region from 1984 to 2010 can be found in Bangle et al. (2014).

In 1997, Tallent et al. (2011) conducted riparian vegetation transect surveys at the two widest basins (Little Basin and Cottonwood Basin) and interconnecting area in Lake Mohave. Occurrence and composition data from Tallent et al. (2011) study are used to provide baseline information regarding Lake Mohave's riparian vegetation condition.

Using photographs and general information on riparian plant species collected from the U.S. Natural Resources Conservation Service PLANTS Database (*http://plants.usda.gov*) and other references available, Abella and Engel (2012) summarized riparian vegetation found along Lake Mead's shoreline between 1995 and 2006.

Geographic Information Systems (GIS) data obtained from the National Agriculture Imagery Program (NAIP) in 2010 were also used to estimate riparian vegetation composition and coverage at lakes Mead and Mohave using designated riparian vegetation classes (Table 4.2.9-3) (Bangle et al., 2014). The vegetation class was defined by Younker and Anderson (1986), and acreage estimates were calculated using the GIS data by Lake Mead NRA staff.

Table 4.2.9-3. Riparian vegetation classifications.

Riparian Vegetation Class	Plant Species
Marsh	Predominately cattail/bulrush (*Typha/Scirpus*) and Carrizo (*Phragmites*)
Cottonwood-Willow	Fremont cottonwood (native, *Populus fremotii*) and Goodding's willow (native, *Salix gooddingii*) with low densities of cottonwood (at least 10% of total trees)
Honey mesquite	Honey mesquite (*Prosopis glandulosa*) constituting 90–100% of total vegetation in area.
Saltcedar-Honey mesquite	Saltcedar (*Tamarix* sp.) and Honey mesquite. Honey mesquite constituting at least 10% of total trees but rarely found to constitute greater than 40% of total trees.

Table 4.2.9-3 (continued). Riparian vegetation classifications.

Riparian Vegetation Class	Plant Species
Saltcedar-Screwbean mesquite	Screwbean mesquite (*Prosopis pubescens*) constituting at least 20% of the total trees.
Saltcedar	Saltcedar tamarisk constituting 80–100% of total trees.
Shrubs and Agriculture	Shrubs and Agricultural lands

As part of the NPS Inventory and Monitoring Program (I&MP), vegetation mapping for Lake Mead NRA was completed and published in December 2016. Detailed description of locations sampled, data reviewed and protocol used can be found in the original publication (Salas et al., 2016). The vegetation classification map produced provides good baseline information for future comparisons of conditions and assist with restoration effort and other management issues.

Reference Conditions

Although a series of riparian vegetation maps have been developed for lakes Mead and Mohave since 1986, Bangle et al. (2014) warned that direct comparison should not be made to data between the 2010 vegetation map with previous efforts due to differing methodologies and sample regions. For this assessment, the reference condition was established based on desirable conditions as identified in the Long-term Limnology and Aquatic Resources Monitoring and Research Plan (Table 4.2.9-4) (Lake Mead NRA, 2010). Composition and occurrence were compared between the data summarized by Abella and Engel (2012), the 2010 assessment (Bangle et al., 2014) and the recently published NPS vegetation inventory (Salas et al., 2016.

Table 4.2.9-4. Reference conditions for riparian vegetation used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
• Presence/Absence • Composition	Low vegetation diversity with majority being non-native species and noxious weeds.	A mixture of desired and non-native species, where proportion of non-native species may be slightly elevated above acceptable level.	A diverse mix of desired species in varies structural stages and an acceptable proportion of non-native species

Condition and Trend

Lake Mead

Historical riparian vegetation of the Colorado River's former channel was not well documented along the present-day Lake Mead corridor. Studies of historical photographs and non-impounded portions of the contemporary Colorado River and its tributaries suggest that the river corridor was not heavily vegetated with riparian vegetation because of the scouring action of the water and the desert climate (Rosen et al., 2012). Aside from deltas at tributary inflow areas, and a few small areas containing shoreline springs, the vast majority of Lake Mead shoreline currently does not provide substantial

riparian habitat (Rosen et al., 2014). Historically, the riparian zone was thought to include riparian forests containing honey mesquite (*Prosopis glandulosa*), screwbean mesquite (*Prosopis pubescens*) and Goodding's willow (*Salix gooddingii*) which were mainly found in protected canyon areas, flatter bottomlands, and tributaries including the Las Vegas Wash. In most of the drier marshes, shrubby or herbaceous wetland species such as rush (*Juncus* sp.) were found. Various transitional communities of upland vegetation, such as creosote bush (*Larrea tridentate*) were also found along the river (Rosen et al., 2012).

Using photographs and general information on riparian plant species collected from the U.S. Natural Resources Conservation Service PLANTS Database (*http://plants.usda.gov*) and other available references, Abella and Engel (2012) estimated that current vegetation along Lake Mead included riparian forest communities typified by Goodding's willow which occurred in locales such as the Muddy River confluence with Lake Mead, southeast of Overton; mesquite and catclaw acacia (*Acacia greggii*) in steep shoreline areas and flatter areas like washes entering the Lake Mead NRA; Fremont cottonwood (*Populus fremontii*) along the Las Vegas Wash entering Lake Mead (Stave, 2001); marshy areas with species including common reed (*Phragmites australis*) or rushes (Patten et al., 2008); Arrowweed (*Pluchea sericea*), big saltbush (*Atriplex lentiformis*), or other species comprising moist shrubby communities; upland vegetation like creosote bush (*Larrea tridentata*) present down to near-shoreline areas (Abella and Engel, 2012).

Monocultures of the exotic **phreatophyte** saltcedar/tamarisk (*Tamarix* spp.; hereafter Saltcedar) and related species are also found along the shoreline of Lake Mead (Walker et al., 2006; Salas et al., 2016). Saltcedar was introduced to the United States in the 19th century as an erosion control agent and ornamental plant. The highly invasive saltcedar can spread quickly, consuming a large amount of groundwater, alter soil properties such as pH, and crowd out native vegetation. Since its introduction to Lake Mead, saltcedar has become the most prolific invasive species around the shoreline of Lake Mead. Other non-native species, such as crimson fountaingrass (*Pennisetum setaceum* and Sahara mustard (*Brassica tourneforti*) can also be found along Lake Mead shoreline. If left unmanaged, these species can limit the 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. Further discussion of the impact of non-native vegetation on native riparian species can be found in section 4.5.2.

Riparian vegetation composition and occurrence (2010) remained similar to Abella and Engel (2012) summary of the 1995 and 2006 surveys. Invasive saltcedar was the dominant plant species found in Lake Mead riparian areas, covering over 90% of the study area (Table 4.2.9-5). However, riparian vegetation management along the Lake Mead shoreline by the NPS Exotic Plant Management Team has prevented new establishments of and reduced the spread of non-native vegetation.

Efforts – such as shoreline boat surveys to detect early-stage, non-native species infestations and subsequent removal of these early establishments – have stalled invasions both along the shoreline and in surrounding drainages and uplands (Abella et al., 2009). While the scale of invasion by saltcedar is large, the NPS has effectively treated some saltcedar monocultures by cutting (burning also can be effective) followed by immediate herbicide application to the stump. Removing saltcedar

using the same method has also 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 2015, the beetle had dispersed throughout Lake Mead NRA, damaging saltcedar by repeated leaf defoliation (Tamarisk Coalition, 2015). Ongoing efforts of non-native riparian vegetation removal and revegetation of seedling and seeding native species at nonvegetated shoreline areas by NPS have had limited degradation and improved riparian habitat.

Table 4.2.9-5. Riparian plant communities' coverage in lakes Mead and Mohave. Acreages estimated using GIS data from 2010 NAIP by NPS staff.

	Lake Mead		Lake Mohave	
Riparian Vegetation	**Acre**	**%**	**Acre**	**%**
Marsh	1273.27	2.6	7.27	0.1
Cottonwood-Willow	218.40	0.4	82.31	1.2
Honey mesquite	334.16	0.7	0	0.0
Saltcedar-Honey mesquite	429.35	0.9	4067.32	61.5
Saltcedar-Srewbean mesquite	25.73	0.1	10.78	0.2
Salt cedar (*Tamarisk*)	45392.10	93.0	2444.86	37.0
Shrubs and Agriculture	1116.77	2.3	0	0.0

Lower water levels as a result of persistent drought conditions in Lake Mead have exposed new acreages of riparian plant habitat. From 1999 to 2010, the elevation of the lake declined from an elevation of 1,215 ft (370.3 m), which was slightly below the full-pool elevation, to a low of 1083 ft (330.1 m). (Holdren and Turner, 2010). This drawdown exposed more than 25,000 ha of formerly submerged land. The development potential and conditions of these recently exposed shoreline areas are discussed in section 4.3.1.

Lake Mohave

With 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 pre-impoundment riparian zone along the Colorado River's former channel along the present-day Lake Mohave corridor was dominated by native riparian woodlands of cottonwood and willow (Tallent et al, 2011). Tallent et al. (2011) found that the majority of Lake Mohave's shoreline during the December 1997 drawdown consisted of non-native saltcedar, with a few areas populated by native Gooding's willow where topography and soils provided better habitat for this species. Lake Mohave also supports substantial mesquite groves that line much of the upper riparian habitat fringe created by the more consistent lake levels (Rosen et al., 2012). These groves contain two native mesquite species; screwbean mesquite and honey mesquite (Tallent et al., 2011).

Assessment of riparian vegetation composition and coverage from data collected in 2010 (Bangle et al., 2014) indicated that vegetation composition and occurrence remained the same as what was observed in 1997 by Tallent et al. (2011). Invasive saltcedar remains the dominant riparian plant species found in Lake Mohave riparian areas with most areas mixed with native Honey mesquite (Table 4.2.9-5).

Lakes Mead and Mohave

Riparian vegetation composition and occurrence were mapped primarily under three vegetation classifications (riparian woodlands, riparian wash scrub shrublands, and tamarisk shrubland) with the Lake Mead NRA Vegetation Classification and Mapping project (Table 4.2.9-6; Salas et al., 2016). Riparian woodlands covered about 307 acres of riparian areas throughout Lake Mead NRA with extensive elevation range (200–1000m) (Table 4.2.9-6). Vegetation densities range from low to high and can be found predominately on plateaus and terraces, toe slopes, bottoms and swales, valley flats, and gently sloping ridges and hills (Salas et al., 2016). Riparian wash scrub shrublands cover about 1,142 acres of park area (Table 4.2.9-6). The herbaceous cover is sparse to moderate with year-to-year varying shrub composition as a result of succession or renewed disturbance. Tamarisk class forms an open to continuous shrub layer along the lake's margins and drainage channel beds, covering a total of 29,058 acres of park areas (Table 4.2.9-6). Elevations range from 150 to 700m. Overall shrub cover ranges from 5 to 100% where the densest stands are often impenetrable. Beach and barren sand draw-down areas were not sampled as these areas are ephemeral given the changing hydrological variability. However, *Tamarix* spp. stands were found in the drawdown area adjacent to and below drainages. They are also found along the river edge below Hoover Dam mixed with other riparian map classes. Refer to Salas et al (2016) for mapped distribution of vegetation classes described here.

Table 4.2.9-6. Summary of vegetation classification and mapping results from Vegetation Mapping of Lake Mead NRA (Salas et al., 2016).

Lake Mead NRA Vegetation Map Class Name	Alliance Name(s)	Acres
Riparian Woodland	• Fremont cottonwood (Populus fremontii) riparian forest • Goodding's willow (Salix gooddingii)-Red willow (Salix laevigata)-Shining willow (Salix lucida) riparian forest	307
Riparian Wash Scrub Shrubland	• Baccharis (Baccharis emoryi – Baccharis sergiloides) dry wash shrubland, • Mesquite (Prosopis glandulosa – Prosopis velutina – Prosopis pubescens) riparian forest, woodland & shrubland, • Narrowleaf willow (Salix exigua) warm desert riparian shrubland, • Wild grape (Vitis arizonica – Vitis girdiana) desert shrubland	1,142
Tamarisk Shrubland	• *Tamarix* spp. Semi-natural shrubland	29,058

Assessment Confidence and Key Data Gaps

The assessment confidence for this section is high as the NPS vegetation mapping of Lake Mead NRA report provides validated information (accuracy assessment result: 77%) pertaining to the current condition of riparian vegetation in Lake Mead NRA (Salas et al., 2016). In addition, a supplementary analysis was performed by NPS staff using GIS data collected for the National Agriculture Imagery Program (NAIP) to provide additional assessment of riparian vegetation condition.

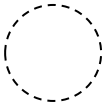
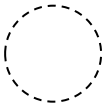
Ongoing monitoring and assessment of riparian vegetation are important for determining the effectiveness of the tamarisk leaf beetle and other control methods for controlling *Tamarisk* and other non-native riparian plant species, as well as for understanding the health and diversity of native riparian vegetation. Data collected could inform the development of appropriate management strategies for controlling and limiting the spread of non-native plants along the shorelines of lakes Mead and Mohave.

4.2.10. Aquatic Vegetation

Assessment Outcome

A summary of the parameters used assess aquaitc vegetation are shown in Table 4.2.10-1.

Table 4.2.10-1. Overall assessment outcome for the condition status and trend of aquatic vegetation.

Indicator(s)	Measurement(s)	Lake	Condition Status/Trend	Rationale
Occurrence	Presence/ Absence	• Mead • Mohave		Aquatic vegetation has received minimal inventory or monitoring to date. Insufficient data prohibited assessment of this resource. Vegetation surveys to collect baseline data is critical for future condition assessment.
Aquatic Vegetation overall				–

Description

Littoral zone aquatic vegetation provides cover and habitat and can affect the diversity and abundance of littoral zooplankton and fish in lake systems. Aquatic vegetation also provides important spawning habitat for a variety of nest-building fish, such as largemouth bass (Haley et al., 1987) and substrate for which eggs are laid, protecting eggs from wave action and erosion (Kimmel et al., 1990).

Littoral zones in Lake Mead are relatively narrow due to the steep nature of the shoreline. Therefore, relatively few regions exist where the shoreline is shallow enough to sustain littoral aquatic vegetation. Lake Mead's fluctuating water levels also present difficult conditions for aquatic plants that require submersion (Rosen et al., 2012).

With its predictable lake level fluctuation range, Lake Mohave provides more stability for the formation of littoral vegetation and shoreline riparian habitats.

Data and Methods

Table 4.2.10-2 shows the data and methods used to assesss aquatic vegetation.

Table 4.2.10-2. Indicators and measurements used in the assessment of aquatic vegetation.

Indicator(s)	Measurement(s)	Scale of Analysis
Occurrence	Presence/Absence	Lake

Littoral or shallow zone aquatic vegetation has not been well studied in lakes Mead and Mohave. A limited number of surveys have outlined the species that comprise the near-shore habitat zone.

As part of a largemouth bass habitat enhancement project, Haley et al., (1987) conducted underwater surveys at 10 ft (3m) and between 15 and 20 ft (4–6m) to record the composition and cover of aquatic vegetation at different coves within Lake Mead.

No record of Lake Mohave littoral vegetation occurrence was found during our data mining effort for this assessment.

Reference Conditions

No reference conditions were developed.

Condition and Trend

Documentation of littoral aquatic vegetation along lakes Mead and Mohave shoreline was limited. Cove surveys by scuba divers within Las Vegas Bay in 1986 indicated that most nearshore areas did not have aquatic vegetation in winter and exhibited only patchy vegetation in the summer and fall. Aquatic vegetation was found in shallow areas no deeper than 16.4 ft (5.0 m) (Haley et al., 1987; Sollberger & Paulson, 1992). Haley et al. (1987) surveyed 30 coves in Lake Mead and found aquatic plants in 24 coves. Spiny naiad (*Najas marina*) was the dominant species. They also found sago pondweed (*Potamogeton pectinatus*), curlyleaf pondweed (*Potamogeton crispus*), widgeon grass (*Ruppia maritima*), and algae (*Chara* sp.) (Haley et al.,1987).

In Lake Mead, formation of extensive areas of littoral aquatic vegetation has been limited. Rosen et al. (2012) suggested that in areas of Lake Mead that do support aquatic 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*).

A number of invasive aquatic plants currently persist within and near the littoral zone of Lake Mead. Eurasian watermilfoil (*Myriophyllum spicatum*) is a submerged plant that can adversely impact aquatic ecosystems by forming dense canopies over the surface of a lake. It is 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 loading (Smith & Barko, 1990; Madsen et al., 1991). Giant reed (*Arundo donax*) is another species of invasive aquatic plants found in Lake Mead. A grass that can grow taller than 20 ft (6.1 m) in height, giant reed has become established via floating root and stem fragments. This species provides poor wildlife habitat, and, once established, often forms pure stands that outcompete native vegetation (Bell, 1997). Fountain grass (*Pennisetum setaceum*) has established in areas that are not waterlog (Abella et al., 2009). This clumping and readily propagating grass can out-compete other species, clog shorelines and waterways that are useful for human recreation, and limit establishment of native species (Cronk & Fuller, 1995).

Current aquatic plant condition and trend in lakes Mead and Mohave are unknown due to insufficient data and information collected for this resource.

Assessment Confidence and Key Data Gaps

With limited documentation of littoral aquatic vegetation conditions, high uncertainty exists regarding potential threats to current littoral vegetation communities. Periodic inventories of littoral aquatic vegetation in lakes Mead and Mohave following baseline assessment and analyses should be implemented to determine the trend in distribution, composition, and abundance of aquatic plants. Regular aquatic vegetation surveillance is necessary for early detection of new invasions and to guide management on how to prevent or limit future invasions.

4.2.11. Literature Cited

Abella, S., & Engel, E. (2012). Riparian Vegetation. In M. Rosen, K. Turner, S. Goodbred, & J. Miller (Eds.), A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave (pp. 89–91). U.S. Geological Survey Circular 1381.

Abella, S., Spencer, J., Hoines, J., & Nazarchyk, C. (2009). Assessing an Exoctic Plant Surveying Program in the Mojave Desert, Clark County, Nevada, USA. *Environmental Monitoring and Assessment*, 15:221–230.

Albrecht, B., Rogers, R., Kegerries, R., & Holden, P. (2010). Razorback Sucker Studies on Lake Mead, Nevada and Arizona-2009–2010 Final Report. Logan, UT: BIO-WEST Inc.

Albrecht, B., Shattuck, Z., Rogers, R., & Kegerries, R. (2013). Razorback Sucker (*Xyrauchen texanus*) Studies on Lake Mead, Nevada and Arizona – 2012–2013 Annual Report. Logan, UT: BIO-WEST Inc.

Albrecht, B., Shattuck, Z., Rogers, R., & Kegerries, R. (2014). Razorback Sucker (*Xyrauchen texanus*) Studies on Lake Mead, Nevada and Arizona – 2013–2014 Annual Report. Logan, UT: BIO-WEST Inc.

Bangle, D., Ahlbrandt, R., Baker, M., & Milliken, J. (2014). 2010–2011 Vegetation Mapping along the Lower Colorado River. Lower Colorado River Region: U.S. Department of the Interior, Bureau of Reclamation.

Barnes, J. (2011). An Ecological Study of Peregrine Falcons (*Falco peregrinus*) at Lake Mead National Recreation Area, 2006–2010. Las Vegas, NV: University of Nevada, Las Vegas, M.S. Thesis.

Barnes, J., & Gerstenberger, S. (2015). Using Feathers to Determine Mercury Contamination in Peregrine Falcons and Their Prey. Journal of Raptor Research, 49:43–58.

Barnes, J., & Jaeger, J. (2010). Peregrine Falcon Monitoring within Lake Mead National Recreation Area, 2008–2009. Clark County Desert Conservation Program. Retrieved from http://www.clarkcountynv.gov/airquality/dcp/Pages/ProjectFinalReports.aspx

Barnes, J., & Jaeger, J. (2011). Inventory and Monitoring of Shoreline and Aquatic Bird Species on Lakes Mead and Mohave: 2004–2009. University of Nevada, Las Vegas, Public Lands Institute. Boulder City, NV: Lake Mead National Recreation Area, National Park Service.

Barnes, J., Haley, R., Thompson, D., & Jaeger, J. (2015). Attributes of a Breeding Population of Peregrine Falcons Associated with Reservoirs on the Colorado River. Journal of Raptor Research, 49:269–280.

Best, E., & Lantow, J. (2010). Investigations in Flannelmouth Sucker Habitat Use, Preference, and Recruitment Downstream of Davis Dam in the Lower Colorado River-2008 Annual Report. Boulder City, NV: Bureau of Reclamation, Lower Colorado River Multi-Species Conservation Program.

Beaver JR, Tietjen TE, Blasius-Wert BJ, Kirsch JE, Rosati TC, Holdren GC, Kennedy EM, Hollis RM, Teacher CE, Buccier KM, Evans SK. (2010). Persistence of *Daphnia* in the epilimnion of Lake Mead, Arizona–Nevada, during extreme drought and expansion of invasive quagga mussels (2000–2009). Lake Reserv Manage. 26: 273–282.

Bell, G. (1997). Ecology and Management of *Arundo donax* and Approaches to Riparian Habitat Restoration in Southern California. In J. Brock, M. Wade, P. Pysek, & D. Green (Eds.), Plant Invasions – Studies from North America and Europe (pp. 103–113). Leiden, The Netherlands: Blackhuys Publishers.

BIO-WEST (2017). Razorback Sucker Research & Monitoring Work-Lower Grand Canyon & Colorado River. Monthly Progress Report Feburary 2017 to Bureau of Reclamation. Logan, UT: BIO-WEST Inc.

Brandon, A., Kegerries, R., Holden, P., & Bio-West, Inc. (2013). Long-Term Management Plan for the Conservation of Razorback Sucker in Lake Mead, Nevada and Arizona. Report to the Lower Colorado River Multi-Species Conservation Program.

Caldwell, T., Rosen, M., Chandra, S., Acharya, K., Caires, A., Davis, C., Thaw, M., and Webster, D. (2015). Temporal and Basin-Specific Population Trends of Quagga Mussels on Soft Sediment of a Multibasin Reservoir. In W. Wong, & S. Gerstenberger (Eds.), Biology and Management of

Invasive Quagga and Zebra Mussels in the Western United States (pp. 566–587). Boca Raton, FL: CRC Press.

Chandra S., M.J. Vander Zanden, A.C. Heyvaert, B.C. Allen, and C.R. Goldman. (2005). The effects of cultural eutrophication on the coupling between pelagic primary producers and benthic consumers. Limnology and Oceanography. 50: 1368–1376.

Cronk, Q., & Fuller, J. (1995). Plant Invaders-The Threat to Natural Ecosystems. London: Chapman and Hall.

Cummins, G. (2016, January 6). 2015 Lake Mohave General Fish Survey. Colorado River Aquatic Biologists (CRAB) Meeting. Laughlin, Nevada. Retrieved from http://www.lcrmscp.gov/crab/presentations/2016/crab16_14.pdf

Davis, C. J., Caldwell, T., Caires, A., & Chandra, S. (2014). Decadal Changes to Zoobenthos in a Subtropical Reservoir: Establishment of Non-native Invertebrates Shift Assemblage Structure. Lake Mead Science Symposium.

Fletcher, D., & Barnes, J. (2005). Report on Riparian Lowland, and Upland Bird Monitoring (2004–2005), including Southwest Willow Flycatcher, within Lake Mead National Recreation Area. Las Vegas, NV: Clark Country Multiple Species Habitat Conservation Plan.

Fletcher, D., & Jaeger, J. (2011). Bald Eagle monitoring, 2010–2011: Prepared by the Public Lands Institute, University of Nevada, Las Vegas. Boulder City, NV: Lake Mead National Area, National Park Service.

Glinski, R., & Garrison, B. (1992). Presence and Movement of Peregrine Falcons in the Area of the Proposed Black Canyon Bridge Project – Final Report. Phoenix, AZ: Arizona Game and Fish Department.

Great Basin Bird Observatory. (2010). Nevada Comprehensive Bird Conservation Plan. Reno, NV: Great Basin Bird Observatory. Retrieved from www.gbbo.org/bird_conservation_plan.html

Gregory, S., Swanson, F., Arthur, M., & Cummins, K. (1991). An Ecosystem Perspective of Riparian Zones. BioScience, 8:540–550.

Haley, J., Leavitt, S., & Paulson, L. B. (1987). Lake Mead Cover Enhancement Project. Technical Report Series 18: Lake Mead Limnological Research Center.

Harms, R., & Hiebert, R. (2006). Vegetation Response Following Exotic Tamarisk (*Tamarix* spp.) Removal and Implications for Riparian Restoration. Restoration Ecology, 14: 461–472.

Holdren, G., Horn, M., & Lieberman, D. (2008). The Limnology of Lake Mead, Arizona-Nevada, 2006 Report of Findings. Denver, CO: Bureau of Reclamation, Technical Service Center.

Kimmel, B., Lind, O., & Paulson, L. (1990). Reservoir Primary Production. In K. Thorton, B. Kimmel, & F. Payne (Eds.), Reservoir Limnology-Ecological Perspectives (pp. 133–193). New York: Wiley.

LaBounty & Burns. (2005). Characterization of Boulder Basin, Lake Mead, Nevada-Arizona, USA-Based on analysis of 34 Limnological Parameters.

LaBounty JF, Holdren GC, and Horn MJ. (2004). The limnology of Boulder Basin, Lake Mead, Arizona-Nevada: Report of Findings 1990–1998. Denver (CO): US Bureau of Reclamation Technical Memorandum 8220-04-10.

Lake Mead NRA. (2010). Long-term Limnology and Aquatic Resources Monitoring and Research Plan for Lakes Mead and Mohave: Boulder City, NV. Lake Mead National Recreation Area and University of Nevada, Las Vegas. Retrieved from http://www.nps.gov/Lake Mead NRA/learn/nature/upload/Eco_Monitoring_Plan_for_Lakes_Mead_and_Mohave_4-27_update.pdf

Loomis, E., Sjoberg, J., Wong, W., & Gerstenberger, S. (2011). Abundance and Stomach Content Analysis of Threadfin Shad in Lake Mead, Nevada: Do Invasive Quagga Mussels Affect This Prey Species? Aquatic Invasions, 6:157–168.

Madsen, J., Sutherland, J., Bloomfield, J., Eichler, L., & Boylen, C. (1991). The Decline of Native Vegetation under Dense Eurasian Watermilfoil Canopies. Journal of Aquatic Plant Management, 29:94–99.

Marsh & Associates LLC. (2015). March 2015 Razorback Sucker Summary, Lake Mohave, AZ-NV. Tempe, AZ: Marsh & Associate LLC.

Marsh, P., Pacey, C., & Kesner, B. (2003). Decline of the Razorback Sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society, 132:1251–1256.

Minckley, W. (1983). Status of the Razorback Sucker, *Xyrauchen texanus* (Abbott), in the Lower Colorado River Basin. Southwestern Naturalist, 28: 165–187.

Mueller G & Horn MJ. (1999). Distribution and abundance of the pelagic fish in Lake Powell, Utah and Lake Mead, Arizona – Nevada. West N Am Naturalist. 64:306–311.

Mueller, G., & Marsh, P. (2002). Lost, A Desert River and its Native Fishes: A Historical Perspective of the Lower Colorado River. USGS (USGS/BRD/ITR—2002—0010).

NDOW. (2010). 2009 Federal Aid Job Progress Report, Statewide Sport Fisheries Management F-20-45-Lake Mead, Southern Region: Nevada Department of Wildlife.

NDOW. (2015a). 2014 Federal Aid Job Progress Report, Statewide Sport Fisheries Management F-20-50-Lake Mead. Lake Mead, Southern Region: Nevada Department of Wildlife.

NDOW. (2015b). 2014 Federal Aid Job Progress Reports, Statewide Sport Fisheries Management F-20-50-Lake Mohave. Lake Mohave, Southern Region: Nevada Department of Wildlife.

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region.

Pacey, C., & Marsh, P. (2008). Evaluation of Past Bonytail Stocking – Final Report 2008. Lower Colorado Region, Boulder City, NV: Lower Colorado Multi-Species Conservation Program, Bureau of Reclamation.

Patten, D., Rouse, L., & Stromberg, J. (2008). Vegetation Dynamics of Great Basin Springs-Potential Effects of Groundwater Withdrawal. In Aridland Springs in North America-Ecology and Conservation (pp. 279–289). Tuscon, AZ: University of Arizona Press and Arizona-Sonora Desert Museum.

Peck, S., Pratt, W., Pollard, J., Paulson, L., & Baepler, D. (1987). Benthic invertebrates and crayfish of Lake Mead. Las Vegas, NV: Lake Mead Limnological Research Center, Environmental Research Center, University of Nevada Las Vegas.

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

Salas, D.E., Stevens, J., Evens, J., Cogan, D., Ratchford, J.S., & Hasting, D. (2016) Vegetation Mapping of Lake Mead National Recreation Area. Natural Resource Report NPS/MOJN/NRR-2016/1344. National Park Service, Fort Collins, Colorado.

Shuford, W., Page, G., & Stenzen, L. (2002). Patterns of Distribution and Abundance of Migratory Shorebirds in the Intermountain West of the United States. Western Birds, 33:134–322.

Sjoberg, J. (1995). Historic Distribution and Current Status of the Razorback Sucker in Lake Mead, Nevada-Arizona. Proceedings of the Desert Fishes Council, 26:24–27.

Skagen, S. (2006). Migration Stopovers and the Conservation of Arctic-Breeding Calidridine Sandpipers. Auk, 123:313–322.

Smith, C., & Barko, J. (1990). Ecology of Eurasian Watermilfoil. Journal of Aquatic Plant Management, 28:55–64.

Sollberger & and Paulson. (1992). Littoral and limnetic zooplankton communities in Lake Mead, Nevada-Arizona, USA. Hydrobiologia, v237, 3: 175–187.

Stave, K. (2001). Dynamics of Wetland Development and Resource Management in Las Vegas Wash, Nevada. Journal of the American Water Resources Association, 37:1369–1379.

Tallent, N., Nash, M., Cross, C., & Walker, L. (2011). Patterns in Shoreline Vegetation and Soils Around Lake Mohave, Nevada and Arizona: Implication for Management. Western North American Naturalist, 71:374–387.

Umek, J., Chandra, S., Rosen, M., Wittmann, M., Sullivan, J., & Orsak, E. (2010). Importance of Benthic Production to Fish Populations in Lake Mead Prior to the Establishment of Quagga Mussels. Lake and Reservoir Management, 26:293–305.

USFWS. (2002). Razorback Sucker (*Xyrauchen texanus*) Recovery Goals: Amendment and Supplement to the Razorback Sucker Recovery Plan. Mountain-Prairie Region (6), Denver, Colorado: U.S. Fish and Wildlife Service.

Walker, L., Barnes, P., & Powell, E. (2006). Ta*marix aphylla* – A Newly Exotic Tree in Southern Nevada. Western North American Naturalist, 66:191–201.

Wittmann, M., Chandra, S., Caires, A., Denton, M., Rosen, M., Wong, W., Tietjen, T., Turner, K., Roefer, P., and Holdren, G. (2010). Early Invasion Population Structure of Quagga Mussel and Associated Benthic Invertebrate Community Composition on Soft Sediment in a Large Reservoir. Lake and Reservoir Management, 26: 316–327.

Wong, D. F. Turner, S Gerstenberger. (2011). Interagency Monitoring Action Plan (I-MAP): Quagga Mussels in Lakes Mead and Mohave – Approved Working Document.

Young, T., O.P. Jensen, B.C. Weidel, and S. Chandra. (2015). Natural trophic variability in a large, oligotrophic, near-pristine lake. Journal of Great Lakes Research 41: 463–472

Younker, G., & Anderson, G. (1986). Mapping Methods and Vegetation Changes Along the Lower Colorado River between Davis Dam and the Border of Mexico. Salt Lake City, UT: AAA Engineering and Drafting

4.3. Ecological Processes

4.3.1. Near Shore Processes

Assessment Outcome

A summary of the parameters used assess the near shore process are shown in Table 4.3.1-1.

Table 4.3.1-1. Overall assessment outcome for the condition status and trend of near shore processes.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Plant Colonization	Native plant species abundance vs. non-native species abundance		Native plant colonization is greatest on the oldest of formerly inundated surfaces. Non-native plant dominance declined with increasing surface age.
Near Shore Processes overall			–

Description

Over the last 16 years, an extended drought and increasing water demands from growing population in the Lake Mead watershed have reduced the lake's perimeter and increased exposed shoreline area around Lake Mead (Holdren & Turner, 2010). By 2011, more than 25,000 ha of formerly submerged land was exposed as a result of the drawdown (Engel et al., 2014).

Fluctuating water levels can significantly influence shoreline habitat and nearshore processes in lakes. This vast area of newly exposed terrestrial habitat presents some management challenges to Lake Mead NRA natural resource managers. Newly exposed area offers great potential for supporting a variety of terrestrial desert communities, such as those that contain endangered native plants and animals. Additional shoreline area can also present new recreation opportunities for park visitors. However, previously submerged land can also be colonized by invasive phreatophytes such as saltcedar, instead of native species. In addition, plant colonization can be a slow process, leaving exposed soil vulnerable to soil erosion and fugitive dust emissions, thus creating air and water quality issues (Engel et al., 2014). Therefore, understanding vegetation colonization patterns and soil properties in response to Lake Mead's recession is critical for identifying effective management strategies for these newly emerged habitats.

Data and Methods

Table 4.3.1-2 shows the data and methods used to assesss the near shore process.

Table 4.3.1-2. Indicators and methods used in the assessment of near shore processes.

Indicator(s)	Measurement(s)	Scale of Analysis
Plant Colonization	Native plant species abundance vs. non-native species abundance	Lake

Engel et al. (2014) examined plant community colonization patterns and soil properties along a time-since-submersion, surface age gradient in the new shoreline habitat exposed by the drawdown of Lake Mead from 1998 to 2011. The study was conducted at three locations in Lake Mead: Boulder Beach, Overton, and Stewarts Point, which represent a range of topography, soil parent material, and management consideration (Table 4.3.1-3) (Figure B-1). Plots were established along transacts during December 2010 at elevations representing average lake levels for 1998 (the most recent time when the lake was near full pool; 370 m), 2002 (354 m), 2005 (347 m), and 2008 (338 m). Plant and soils data were collected from February to May, 2011 which corresponded to the peak flowering period and biomass of most of Mojave Desert species (Engel et al., 2014). Plant community colonization pattern was characterized by percent coverage, species composition, and density. Soil properties are characterized by texture and particle size, chemical makeup, and nutrient content (Engel et al., 2014).

Table 4.3.1-3. Reference conditions for native plant and non-native plant abundance used in the assessment.

	Condition Status		
Measurment(s)	**Significant Concern***	**Moderate Concern***	**Good***
Native plant species abundance vs. non-native species abundance	Lowering Lake levels opens up disturbed shoreline habitats that support non-native weed colonization without competition	Colonization of native and non-native plant species at formerly inundated area is low.	New shoreline habitat largely supports native and rare plant species colonization.

Condition and Trend

Engel et al. (2014) surveyed 150 100 m^2 plots of varying surface age at the three sites and found that native perennial species richness increased with surface age at all sites. Native perennial species were sparse across all 3 locations but increased in frequency with site age. In particular, at the Boulder Beach site, native species richness in the oldest disturbed plots (last submerged 13 years before sampling) was equivalent to the control plots. Native annual species established more prolifically than native perennial species. Early successional native perennial species colonized the 13-year-old surface. In addition, evidences of recolonization of rare species were also found adjacent to the oldest disturbed plots (Engel et al., 2014).

Across sites, non-native saltcedar was the most abundant species, and its density decreased with surface age. Presence of dense, dead saltcedar stems found on the older, formerly submerged surfaces suggested that these surfaces were no longer suitable for survival of adult plants or for recruitment as saltcedar typically requires habitats with ample groundwater supply (Engel et al., 2014). **Evapotranspiration** by saltcedar can contribute to significant ground water loss and cause structural destabilization (NPS, 2014). Other non-native plant species did not display colonization patterns with surface age. This is consistent with their ability to occupy both moist and dry habitats (Engel et al., 2014).

While soil properties were variable across sites, there were generally few differences in soil properties within sites. There were also little differences between submerged and control plots suggesting that submersion did not alter soil texture or the net effect resulted in no textural changes (Engel et al., 2014). Although all tributaries to Lake Mead carry heavy sediment loads, lasting effects of silt deposition on younger soil surfaces were not observed (Holdren & Turner, 2010; Engel et al., 2014). Engel et al. (2014) suggested that sediment deposited during submersion may not be detected years later due to redistribution by shallow water turbulence or dispersal by desert winds after exposure. Results from the soil properties study also suggested that properties of formerly submerged soil may not be the limiting factor for native plants colonization relative to never-submerged areas.

Assessment Confidence and Key Data Gaps

Assessment confidence was high. Engel et al. (2014) conducted an extensive study in Lake Mead to examine plant colonization and soil properties on newly exposed shoreline. Sampling sites were selected to represent a range of topography, soil parent material, and management considerations.

Fluctuating lake levels can complicate the development of shoreline habitat management strategies. While Lake Mead water elevation may continue to fluctuate, scientific consensus has concluded that a return to full pool elevation is unlikely within future decades. Therefore, newly exposed land will remain present along Lake Mead's shoreline. Periodic reiterations of plant and soil surveys should be conducted to detect and monitor changes over time. Information collected can be used to inform management decisions and strategic planning for the Lake Mead NRA.

4.3.2. Hydrologic Regime

Overall Assessment Outcome

A summary of the parameters used assess the hydrologic regime are shown in Table 4.3.2-1.

Table 4.3.2-1. Overall assessment outcome for the condition status and trend of hydrologic regime.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Hydrologic condition of the Colorado River Basin	Colorado River computed natural flow (Annual flow volume, in million acre-feet, maf)		The 10-year average natural flow shows mostly below long-term average annual flow since the 1990. The period from water year 2000 to 2015 was the driest 16-year period in the 100-year historical record for the Colorado River Basin. Observed unregulated inflows since 2011 have been below the 30-year (1981–2010) long-term average with 2012 at only 30% (2.06 maf) of the long-term average. The observed 2016 April through July unregulated inflow is 6.61 maf, which is at 92% of the 30-year average from 1981 to 2010.

Table 4.3.2-1n (continued). Overall assessment outcome for the condition status and trend of hydrologic regime.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Floodflow in Streams; Future Projections	• Elevation (intensity) • Frequency		Climate models project changes in rainfall patterns with greater probabilities for higher intensities and frequencies of rainfall, flashfloods, and storm events in the Colorado River Basin.

Hydrologic Condition of the Colorado River Basin

A summary of the parameters used assess hydrologic condition are shown in Table 4.3.2-2.

Table 4.3.2-2. Assessment outcome of the Colorado River Basin.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Hydrologic condition of the Colorado River Basin	Colorado River computed natural flow (Annual flow volume, in million acre-feet, maf)		The 10-year average natural flow shows mostly below long-term average annual flow since the 1990. The period from water year 2000 to 2015 was the driest 16-year period in the 100-year historical record for the Colorado River Basin. Observed unregulated inflows since 2011 have been below the 30-year (1981–2010) long-term average with 2012 at only 30% (2.06 maf) of the long-term average. The observed 2016 April through July unregulated inflow is 6.61 maf, which is at 92% of the 30-year average from 1981 to 2010.

Description

The Colorado River Basin covers parts of seven States; Colorado, Wyoming, Utah, New Mexico, Nevada, Arizona, and California. The Colorado River is the seventh longest river in the United States. Through a series of compacts and treaty obligations, the water rights to the Colorado River have been allocated to the seven basin States, along with a treaty obligation for water availability for Mexico. The overall Colorado River allocations total 16.5 maf/yr. Within these legal requirements, the Colorado River is managed as two areas: The Upper Basin States of Colorado, New Mexico, Utah, and Wyoming; and the Lower Basin States of Arizona, California, and Nevada (Figure 2.3.1-1). The dividing line for Upper and Lower Basin is set as Lees Ferry, Arizona, below Lake Powell. 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.

Over 20 dams and reservoirs within the Colorado River Basin provide 60 maf of total system storage. The majority (~85%) of this available storage is stored in Lake Powell (24.3 maf) located in the Upper Basin and Lake Mead (26.1 maf) in the Lower Basin (Figure 2.3.1-1). Natural water supply to the basin and these reservoirs can be highly variable as this is dependent on the amount of snowfall in the western Rocky Mountains and precipitation patterns for the side tributary inflows (Rosen et al., 2012).

Lake Mead located in the Lower Colorado Basin is a critical component of the overall Colorado River management as it provides the capacity to store almost 2 years of the average runoff of the river (Rosen et al., 2012). Since most of the Basin's supply comes from the Upper Basin, changes in the hydrologic condition of the Upper Basin can have a significant impact to the water supply and resources in both the Upper and Lower Basins of the Colorado River.

Data and Methods

Table 4.3.2-3 shows the data and methods used to assesss hydrologic condition.

Table 4.3.2-3. Indicatiors and measurements used in the assessment of the hydrologic condition of the Colorado River Basin.

Indicator(s)	Measurement(s)	Scale of Analysis
Hydrologic condition of the Colorado River Basin	Colorado River computed natural flow and unregulated inflow to Lake Powell (Annual flow volume, in million acre-feet, maf)	Tributary

The Colorado River computed natural flows at the USGS gaging station at Lees Ferry, AZ (#09380000) were used as a proxy to assess the hydrologic condition of the Colorado River Basin. The Lees Ferry gage is the lowermost mainstem gage in the Upper Basin, located about 12 miles downstream of Glen Canyon Dam and about 1 mile upstream of the Compact Point between the Upper and Lower Basins (USDOI, 2015; Figure 2.3.1-1). Natural flow refers to the streamflow that would have otherwise occurred with the absence of human development such as reservoir regulation, water depletions, and river diversions. It is computed streamflow that begins with the historical stream-gage record, then adds depletions and adds or subtracts impacts from reservoir regulation (Rosen et al., 2012). Natural flow data were downloaded from https://www.usbr.gov/lc/region/g4000/NaturalFlow/current.html.

While Lake Powell releases through Glen Canyon Dam have a significant effect on Lake Mead's elevation and inflow-outflow regime, the released volume is highly regulated and is not a good indicator of the hydrology of the Basin (see section 4.1 for discussion on the inflow volume to Lake Mead from the Colorado River). Instead, unregulated inflow estimates to Lake Powell are also examined to assess the impact of changing hydrology of the Colorado River Basin to lakes Mead and Mohave' hydrologic health. Volume data of observed unregulated inflows into Lake Powell from April to July, the four months most tied to spring runoff and snowpack condition of the headwater were provided by the National Weather Service's Colorado Basin River Forecast Center from https://www.cbrfc.noaa.gov/rmap/wsup/point.php?id=GLDA3.

Reference Conditions

Table 4.2.3-4 shows the reference conditions used to assess hydrologic condition.

Table 4.3.2-4. Reference conditions of the Colorado River Basin used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Total annual inflow volume (million acre-feet, maf)	Annual flows are consistently less than the long-term averages with consistent downward trend.	Annual inflow occasionally less than historical average with slight downward trend.	Similar or above long-term averages with stable or rising trend.

Temporal trends of the Colorado River computed natural flows and the Lake Powell unregulated inflows were examined for this assessment. For the Colorado River computed natural flows assessment, long-term averages and centralized 10-year moving averages are computed for trend comparison where applicable. The long-term average is calculated where each subsequent year is 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 year examined. For Lake Powell, unregulated inflows, the 30-year average from 1981to 2010 (7.16 maf) was used as reference condition for assessment.

Condition and Trend

While natural water availability within the Colorado River Basin is highly variable from year-to-year due to annual variability in precipitation and snowmelt within the watershed, the 10-year average natural flow shows mostly below average annual flow (1906–2014 average: 14.8 maf) since 1990 (Figure 4.3.2-1). The Colorado River watershed has experienced a significant drought period since 2000, with Lake Mead elevation declining some 139 feet from 2000 through 2015 (Bureau of Reclamation, 2016). The period from water year 2000 to 2015 was the driest 16-year period in the 100-year historical record for the Colorado River Basin (average annual flow of 12.4 maf) (Figure 4.3.2-1). Such periods of long-term drought are not uncommon within the long-term hydrologic record of the Colorado River; and climate change models predict that water availability within the Colorado River watershed to be from 5 to 20 % less than current long-term averages by the end of the century (Rosen et al., 2012).

Observed unregulated inflow into Lake Powell demonstrated that the Colorado River Basin has experienced a period of drought condition through the late 1980s. Conditions improved in the late 1990s, but drought conditions persisted between 2000 and 2010 (Figure 4.3.2-2). Hydrologic conditions improved in 2011 with the April –July inflow to Lake Powell at its highest (12.58 maf) since 1984. However, observed unregulated inflows since 2011 have been below the 30-year (1981–2010), long-term average with 2012 at only 30% (2.06 maf) of the long-term average. The observed 2016 April through July unregulated inflow is 6.61 maf which is at 92% of the 30-year average from 1981 to 2010 (Figure 4.3.2-2).

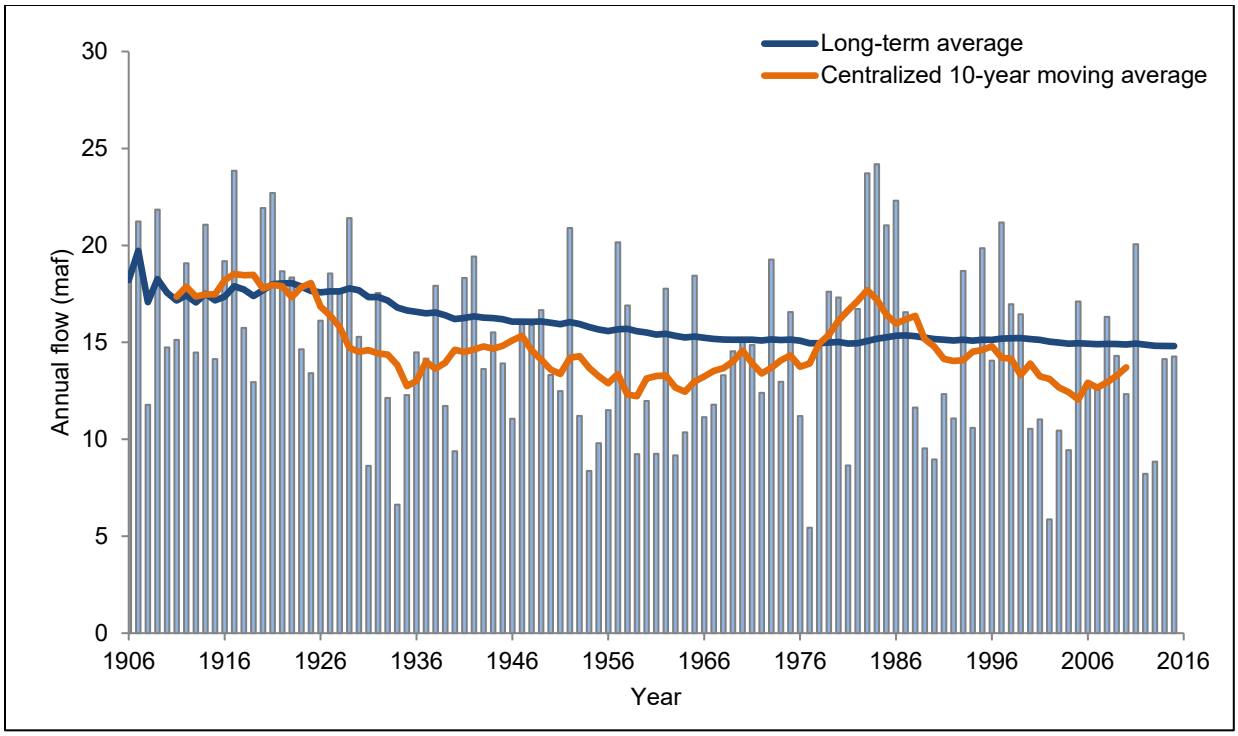


Figure 4.3.2-1. Colorado River computed natural flows at the USGS gaging station at Lees Ferry, AZ (#09380000). Natural flow refers to the streamflow that would have otherwise occurred with the absence of human development such as reservoir regulation, water depletions, and river diversions (USGS).

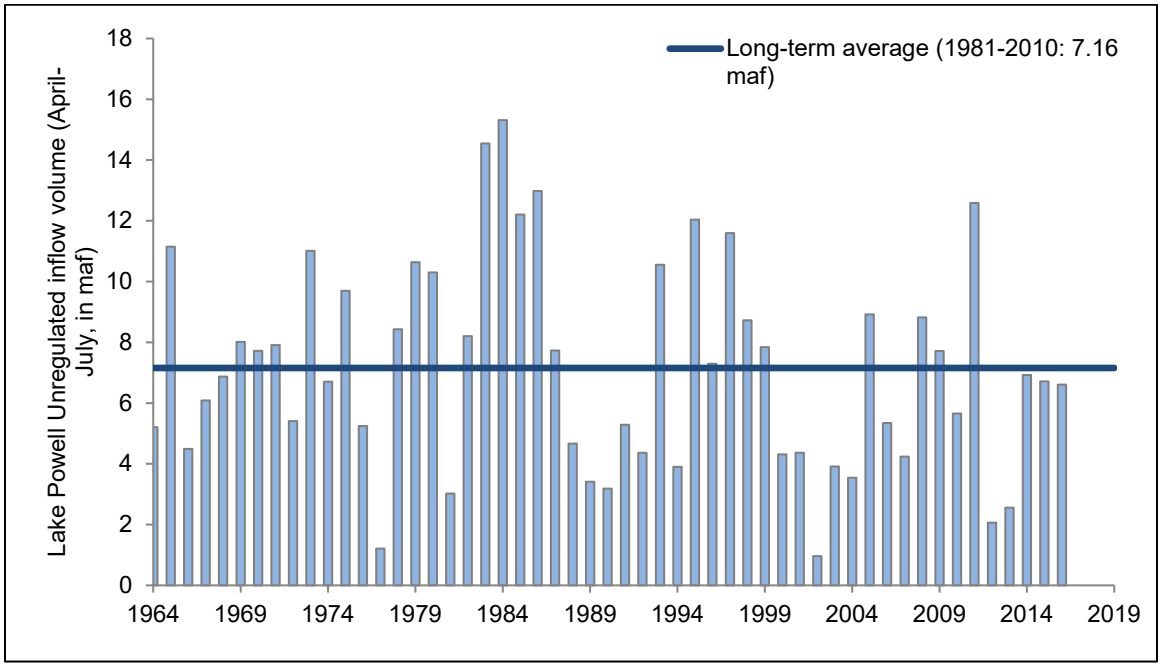


Figure 4.3.2-2. Lake Powell observed unregulated inflow volume between April and July from 1964 to 2016. Data were provided by the National Weather Service's Colorado Basin River Forecast Center.

Assessment Confidence and Key Data Gaps

Assessment Confidence is high. While computed flow estimates contain some level of inherent uncertainty, these estimates were derived from long-term gauging stations flow data. These estimates were validated against observed natural flow records developed by BOR. In addition, observed unregulated inflow data from Lake Powell were also examined to validate the assessment.

Climate models predict longer periods of reduced snowpack within the Colorado River Basin which may result in less water entering Lake Mead. With increased water demands from development and considering the lower basin is approaching full allocations, water shortages are predicted in the future. Simulations of future climate with climate models have projected that flow in the Colorado River basin will become more variable and overall will be reduced by 5–15% from current levels in 2035–2064 (Lukas et al., 2014).

Floodflows in Streams with Future Projections

A summary of the parameters used assess floodflows in streams with future projections are shown in Table 4.3.2-5.

Table 4.3.2-5. Assessment outcome for floodflows in streams with future projections.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Floodflows in Streams with Future Projections	• Elevation (intensity) • Frequency		Climate models project changes in rainfall patterns with greater probabilities for higher intensities and frequencies of rainfall, flashfloods, and storm events in the Colorado River Basin.

Description

The construction of the Hoover Dam and the formation of Lake Mead were intended to provide flood control for the Colorado River. Urban development within the Colorado River Basin in Nevada, Arizona, and southern California has steadily increased since then. The massive expansion has led to extensive land use changes in areas near Lake Mead NRA. Floodplains are replaced with housing development and impermeable surfaces. The urban surfaces intensify the desert tendency for rapid runoff during rain events, filling washes and drainages that are tributaries to Lake Mead. Despite a decade of sustained drought, the frequency of large storm events and flash flooding has increased, resulting in increased flood damages (Batker, et al., 2014). Flash flood events within Lake Mead NRA have caused significant damages to park infrastructure, loss of human life, and economic loss. Projected changes in climate, particularly increased summer rainfall intensities and the potential for more frequent flash floods can have widespread effect on the condition of the lakes. Therefore, an understanding of how flood frequency and intensity may change with projections of future climate is important for assisting managers to effectively plan for necessary actions needed to reduce damages and related impacts to water quality.

Data and Methods

Table 4.3.2-6 shows the data and methods used to assesss floodflows in streams.

Table 4.3.2-6. Indications and measures used in the assessment of floodflows in streams.

Indicator(s)	Measurement(s)	Scale of Analysis
• Floodflows in streams • Future projections	• Elevation (intensity) • Frequency	Tributary

Information regarding future projections of flood events in Lake Mead NRA was compiled from several climate change research publications on the Colorado River Basin, for example, Brekke, et al., 2009, Miller et al., 2011, SNWA, 2011, and Rosen et al., 2012.

Reference Conditions

Table 4.2.3-7 shows the reference conditions used to assess floodflow in streams.

Table 4.3.2-7. Reference conditions for floodflows in streams used in the assessment.

	Condition Status		
Measurment(s)	**Significant Concern***	**Moderate Concern***	**Good***
• Floodflows. in streams • Future projections	Significant increase in frequencies and/or intensities (elevation) of flood events, and corresponding frequent detection of delivery of pathogens, nutrients, or development of algae related to floods.	Moderate increase in frequencies and/or intensities (elevation) of flood events, and occasional detection of delivery of pathogens, nutrients, or development of algae related to floods.	No increase in frequencies and/or intensities (elevation) of flood events, and no increase or no detection of delivery of pathogens, nutrients, or development of algae related to floods.

Condition and Trend

Climate change is a pervasive threat to all park habitats. Southwestern US climate models have predicted changing precipitation patterns, including the seasonality, frequency, and intensity of precipitation events. The models forecast scenarios of increased storm intensity and frequency of seasonal flashflood events (NPS, 2014).

Climate change research has indicated warming temperature trends over the Colorado River Basin region of up to 3°C in the next 50 to 100 years, with corresponding changes in the timing and magnitude of peak streamflow and rainfall patterns (Miller et al., 2011). Forecasted changes in rainfall patterns, including greater probabilities for higher intensity summer rainfall and more frequent storm events are likely to increase the intensity and frequency of flash floods at lakes Mead and Mohave (Brekke, et al., 2009). These events are also likely to 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 (SNWA, 2011). For example, past flooding events in Las Vegas Wash resulted in elevated nutrient and sediment loads, as well as temporary spikes in bacteria and potential pathogens (Rosen et al., 2012).

Assessment Confidence and Key Data Gaps

Quantitative flood flows intensity/elevation data were not available for this assessment. Condition status was assigned based on general descriptive projections by climate models. Projections of future climate patterns through climate models inherently contain higher levels of uncertainty.

With climate models projecting increased frequency and magnitude of storm events in the Colorado River Basin, increases in flashflood events in Lake Mead NRA is likely. These events would further increase the potential for transfer of nutrients and pollutants, including pathogenic bacteria, to lakes Mead and Mohave. Shoreline facilities and cultural resources at many locations in the park are already in areas at risk for flash flooding. These facilities should be re-assessed to minimize threats to life and safety of park visitors and staff. For example, in Lake Mohave, Willow Beach has already been redesigned. Katherine Landing and Cottonwood Cove are currently being evaluated for redesign in a development concept plan (NPS, 2014). Systematic assessment of flash flood hazard to major park facilities and cultural resources is necessary to protect these resources. NPS managers should work with partners for monitoring protocols and capacity to measure potential impacts from increasing frequency and intensity of flash floods. Such data would be critical to initiating discussion among local agencies on any potential mitigation should impacts prove significant.

4.3.3. Sediment

Overall Assessment Outcome

A summary of the parameters used assess sediment are shown in Table 4.3.3-1.

Table 4.3.3-1. Overall assessment outcome for the condition status and trend of sediment.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Sediment Accumulation	• Total annual sediment yield per tributary (tons per year • Volume (acre-ft) accumulated, if data available; or qualitative description		The 2001 sedimentation survey measured a 219,150 acre-ft increase in reservoir capacity since 1963–1964. Increase in Lake Mead's capacity was likely due to significant reduction of sediment inflow since the upstream closure of Glen Canyon Dam in 1963, as well as significant compaction of sediments in the lower elevation portions of the reservoir. No recent sedimentation and lake capacity survey has been conducted after 2001. Little sediment (~ 4% of lake floor) has accumulated in Lake Mohave since its impoundment in 1953.

Table 4.3.3-1 (continued). Overall assessment outcome for the condition status and trend of sediment.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Alluvial Delta Changes	• Temporal changes in location (distance) • Areal extent of tributary confluences and deltas		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. New delta areas provide potential for riparian habitats for vegetation and shoreline birds. Thus, the trend in condition is considered improving with this indicator. Visual comparison of Landsat images of Lake Mead's Las Vegas Wash and Virgin, Muddy, and Colorado rivers confluences shows significant reduction in water level with receding lake boundaries, forwarding the confluences to further downstream of the tributaries, and growth of delta areas at the confluences.
Sediment overall			–

Sediment Accumulation

A summary of the parameters used assess sediment accumulation are shown in Table 4.3.3-2.

Table 4.3.3-2. Assessment outcome for sediment accumulation.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Sediment Accumulation	• Total annual sediment yield per tributary (tons per year • Volume (acre-ft) accumulated, if data available; or qualitative description		The 2001 sedimentation survey estimated a 219,150 acre-ft increase in reservoir capacity since 1963–1964. Increase in Lake Mead's capacity was likely due to significant reduction of sediment inflow since the upstream closure of Glen Canyon Dam in 1963, as well as significant compaction of sediments in the lower elevation portions of the reservoir. No recent sedimentation and lake capacity survey has been conducted after 2001. Little sediment (~ 4% of lake floor) has accumulated in Lake Mohave since its impoundment in 1953.

Description

Lake Mead was formed by the completion of Hoover Dam in 1935. The intended purposes of the dam and lake were to provide flood control for the Colorado River, hydroelectric power, navigation, and a reliable water supply for agricultural and municipal use (Holdren & Turner, 2010). The lake and surrounding areas also provide numerous recreational opportunities as well as additional habitat for both aquatic and terrestrial wildlife. Downstream of Lake Mead, Lake Mohave was created in 1951 with the completion of Davis Dam to stabilize flows from Hoover Dam and to help provide required down stream water deliveries. Lakes Mead and Mohave play a key role in the entire storage capacity (approximately 50%) and operational framework of Colorado River Compact. Sediment accumulation information is important in reservoirs because sediment can diminish holding capacity, thus affecting the longevity of a reservoir and ability to deliver water to users (Foster et al., 2004).

Sediment accumulation describes the storage of sediments in lakes Mead and Mohave. Sediment yield is defined as the amount of sediment per unit area removed from a watershed by flowing water during a specified period. Calculation of sediment yield requires measures of the area drained, the volume (or mass) of sediment removed, and the time interval over which deposition has occurred (Griffiths et al., 2006).

Data and Methods

Table 4.3.3-3 shows the data and methods used to assesss sediment accumulation.

Table 4.3.3-3. Indicators and measures used in the assessment of sediment accumulation.

Indicator(s)	Measurement(s)	Scale of Analysis
Sediment Accumulation	• Total annual sediment yield per tributary (tons per year • Volume (acre-ft) accumulated, if data available; or qualitative description	Tributary

Sediment accumulation in Lake Mead has been extensively studied. The earliest studies preceded construction of the Hoover Dam and involved the planning and mapping of the region to be flooded by the reservoir (Longwell, 1936 and 1960). Shortly after completion of the dam, annual **bathymetric** surveys were conducted along the pre-impoundment Colorado River channel to monitor sediment (Gould, 1960). Additional bathymetric surveys were completed in 1963–1964 prior to the construction of the Glen Canyon Dam to form Lake Mohave) by Lara and Sanders (1970) and in 2001 by Ferrari (2008). A survey was undertaken in 1948–49 to determine Lake Mead volume losses by sedimentation from the Colorado River, prior to the closure of Glen Canyon Dam (Holdren & Turner, 2010). The purpose of the 1963–1964 survey was to update the capacity of Lake Mead at the time of the closure of Glen Canyon Dam in March 1963 (Lara & Sanders, 1970). USGS and BOR contracted a new survey between 1999 and 2001 to develop a storage-elevation relationship for Lake Mead. Foster et al. (2004) completed a geophysical survey of Lake Mohave in 2002 and collected side scan-sonar imagery and high-resolution seismic-reflection profiles of Lake Mead.

For sediment discharge rate assessment, see section 4.1.

Reference Conditions

Table 4.3.3-4 shows the reference conditions used to assess sediment accumulation.

Table 4.3.3-4. Reference conditions for sediment accumulation used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Sedimentation	Significant increase in sediment accumulation and resulted in reduction in lakes Mead and Mohave capacity.	Sediment accumulation has increased, but less than historical increases.	Little or further reduction of sediment accumulation

Historical reservoir capacity and sediment volume after completion of these dams are used as the reference condition for assessing current conditions and trends (Rosen et al., 2012).

Condition and Trend

Lake Mead

Sediment accumulation in Lake Mead was significant prior to the closure of Glen Canyon Dam and formation of Lake Powell (Ferrari, 2008; Rosen et al., 2012) (Figure 4.3.3-1). Prior to the closure of Glen Canyon Dam in 1963, Lake Mead was the repository of vast quantities of sediments making their way through the Grand Canyon. In the first 14 years after Lake Mead was formed, suspended sediment entered the Lake Mead through the Colorado River at an average yield of 142 million tons a year. From 1926 to 1949, the annual sediment load in to the lower Colorado River fluctuated between 50 million tons to 500 million tons (Thomas, 1954).

Between 1935 and 1948–1949, Lara and Sanders (1970) reported 1.4259 x 10^6 acre-ft of sediment accumulation in Lake Mead. Additional accumulation of 1.2931 x 10^6 acre-ft was estimated between 1948–1949 and 1963–1964 (Holdren & Turner, 2010). The Glen Canyon Dam greatly slowed and reduced the amount of sediment transport to Lake Mead by the Colorado River since its completion. Suspended sediment yield from the Colorado River decreased to an average of 16 million tons per year after Lake Powell was formed in 1963 by the creation of Glen Canyon Dam. The 2001 sedimentation survey measured a 219,150 acre-ft increase in reservoir capacity since 1963–1964 (Ferrari, 2008). Buildups at the upstream sediment delta in the Colorado River reach mainly consists of heavy material deposition (e.g. sand size and greater) that drops out due to decreased transport capacity of the river as it enters the upper reservoir. Finer silt type sediments travel further throughout Lake Mead down to the lower reaches towards the dam. These finer materials eventually settle out, and with compaction would become consolidated. Ferrari (2008) concluded that increases in Lake Mead's capacity have been due to significant reductions of sediment inflow since the upstream closure of Glen Canyon Dam in 1963, as well as significant compaction of sediments in the lower elevation portions of the reservoir. Post-impoundment sediment extends the entire length of the Lake Mead from the mouths of the Colorado River and its tributaries to the Hoover Dam (Figure 4.3.3-1).

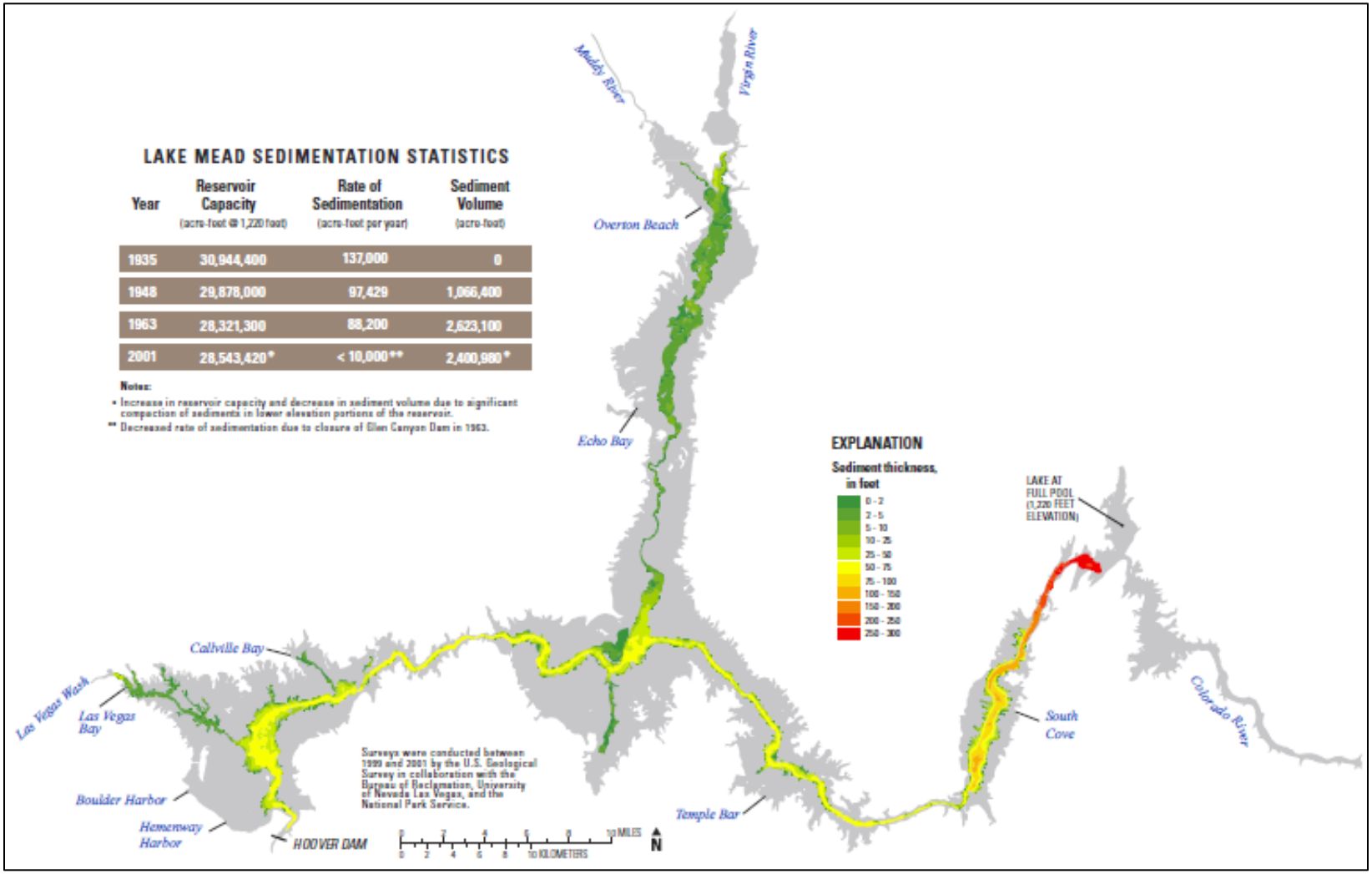


Figure 4.3.3-1. Sedimentation patterns in Lake Mead. Reprinted from Rosen et al., 2012.

Sediment deposit contributions of other reaches, such as Overton and Las Vegas Wash are not well documented. However, until the closure of Glen Canyon Dam, these other sediment sources were insignificant compared to the total sediment inflow from the Colorado River drainage basin. Studies within the Grand Canyon have indicated that the Colorado River has been relatively sediment deprived, and since the Colorado River has been the main sediment source to Lake Mead, reduced annual sediment load is expected to continue in the future (Ferrari, 2008). No sedimentation and lake capacity surveys have been conducted after 2001.

Lake Mohave

The floor of Lake Mohave is characterized by pre-impoundment features (Figure 4.3.3-2). Since almost all sediment transported by the Colorado River is trapped in Lake Mead or in other upstream reservoirs, little sediment (~ 4% of lake floor) has accumulated in Lake Mohave since its impoundment in 1953 (Foster et al., 2004).

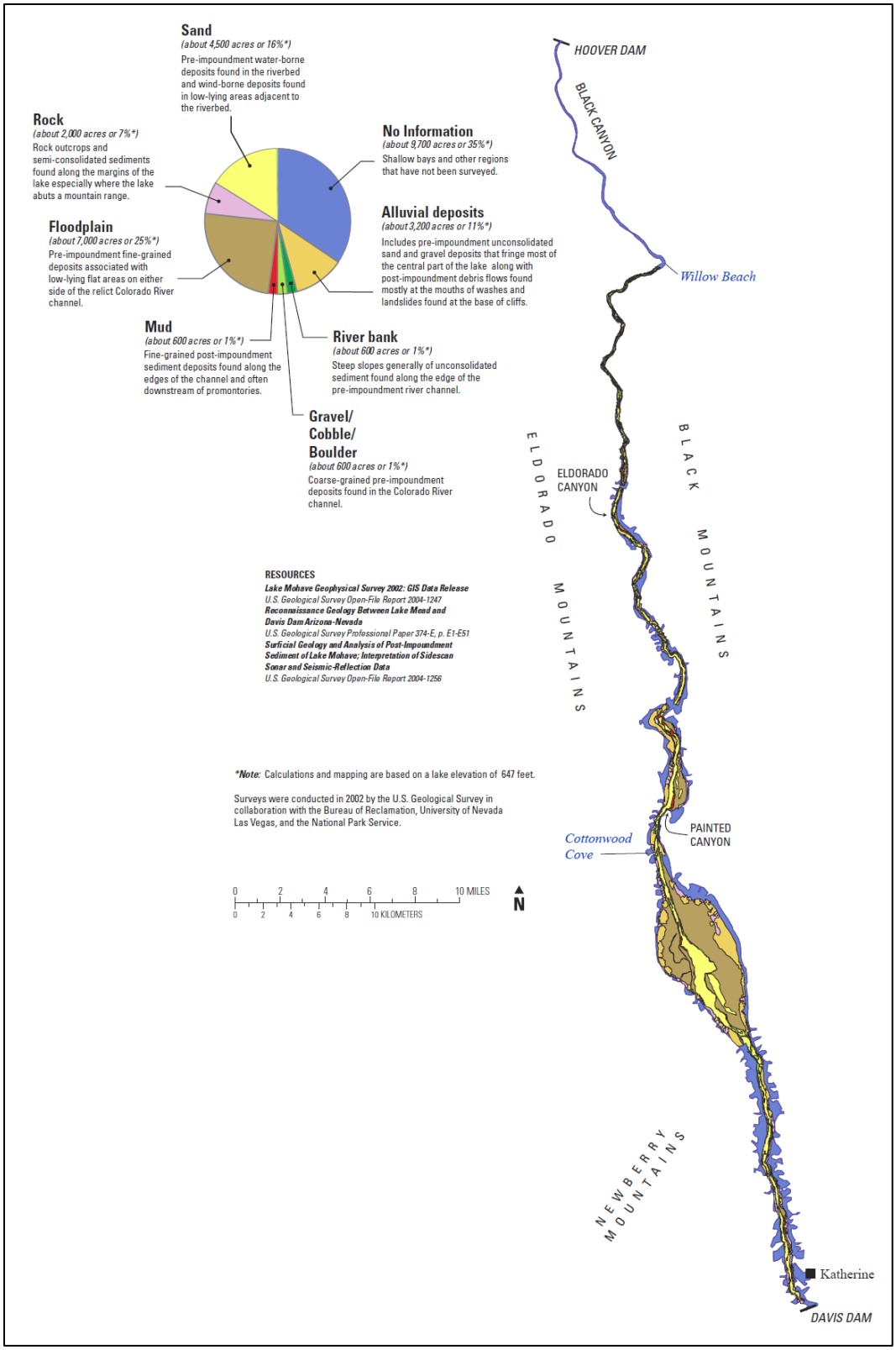


Figure 4.3.3-2. Sedimentation patterns in Lake Mohave. Reprinted from Rosen et al., 2012.

Assessment Confidence and Key Data Gaps

Assessment confidence is moderate due to the length of time since sedimentation surveillance has occurred. The sedimentation information presented herein is from the published literature; however, calculations of sediment volume and lakes Mead and Mohave capacities were based on data collected 5 to 10 years prior and may not fully reflect current conditions.

A decade of persistent drought conditions within the Colorado River Basin has led to reduced flows from Lake Mead tributaries. In addition, simulations made with models of future climate in the Southwest forecast significant declines in overall precipitation and flow in the Colorado River basin. These declines will likely reduce sediment loading into Lake Mead.

Alluvial delta changes

A summary of the parameters used assess alluvial delta changes are shown in Table 4.3.3-5.

Table 4.3.3-5. Assessment outcome for alluvial delta changes.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Alluvial Delta Changes	• Temporal changes in location (distance) • Areal extent of tributary confluences and deltas		More than a decade of lowered lake levels from 1999 through 2011 have exposed additional delta areas at Las Vegas Wash, Virgin River and Muddy River tributaries, and at the main stem of the Colorado River. New delta areas provide potential for riparian habitats for vegetation and shoreline birds. The condition trend is considered to be improving. Visual comparison of Landsat images of Lake Mead's Las Vegas Wash and the confluences of the Virgin, Muddy and Colorado River confluences shows significant reduction in water level with receding lake boundaries, forwarding the confluences to further downstream locations and growth of delta areas at these confluences.

Description

Size and location of confluences and respective deltas are a function of multiple factors such as the hydrology and geomorphology of inflows and the receiving lake. In Lake Mead, the expanded delta areas due to drawdowns of water level have increased the overall limited riparian and shallow water habitats, bringing good bird habitat for riparian dependent species. Extensive deltas formed at confluences of the Virgin, Muddy, and Colorado Rivers. Invertebrate densities are found to be higher in deltas receiving inflows from the Colorado River, Virgin River, Muddy River, and Las Vegas Wash relative to downstream locations. Deltas are also a sink for contaminants and can prevent contaminants from entering Lake Mead. Thus, monitoring of confluences and deltas is needed as tributary delta areas are ecologically important.

Data and Methods

Table 4.3.3-6 shows the data and methods used to assesss alluvial delta changes.

Table 4.3.3-6. Indicators and measures used to in the assessment of alluvial delta changes.

Indicator(s)	Measurement(s)	Scale of Analysis
Alluvial Delta Changes	• Temporal changes in location (distance) • Areal extent of tributary confluences and deltas	Lake

Landsat satellite (Landsat 8, 4–5, and 1–3) images downloaded from the USGS Earth Explorer (http://earthexplorer.usgs.gov/) were used for visual comparison of changes in size and location of confluences and deltas in Lake Mead over time. Additional information was compiled from other literature sources (Ferrari, 2008; Holdren & Turner, 2010; Rosen et al., 2012).

Reference Conditions

Quantifiable local and regional data on the size and location confluences and deltas in lakes Mead and Mohave were not available at the time of this assessment to establish adequate quantitative reference conditions. Temporal changes in location (distance) and areal extent of tributary confluences and deltas at lakes Mead and Mohave were assessed by comparison of Landsat satellite images captured through time.

Condition and Trend

Sedimentation at the entry of the Colorado River to Lake Mead formed a sandy delta that advanced rapidly into Lake Mead during the first thirteen years after the dam was completed, then continued but slowed its advance from 1950 to 1965, and had nearly stopped since 1965 (Ferrari, 2008). The delta began to advance into the Lake Mead again in the early 2000s as lake levels dropped (Figure 4.3.3-3).

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 mainstem of the Colorado River. Due to lower water levels, the Virgin and Muddy rivers have been entering Lake Mead as a combined inflow since 2009 (Holdren & Turner, 2010).

Visual comparison of Landsat images of Lake Mead's Virgin and Muddy River confluences from July of 1985, 1995, 2000, 2005, 2010, and 2015 (Figure 4.3.3-4) shows the significant reduction in water level as a result of persistent drought, forwarding the confluences to further downstream of the tributaries, and growth of delta areas at the confluences. The Virgin and Muddy Rivers have continued to enter Lake Mead as a combined inflow in 2015 (Figure 4.3.3-4). Also, note that the Virgin River Basin (the circular feature in the photos) once connected to Overton Arm through the narrows appeared dry in the 2005 image. Overton Arm also appears narrower in the 2015 image (Figure 4.3.3-4).

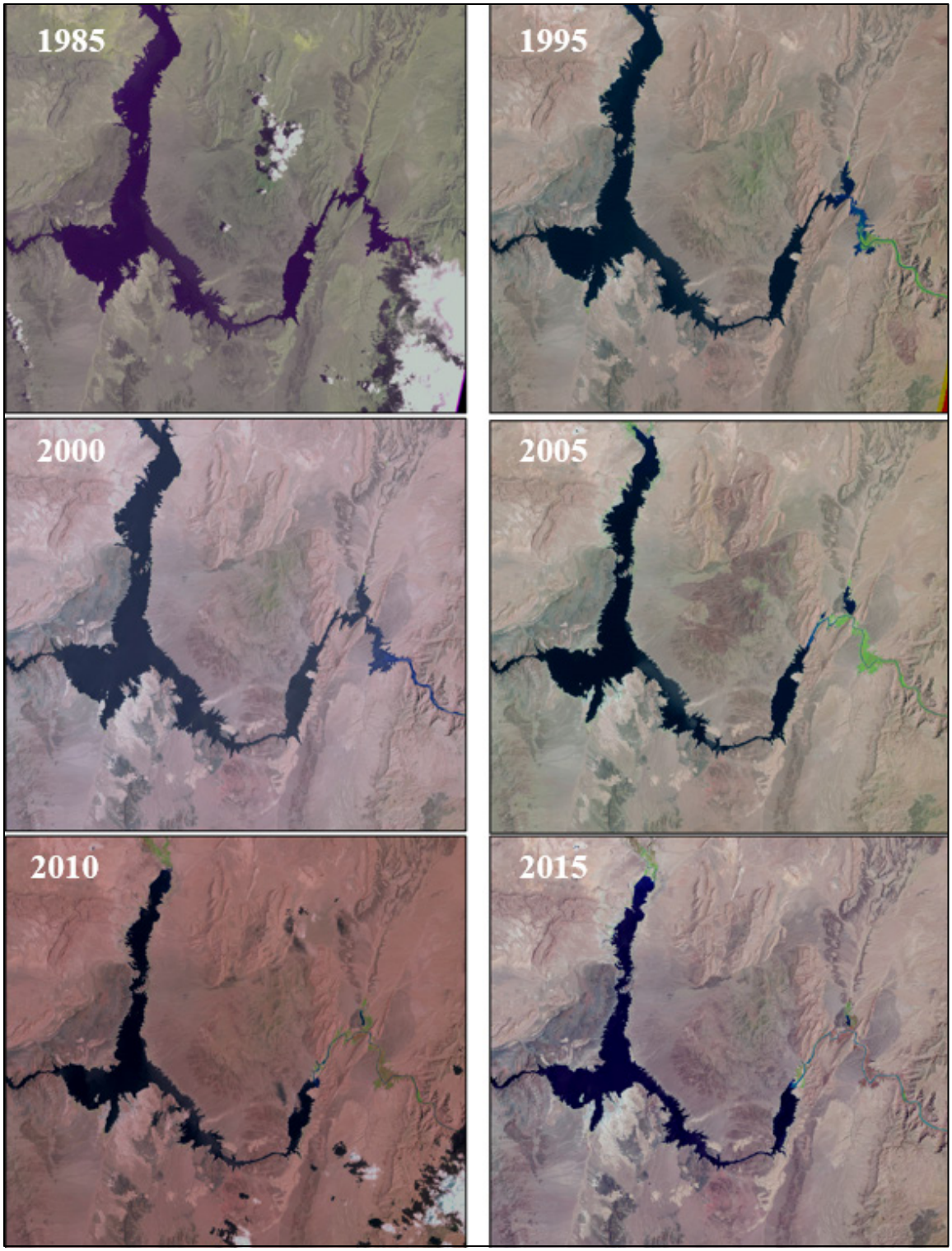


Figure 4.3.3-3. Landsat images of Colorado River confluence, and Gregg and Virgin basins taken in July of 1985, 1995, 2000, 2005, 2010, and 2015.

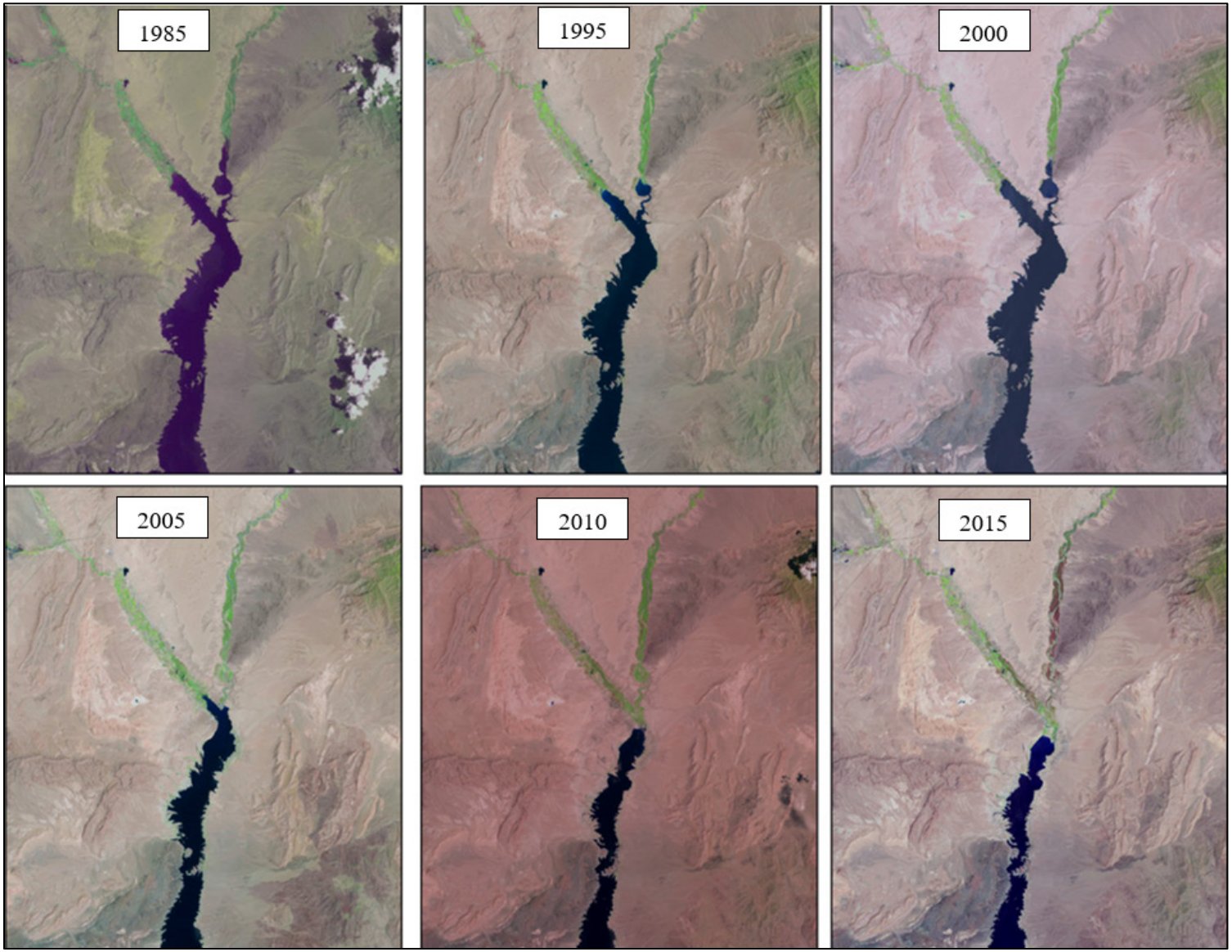


Figure 4.3.3-4. Landsat images of Lake Mead Virgin and Muddy River confluences taken in July of 1985, 1995, 2000, 2005, 2010, and 2015.

The Colorado River and Las Vegas Wash confluences have also moved further downstream. The shorelines of Boulder, Virgin, Temple, and Gregg basins have also changed shape as water levels have declined (Figure 4.3.3-3 and Figure 4.3.3-5). For example, Saddle Island is Boulder Basin was once connected to the shore by a road to provide access to the water intake pumping stations. The roadway still exists, but the water has receded and Saddle Island is no longer an island. (Figure 4.3.3-5) (Allen, 2003).

The Landsat satellite images provide a visual depiction of the expansion of riparian areas. The expansion is illustrated by the green coverage at the confluences, deltas, and along the shoreline of Lake Mead (Figure 4.3.3-3 to Figure 4.3.3-5). Studies have been conducted to examine the riparian vegetation composition of these newly exposed areas of Lake Mead (Engel et al., 2014; See section 4.3.1).

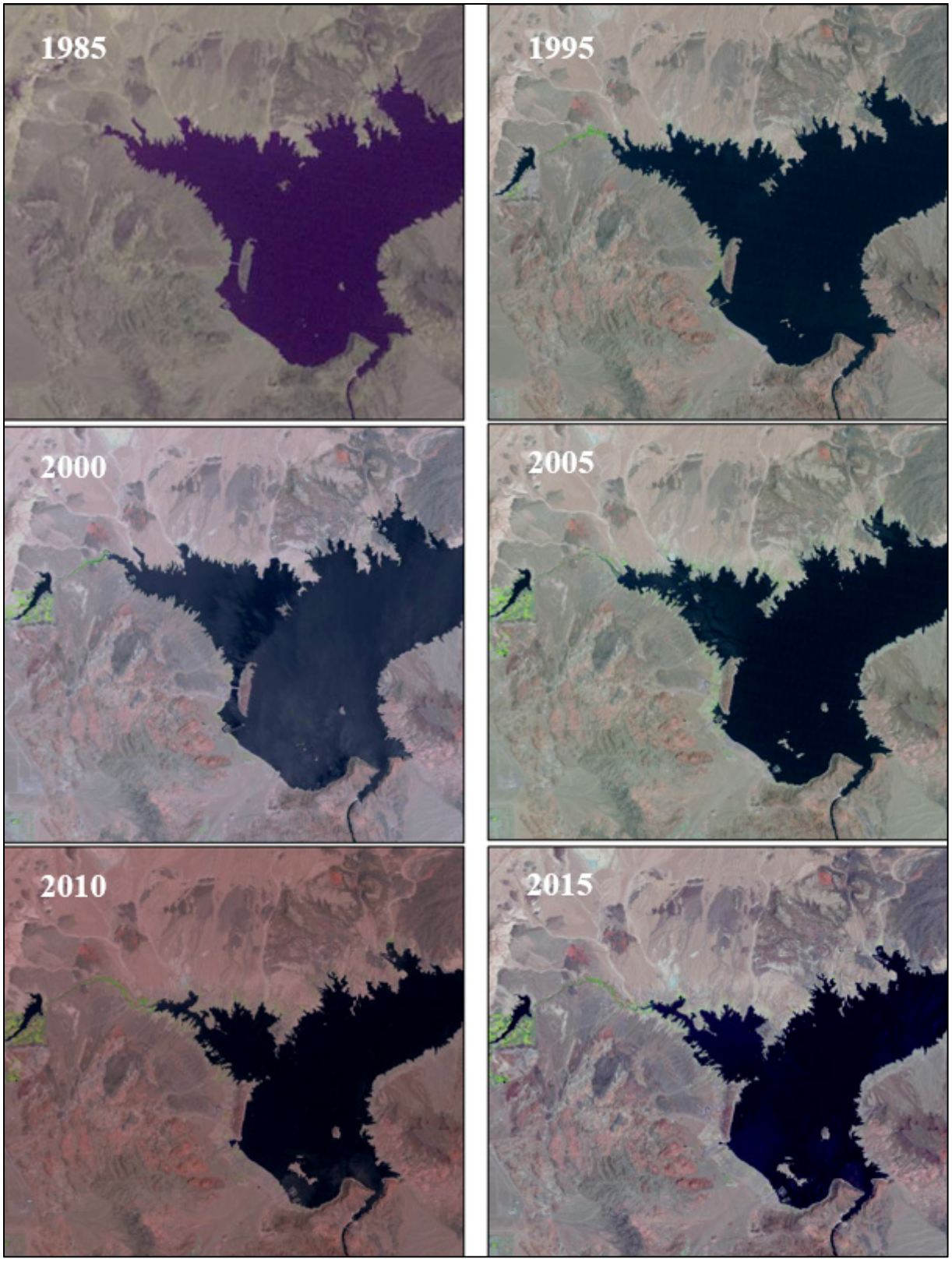


Figure 4.3.3-5. Landsat images of Las Vegas Wash confluences, Las Vegas Bay, and Boulder Basin taken in July of 1985, 1995, 2000, 2005, 2010, and 2015.

Assessment Confidence and Key Data Gaps

Confidence of this assessment is high despite the lack of quantitative data available for this indicator. High-resolution, time-series, satellite images have provided a reliable and visual resource for assessing the changes in sizes and locations of confluences and deltas.

To further increase confidence in the qualitative assessment provided here, GIS analyses should be conducted to quantify and document changes in confluences locations of major tributaries, and the change in size of deltas and riparian areas with Lake Mead's lowering water elevation. These analyses would provide useful information for park and water managers to develop or adjust appropriate strategies to meet water supply, conservation and recreation mandates.

4.3.4. Literature Cited

Allen, J. (2003, November 13). Drought Lowers Lake Mead. Retrieved from NASA Earth Observatory: http://earthobservatory.nasa.gov/Features/LakeMead/

Batker, D., Christian, Z., Cooley, C., Graf, W., Jones, K., Loomis, J., & Pittman, J. (2014). Nature's Value in the Colorado River Basin. Earth Economics, 104p.

Brekke, L., Kiang, J., Olsen, J., Pulwarty, R., Raff, D., Turnipseed, D., Webb, R.S., and White, K. (2009). Climate Change and Water Resources Management-A Federal Perspective. U.S. Geological Survey Circular 1331. Retrieved from https://pubs.er.usgs.gov/publication/cir1331

Engel, E., Abella, S., & Chittick, K. (2014). Plant Colonization and Soil Properties on Newly Exposed Shoreline during Drawdown of Lake Mead, Mojave Desert. Lake Mead NRA and Reservoir Management, 30:105–114.

Ferrari, R. (2008). 2001 Lake Mead Sedimentation Survey. Denver, CO: Bureau of Reclamation, Technical Service Center.

Foster, D., Capone, M., Parolski, K., Twichell, D., & Rudin, M. (2004). Surficial Geology and Analysis of Post-Impoundment Sediment of Lake Mohave – Interpretation of Sidescan Sonar and Seismic-reflection Data. U.S. Geological Survey Open-File Report 2004-1256. Retrieved from http://pubs.usgs.gov/of/2004/1256/index.html

Gould, H. (1960). Character of the Accumulated Sediment . In W. Smith, C. Vetter, G. Cummings, and other, eds, Comprehensive Survey of Sedimentation in Lake Mead, 1948–49 (pp. 149–186). U.S. Geological Survey Professional Paper 295. Retrieved from http://pubs.usgs.gov/pp/0295/report.pdf

Griffiths, P., Hereford, R., & Webb, R. (2006). Sediment Yield and Runoff Frequency of Small Drainage Basins in the Mojave Desert, California and Nevada. United State Geological Survey Fact Sheet 2006-2007. Retrieved from http://pubs.usgs.gov/fs/2006/3007/fs2006-3007.pdf

Holdren, G., Horn, M., & Lieberman, D. (2008). The Limnology of Lake Mead, Arizona-Nevada, 2006 Report of Findings. Denver, CO: Bureau of Reclamation, Technical Service Center.

Holdren, G., & Turner, K. (2010). Characteristics of Lake Mead, Arizona-Nevada. Lake Mead NRA and Reservoir Management, 26 (4): 230–239.

Lara, J., & Sanders, J. (1970). The 1963–64 Lake Mead Study. Bureau of Reclamation Report No. REC-OCE-70-21. U.S. Department of the Interior.

Longwell, C. (1936). Geology of the Boulder Reservoir Floor. Geological Society of America Bulletin, 47: 1393–1476.

Longwell, C. (1960). Geologic Setting of Lake Mead. In W. Smith, C. Vetter, G. Cummings, and others, eds, Comprehensive Survey of Sedimentation in Lake Mead*, 1948–49* (pp. 11–20). U.S. Geological Survey Professional Paper 295. Retrieved from http://pubs.usgs.gov/pp/0295/report.pdf

Lukas, J., Barsugli, J., Doesken, N., Rangwala, I., & Wolter, K. (2014). Climate Change in Colorado – A Synthesis to Support Water Resources Management and Adaption. Colorado Water Conservation Board, State of Colorado. Retrieved from http://wwa.colorado.edu/climate/co2014report/Climate_Change_CO_Report_2014_FINAL.pdf

Miller, W., Piechota, T., Gangopadhyay, S., & Pruitt, T. (2011). Development of Streamflow Projections under Changing Climate Conditions over Colorado River Basin Headwaters. Hydrology and Earth System Sciences, 15:2145–2164.

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

Shanahan, S., & Zhou, X. (2011). Water Quality Monitoring and Assessment Plan. Las Vegas Wash Coordination Committee.

SNWA. (2011). Water Quality Report, Southern Nevada Water System. Southern Nevada Water Authority. Retrieved from https://www.snwa.com/wq/report.html

Thomas, H. (1954). First Fourteen Years of Lake Mead. Washington, D.C.: U.S. Geological Survey Circular 346.

USDOI. (2015, December 16). Drought in the Colorado River Basin – Insights Using Open Data. Retrieved from Open Water Data Initiative: https://www.doi.gov/water/owdi.cr.drought/en/index.html

4.4. Recreation Suitability

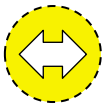
4.4.1. Human Health Effects

A summary of the parameters used assess human health effects are shown in Table 4.4.1-1.

Table 4.4.1-1. Overall assessment outcome for condition trend and status of human health effects.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Pathogens	• Fecal coliform concentration (cfu/100 ml) • *E. coli* concentration (cfu/100 ml)		Pathogen concentrations at Boulder Basin were below established full body-contact recreation standards for fecal coliform and *E. coli*. Low incidences of pathogen detection from Overton Arm and Colorado River inflow/upper Lake Mead have led to discontinuation of pathogen monitoring in April 2005 at those locations. Fecal coliform and *E. coli* concentrations measured at Las Vegas Bay were below established "good' range standards across years examined but recent increases (2014 and 2015) in concentrations of both fecal coliform and E. coli have been detected. Surface water samples collected at high-use recreational covers and beaches between 2003 and 2015 at lakes Mead and Mohave were generally within the acceptable range for pathogens concentrations. Two locations in Lake Mohave were identified as having the highest single-occurrence frequency of exceedances.
Harmful Algal Bloom, (HAB)/Toxin	• *Microcystin* concentration		Lakes Mead and Mohave posted low risk of exposure to algal toxin based on microcystin concentration measurements. In addition, *Microcystis aeruginosa* (microcystin-producing) concentrations are monitored in Lake Mead and only very low levels have been detected. On occasion, increased *Microcystis* spp. abundance has been noted in Lake Mohave in recent years. While most *Microcystis* spp. are not toxic, bloom-forming species and increased detection do warrant for further investigation. In addition, other species of toxin producing algae, such as Golden alga (*Prymnesium parvum*) have been detected in Lake Mead and have caused harmful algal blooms in Lake Las Vegas.

Table 4.4.1-1 (continued). Overall assessment outcome for condition trend and status of human health effects.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Mercury (Hg) in Fish Flesh (Consumption)	• Hg concentration		A 2008 analysis of concentrations of Hg in fish tissues from all basins in Lake Mead found that the mean concentration did not exceed USEPA standards. 10 of the 221 total fish sampled did, however, exceed USEPA standards. Nevada Division of Public Health and NDOW issued a fish consumption advisory for Hg which remains active.
Human Health Effects overall			–

Overall Description

Lakes Mead and Mohave provide opportunities for regional, national, and international visitors to enjoy a wide variety of water-based recreational activities that often involve full-body contact, such as swimming, water-skiing, and personal watercraft use. The recreational industry is valued at over $479 million and $200 million annually in lakes Mead and Mohave, respectively (Batker, et al., 2014). The Lake Mead NRA's Foundation Document states that "the purpose of Lake Mead National Recreation Area is to provide diverse public recreation, benefit and use on lakes Mead and Mohave and surrounding lands in a manner that preserves the ecological, geological, cultural, historical, scenic, scientific, and wilderness resources of the park." (NPS, 2015a). Lake Mead NRA has mandated responsibilities to provide safe and healthy water-based recreation, in the context of an outstanding water-based recreational setting.

In its 2003 Guidelines for Safe Recreational Water Environments, the World Health Organization (WHO) suggested that water recreation managers are responsible to provide experiences that are safe, healthy, and aesthetically pleasing (NPS, 2015a). The USEPA NLA (USEPA, 2009) utilized three indicators for what it termed "Suitability for Recreation." These indicators include algal toxins, fish tissue mercury contamination, and human pathogen indicator bacteria. In 2015, Lake Mead NRA developed Recreation Suitability Guidelines documenting water quality parameters to assess the recreational suitability of lakes Mead and Mohave (Lake Mead NRA, 2015). Indicators were chosen to encompass relevant Nevada state water quality standards, WHO recreational water guidelines, and USEPA guidelines and include: human pathogens, hazardous algal blooms (HAB)/algal toxins, fish tissue (mercury) contamination (relative to human consumption), and the aesthetic/setting indicators of chlorophyll *a*, Secchi depth monthly averages, and the presence/absence of debris or surface scum (See section 4.4.2 for aesthetic quality assessment). Given the importance of water-based recreation and existing recreation setting within the Lake Mead NRA's enabling legislation, managers consider the quality of the recreational setting as a park resource, analogous to other NPS experiential resources such as dark night sky and natural quiet (NPS, 2015a).

Pathogens

A summary of the parameters used assess pathogens effects are shown in Table 4.4.1-2.

Table 4.4.1-2. Assessment outcome of pathogens.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Pathogens	• Fecal coliform concentration (cfu/100 ml) • *E. coli* concentration (cfu/100 ml)		Pathogen concentrations at Boulder Basin were below established full body-contact recreation standards for fecal coliform and *E. coli*. Low incidences of pathogen detection from Overton Arm and Colorado River inflow/upper Lake Mead have led to discontinuation of pathogen monitoring in April 2005 at those locations. Fecal coliform and *E. coli* concentrations measured at Las Vegas Bay were below established acceptable range standards across years examined, but recent increases (2014 and 2015) in concentrations of both fecal coliform and E. coli have been detected Surface water samples collected at high-use recreational covers and beaches between 2003 and 2015 at lakes Mead and Mohave were generally within the “good” range for pathogen concentrations. Two locations in Lake Mohave were identified as having the highest single-occurrence frequency of exceedances.

Description

Bodies of water within Lake Mead NRA all 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. Agencies responsible for water-quality standards and management at lakes Mead and Mohave have concern over the potential for human illness from microbial organisms, algal toxins, or other contaminants. Lake Mead receives treated wastewater effluent and urban runoff from Las Vegas Valley via Las Vegas Wash. A discharge permit from 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 (Rosen et al., 2012). During periods of higher urban run-off into the Wash, indicator bacterial counts within Las Vegas Wash can be temporarily elevated above the limits recommended for body contact recreation (SNWA, 2016).

Data and Methods

Table 4.4.1-3 shows the data and methods used to assesss pathogens.

Table 4.4.1-3. Indicators and measures used in the assessment of pathogens.

Indicator(s)	Measurement(s)	Scale of Analysis
Pathogens	• Fecal coliform concentration (cfu/100 ml) • *E. coli* concentration (cfu/100 ml)	Lake; Lake Basin

Pathogenic bacteria and organisms are often difficult to isolate and monitor as they usually occur in small numbers. Therefore, other bacteria, such as fecal coliform and *E. coli*, are typically used as indicators of fecal contamination to assess a lake's potential to harbor pathogens and cause illness for recreational water users. *Escherichia coli* (*E. coli*) and fecal coliform are coliform bacteria that are found in the feces of humans and other warm-blooded animals. In 2012, USEPA issued new recreational water quality criteria (RWQC) to protect people from exposures to pathogens by ways of water-based recreation activities (USEPA, 2015a). USPEA recommends using *E. coli* as an indicator bacteria for health risk from primary contact recreation use. NDEP has issued Nevada state water quality standards related to fecal coliform human pathogen indicators for body contact recreation. Lake Mead NRA is required to meet these standards. Therefore, the Recreation Suitability Guide has adopted *E. coli* and fecal coliform bacteria as the indicators for human pathogens (Lake Mead NRA, 2015).

NDEP mandates routine bacteriological water-quality monitoring in Boulder Basin and Las Vegas Wash by the wastewater dischargers as an NPDES permit condition. Las Vegas Wash and Boulder Basin are sampled weekly as mandated by NDEP. The long-term water quality monitoring program maintained by BOR, SNWA, and NPS also routinely collects *E. coli* and fecal coliform concentration data at 22 locations throughout Lake Mead on monthly or quarterly basis and one location on Lake Mohave on a quarterly basis (Table 2.3.2-1).

Since 2003 NPS Lake Mead NRA has sampled for fecal coliform and other human pathogen indicators at some ten locations on both lakes Mead and Mohave during May through September on a biweekly basis, the peak water recreation season (Rosen et al., 2012; Table 2.3.2-1). Eleven additional locations were added to the monitoring program in 2015 and 2016 due to lowering lake levels and expansion of monitoring program. Locations were selected to include high recreational use coves and beaches within Lake Mead NRA. See Figure B-7 for current locations of NPS bacterial monitoring sites and Table B-3 for site descriptions.

Primary data used for pathogen from NDEP and BOR collections were download from the SNWA database (http://snwaexapps.lvvwd.com/WaterQuality/wqv3/WQSearch.aspx?action=&uuid=). NPS provided additional information on recreation coves and beaches bacteriological monitoring. Note that pathogen levels can be sensitive to the time of day and place of collectionl since turnover rates are high and incubation periods change.

Reference Conditions

USEPA has updated and developed new RWQC recommendations in 2012 for states to adopt into their water quality standards to protect primary contact recreation (USEPA, 2015a). NDEP has adopted these recommendations and issued state water quality standards for body contact recreation,

related to fecal coliform and *E. coli*. The Recreation Suitability Guide established by NPS has adopted the *E. coli* and fecal coliform bacteria standards for lakes Mead and Mohave (Lake Mead NRA, 2015). The Nevada state standard for bacterial indicators have both a single sample standard, and a standard that relates to the logarithmic or log mean of no fewer than five samples taken in the area over a 30-day period (Table 4.4.1-4). Lake Mead NRA is required to meet these standards and take appropriate actions when alert or advisory levels have been reached.

Condition and Trend

A review of routine lakes Mead and Mohave bacteriological water-quality monitoring data collected from open water locations was conducted for this assessment (See Table 4.1.1-5 for locations sampled and Figure B-3 and Figure B-5 for station locations). Fecal coliform and *E. coli* samples have been collected at quarterly or monthly intervals from both lakes Mead and Mohave. Since less than 5 samples were taken at each location within a 30-day period, the single sample standard criteria were used for assessing the current condition of the pathogen indicator.

At Lake Mead, fecal coliform and *E. coli* concentrations were well below established single sample and 30-day period standards for full body-contact recreational (Table 4.4.1-4) at Boulder Basin (1996–2015 and 2001–2015, respectively), Virgin, Temple, Gregg Basins, and Overton Arm (Colorado mainstem 2001–2005) (Table 4.4.1-5 and Table 4.4.1-6). Sampling for pathogens in Overton Arm and Colorado main stem locations was discontinued after April 2005 as pathogens were rarely detected at these locations (Holdren et al., 2008). Therefore, *E. coli* and fecal coliform concentrations are considered in the "good" range for Boulder Basin, Colorado mainstem basins, and Overton Arm. Indicator bacteria concentrations were stable across years in Boulder Basin (1996–2015; Table 4.4.1-5 and Table 4.4.1-6).

Within the inner Las Vegas Bay (LVB4.15), the area of the lake most impacted by the water quality of the Wash, fecal coliform and *E. coli* concentrations (2001–2015) also has not exceeded established NDEP and NPS full body contact recreation standards (LaBounty, 2005; Table 4.4.1-5). However, recent (2014 and 2015) increases of fecal coliform and E. coli concentrations have been detected (Table 4.4.1-5 and Table 4.4.1-6). This is likely the result of increased indicator bacteria concentrations from dry weather urban run off and stormwater in the Las Vegas Wash.

Table 4.4.1-4. Lake Mead NRA Human pathogen criteria (Lake Mead NRA, 2015).

	Condition Status			
Measurment(s)	**Significant Concern***	**Moderate Concern***	**Good* Single sample**	**Good 30 day log mean (≥5 samples taken over a 30-day period)**
Fecal coliform levels (Membrane Filter method, MF)	Extended period > 200 cfu /100 ml	>400 cfu /100 ml (single sample standard criteria) for two successive samples at one location	<400 cfu/100 ml	≤ 200 cfu/100 ml Or <10% of total samples taken during any 30-day period > 400 cfu /100 ml
E. coli levels (Membrane Filter method, MF)	Extended period > 126 cfu /100 ml	>235 cfu /100 ml (single sample standard criteria) for two successive samples at one location	≤ 235 cfu /100 ml	≤ 126 cfu /100 ml

Table 4.4.1-5. Fecal coliform average concentrations (cfu/100 ml) detected in lakes Mead and Mohave. Calculation of averages excluded single detection of uncommonly high concentration (>10000 cfu/100ml) where successive samples at the same location return to common concentration range detected within the same period. Stations are arranged by distance from the Las Vegas Wash confluence. See Figure B-3 and Figure B-5 for station locations.

Basin	Station	Statistic	Fecal coliform concentration (cfu/100 ml)									
			1986–1990	1991–1995	1996–2000	2001–2005	2006–2010	2011	2012	2013	2014	2015
Las Vegas Wash	LWLVB	Average	–	–	571.98[1]	262.75	396.91	–	120.22	149.33	195.38	516.7
		Range	–	–	0.67–4500[1]	<1–7400	<1–5000	–	20–550	20–850	20–830	20–3400
	LWLVB_B	Average	–	–	560.48[1]	159.02	561.13	72.42	614.92	125.5	82.5	427.27
		Range	–	–	<1–9800[1]	<1–6800	<1–6900	<1–240	<1–6700	<1–1100	20–200	20–2800
Las Vegas Bay	LVB 4.15	Average	–	–	–	80.54	16.95	18.25	153.83	27	49.38	275.8
		Range	–	–	–	<1–2120	<1–121	4–92	<1–1660	<1–238	4–156	4–2300
Boulder Basin	CR346.4	Average	–	–	0.25	1.16	2.82	2.54	2.25	1.5	6.42	1.55
		Range	–	–	<1–2	<1–8	<1–49	<1–8	<1–4	<1–4	<1–54	<1–4
Virgin Basin	CR360.7[2]	Average	–	–	–	1.55	–	–	–	–	–	–
		Range	–	–	–	<1–4	–	–	–	–	–	–
Temple Basin	CR380.0[2]	Average	–	–	–	3.27	–	–	–	–	–	–
		Range	–	–	–	<1–17	–	–	–	–	–	–
Gregg Basin	CR394.0[2]	Average	–	–	–	3.08	–	–	–	–	–	–
		Range	–	–	–	<1–18	–	–	–	–	–	–
Overton Arm	VR25.1[2]	Average	–	–	–	2.33	–	–	–	–	–	–
		Range	–	–	–	<1–7	–	–	–	–	–	–
Willow Beach (Lake Mohave)	CR329.7	Average	15.62[3]	20.21	8.33[4]	10	–	–	–	–	–	–
		Range	10–100	<1–200	<1–10	10	–	–	–	–	–	–

[1] Period of record: 3 years (1998–2000), biweekly to monthly;

[2] Period of record: 3 years (2003–05), monthly;

[3] Period of record: 4 years (1987–90), quarterly;

[4] Period of record: 3 years (1996, 99, and 2000), quarterly.

Table 4.4.1-6. *E. coli* average concentrations (cfu/100 ml) detected in lakes Mead and Mohave. Calculation of averages excluded single detection of uncommonly high concentration (>10000 cfu/100ml) where successive samples at the same location return to common concentration range detected within the same period. Stations are arranged by distance from the Las Vegas Wash confluence. See Figure B-3 and Figure B-5 for station locations.

			***E coli.* concentration (cfu/100 ml)**									
Basin	**Station**	**Statistic**	**1985–1999**	**1990–1995**	**1996–2000**	**2001–2005**	**2006–2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Las Vegas Wash	LWLVB	Average	–	–	–	100.82[1]	104.89	–	99.1	45.75	27.5	79
		Range	–	–	–	<1–1080[1]	<1–2400	–	11–780	7–200	10–97	10–320
	LWLVB_B	Average	–	–	–	72.12[1]	131.59	34.83	42.08	23.08	15.75	85.27
		Range	–	–	–	<1–2000[1]	<1–6800	<1–230	<1–167	<1–110	<1–47	<1–300
Las Vegas Bay	LVB 4.15	Average	–	–	–	3.07[1]	4.33	6.83	12	10.25	6.25	62.91
		Range	–	–	–	<1–4[1]	<1–22	<1–10	<1–53	<1–76	<1–20	<1–200
Boulder Basin	CR346.4	Average	–	–	–	1.67	1.87	1.69	1.75	1.5	1.75	1.55
		Range	–	–	–	<1–4	<1–4	<1–4	<1–4	<1–4	<1–4	<1–4
Virgin Basin	CR360.7[2]	Average	–	–	–	<1	–	–	–	–	–	–
		Range	–	–	–	<1–1	–	–	–	–	–	–
Temple Basin	CR380.0[2]	Average	–	–	–	<1	–	–	–	–	–	–
		Range	–	–	–	<1–1	–	–	–	–	–	–
Gregg Basin	CR394.0[2]	Average	–	–	–	1.27	–	–	–	–	–	–
		Range	–	–	–	<1–4	–	–	–	–	–	–
Overton Arm	VR25.1[2]	Average	–	–	–	3.38	–	–	–	–	–	–
		Range	–	–	–	<1–10	–	–	–	–	–	–
Willow Beach (Lake Mohave)	CR329.7[4]	Average	–	2.45	10.58	11.25	–	–	–	–	–	–
		Range	–	<1–8.7	<1–31	10–20	–	–	–	–	–	–

[1] Period of record: 3 years (2003–05), monthly;

[2] Period of record: 3 years (2003–05), monthly;

[3] Period of record: 3 years (1997–99), quarterly;

[4] Sampling frequency: quarterly

Lake Mead receives treated wastewater effluent and urban runoff from Las Vegas Valley via Las Vegas Wash. A discharge permit from the 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 fecal coliform and *E. coli* concentrations at the Las Vegas confluence were generally below established limits for body-contact recreation (Table 4.4.1-5 and Table 4.4.1-6). Occasionally elevated concentrations above the single sample limits for fecal coliform and E. coli within Las Vegas Wash have been detected (Table 4.4.1-5 and Table 4.4.1-6). In 2015, the highest bacterial concentrations were generally found at the Las Vegas Wash confluence stations and declined with distance from the inflow to much lower concentrations measured at Boulder Basin (Table 4.4.1-5). Fecal coliform concentrations were temporarily elevated above the established limits at the Las Vegas Bay station in May (33,334 cfu/100 ml for fecal coliform and in July at the Las Vegas Wash inflow station with measurements of 1,200,000 cfu/100 ml for fecal coliform and 56,000 cfu/100 ml for *E. coli*. However, no subsequent exceedances have been detected, and therefore moderate concern levels were not met (Table 4.4.1-4). These elevated levels were often detected during periods of higher urban run-off or other inputs into the Wash (Southern Nevada Water Authority, 2011). In addition, Las Vegas Wash has not been designated as body-contact recreational waters by NDEP.

One station in Lake Mohave at Willow Beach has been consistently sampled for fecal coliform and *E. coli* via the routine lakes Mead and Mohave bacteriological water-quality monitoring program between 1993 and 2005. While fecal coliform concentrations have been trending slightly downward while *E.coli* concentrations have been trending upward across the years sampled, surface concentrations were never found to exceed full body-contact recreational standards for both fecal coliform and E. coli (Table 4.4.1-5 and Table 4.4.1-6).

NPS monitors a number of popular recreational coves and beaches on lakes Mead and Mohave. Since 2003, water samples have been collected between May and September at nine high-use recreation sites. An additional sampling site (Placer Cove) was added in 2008. In 2015 and 2016, 11 additional sites were added to the program in response to lower lake levels (Figure B-7 and Table B-3). Analyses of 1086 water samples for concentrations of fecal indicator bacteria showed that fecal coliform has been present in concentrations exceeding the acceptable limit for full-body contact in recreational waters (Table 4.4.1-4) in 3% of samples. *E. coli* concentrations have exceeded the acceptable limit for full-body contact recreation in only 0.3% of the samples (N=1140). No surface water samples have reached concentrations of significant concern. Throughout the 14-year study, Six Mile Cove and Placer Cove at Lake Mohave (Figure B-7) had the highest single-occurrence of levels of fecal coliform that warranted moderate concern (Table 4.4.1-7). The highest number of exceedances occurred in 2014.

Table 4.4.1-7. Number of samples that exceeded the acceptable single sample limit (<400 cfu/100ml) for fecal coliform concentration for full-body contact in recreational waters. Placer Cove was not introduced as a sampling location until 2008.

	Lake Mead							Lake Mohave		
Year	Middle Point Cove	Tea Kettle Cove	James Bay	Sandy Cove	Boxcar Cove	Boulder Beach	Hemenway Harbor	Placer Cove	Six Mile Coves	Katherine's Landing/ Telephone Cove
2003	–	–	–	–	–	–	–	NA	NA	NA
2004	–	–	–	–	–	–	–	NA	–	–
2005	1	–	–	–	–	–	–	NA	1	–
2006	–	–	–	–	–	–	–	NA	2	–
2007	–	–	–	–	–	–	–	NA	1	–
2008	–	–	–	–	1	–	–	2	1	–
2009	–	–	–	–	–	–	–	–	–	–
2010	–	–	–	–	–	–	–	1	–	–
2011	–	–	–	–	–	–	–	2	–	–
2012	–	–	–	–	–	–	–	–	–	–
2013	–	–	–	–	–	–	–	5	3	–
2014	–	–	–	–	1	–	–	3	7	–
2015	–	–	–	–	–	–	–	–	–	–

Water managers at Lake Mead NRA are also concerned with other pathogens, viruses, and protozoans that can cause human illness. *Enterococci* and Fecal *streptococci* concentrations have also been routinely monitored by NPS through their bacteriological cove-monitoring program (Table 2.3.2-1). Water-borne pathogens and those associated with disease carrying organisms like mosquitos that live near water, such as West Nile virus and *Naegleria fowleri*, have been detected in the park vicinity and the potential exists for occurrence within the park. Both species pose health risks to park visitors and employees (NPS, 2014). Two protozoan parasites, *Cryptosporidium* and *Giardia* have also been detected at very low numbers (1–2) over the past 10 years. *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. The SNWA routinely tests for both of these organisms as a part of its drinking-water monitoring requirements. During 2014, neither organism was detected at the drinking-water intakes within Lake Mead (SNWA, 2016).

Assessment Confidence and Key Data Gaps

The assessment confidence for pathogen condition and trend is high. Indicator bacteria concentrations in lakes Mead and Mohave waters have been closely monitored by various agencies providing a continuous record of information regarding this indicator's condition and trend.

The USEPA suggested in the 2007 NLA that *Enterococci* can provide a better indication of the presence of pathogens than more traditional indicators for fecal coliform (USEPA, 2009). Most species of *enterococci* are not considered harmful to humans, but their presence indicates the possibility that other pathogens also carried by fecal material may be present (USEPA, 2009). Currently, *enterococci* is monitored at both lakes Mead and Mohave by NPS at selected coves and beaches; however, LaMEM routine, long-term, water-quality monitoring only monitor *enterococci* at open water locations in Lake Mead but not in Lake Mohave.

Harmful Algal Bloom (HAB)/Toxin

A summary of the parameters used assess harmful albal blooms are shown in Table 4.4.1-8.

Table 4.4.1-8. Assessment outcome for harmful algal blooms.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Harmful Algal Bloom, (HAB)/Toxin	Microcystin concentration		Lakes Mead and Mohave posted low risk of exposure to algal toxin based on microcystin concentration measurements. In addition, *Microcystis aeruginosa* (microcystin-producing) concentrations have been monitored in Lake Mead and only low levels have been detected. Occasional increases in *Microcystis* spp. abundance have been noted in Lake Mohave in recent years. While most *Microcystis* spp. are not toxic, the presence of bloom-forming species, and increased detection of these species do warrant further investigation. Microcystin was detected in several locations in 2015, resulting in NPS posting swim advisory and enchance monitoring. There were no incidents of elevated microcystin in 2016. Other species of toxin producing algae, such as Golden alga (*Prymnesium parvum*), have been detected in Lake Mead and caused harmful algal blooms at Lake Las Vegas.

Description

Recreation suitability can be affected by the presence of harmful algal blooms. Some algae species can produce toxins that are highly toxic to aquatic life, humans, and terrestrial wildlife that utilize affected water. In lakes Mead and Mohave, some blue-green algae (cyanobacteria) exist that have the potential to produce cyanotoxins such as microcystin toxin (Rosen et al., 2012). Microcystin is produced by *Microcystis* taxa and is a potent liver toxin, a known tumor promoter, and a possible human carcinogen (USEPA, 2009). Eutrophication in lakes often provides suitable conditions for cyanobacteria growth and blooms. Cyanobacterial blooms can be unpleasant, often forming a layer of decaying and gelatinous scum on the water surface, affecting the visual water quality of lakes. It is important to note that not all algal blooms are harmful to human health since not all phytoplankton are cyanobacteria and not all cyanobacteria produce cyanotoxins (USEPA, 2009).

Data and Methods

Table 4.4.1-9 shows the data and methods used to assesss harmful algal blooms.

Table 4.4.1-9. Indicators and measures used in the assessment of harmful algal blooms.

Indicator(s)	Measurement(s)	Scale of Analysis
Harmful algal bloom (HAB)/Toxins	Microcystin concentration	Lake; Lake Basin

SNWA routinely collects and analyze water samples for microcystin concentrations in lakes Mead and Mohave (Table 4.4.1-10). Composite samples from 0 to 6 m and grab surface water samples (0 m) and 44–46 m (only at the SNWA's drinking water intake system site) have been collected on a weekly basis. SNWA's drinking water intake system site (LMI_1_2) was the only location where extensive and consistent microcystin measurements had been collected (2005-present; Table 4.4.1-10). Microcystin concentrations have been measured weekly. Primary data used for HAB indicator assessment was downloaded from the SNWA database. Additional information was supplemented from USEPA NLA (USEPA, 2009).

Table 4.4.1-10. List of SNWA microcystin monitoring sites in Lake Mead NRA showing period of record examined. For site coordinates and locations, see Figure B-3, Figure B-5, and Table B-1.

Lake	Location	Site ID	First Record	Last Record
Lake Mead	Las Vegas Wash	LWLVB	9/11/2006	6/30/2015
	Las Vegas Wash	LWLVB_B	4/26/2005	6/30/2015
	Las Vegas Bay	LVB3.5	4/26/2005	6/2/2008
	Las Vegas Bay	LVB4.15	6/10/2008	6/30/2015
	SNWA Drinking Water Intake	LMI_1_2	1/5/2005	6/30/2015
	Boulder Basin	CR346.4	4/26/2005	6/30/2015
	Virgin Basin	CR360.7	7/24/2012	6/10/2015
	Overton Arm	VR2.0	8/14/2012	5/28/2015
	Virgin River Confluence	VRLM_B	8/14/2012	5/28/2015
	Temple Basin	CR380.0	7/24/2012	6/10/2015
	Gregg Basin	CR390.0	7/24/2012	6/10/2015
	Gregg Basin	CR394.0	7/24/2012	6/10/2015
	Colorado River Confluence	CRLM_A	7/24/2012	6/10/2015
Lake Mohave	Willow Beach	CR329.7	1/23/2013	6/2/2015
	Placer Cove	CR316.34	1/23/2013	6/2/2015
	Cottonwood Cove	CR298.5W.5	1/23/2013	6/2/2015
	Katherine's Landing	CR278.0	1/23/2013	6/2/2015

Reference Conditions

WHO has established recommended cyanobacteria (blue-green algae) and related algal toxin (microcystin) guidelines for recreational exposure (Table 4.4.1-11). WHO recommendations have been adopted as guidelines by the USEPA under the Coastal Health Act of 2000 and were used in the

National Lake Mead NRA Assessment (NLA) to assess recreation suitability of lakes across the nation, including Lake Mead (USEPA, 2009). Cyanotoxins are on the EPA Contaminants of Concern List under the SDWA (Lake Mead NRA, 2015). The Recreation Suitability Guide has adopted more stringent thresholds for mycrocystin concentration levels in regards to HAB than the WHO standards used in the NLA (Lake Mead NRA, 2015). The limits are not used as a guideline, but as a broad indicator that further action is needed (e.g. track extent of noticeable algal concentrations, A combination of criteria was adapted to established reference conditions for this condition assessment.

Table 4.4.1-11. Lake Mead NRA Hazardous algae bloom/toxin (HAB) criteria.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Microcystin concentration	>20 µg/L[2]; Management may consider closure of HAB area on temporary basis.	> 5 samples where toxin level detected are >5–<20 µg/L[1,2]	Zero to <5 µg/L[1]

[1] Lake Mead NRA, Recreation Suitability Guidelines, 2015

[2] USEPA, 2009

Condition and Trend

Lake Mead

In 2015, Lake Mead posted low risk of exposure to algal toxin based on measurements of microcystin concentrations. Microcystin concentrations collected between 2005 and 2015 at various sampling stations in Lake Mead were mostly zero or below the minimum detection limit (<0.5µg/L). Concentrations of microcystin reaching 0.5µg/L were detected at Colorado main stem locations (Virgin, Temple, and Gregg basin) in spring of 2014, but these were all single-occurrence exceedance. In March 2015, sampling in Lake Mead at the Las Vegas Boat Harbor Marina detected microcystin and localized chlorophyll a concentrations exceeding hazardous levels for HAB criteria (e.g. microcystin concentration between 0.5 and 3 µg/L). However, SNWA did not detect microcystin in subsequent samples collected in April 2015 (Tietjen, 2015).

In the USEPA NLA, only microcystin concentrations from the SNWA drinking water intake system site were used for the assessment and Lake Mead was ranked as low risk to exposure of algal toxins (USEPA, 2009).

While cyanbacterial blue-green algal counts are available from the monitoring of Lake Mead, there is more limited investigation of dynamics from areas of human exposure near beaches and in so called "hot spot" areas of growth. Concentrations of *Microcystis aeruginosa*, a species of freshwater cyanobacteria that can produce microcystin have been monitored at several sampling stations in Lake Mead between 2012 and 2015. In general, concentrations of *Microcystis aeruginosa* have been very low at open water sites, ranging from 0 to 1000 natural units/L (Figure 4.4.1-1). Higher concentrations (>2000 but less than 20,000 natural units/L) have been measured in Las Vegas Bay (Figure 4.4.1-1). Cyanobacteria growth was noted on Lake Mead during the fall-winter of 2014–2015, and algae growth persisted through March 2015 (Lake Mead NRA, 2015). This is atypical

from seasonal patterns observed for *Microcystis* spp. in previous years. Declining concentrations have been observed since April 2015 (Tietjen, 2015). While *Microcystis* sp. and other nuisance cyanobacteria have been found in Lake Mead, they do not represent a significant proportion of the overall population of phytoplankton.

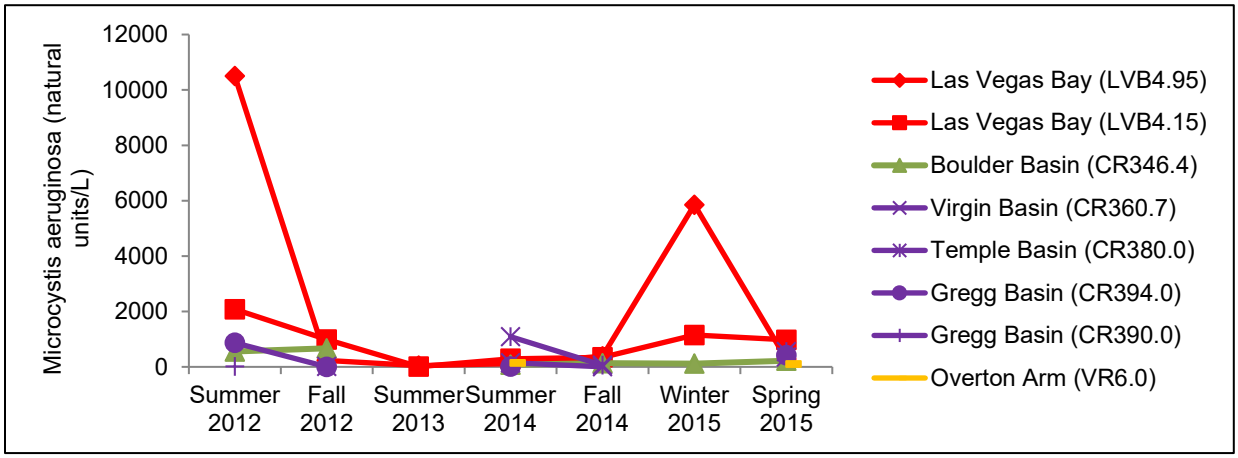


Figure 4.4.1-1. Concentrations of *Microcystis aeruginosa* (natural units/L) in Lake Mead.

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 & Imai, 2006; Southard et al., 2010). In Lake Mead, low densities of golden alga cells have been detected since 2001 (LaBounty & Burns, 2005). Golden algal blooms tend to occur when water temperatures are seasonally low in inland (typically brackish) waters (Sager, et al., 2008). However, in the winter of 2010 for the first time in Nevada, a toxic golden alga bloom was reported in Lake Las Vegas, a man-made lake near Las Vegas and Lake Mead (Weber & Janik, 2010). This event raised concern about the potential for toxic blooms to spread into Lake Mead. The environmental factors responsible for golden algal blooms or how and when they produce toxins are not currently understood (Edvardsen & Imai, 2006; Sager, et al., 2008). As such, it may be difficult to prevent or manage these blooms if they do occur.

Lake Mohave:

Moderate cyanobacterial growth was noted on Lake Mohave in 2011, 2012 and 2013. From 2013 through 2015 all water samples analyzed for algal toxins resulted in non-detection. During the winter of 2014 to 2015, however, concentrations of blue-green algae were noted throughout the winter, which was considered unusual (Lake Mead NRA, 2015). In March 2015, blue-green algae concentrations had become obvious on both lakes Mead and Mohave with positive detection of microcystin concentrations and a swimming advisory was issued for both Lakes (NPS, 2015b). However, it is uncertain as to the specific causes of these *Microcystis* events on Lake Mead and Mohave in 2015. There were no significant issues related to *Microcystis* levels in the summer of 2016.

Microcystis algae, where some species can produce microcystin toxin, have been noted more frequently in Lake Mohave in the last few years, possibly a latent response to quagga mussel invasion or a response to warmer water temperatures. The trend in *Microcystis* abundance appears to be increasing (NPS, 2014). *Microcystis* abundance or cell counts can serve as proxies for the actual presence of algal toxins but not actual detection of algal toxin presence (USEPA, 2009). Additional examinations of phytoplankton (algae) composition completed monthly by SNWA and quarterly by BOR identify phytoplankton to species level and could provide more insight as to the presence and abundance of toxin-producing species of *Microcystis* spp. present in lakes Mead and Mohave waters (See section 4.2.3).

Assessment Confidence and Key Data Gaps

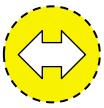
Assessment confidence is high. Microcystin concentrations have been consistently measured at various locations in lakes Mead and Mohave on a regular basis by SNWA and BOR. Further, consistent analytical methods and estimate units have been used for microcystin concentrations.

Increased *Microcystis* abundance has been detected at both lakes Mead and Mohave; however, these detections do not necessarily imply an increase in microcystin toxin concentrations as the Lake Mead environment favors extremely small non-toxic *Microcystis* spp. Therefore, follow up examinations of phytoplankton composition to species level should be conducted when weekly monitoring of microcystin concentrations is conducted. Presently, examinations of phytoplankton (algae) composition completed monthly by SNWA and quarterly by BOR identify phytoplankton to species level and can potentially provide insight as to the presence and abundance of toxin-producing species of *Microcystis* spp. present in lakes Mead and Mohave (See section 4.2.3).

Mercury (Hg) in Fish Flesh (Consumption)

A summary of the parameters used assess mercury in fish flesh are shown in Table 4.4.1-12.

Table 4.4.1-12. Assessment outcome for mercury in fish flesh.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Mercury (Hg) in Fish Flesh (Consumption)	Hg concentration		Until 2008, concentrations of Hg in fish tissues from all basins in Lake Mead do not exceed USEPA standards. Despite lack of data available after 2008, NDOW fish consumption advisory remains active.

Description

A majority of mercury present in the environment today is due to human activities, including mining, mineral extraction, and coal-fired power plants (USEPA, 2015b). Mercury from air deposition can be transformed by microorganisms into methylmercury. Methylmercury can bioaccumulate in the food chain and reach harmful levels in fish (USEPA, 2015c). Humans are primarily exposed to mercury by eating fish and shellfish that have high levels of methylmercury in their tissue. Consumption of fish containing high levels of Hg can have impacts on reproductive, immune, and nervous systems

function to all ages, affecting growth, behavior, disease susceptibility, or even be life threatening (USEPA, 2015b). Mercury concentrations in surface water in lakes Mead and Mohave have been relatively low (see section 4.5.1). However, mercury concentrations in fish can vary throughout lakes Mead and Mohave, indicating different loadings and sources (Kramer, 2009).

Data and Methods

Table 4.4.1-13 shows the data and methods used to assesss mercury in fish flesh.

Table 4.4.1-13. Indicators and measures used in the assessment of mercury in fish flesh.

Indicator(s)	Measurement(s)	Scale of Analysis
Mercury (Hg) in Fish Flesh (Consumption)	Hg concentration	Lake

Published values in the literature indicating concentrations of methyl-Hg in sportfish tissues measured in lakes Mead and Mohave have been used. Cizdziel et al. (2002; 2003) examined 339 sportfish collected from all major basins (Las Vegas Bay, Boulder Basin, Temple Basin, Virgin Basin, Overton Arm, and Gregg Basin) as part of the Lake Mead Fisheries Contaminant Biomarker Survey during the fall of 1998 and spring of 1999 and determined total skeletal muscle mercury concentrations. The species studied were the principal sportfish found in Lake Mead: striped bass, largemouth bass, bluegill, and blue tilapia. Kramer (2009) and Kramer and Gerstenberger (2010) determined the concentrations of mercury present in most commonly consumed fish (largemouth bass, striped bass, channel catfish, and blue tilapia) from the four major basins in Lake Mead using approved USEPA testing methodology. A total of 221 fish samples collected in 2007 and 2008 from selected sites in Boulder Basin, Overton Arm, Virgin Basin, and Gregg Basin were examined (Kramer, 2009).

Reference Conditions

Table 4.4.1-14 shows the reference conditions used to assess mercury in fish flesh.

Table 4.4.1-14. Reference conditions for mercury in fish flesh used in the assessment.

	Condition Status		
Measurment(s)	**Significant Concern***	**Moderate Concern***	**Good***
Mercury (Hg) in fish	Concentrations of Hg in fish harvested from Lake Mead exceed USEPA standards for safe human consumption. Active consumption advisories issued by NDOW for fish consumption.	Elevated concentration of Hg in fish harvested from Lake Mead but do not exceed USEPA standards for safe human consumption. Active consumption advisories issued by NDOW for fish consumption as a result of occasional elevated levels detected.	Concentrations of Hg in fish harvested from Lake Mead do not exceed USEPA standards for safe human consumption. No advisories issued by NDOW for fish consumption.

The degree of exposure to methylmercury depends on both the amount and the type of fish consumed. The USEPA has established a recommended fish tissue residue criterion for methylmercury at 0.3 μg/g wet weight of fish tissue. The criterion defines the maximum advisable concentration of methylmercury in freshwater fish and shellfish tissue based on a total fish and shellfish consumption-weighted rate of 17.5g of fish per day (USEPA, 2001).

Condition and Trend

Mercury concentrations in sportfish studied by Cizdziel et al. (2002; 2003), Kramer (2009), and Kramer and Gerstenberger (2010) varied by species and location.

In 1998 and 1999, total mercury concentrations in muscle samples of blue tilapia were less than the detection limit of the analytical method (0.01 μg/g). Mercury concentrations were highest in striped bass with an average concentration of 0.15 μg/g (Cizdziel et al., 2002; Cizdziel et al., 2003). The low mercury concentrations in blue tilapia are likely a result of their vegetarian diet, placing them at a lower trophic position. On the other hand, striped bass are predators in the food web, live longer, and accumulate more mercury from the smaller fish they eat. The highest individual muscle Hg concentration was found in a striped bass from Gregg Basin at 1.05 μg/g (Cizdziel et al, 2002).

In 2007 and 2008, Kramer (2009) and Kramer and Gerstenberger (2010) found that mean mercury concentrations of largemouth bass, striped bass, and channel catfish in Boulder Basin were significantly lower than that of Gregg Basin, Virgin Basin, and Overton Arm. Fish collected in Gregg basin contained the highest mean mercury concentration. Mean total mercury concentrations were 0.089, 0.154, 0.098 μg/g in largemouth bass, striped bass, and channel catfish, respectively. The mean concentrations of mercury detected were all less than the USEPA's tissue residue criterion of 0.3 μg/g wet weight. Results of the study included 10 samples (less than 5%) with concentrations that exceeded USEPA tissue residue criterion (Kramer & Gerstenberger, 2010). With individual fish samples having concentrations that exceeded USEPA recommendation for methylmercury, the State of Nevada has issued statewide fish consumption recommendations (Table 4.4.1-7) for sportfish in lakes Mead and Mohave.

No fish tissue mercury concentration data collected after 2008 were found. However, the statewide fish consumption advisory issued by NDOW remains in place for sportfish harvested from lakes Mead and Mohave (NDOW, 2016).

Table 4.4.1-15. Nevada Department of Wildlife Fish Consumption Advisory, based on methylmercury (NDOW, 2016).

Lake	Location	Fish Species	Maximum Number of Meals per Month
Lake Mead	Boulder Basin	Common carp	8
	Boulder Basin	Channel catfish	12
	Boulder Basin	Largemouth bass	16
	Boulder Basin	Striped bass	4

Table 4.4.1-15 (continued). Nevada Department of Wildlife Fish Consumption Advisory, based on methylmercury (NDOW, 2016).

Lake	Location	Fish Species	Maximum Number of Meals per Month
Lake Mead (continued)	Boulder Basin	Tilapia	Unrestricted, >16
	Colorado River Inflow Arm	Channel catfish	8
	Colorado River Inflow Arm	Largemouth bass	16
	Colorado River Inflow Arm	Striped bass	4
	Colorado River Inflow Arm	Tilapia	Unrestricted, >16
	Overton Arm	Channel catfish	4
	Overton Arm	Largemouth bass	4
	Overton Arm	Smallmouth bass	4
	Overton Arm	Striped bass	4
Lake Mohave	–	Common carp	12
	–	Channel catfish	8
	–	Largemouth bass	4
	–	Striped bass	4

Assessment Confidence and Key Data Gaps

Assessment confidence is low. There have been no analyses for Hg in fish tissue from lakes Mead and Mohave since 2008, so current condition is assigned only based on the active consumption advisory issued by NDOW.

Periodic monitoring of Hg concentrations in fish tissues of commonly consumed fish from lakes Mead and Mohave should be conducted to ensure consumption safety of anglers and other consumers.

4.4.2. Visual Water Quality

A summary of the parameters used assess visual water quality are shown in Table 4.4.2-1.

Table 4.4.2-1. Assessment outcome for condition status and trend of visual water quality.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Aesthetic Quality	• Chlorophyll *a* • Secchi depth		Chlorophyll *a* concentrations were within the "good" range for aesthetic standards. Secchi disk depth at most open water stations remained within the good water clarity range. However, decreasing water clarity has been measured at lakes Mead and Mohave.
Visual Water Quality overall			–

Description

Aesthetic qualities are important components of recreation suitability. They relate mainly to visitor experience values that are important to Lake Mead NRA. Aesthetic considerations include water quality that supports a high-quality setting for water recreation at Lake Mead NRA (Lake Mead NRA, 2015). World Health Organization (WHO) guidelines suggest that waterbodies that have high water clarity. Water that is free from noxious non-toxic algae blooms, surface scums, odors, and debris is considered to have high aesthetic values (WHO, 2003).

Below excerpted from Lake Mead National Recreation Area, Recreation Suitability Guidelines, 2015:

Chlorophyll *a* is frequently used as a surrogate measure for algal biomass. Concentrations of chlorophyll *a* in Lake Mead have generally been highest near the tributaries (Las Vegas Wash, Overton Arm), which contribute the largest loads of nutrients (nitrogen and phosphorus) that can enhance algal growth (Rosen et al., 2012). For the purpose as an aesthetic metric, monitoring of chlorophyll *a* is only to be associated with non-toxic algal biomass. Detection of algae concentration or bloom consisting of cyanobacteria and microcystin algal toxin would trigger the HAB metric (see 4.4.1.1).

Secchi disk depth has been used as an inexpensive but effective method for measuring water clarity. Secchi depth is measured by lowering an eight-inch black and white disk into the water with multiple replicates per location. The depth at which the disk visually disappears and then reappears as the disk is raised is recorded. Secchi depth data taken over time can reflect changes in the concentration of suspended sediments or algal abundance. While the measurements do not quantify or characterize particles present, this method provides a quick snapshot of water clarity. Secchi depths have been measured at stations throughout Lake Mead for over 20 years. Secchi depths are taken as a part of the interagency monitoring of lakes Mead and Mohave.

Data and Methods

Table 4.4.1-13 shows the data and methods used to assesss visual water quality.

Table 4.4.2-2. Indicators and measures used to in the assessment of visual water quality.

Indicator(s)	Measurement(s)	Scale of Analysis
Aesthetic Quality	• Chlorophyll *a* • Secchi depth	Lake; Lake Basin

The Recreation Suitability Guide has identified three metrics (chlorophyll *a*, Secchi depth monthly averages, and the presence/absence of surface scums and debris) for assessing aesthetic quality at lakes Mead and Mohave. For this assessment, only chlorophyll *a* and Secchi depth monthly averages were examined. Secchi depth and Chlorophyll *a* are monitored at open water locations within each lake basin on a regular basis (See section 4.1.1.3 for sampling details). Data used were download from the SNWA database.

Reference Conditions

The Recreation Suitability Guide has identified thresholds for the measurements of chlorophyll *a* and Secchi depth monthly averages used for assessing aesthetic quality at Lake Mead NRA (Table 4.4.2-3). These thresholds were established based on consultations of Nevada State criteria, USEPA and WHO recommendations, and park experts' opinion on aesthetic qualities (Lake Mead NRA, 2015).

The NDEP has also established regulatory water quality standards for chlorophyll *a* (Lake Mead NRA, 2015). The standards recognize that the values within the mixing zones of the tributary confluences will be higher than those of the open waters of the Lakes. Therefore, the standards are specifically for open water sites, including Boulder, Virgin, Gregg, Temple, and Pierce Basins, and were adopted for this assessment as reference conditions.

Table 4.4.2-3. Lake Mead NRA Aesthetics Criteria (Lake Mead NRA, 2015).

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Chlorophyll a (Open waters)	• > 20 µg/L for more than two samples or single sample > 50 µg/L	• Growing season (April 1-September 30) averages > 5 µg/L • > 5% samples have single value > 10 µg/L	• Growing season (April 1-September 30) averages ≤ 5 µg/L. • No > 5% samples have single value > 10 µg/L • (Open-water locations, not including tributary confluences and Las Vegas Bay)
Secchi depth (Open waters)	• Monthly average < 3 m for more than one month	• Single monthly average < 4.5 m	• ≥ 7.62 m 12-month smoothed annual averages

Condition and Trend

Chlorophyll a

Reviewing the monitoring data from 1999 to 2012 in Lake Mead, only during a 2001 algal bloom the chlorophyll *a* aesthetics criteria were not met (Growing season averages ≤ 5 µg/L). A large green algae bloom occurred across the entire Boulder Basin in 2001 where chlorophyll *a* concentrations were measured in excess of 300 µg/L in individual samples (Rosen et al., 2012). In response to the 2001 algae bloom, the wastewater dischargers to Las Vegas Wash have since improved treatment plant processes and phosphorus removal (Lake Mead NRA, 2015). With the exception of the algal bloom observed in 2001, chlorophyll *a* values for Lake Mead have ranged from 1 µg/L to 5 µg/L.

In August 2013, the chlorophyll *a* aesthetics criterion was not met at Gregg Basin (20–21 µg/L). Subsequent sampling did not detect an exceedance; thus, conditions did not reach warning level. No exceedance of threshold was observed during the growing season in 2014. In 2015, composite chlorophyll *a* concentrations recorded ranged from 2.2 µg/L to 5 µg/L during the growing season at all open water locations in Boulder, Virgin, Temple, Gregg basins and Overton Arm. This indicates

that Lake Mead has sustained a long (1999 to 2015) period of high aesthetic water quality based on the chlorophyll *a* parameter.

In 2014, chlorophyll *a* concentrations sampled from 5 locations in Lake Mohave between January and July ranged from 0.5 µg/L to 1.6 µg/L (BOR data), however, no routine chlorophyll *a* concentration data for Lake Mohave were available at this time of this assessment.

Secchi depth

Water clarity (Secchi depth) at open water sampling stations in Lake Mead were generally within the clear water range between 2003 and 2015, except for Gregg Basin where Secchi depth consistently fell in the moderate range, where single monthly averages were more than 3 m but less than 4.5 m (Figure 4.4.2-1).

Between 2000 and 2009, the overall trend in Boulder Basin was of increasing clarity, with the 12-month smoothed average range from 8 to 12 meters. Currently, water clarity in Bolder Basin remains within the clear water high aesthetic value range (Figure 4.4.2-1); however, water clarity in Boulder Basin has been trending downward since 2010.

Secchi depth has been measured at Overton Arm on a quarterly basis; therefore, no 12-month (yearly) smoothed averages could be calculated. Figure 4.4.2-2 shows quarterly Secchi depths recorded at Overton Arm. No measurement reached the moderate Secchi depths threshold of single monthly Secchi depth criteria of less than 4.5 m (Figure 4.4.2-2).

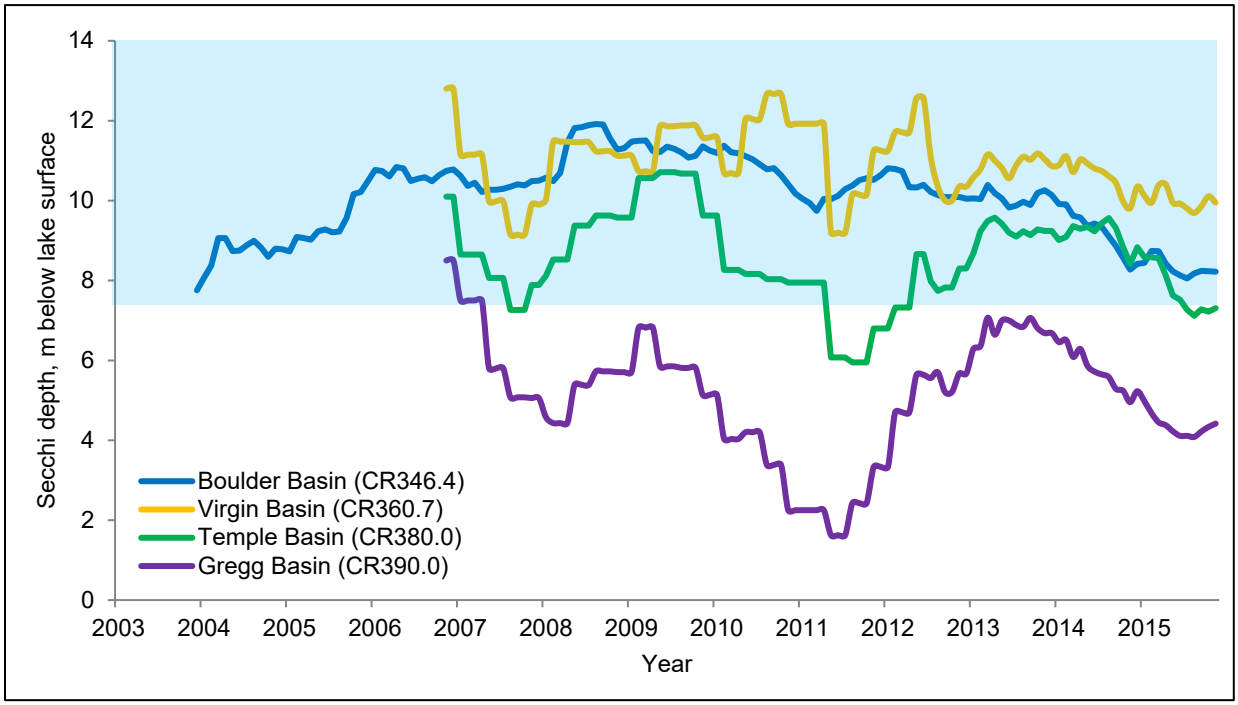


Figure 4.4.2-1. Average monthly Secchi depth at Boulder, Virgin, Temple, and Gregg basins, 2003–2015. Values greater than 7.62 m (25ft – blue shading) indicate good water clarity by criteria defined in the Lake Mead NRA Recreation Suitability Guidelines (Lake Mead NRA, 2015).

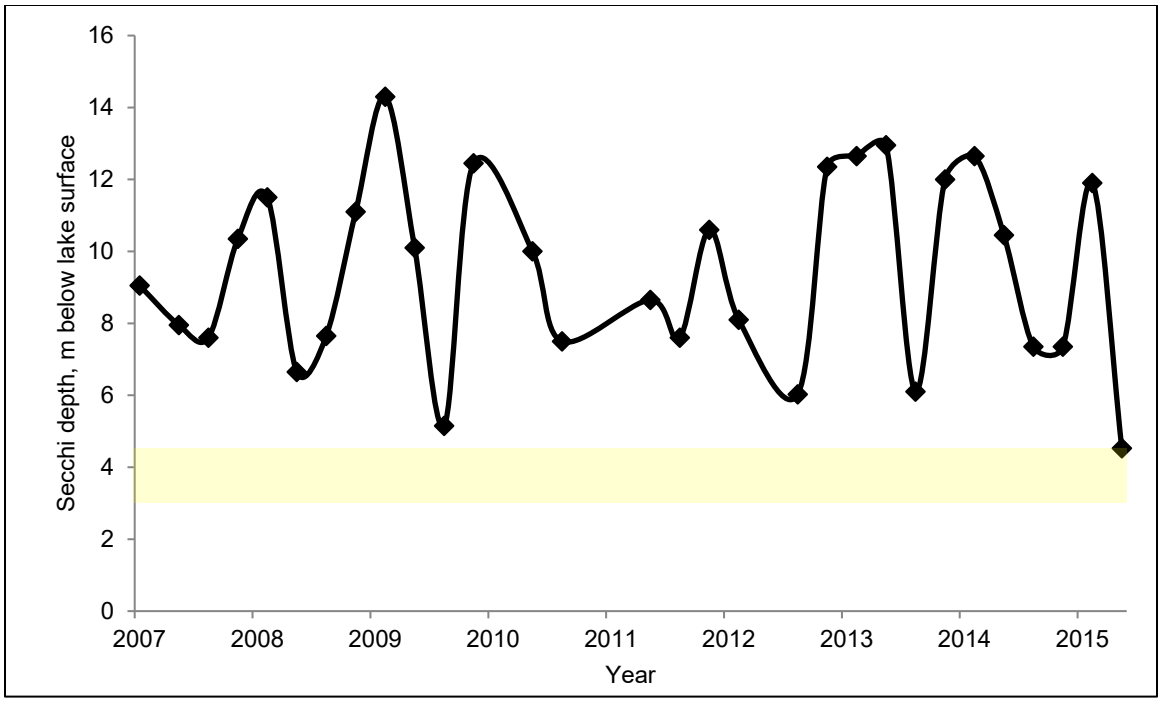


Figure 4.4.2-2. Quarterly Secchi depth measurements at Overton Arm, 2007–2015. Monthly measurements less than 4.5 m but more than 3m (15ft and 10 ft, respectively – yellow shading) warrants moderate concern for water clarity based on aesthetics criteria defined in the Lake Mead NRA Recreation Suitability Guidelines (Lake Mead NRA, 2015).

Water clarity (Secchi depth) at Lake Mohave sampling locations were generally within the clear water range between 2007 and 2014, except at Willow Beach which is located in a riverine setting (Figure 4.4.2-3). Water clarity has declined since 2010 and 2011 at Placer Cove, Cottonwood Cove, and Katherine's Landing. Willow Beach has shown increasing clarity in recent years (Figure 4.4.2-3).

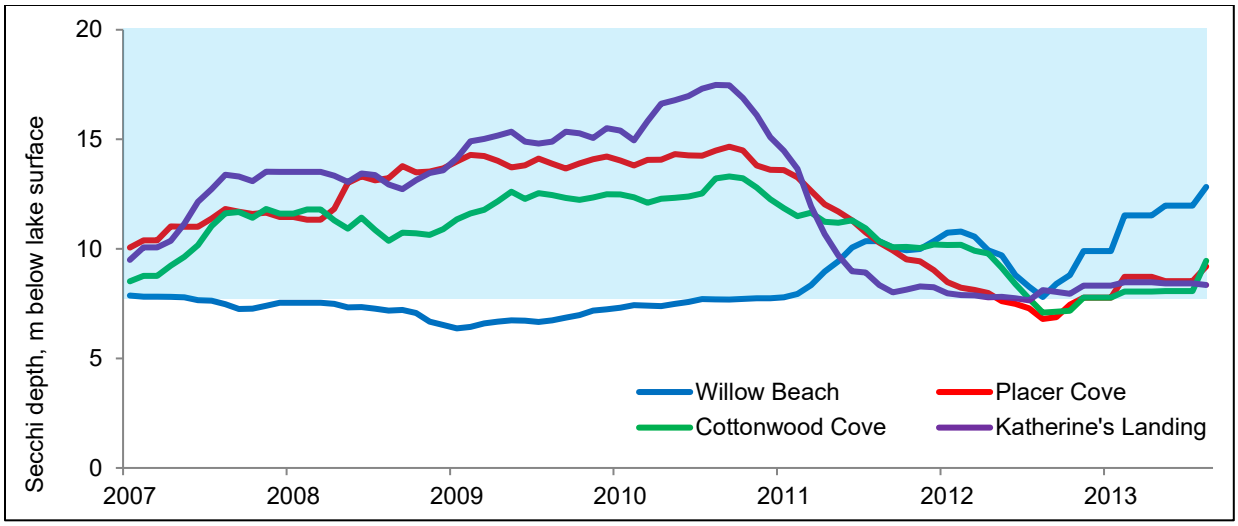


Figure 4.4.2-3. Average monthly Secchi depth for Lake Mohave, 2007–2014. Values greater than 7.62 m (25ft – blue shading) indicate good water clarity by criteria defined in the Lake Mead NRA Recreation Suitability Guidelines (Lake Mead NRA, 2015).

Assessment Confidence and Key Data Gaps

Assessment confidence is moderate. While long-term monitoring data from Lake Mead were available for analysis for chlorophyll *a* and Secchi depth, Lake Mohave did not have sufficient chlorophyll *a* to assess current condition and trend. Consistent sampling of aesthetic quality indicators in Lake Mohave is lacking and should be implemented.

While aesthetic qualities are not related to human health, requirements under the Clean Water Act to maintain existing high water quality values (anti-degradation) does apply to water clarity and non-toxic noxious algae blooms. In addition, aesthetic quality is an important element to public perceptions of the value of a water recreation area. Therefore, monitoring of aesthetic quality parameters in lakes Mead and Mohave is important for park management to ensure park mandate, such as providing an outstanding water-based recreational setting is met.

4.4.3. Literature Cited

Cizdziel, J., Hinners, T., Cross, C., & Pollard, J. (2003). Distribution of Mercury in the Tissues of Five Species of Freshwater Fish from Lake Mead, USA. Journal of Environmental Monitoring, 5:802–807.

Cizdziel, J., Hinners, T., Pollard, J., & Heithmar, E. C. (2002). Mercury Concentration in Fish from Lake Mead, USA, Related to Fish Size, Condition, Trophic Level, Location, and Consumption Risk. Archives of Environmental Contamination and Toxicology, 43:309–317.

Edvardsen, B., & Imai, I. (2006). The Ecology of Harmful Flagellates with Prymenesiophyceae and Rapidophyceae. Ecological Studies, 189:67–69.

Holdren, G., Horn, M., & Lieberman, D. (2008). The Limnology of Lake Mead, Arizona-Nevada, 2006 Report of Findings. Denver, CO: Bureau of Reclamation, Technical Service Center.

Kramer, J. (2009). Mercury Concentrations in Muscle Tissue from Sportfish in Lake Mead, Nevada. Las Vegas, NV: University of Nevada, Las Vegas, M.P.H. Thesis.

Kramer, J., & Gerstenberger, S. (2010). Mercury Concentration in Muscle Tissue from Sportfish in Lake Mead, Nevada. Lake and Reservoir Management, 26:240–248.

LaBounty, J., & Burns, N. (2005). Characterization of Boulder Basin, Lake Mead, Nevada-Arizona, USA-Based on analysis of 34 Limnological Parameters. Lake and Reservoir Management, 21:277–307.

Lake Mead NRA. (2015). Recreation Suitability Guidelines. National Park Service.

NDOW. (2016). Health Advisory Status of Southern Nevada Waters. Retrieved from Fish: http://www.ndow.org/Fish/Fish_Safety/Mercury/Health_Advisory_Status_of_Southern_Nevada_Waters/

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region.

NPS. (2015a). Foundation Document. Lake Mead National Recreation Area, Arizona and Nevada: National Park Service, U.S. Department of the Interior.

NPS. (2015b, March 13). Swimming Advisory issued at Lakes Mead, Mohave. Retrieved from Lake Mead National Recreation Area: http://www.nps.gov/lake/learn/news/2015-swimming-advisory.htm

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

Sager, D., Barkoh, A., Buzan, D., Fries, L., Glass, J., Kurten, G., Swanson, E. (2008). Toxic Prymnesium parvum – A Potential Threat to U.S. Reservoirs. In M. Allen, S. Sammon, & M. Maceina (Eds.), Balancing Fisheries Management and Water Uses for Impounded River Systems (pp. 261–273). Bethesda, MD: American Fisheries Society Symposium.

SNWA. (2016). Water Quality Report, Southern Nevada Water System. Southern Nevada Water Authority. Retrieved from https://www.snwa.com/wq/report.html

Southard, G., Fries, L., & Barkoh, A. (2010). Prymnesium parvum – The Texas Experience. Journal of the American Water Resources Association, 46:14–23.

Tietjen, T. (2015). Microcystis in Lakes Mead, Mohave and Havasu: 2014–2015. American Water Works Association Annual Conference and Exposition. Anaheim, CA.

USEPA. (2001). Water Quality Criterion for the Protection of Human Health: Methylmercury. Washington, D.C.: Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency.

USEPA. (2009). National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. Washington, D.C.: U.S. Environmental Protection Agency, Office of Water and Office of Research and Development.

USEPA. (2015a, December 2). 2012 Recreational Water Quality Criteria. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/wqc/2012-recreational-water-quality-criteria

USEPA. (2015b, October 19). Basic Information about Mercury. Retrieved from United States environmental protection Agency: http://www.epa.gov/mercury/basic-information-about-mercury

USEPA. (2015c, October 19). How People are Exposed to Mercury. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/mercury/how-people-are-exposed-mercury

Weber, S., & Janik, J. (2010). Prymnesium parvum Bloom in a Nevada Reservoir. LakeLine-A Publication of the North American Lake Management, 30:27–31.

WHO. (2003). Guidelines for Safe Recreational Water Environments. Geneva: World Heath Organization.

4.5. Stressors and Disturbance Regimes

4.5.1. Contaminants

A summary of the parameters used assess contaminants are shown in Table 4.5.1-1.

Table 4.5.1-1. Assessment outcome of condition status and trend of contaminants.

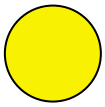
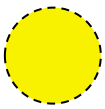
Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Volatile organic compounds (VOCs)	• Concentration related to standards or published guidelines that support aquatic life • Safety of drinking water, if data available; or qualitative description.		VOCs concentrations at boat launching facilities and marina locations at both lakes Mead and Mohave are greater than in open lake waters. However, no exceedances of legal criteria or elevated levels at both open water and nearshore locations were detected. Concentrations of VOCs in ambient water do not exceed USEPA standards for human health. Boating regulations introduced in the Lake Mead NRA Management Plan (2002) for the elimination of two-stroke personal watercraft on lakes Mead and Mohave by 2013 have resulted in decreased concentrations detected at lower Las Vegas wash.
Endocrine disrupting contaminants (EDCs)	• Concentration related to standards or published guidelines that support aquatic life • Safety of drinking water, if data available; or qualitative description.		EDCs present at trace concentrations in lakes Mead and Mohave. Studies have shown that the endocrine system and reproduction in aquatic biota have been altered by some of these chemicals at Las Vegas Bay and Willow Beach. However, few or no effects have been detected from fish collected at Lake Mead proper. Overall, despite detection of EDCs at Lake Mead, concentrations are not seen at levels currently known to pose a problem to human health for drinking water or the recreating public, but have been documented to cause a number of health effects to individual fish. Insufficient data to deduce a trend.
Pharmaceutical Compounds and Personal Care Products (PPCPs)	• Concentration related to standards or published guidelines that support aquatic life • Safety of drinking water, if data available; or qualitative description.		PPCPs present at trace concentrations in Lake Mead NRA. Limited studies have been conducted regarding the effects of PPCPs to human health at environmental exposure levels. However, Rosen et al., (2012) concluded that PPCPs are not seen at levels currently known to pose a problem to human health for drinking water or recreation. Insufficient data to deduce a trend

Table 4.5.1-1 (continued). Assessment outcome of condition status and trend of contaminants.

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Mercury (Hg)	• Concentration related to standards or published guidelines that support aquatic life • Safety of drinking water, if data available; or qualitative description.		No exceedances of legal criteria or elevated levels potentially harmful to aquatic life, birds, or the safety of drinking water.
Selenium (Se)	• Concentration related to standards or published guidelines that support aquatic life • Safety of drinking water, if data available; or qualitative description.		While selenium concentration is not an issue for Lake Mead in terms of meeting safe drinking water standards, concerns for elevated concentration of selenium to aquatic life and birds are warranted as selenium concentrations from open water locations did exceed the selenium criterion for protection of aquatic life in for lentic waters (1.5 µg/L) in 2015. Overall, selenium concentrations have decreased from 2008 to 2015 in Lake Mead.
Perchlorate (ClO_4)	• Concentration related to standards or published guidelines that support aquatic life • Safety of drinking water, if data available; or qualitative description.		Perchlorate entering the Las Vegas Wash has been reduced approximately 90% since 1997 with remediation efforts undertaken by NDEP. Except for one station in Las Vegas Bay, perchlorate concentrations detected at all other stations currently meet the NDEP provisional drinking water standard (≤18 µg/L). Occasional exceedances have been observed in the spring and summer at Las Vegas Bay in the past 10 years, but not in the fall or winter. Insufficient data to deduce a trend for Lake Mohave.
Bromide (Br)	• Concentration related to standards or published guidelines that support aquatic life • Safety of drinking water, if data available; or qualitative description.		According to the 2014 and 2015 water quality reports issued by the LVVWD, bromate concentration in drinking water averaged between 0.007 and 0.008 mg/L, thus did not exceed the USEPA standard. Data not available for Lake Mohave.
Contaminants overall			–

Description

Significant alterations to the environment and community structure by contaminants can affect aquatic biota and foodweb dynamics within lakes Mead and Mohave. Contaminants and health

concerns can impact drinking water quality can be triggered if contaminant concentrations exceed USEPA standards for safe drinking water. Human health can be at risk when contaminants are present in water at elevated concentrations, often for extended periods of time. Humans can be exposed to these contaminants when drinking raw water or when eating fish and shellfish from contaminated waters since these contaminants can bioaccumulate in these organisms. Therefore, examination of the status and trends of contaminants in the water column of lakes Mead and Mohave is important (Table 4.5.1-2).

Table 4.5.1-2. A total of 7 indicators were examined for this resource attribute.

Indicators	Description
Volatile organic compounds (VOCs)	Gasoline-derived volatile organic compounds (VOCs) are toxic to varying degrees. Therefore, they are a potential source of environmental pollution and pose a health hazard. VOCs, known as BTEX compounds (benzene, toluene, ethylbenzene, and xylenes), oxygenated additives such as methyl tert-butyl ether (MTBE), and polycyclic aromatic hydrocarbon (PAH) compounds, e.g. pyrene, are produced during combustion of gasoline from motorized watercraft and can be detected in lakes Mead and Mohave. Benzene is thought to be carcinogenic and long-term, chronic exposures can have a harmful effect on bone marrow tissues that form blood cells. With both acute and chronic exposures, toluene and xylenes can cause central nervous system dysfunction and narcosis. Acute exposures to ethylbenzene can lead to respiratory issues and chronic exposures can damage the liver and kidneys (Crater, 2000). Benzon(a) pyrene is a carcinogen and chronic exposures can lead to reproductive difficulties (USEPA, 2015a).
Endocrine disrupting contaminants (EDCs)	There has been a growing awareness of possible adverse effects in humans from exposure to chemicals that can interfere with the endocrine system. These chemicals are known as endocrine disrupting compounds (EDCs). EDCs mimic the response of normal calls, modify or block the action of hormones, disrupt normal physiology, and can lead to reproductive effects in aquatic organisms (Rosen et al., 2012; USEPA, 2015b). In laboratory studies, exposures to EDCs have been associated with potential human health effects, such as development malformations, interference with reproduction, increased in cancer risk, and disturbances in the immune and nervous system function (USEPA, 2015c). Strong evidence of adverse developmental and reproductive effects on fish has been found in the field. However, limited evidence exists regarding their effects to human health at environmental exposure levels (USEPA, 2015c). Studies on the fate and transport of EDCs and other contaminants of emerging concern (CECs) at Lake Mead began in 1996 with the study conducted by Bevans et al. (1996) identifying the occurrence of endocrine disruption in common carp. 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 (Figure B-1); however, the cause of the endocrine disruption was unknown at the time. Subsequent work used toxicity identification and evaluation methodology to screen Lake Mead for estrogenic compounds. Snyder et al. (2001) provided a link between endocrine disruption and natural and synthetic hormones present in Las Vegas Wash. Studies, such as these, provided better understanding of the possible impacts of EDCs on aquatic life, in particular for sportfish and endangered native fish species in lakes Mead and Mohave.

Table 4.5.1-2 (continued). A total of 7 indicators were examined for this resource attribute.

Indicators	Description
Pharmaceutical and Personal Care Products (PPCPs)	Pharmaceuticals and personal care products (PPCPs) are contaminants of emerging concern (CECs). PPCPs are increasingly being detected at low levels in surface water. There is concern that these compounds may have an impact of aquatic life and humans that consume these aquatic organisms (USEPA, 2015b). Wastewater treatment processes typically can remove PPCPs to levels below detection but they are not completely removed prior to effluent discharge, so they may be directly released into Lake Mead via Las Vegas Wash and other tributaries (Rosen et al., 2012). PPCPs may demonstrate low acute toxicity but cause significant reproductive effects at low levels of exposure. In addition, exposure effects during the early stages of life may not be observed until adulthood. Many PPCPs can also act as EDCs (USEPA, 2015b).
Mercury (Hg)	Nearly 87 percent of mercury present in the environment today is due to human activities, including mining, mineral extraction, and coal-fired power plants (USEPA, 2015d). These activities 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 (Rosen et al., 2012). For this section, the assessment focuses on the concentration of mercury in lakes Mead and Mohave water column. Chronic exposures of mercury in drinking water can lead to kidney damages (USEPA, 2015a). Assessment of the concentrations of organic methyl mercury found in Lake Mead's fish is discussed in section 4.4.1.3.
Selenium (Se)	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. However, at elevated concentrations, it is toxic and the threshold between providing a benefit and toxicity is narrow (National Reserach Council Committee on Minerals and Toxic Substances in Diets and Water for Animals, 2005). Selenium is a bioaccumulative contaminant. In aquatic environment, risks primarily stem from aquatic life consuming food that is contaminated with selenium rather than direct exposure. Selenium can affect the growth and survival of juvenile fish and reproductive health of aquatic biota. Excessive selenium can also cause skeletal deformities in birds (USEPA, 2016b). Low selenium concentrations in Lake Mead itself resulted in a focus on concentrations and loading of selenium in Las Vegas Wash. Monitoring selenium concentrations in Las Vegas Wash is important because soils in up-gradient areas in Las Vegas Valley are known to contain selenium, which may leach into the shallow groundwater that enters the Wash and flows into Lake Mead (Zhou et al., 2004).
Perchlorate (ClO_4)	Perchlorate (ClO_4) is a naturally occurring and manufactured oxidizer derived from inorganic salts. Perchlorate 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 (e.g. BMI Complex in Henderson, NV) near and up-gradient 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, and efforts to remove the perchlorate from groundwater and surface water have been underway for many years (Urbansky, 1998; Boralessa, 2001). Perchlorate can act as an endocrine disruptor and impairs the ability of the thyroid gland to produce hormones needed for normal growth and development (USEPA, 2015e).

Table 4.5.1-2 (continued). A total of 7 indicators were examined for this resource attribute.

Indicators	Description
Bromide (Br)	Bromide (Br), in the form of potassium bromide, is a by-product of salt used in water conditioning commonly used in Southwest United States desert communities. Bromide enters Lake Mead mainly through urban drainage from the Las Vegas Valley via Las Vegas Wash. A byproduct of drinking water disinfection, bromate is formed when ozone reacts with bromide in the ozonation stage when treating drinking water (LaBounty & Burns, 2005). Bromate is a known carcinogen and is regulated in drinking water standards. Higher bromide concentrations in source water can result in production of more bromate in drinking water supplies.

Data and Methods

Table 4.5.1-3 shows the data and methods used to assesss contaminants.

Table 4.5.1-3. Indicators and measurements used in the assessment of contaminants.

Indicator(s)	Measurement(s)	Scale of Analysis
Volatile organic compounds (VOCs)	Concentration related to standards or published guidelines that support aquatic life and safety of drinking water if data available; or qualitative description.	Lake; Tributaries
Endocrine disrupting contaminants (EDCs)	Concentration related to standards or published guidelines that support aquatic life and safety of drinking water if data available; or qualitative description.	Lake; Tributaries
Pharmaceutical and Personal Care Products (PPCPs)	Concentration related to standards or published guidelines that support aquatic life and safety of drinking water if data available; or qualitative description.	Lake; Tributaries
Mercury (Hg)	Concentration related to standards or published guidelines that support aquatic life and safety of drinking water if data available; or qualitative description.	Lake; Tributaries
Selenium (Se)	Concentration related to standards or published guidelines that support aquatic life and safety of drinking water if data available; or qualitative description.	Lake; Tributaries
Perchlorate (ClO_4)	Concentration related to standards or published guidelines that support aquatic life and safety of drinking water if data available; or qualitative description.	Lake; Tributaries
Bromide (Br)	Concentration related to standards or published guidelines that support aquatic life and safety of drinking water if data available; or qualitative description.	Lake; Tributaries

All public water systems must ensure that the water they provide meets the USEPA National Primary Drinking Water Regulations (NPDWRs) standards and must test the water according to schedules in the regulations (USEPA, 2015a). Primary data presented for VOCs, Se, Hg, ClO_4, and Br were downloaded from the SNWA database. See Table 4.5.1-1 for a list of monitoring stations where data were examined; Table B-1 and Figure B-3 for monitoring locations and descriptions.

Limited information was available for VOCs in lakes Mead and Mohave waters. Two studies (Crater, 2000; Lico & Johnson, 2007) and snapshot collection of VOCs concentration by USGS and SNWA were available. Lico and Johnson (2007) investigated the distribution of VOCs from 2004 to 2006 in Lake Mead (Las Vegas Wash) and Lake Mohave. They sampled 8 sites in Lake Mohave, 12 sites spread across all major basins in Lake Mead, 2 sites in Las Vegas Wash, (Figure 4.5.1-1 and Figure 4.5.1-2). Water samples for gasoline-related VOCs were collected using a stainless-steel grab sampler. Semipermeable membrane sampling devices (SPMDs) were used to sample PAHs.

Concentrations of perchlorate (ClO_4), and bromide (Br) were analyzed from the water samples collected for nutrient analysis for Las Vegas Bay and Boulder Basin stations (Table 4.5.1-4). ClO_4 sampling for Overton Arm and Colorado River mainstem locations (Gregg, Temple, and Virgin Basins) were collected monthly from the surface and at the interflow depths of each basin. ClO_4 sampling was discontinued after April 2005 for Overton Arm and Colorado River main stem locations because ClO_4 was rarely detected at these locations.

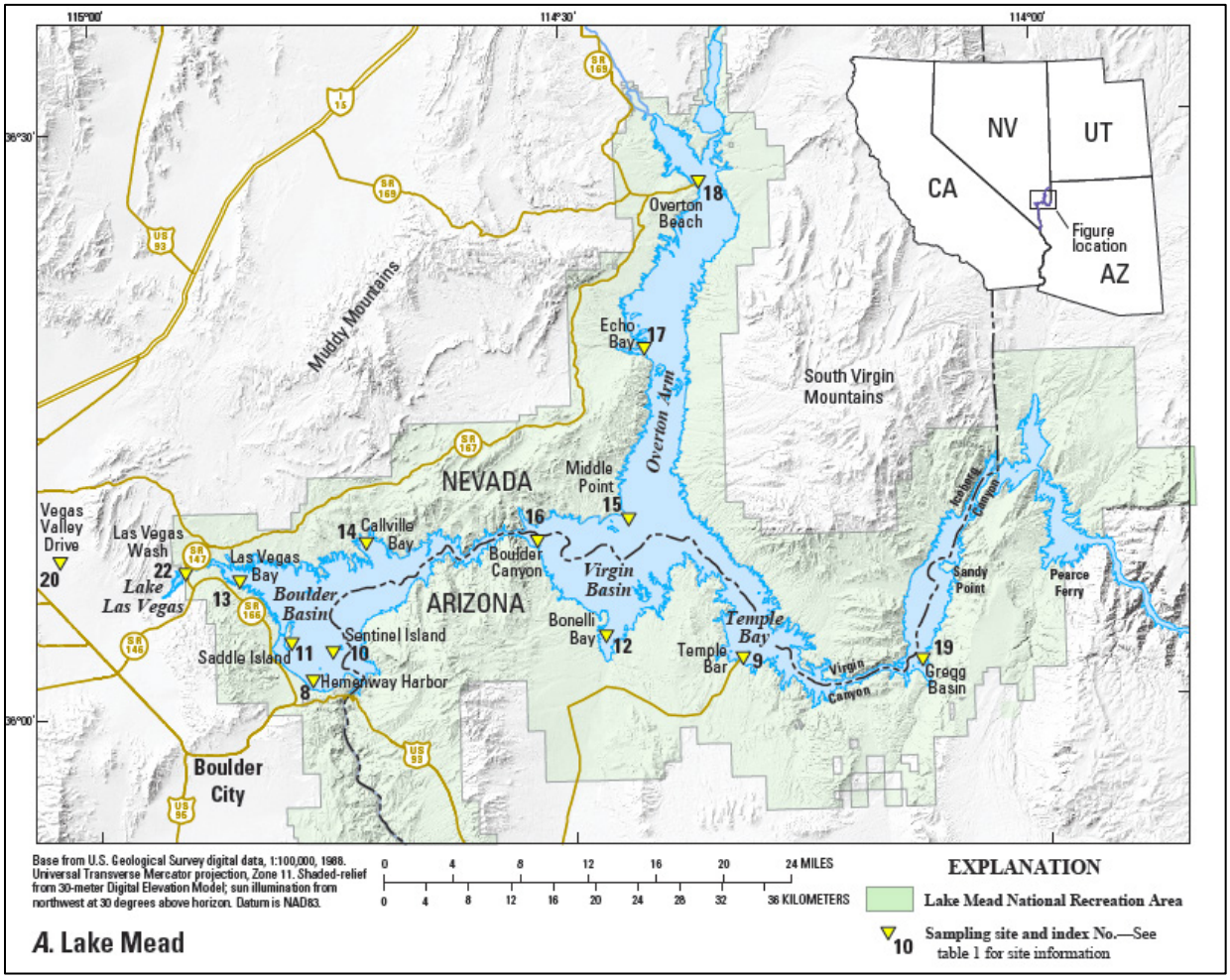


Figure 4.5.1-1. Map showing location of study area and sampling sites for VOC in Lake Mead by Lico & Johnson, 2007.

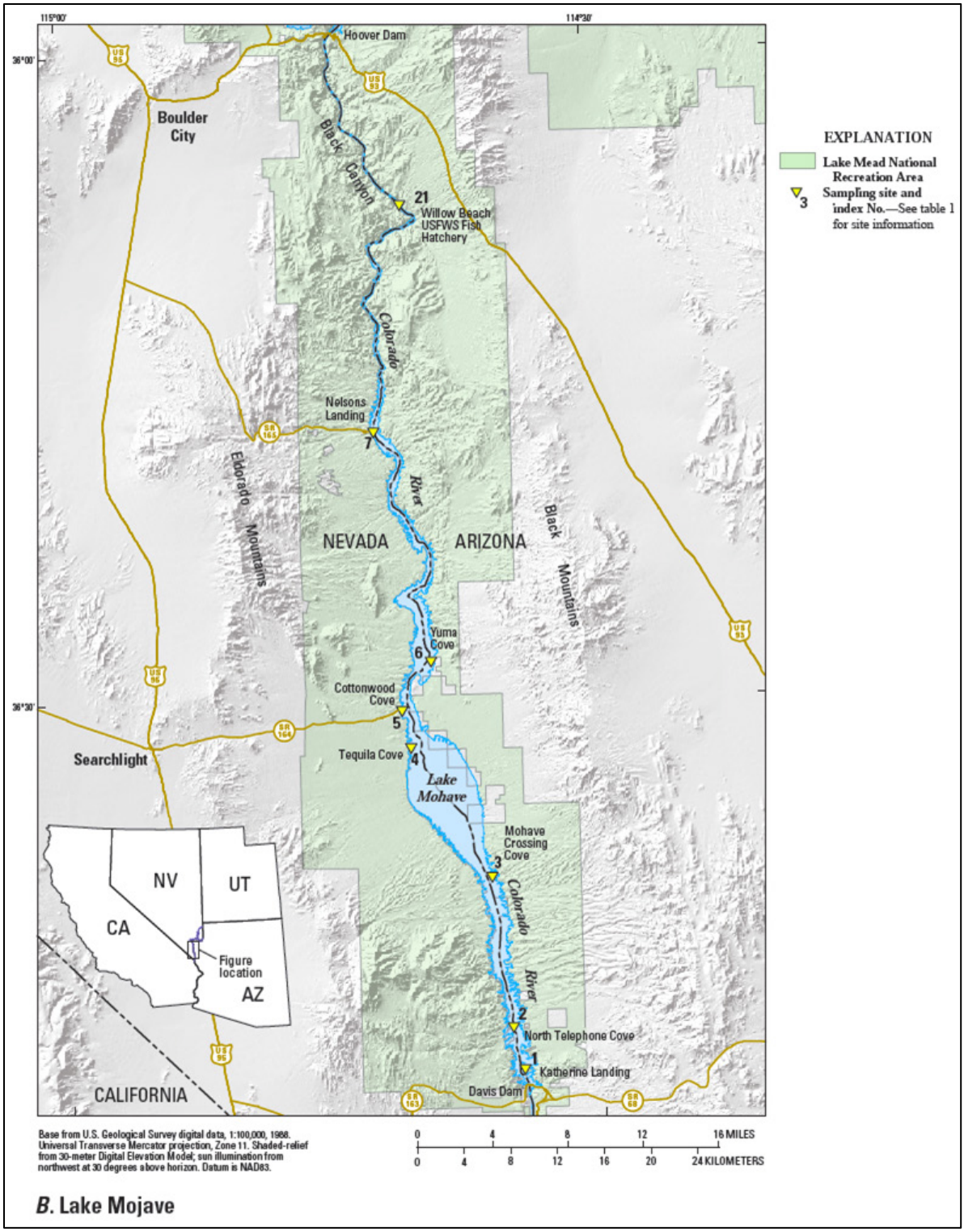


Figure 4.5.1-2. Map showing location of study area and sampling sites for VOC in Lake Mohave by Lico & Johnson, 2007.

Table 4.5.1-4. List of contaminant monitoring sites in Lake Mead NRA from SNWA, BOR, and NPS monitoring programs examined for this assessment. For site coordinates and locations, see Table B-1 and Figure B-3 for monitoring locations and descriptions.

Station ID	VOCs	Se	Hg	Perchlorate	Br	PPCPs
LW0.8	–	√	√	–	–	–
LW0.9	√	–	√	–	–	√
LVB4.15	–	√	–	√	√	–
LVB4.95	–	–	–	√	–	–
CR348.4NW0.8	√	–	–	–	–	–
CR346.4	√	√	–	√	√	√
CR360.7	√	√	–	–	√	–
CR380.0	√	√	–	–	√	–
CR390.0	√	√	–	–	√	–
CR394.0	–	–	–	–	√	–
VR6.0	–	–	–	–	√	–
VR25.1	–	–	√	–	√	–
CR342.0	√	–	√	–	–	√
CR329.7	–	–	√	√	–	–
CR316.34	–	–	–	√	–	–
CR298.5	–	–	–	√	–	–
CR278.0	–	–	–	√	–	–

For this assessment, a summary of existing research regarding the impact of EDCs on aquatic organisms in lakes Mead and Mohave, their associated findings, and their impacts in relations to human health were presented. Any recommended water quality standards or criteria for any EDCs that have been identified in lakes Mead and Mohave for the protection of aquatic life will be noted here. Most the information presented in this LRCA regarding EDCs has been summarized from Rosen et al., 2012.

Sparse data exist on the long-term bioaccumulation of CECs (EDCs and PPCPs) in lakes Mead and Mohave, as well as other reservoirs throughout the world. Snyder et al. (1999) collected water samples from five locations in Las Vegas Wash and in Lake Mead in April and September of 1997 and analyzed concentrations of selected estrogenic compounds in the water. Estrogenic compounds are commonly found in oral contraception. Snyder et al. (2001) investigated various locations in Las Vegas Wash and Boulder Basin between 1997 and 1999 to determine which PPCPs entering Lake Mead may induce endocrine disruptive effects on aquatic life and to identify previously unreported xenobiotic compounds. Details on methods used for analysis can be found in Snyder, et al., 2001. Boyd and Furlong (2002) conducted a reconnaissance study to investigate the occurrence of selected PPCPs in water samples collected from Lake Mead on the Colorado River and Las Vegas Wash. Data on the concentrations of selected PPCPs data in Lake Mead waters were also downloaded from the SNWA database and utilized for this assessment. A subset of PPCPS and sampling locations

where data were compiled was selected based on Boyd and Furlong (2002). See Table 4.5.1-4 for a list of monitoring stations where data were examined as well as Table B-1 and Figure B-3 for monitoring locations and descriptions.

Reference Conditions

Table 4.5.1-5 shows the reference conditions used to assess contaminants.

Table 4.5.1-5. Reference conditions of contaminants used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
• Volatile organic compounds (VOCs)	Chronic exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life and the safety of drinking water.	Slight or occasional exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life the safety of drinking water.	Rare or no exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life the safety of drinking water.
• Selenium (Se) • Mercury (Hg) • Perchlorate (ClO_4) • Bromide (Br)	Chronic exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life and the safety of drinking water.	Slight or occasional exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life the safety of drinking water.	Rare or no exceedance of published NDEP water quality standards, or USEPA criterion guidelines that is potentially harmful to aquatic life the safety of drinking water.
• Endocrine disrupting contaminants (EDCs)[1]	–	–	–
• Pharmaceutical and Personal Care Products (PPCPs)[1]	–	–	–

[1] No established water quality criteria available. Concentration trends of selected compounds were examined for condition assessment.

The Congress passed the Safe Drinking Water Act (SDWA) in 1974 and then amended the SDWA in 1984 and in 1996 to authorized risk-based standard-setting for contaminants that may affect public health (USEPA, 2015e). The National Primary Drinking Water Regulations (NPDWRs) are legally enforceable standards that apply to all public water system and regulate over 65 contaminants. The rules are intended to provide public health protection by limiting the levels of contaminants in drinking water. USEPA set a Maximum Contaminant Level (MCL) for each contaminant. MCLs are enforceable standards of maximum levels of contaminants allowed in drinking water. For this assessment, MCLs for some VOCs, Se, Hg, bromate, and THMs were used as thresholds for the reference conditions (Table 4.5.1-6).

The USEPA has also issued a separate set of ambient water quality criteria for human health under the Clean Water Act section 304 (a). The human health criteria specify the concentration threshold of

a chemical before there is a threat to human health. These criteria are established with consideration of body weight, drinking water consumption rate, fish consumption rate, bioaccumulation factors, health toxicity values, and relative source contributions (USEPA, 2016a). The human health ambient water quality criteria represent specific levels of chemicals or conditions in a water body that are not expected to cause adverse effects to human health. Recommendations are provided for "water + organism" and "organism only" human health criteria for states and authorized tribes to consider when adopting criteria into their water quality standards (USEPA, 2016c). For this assessment, these recommendations for VOCs were also considered as thresholds for the reference conditions (Table 4.5.1-6). The human health ambient water quality recommendations are more stringent than the NPDWRs standards.

Table 4.5.1-6. USEPA National Primary Drinking Water Regulations primary standards and recommendations for contaminant levels in drinking water and human health ambient water quality.

Class of Contanimant	Contaminants	USEPA Maximum Allowable Contaminant Level (MCL, µg/L or ppb)	Human health for the consumption of water and organism (µg/L)[4]	Human health for the consumption of organism only (µg/L)[4]
VOCs	Benzene	5[1]	0.58–2.1	16–58
	Toluene	1000[1]	57	520
	Ethylbenzene	700[1]	68	130
	Xylene (total)	10000[1]	–	–
	Benzo(a)pyrene (PAH)	0.2[1]	0.00012	0.00013
Selenium	Aquatic life (30-day average) – Lentic	1.5[2]	–	–
	Aquatic life (30-day average) – Lotic	3.1[2]	–	–
	Drinking water	50[1]	–	–
	Mercury (inorganic)	2[1]	–	–
	Perchlorate (ClO_4)	≤ 18 µg/L[3] Provisional action level for safe drinking water	–	–
	Bromide (Br)	≤ 0.01 mg/L[1] USEPA MCL for bromate in drinking water	–	–

[1] USEPA, Table of Regulated Drinking Water Contaminants, 2015

[2] USEPA, Final Aquatic Life Ambient Water Quality Criterion for Selenium (Freshwater) 2016

[3] NDEP, Defining a Perchlorate Drinking Water Standard, 2015

[4] USEPA, Human Health Water Quality Criteria, 2016

One should note that the different first two selenium MCLs listed in Table 4.5.1-6 were based on the USEPA Aquatic Life Ambient Water Quality Criterion. The USEPA has implemented a revision to the chronic aquatic life criterion for selenium in freshwater which defines the concentration of selenium in water and fish tissue that is considered safe for aquatic life (USEPA, 2016d). These criterions are different from the SDWA drinking water standard.

A byproduct of drinking water disinfection, bromate is formed when ozone reacts with bromide in the ozonation stage when treating drinking water (LaBounty & Burns, 2005). Bromate is a known carcinogen and can increase the risk of cancer at concentrations higher than the maximum acceptable concentration level (MCL) of 0.01 mg/L in drinking water (USEPA, 2015a).

In 2011, the USEPA determined that perchlorate meets the criteria for regulation under the Safe Drinking Water Act. Since then, USEPA has initiated the process to develop and establish a national primary drinking water regulation, which is a legally enforceable standard that applies to public drinking water supplies. An Interim Lifetime Drinking Water Health Advisory has been issued while the enforceable standard is in development. NDEP has issued a provisional drinking water standard for perchlorate based upon USEPA guidance (NDEP, 2015; Table 4.5.1-6).

Currently, there are no USEPA ambient water quality criteria for CECs, including EDCs and PPCPs established for the protection of aquatic life. USEPA have developed a "White Paper Aquatic Life Criteria for Contaminants of Emerging Concern: Part I Challenges and Recommendations" in 2008 to identify the technical issues and recommendations to serve as a basis for modifying the 1985 guidelines for deriving numerical national water quality criteria for CECs. These modifications should enable the Agency to better address CECs and develop ambient water quality criteria when appropriate for protection of aquatic life by making the best use of available science (USEPA, 2015b). At the time of this assessment, no numerical criteria were available as thresholds for the reference conditions of CECs. For parameters where no recommended water quality standards or criteria are available, conditions were assessed based on temporal trends observed, where available.

Condition and Trend

Volatile organic compounds (VOCs)

Lico and Johnson (2007) conducted a study at lakes Mead and Mohave between 1999 and 2006 and detected VOCs at all sampled sites. They found that compounds concentrations increased as the boating season progressed and decreased to less than detectable levels in the winter when boating activities are much reduced. VOCs were also at their highest concentrations near marinas and popular launching areas suggesting that motorized watercrafts are the main VOCs source to the Lakes. Median BTEX concentrations in the lakes ranged from 0.17 µg/L at Bonelli Bay in Virgin Basin in Lake Mead to 7.52 µg/L at Katherine Landing in Lake Mohave (Figure 4.5.1-1 and Figure 4.5.1-2) which were under the USEPA MCLs for BTEX. Among the BTEX compounds, toluene generally was the highest concentration at most sites (0.01–9.05 µg/L) with the xylene isomers (0.01-7.68 µg/L) being the second highest (Lico & Johnson, 2007). Benzene concentrations ranged from <0.01 µg/L to 1.25 µg/L among all sampled sites (Lico & Johnson, 2007). In general, BTEX concentrations

were higher in Lake Mohave (median: 2.2 µg/L) than in Lake Mead (median: 0.7 µg/L). Despite higher concentrations, concentrations of all BTEX compounds (each compound) at all sites (Lakes Mead and Mohave and Las Vegas Wash) for all seasons were significantly lower than NPDWRs MCLs and Human Health Water Quality Criteria for consumption of water and organisms (Table 4.5.1-2; Lico & Johnson, 2007). Examination of median sum of BTEX concentrations shows that all of the highest BTEX concentrations were detected at locations where there are launching facilities and marinas and followed the seasonal boating pattern (Lico & Johnson, 2007). These sites include Katherine Landing and Cottonwood Cove in Lake Mohave and Hemenway Harbor, Temple Bar, Callville Bay, and Echo Bay in Lake Mead (Figure 4.5.1-1 and Figure 4.5.1-2).

VOC concentrations from the SNWA database indicated that BTEX was present, but concentrations in the waters of Virgin, Temple, and Gregg basins and near Hoover Dam were less than analytical detection limits (0.5 µg/L) in 2003 and 2004. Water samples were collected in the open water of Boulder Basin in 2006, and all BTEX compounds concentrations were less than the detection limit (0.5 µg/L). Therefore, concentrations of BTEX in these basins did not exceed both the human health for consumption of water and organism and for consumption of organism-only criteria (Table 4.5.1-2).

BTEX and benzo(a)pyrene concentration data collected from the lower Las Vegas Wash between 2007 and 2015 also had concentrations below detection limits. Concentrations of benzo(a)pyrene, a PAH, were less than the detection limit of the analytical method (0.001µg/L) at various depths in 2004 in Boulder Basin (CR346.4). At lower Las Vegas Wash, benzo(a)pyrene had concentrations less than the detection limits between 2007 and 2015. However, detection limits for the analytical method used for benzo(a)pyrene were between 0.07 and 10 µg/L. These detection limits were higher than the USEPA human health water quality criteria, thus it is not possible to determine whether the threshold for benzo(a)pyrene had been exceeded. (Table 4.5.1-2)

Lico and Johnson (2007) found the distribution of PAHs in lakes Mead and Mohave followed a similar pattern to that of BTEX compounds between 1999 and 2006. The most commonly detected PAH compounds were fluoranthene, pyrene, and naphthalenes. Bioavailable PAH concentrations are relatively non-toxic as determined by Microtox EC50 and Toxicity Index calculations (Lico & Johnson, 2007).

New boating regulations were introduced in the Lake Mead NRA Management Plan (2002) for the phased elimination of two-stroke personal watercraft on lakes Mead and Mohave in hopes to reduce VOCs related to gasoline and boating traffic in Lake Mead NRA. Those restrictions went fully into effect in 2013 with an allowance for watercraft that meet the US Environmental Protection Agency (EPA) 2006 emission standards through the use of direct-injection two-stroke or four-stroke engines.

VOCs concentration data collected from the lower Las Vegas Wash between 2007 and 2015, a period spanning from before to after the new boating regulations were implemented, show samples from all years had BTEX concentrations less than the detection limit, thus within the USEPA MCLs (Table 4.5.1).

Endocrine disrupting contaminants (EDCs)

More than 100 organic compounds have been detected in various media in lakes Mead and Mohave, such as water, sediment, and fish (Rosen et al., 2012). Some of these compounds are toxic to aquatic organisms, are carcinogens, or are thought to be endocrine disruptors. EDCs mimic the response of normal cells and 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, organochlorine compounds, such as polychlorinated biphenyls (PCBs) and dichlorodiphenyl trichloroethane (DDT/DDE, degradation products of DDT), perchlorate, flame retardants (e.g. polybrominated diphenyl ethers, PBDEs), and some heavy metals, such as cadmium (Rosen et al., 2012). EDCs have been detected at trace concentrations in lakes Mead and Mohave waters as they cannot be completely removed by wastewater treatment processes (Rosen et al., 2012).

Between 1995 and 2008, EDCs such as PCBs, PDBEs, organochlorine pesticides, and dioxins have been consistently detected in the water, sediment, and fish of Lake Mead (Bevans, et al., 1996; Covay & Leiker, 1998; Alvarez, et al., 2012). In general, concentrations of organochlorine compounds and dioxins detected in water and sediment from Las Vegas Wash were higher than from Las Vegas Bay, Overton Arm, and Virgin Basin (Bevans, et al., 1996; Covay & Leiker, 1998). This confirms that the main source for EDCs in lakes Mead and Mohave is sourced from Las Vegas Wash as it is the main drainage for natural and urban discharge and treated wastewater effluent from Las Vegas Valley. Areas adjacent to and up-gradient of the Wash have historically been used for production of EDCs such as DDT, PCBs, and dioxins. Concentrations of legacy compounds as these were elevated in the 1980s to levels that may negatively impact the health of down-gradient aquatic ecosystems in Lake Mead. Since 1980, better containment of waste piles have helped to reduce DDT and its breakdown products in Lake Mead sediments, but these compounds are still detected in fish and water in Las Vegas Bay (Bevans, et al., 1996; Goodbred, et al., 2007; Rosen et al., 2010).

More recent information from environmental studies at Lake Mead suggest that EDCs likely include a relatively broad group of organic chemicals, including contaminants of emerging concerns (CECs), such as triclosan, a commonly used antimicrobial (Leiker et al., 2009), several types of fragrances like galaxolide (Osemwengie & Gerstenberger, 2004; Rosen et al., 2010), and pharmaceuticals (Boyd & Furlong, 2002). These organic chemicals have also been detected in lakes Mead and Mohave.

Limited studies have been conducted regarding the effects of EDCs to human health at environmental exposure levels (USEPA, 2015). Therefore, currently there are no established water quality standards specifically identified for endocrine disruptors. However, some of these contaminants (e.g. PCBs and dioxin) are also regulated under the NPDWRS for toxicity. For this assessment, USEPA primary standards for safe drinking water for PCBs (MCL: 0.5 µg /L) and dioxin (MCL: 0.00003 µg /L) were used as surrogate reference conditions. Concentrations of PCBs and dioxin (TCDD) at the lower Las Vegas Wash station were examined. Total PCBs concentrations have been regularly monitored at the lower Las Vegas Wash station between 2011 and 2015, and only trace concentrations were detected in 2012 (below detection limit of 0.049 µg /L). The concentrations of PCBs in the water at Lake Mead have decreased over time since environmental

regulations based the production of PCBs in 1979. PCBs were not detected in samples collected in 2015. Different types of waste-burning incinerators produce dioxin (TCDD). It may also be a breakdown product of triclosan, an antibacterial agent used in deodorants, toothpaste, and other PPCPs. Chronic exposure to dioxin through drinking water could result in reproductive difficulties and increase risk for cancer (USEPA, 2016d). In the Las Vegas Bay sediment core, Rosen and Van Metre (2009) found that concentrations of TCDD have been steadily increased since the completion of Hoover Dam and appeared to correlate with the urbanization and population growth of Clark County, which includes the Las Vegas metropolitan area. Increases urbanization and population growth, which lead to increased area of impervious surfaces and use of triclosan-containing products, may have allowed more TCDD to flow into Las Vegas Wash and bound to sediments at Las Vegas Bay. The discharge from wastewater treatment plants in Las Vegas Wash to Las Vegas Bay is monitored for TCDD biannually between 2007 and 2015. Reporting limit of TDCC varies from year to year and ranged between 0.0000014 to 0.00001 μg /L which were all below USEPA MCL for drinking water dioxin concentrations (0.00003 μg /L).

Between May 1999 and May 2000, Goodbred et al. (2007) found that both the number and concentrations of organic contaminants detected in fish were greater in Las Vegas Bay than in Overton Arm. In addition, many of these contaminants are known or suspected endocrine disrupting compounds, e.g. PCBs, PBDEs, and triclosans (Goodbred, et al., 2007). For example, the average concentrations of PCBs in seven fish sampled from Las Vegas Bay were greater than 0.156 mg/ kg as compared to fish PCB concentrations in Overton Arm of 0.026 μg/kg. Concentrations of PCBs found in fish tissues collected in Las Vegas Bay were greater than the 0.11mg/kg wet weight value calculated by New York State to protect piscivorous wildlife (Newell et al., 1987).

Marr (2007) studied organic contaminants in fish within Lake Mohave, and showed that based on data collected in 2002, DDT metabolites, PDBEs, PCBs, and estrogenic compounds were present in fish tissues. While all concentrations of PCBs in fish tissue were below the 0.11 mg/kg value, PCBs were detected in plasma of both razorback suckers and common carp at levels up to 4 ng/mL (Marr, 2007). However, endocrine disruption in razorback suckers was not found but some indications of endocrine disruption in Carp was found.

Several environmental studies have documented altered health and endocrine effects in some aquatic biota at lakes Mead and Mohave, including reduced testicular growth and sperm quality in male carp from Las Vegas Bay (Bevans, et al., 1996; Goodbred, et al., 2007), and a number of abnormalities in male carp at Willow Beach on Lake Mohave, such as lesions, liver and kidney abnormalities, intersexed ovaries and testicular abnormalities (Hinck, et al., 2006).

Endocrine disruption has been observed in male common carp in Las Vegas Wash and Las Vegas Bay where reduced male hormone levels and the presence of a female egg yolk precursor compared to male fish from a reference site, a sign that feminization was occuring (Bevans, et al., 1996). 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). Subsequently, water sampled from Las Vegas Wash and Bay was found to contain detectable

levels of natural female hormone (estradiol, E2) and the artificial female hormone used in birth control (ethinylestradiol, EE2) (Snyder, et al., 2001).

Results of studies in Lake Mead 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, et al., 1996; Hinck, et al., 2006; Marr, 2007; Goodbred, et al., 2007). Legacy compounds like DDE and PCBs have bioaccumulated through the food chain to higher concentrations and may affect endocrine and reproduction health in aquatic biota and birds.

Overall, despite detection of EDCs at Lake Mead, concentrations are not seen at levels currently known to pose a problem to human health for drinking water or the recreating public but have been documented to cause a number of health effects to individual fish (Rosen et al., 2012).

Pharmaceutical and Personal Care Products (PPCPs)

Snyder et al. (1999) detected very low concentrations of ethnylestradiol (EE2, an estrogenic compound found in oral contraception) in Las Vegas Wash and Las Vegas Bay (ranged between 0.0002 and 0.0005 µg/L). No estrogenic compounds were detected in Boulder Basin in spring and fall of 1997 (Snyder, et al., 1999).

The study conducted by Snyder et al. (2001), using water samples collected between 1997 and 1999 in Las Vegas Wash, Las Vegas Bay, and Boulder Basin, found detectable concentrations of PPCPs (ranged from 0.001 to 0.4 µg/L) at Las Vegas Wash and Las Vegas Bay (Table 4.5.1-7). Except DEET, an active ingredient commonly found in insect repellents, PPCPs were not detected at Boulder Basin sites. Concentrations were greater in samples collected near the confluence of Las Vegas Wash with Lake Mead at Las Vegas Bay.

Table 4.5.1-7. Pharmaceuticals and Personal Care Products (PPCPs) detected in Las Vegas Bay of Lake Mead between 2007 and 2009. Modified from Snyder, et al., 2001.

Compound	Usage	Concentration range (µg/L)
Phenytoin (Dilantin)	Seizure treatment	0.053-0.261
Phenobarbital (Luminal)	Seizure treatment	0.011-0.039
Carbamazepine (Tegretol)	Seizure treatment	0.014-0.035
Primidone (Myidone)	Seizure treatment	0.011-0.13
Hydrocodone	Pain medication	0.006-0.013
Codeine	Pain medication	0.017-0.123
Diazepam (Valium)	Depression	0.003-0.062
Guaifenesin (Robotusin)	Expectorant	0.021-0.052
Pentoxifyline (Trental)	Blood thinner	0.005-0.05
Meprobamate	Antianxiety	Qualitative
Carisoprodol	Muscle spasms	Qualitative
Methocarbamol	Muscle spasms	Qualitative

Table 4.5.1-7 (continued). Pharmaceuticals and Personal Care Products (PPCPs) detected in Las Vegas Bay of Lake Mead between 2007 and 2009. Modified from Snyder, et al., 2001.

Compound	Usage	Concentration range (µg/L)
Mequinol	Skin pigments	Qualitative
Fulvicin	Antifungal	Qualitative
Triclosan	Antibacterial	Qualitative
Acetophenone	Fragrance	Qualitative
o-methoxyacetophenone	Fragrance	Qualitative
Vanillin	Fragrance	Qualitative
Octylphenol	Surfactant (degradation)	0.002-0.023
Nonylphenol	Surfactant (degradation)	0.005-0.308
Bisphenol A	Plasticizer	0.0024
DEET	Insect repellant	0.003-0.268
Oxybenzone	Sunscreen	0.03-0.364
Homomenthyl salicylate	Sunscreen	Qualitative
Acridine	Dye	Qualitative
p-Chloroaniline	Dye	Qualitative
Caffeine	Coffee, tea, etc.	0.01-0.047
Nicotine	Tobacco products	0.005-0.023

Boyd and Furlong (2002) detected 13 of 33 targeted PPCP compounds in at least one water sample collected between October 2000 and August 2001. Sample sites are located in Las Vegas Wash, Las Vegas Bay, Boulder Basin, Virgin Basin, and Echo Bay at Overton Arm. All concentrations detected were less than or equal to 0.2 µg/L. Caffeine, cotinine (a metabolite of nicotine), and 1,7-dimethylxanthine (nonprescription dieting aids and appetite suppressants) were most frequently detected. Prescription-pharmaceutical compounds were most frequently detected in samples collected from Las Vegas Wash. Fewer PPCP compounds were detected in samples collected in Boulder and Virgin basins and Overton Arm than from Las Vegas Wash. Caffeine was detected in all samples collected from Lake Mead. This may be attributed to the dilution of Las Vegas Wash discharge as it mixes with Lake Mead NRA water (Boyd & Furlong, 2002).

Concentrations of a subset of PPCPs (Caffeine, estrogenic compounds (estradiol, E2 and ethynylestradiol, EE2), and DEET) were examined from three locations, 1) lower Las Vegas Wash below Lake Mead NRA Las Vegas (LW0.8 and LW0.9), 2) Boulder Basin (CR346.4), and 3) near Hoover Dam (CR342.5) (Figure B-3). Caffeine, E2 and EE2 concentrations at Boulder Basin in February, June, and August 2004 were below instrumental detection limit (0.01 ug/L and 0.001 ug/L, respectively). DEET concentrations ranged between 0.002 and 0.011 ug/L.

Caffeine concentrations were also sampled at the Lake Mead NRA Las Vegas outflow sites and either no caffeine was detected or levels ranged from 0.064 ug/L in February 2012 to 0.42 ug/L in November 2014.

The sampling site near Hoover Dam was most consistently sampled and had the longest time series of any site. E2 and EE2 concentrations between 2006 and 2016 were all below the detection limits (0.0005 ug/L and 0.001 ug/L, respectively). However, Linder and Little (2009) have indicated that estradiol at a concentration of 0.0001 µg/L or greater in lakes can pose a risk to more sensitive aquatic life. Caffeine and DEET concentrations were either below the detection limits (0.005 ug/L and 0.001 ug/L, respectively) or were at concentrations shown in Figure 4.5.1-3. Caffeine concentrations are higher in the summer (Figure 4.5.1-3). This observation may reflect anthropogenic impacts in the summer months when recreational use of Lake Mead is at its peak.

While PPCP concentrations in Las Vegas Wash have generally been higher than in Lake Mead, PPCPs have only been detected in trace amounts. Detection of higher PPCP concentrations in Las Vegas Bay is expected given that Las Vegas Wash discharges highly treated effluent to Las Vegas Bay before dispersal throughout Lake Mead. No PPCP data were available for Lake Mohave.

Overall, little is known regarding the toxicity of trace PPCP concentrations to aquatic life and human health in lakes Mead and Mohave. Rosen et al. (2012) concluded that PPCPs are not seen at levels currently known to pose a problem to human health for drinking water or recreation.

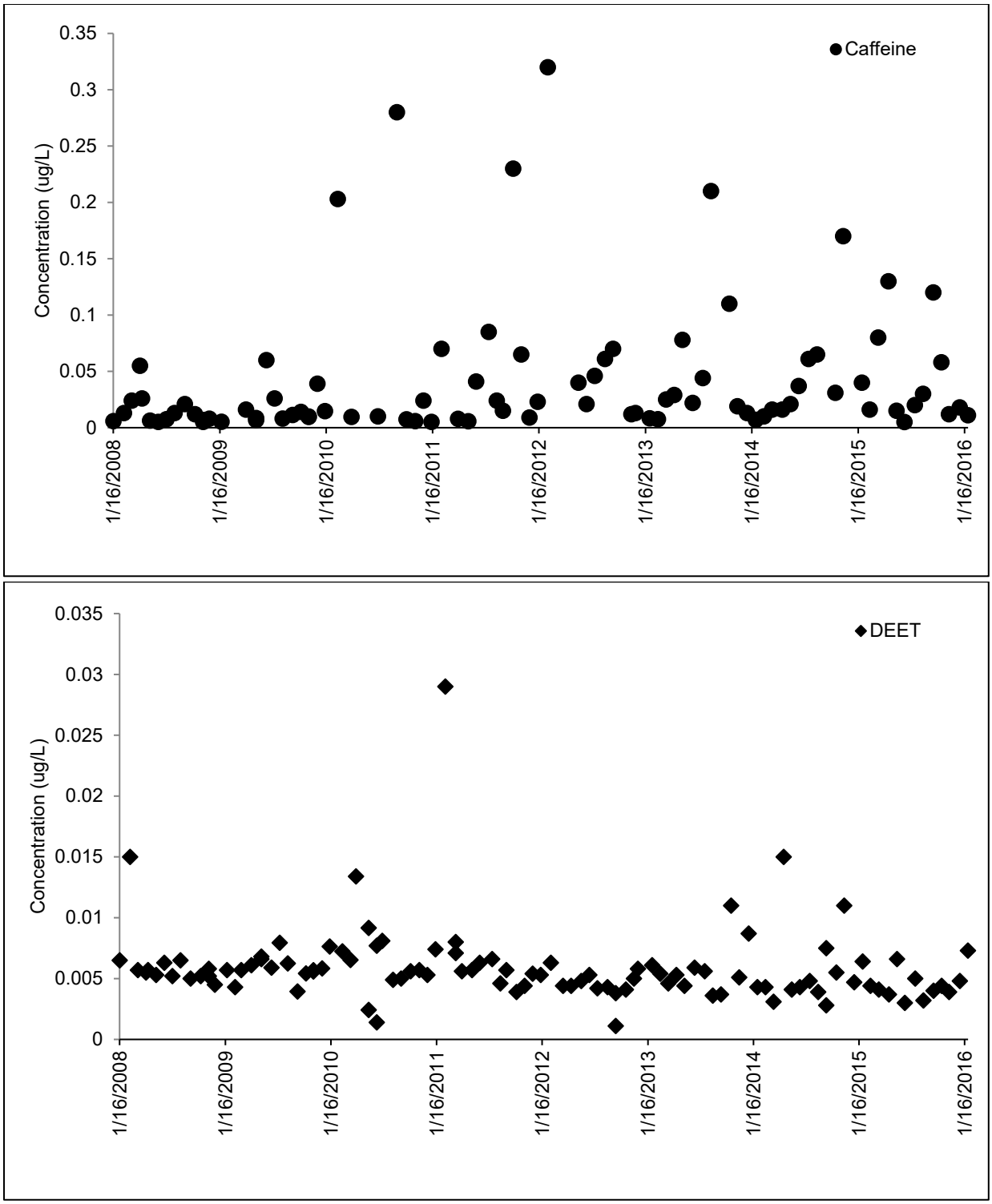


Figure 4.5.1-3. Caffeine and DEET concentrations detected at sampling site near Hoover Dam (CR342.0) between 2008 and 2016.

Selenium (Se)

Experts believe that natural background levels of selenium in the Colorado River Basin prior to human settlement in the 1800s averaged at about 1 µg/L or less. As the Western United States was settled and human activities, such as farming and mining increased, selenium concentrations throughout the Colorado River Basin became elevated with an average concentration of 2 to 4 µg/L (Seiler et al., 2003).

Overall, selenium concentrations of all samples from all locations (pooled by collection depth) were well below the USEPA selenium criterion for safe drinking water (50 µg/L) and did not exceed the USEPA selenium criterion for protection of aquatic life in lotic waters (3.1 µg/L) from 2008 to 2009 (Table 4.5.1-2 and Figure 4.5.1-4). However, selenium concentrations from open water locations did exceed the selenium criterion for lentic waters (1.5 µg/L) in 2015. No recent records of selenium concentrations in Overton Arm and Lake Mohave were available at the time of this assessment.

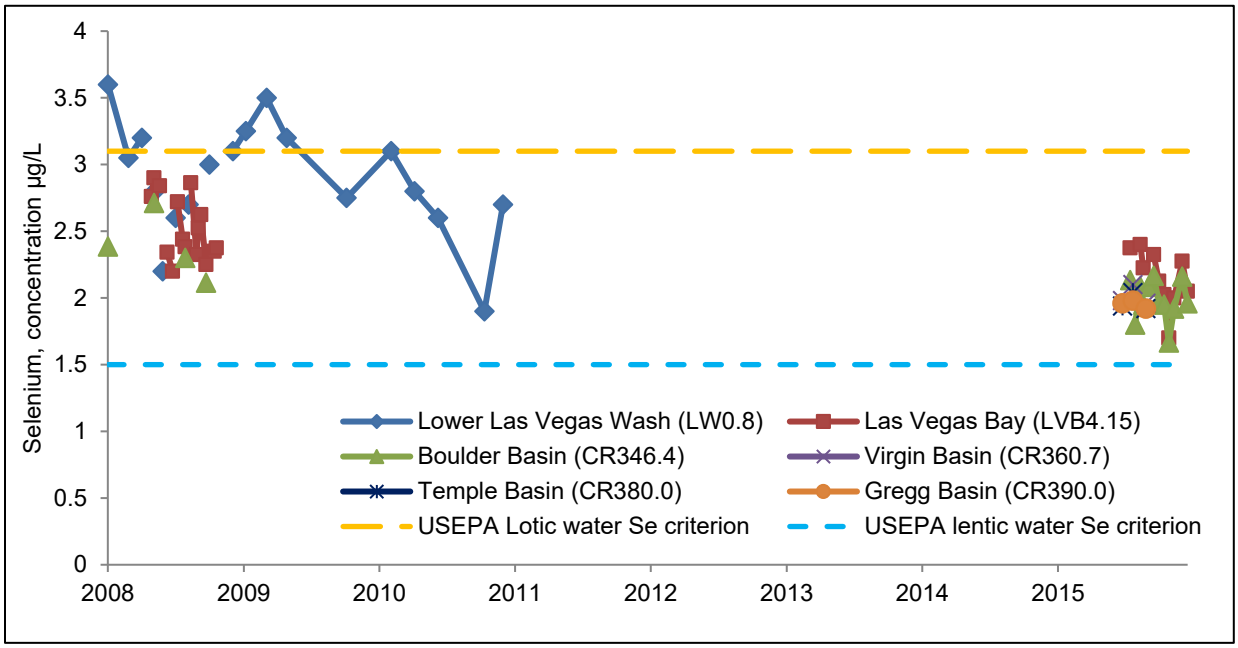


Figure 4.5.1-4. Selenium (Se) concentrations measured at lakes Mead and Mohave, 2008–2015. The yellow dotted line (long dash) represents the USEPA selenium criterion for protection of aquatic life in lotic waters. The blue dotted line (short dash) represents the USEPA selenium criterion in lentic waters.

Average selenium concentrations at the same lower Las Vegas Wash location in 2009 and 2010 were 3.16 and 2.6 µg/L, respectively. Selenium concentrations at lower Las Vegas Wash have had a decreasing trend between 2008 and 2011 (Figure 4.5.1-4).

While selenium concentration is not an issue for Lake Mead in terms of meeting safe drinking water standards, concerns for elevated selenium concentrations impacts to aquatic life and birds are warranted as selenium concentrations from open water locations did exceed the selenium criterion for lentic waters (1.5 µg/L) in 2015. Aquatic life may experience adverse health effects at a much lower level because selenium can bioaccumulate and biomagnify within the food web. As a result, top

predators, such as bald eagle and striped bass can be exposed to selenium and may be at risk for selenium toxicity (Seiler et al., 2003). Selenium concentrations in fish captured in Gregg Basin and near Willow Beach have been found to exceed the 1.0 µg/g wet weight fish tissue limit recommended to prevent toxicity (Hamilton, 2004; Hinck et al., 2006). A study of razorback suckers in the Upper Colorado River basin by Hamilton et al. (2002) indicated that selenium concentrations greater than 4.6 µg/g in razorback sucker food sources can adversely affect their reproductive success. The highest selenium concentrations in Lake Mohave fish have been measured at 1.70 µg/g and in Lake Mead at 2.19 µg/g (Hinck et al., 2006). However, the effect of selenium on reproduction of razorback suckers in lakes Mead and Mohave is unknown and is currently an area of current research. Recent concern also includes the risks associated with bioaccumulation of selenium in quagga mussels and subsequent potential impacts to aquatic birds which may use quagga mussels as a food source within Lake Mead NRA (Wong et al., 2011; Rosen et al., 2012).

Mercury (Hg)

There has been little mercury surveillance in the open water areas of lakes Mead and Mohave. A one-time measurement in Overton Arm in May 2002 recorded mercury concentrations to be less than the detection limit of 0.5 µg/L. Near Hoover Dam, mercury concentrations in surface water were also below detection limit of 0.2 µg/L between 2005 and 2015.

In 2002, average mercury concentrations in the lower Las Vegas Wash to be less than 0.01 µg/L, significantly below the USEPA MCL of 2 µg/L (Table 4.5.1-2; Cizdziel and Zhou, 2005). Between 2003 and 2015, at the same location in the lower Las Vegas Wash mercury was either not detected or at less than the 0.003 µg/L detection limit.

At Willow Beach in Lake Mohave, surface water mercury concentrations were also less than the detection limit of 0.5 µg/L in 1999 to 2003 and at less than the detection limit of 0.2 µg/L in both 2004 and 2005.

Overall, mercury concentrations in surface water of Las Vegas Wash, lakes Mead and Mohave have not exceeded the USEPA safe drinking water standards (Table 4.5.1-6).

Perchlorate (ClO_4)

See section 4.1.2.3 for details on the history and source of perchlorate at Lake Mead NRA.

Perchlorate concentrations were highest at the Las Vegas Bay station (LVB4.15) closer to the Las Vegas Wash confluence. Concentrations decreased with distance from the confluence (Figure 4.5.1-5). Seasonal stratification influences perchlorate concentrations in the water column in open water with highest concentrations typically detected within the epilimnion. When the water column mixes in the winter, perchlorate concentrations have been observed to equalize throughout the water column (Figure 4.5.1-5). In Boulder Basin (CR346.4), epilimnetic perchlorate concentrations have decreased from 20 µg/L measured in 2000 to less than 5 µg/L in 2014 and 2015, showing a significant downward trend ($p < 0.05$). Similarly, hypolimnetic concentrations have also decreased at the same location.

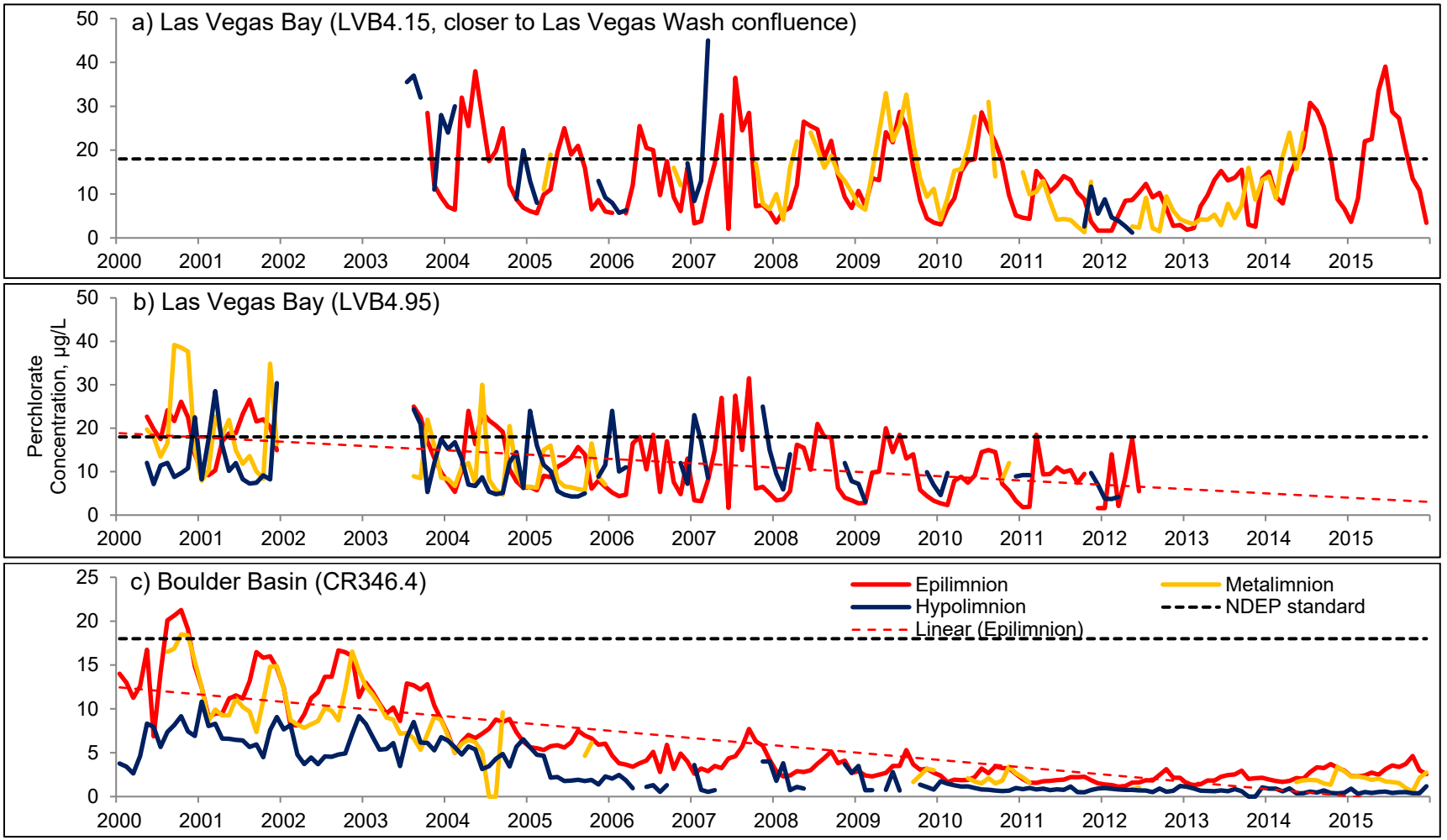


Figure 4.5.1-5. Time series (epilimnion, metalimnion, and hypoliminon) of perchlorate concentration data collected monthly between 2000 and 2015 from Las Vegas Bay stations (LVB4.15 and LVBV4.95) and Boulder Basin station (CR346.4). Stations ordered by distance from Las Vegas Wash confluence. See Table B-1 and Figure B-3 for monitoring locations and descriptions.

SNWA (2010) has reported perchlorate concentrations of up to 100 µg/L at LVB4.15. While current concentrations remain higher than other Lake Mead locations, there has been a significant reduction relative to historical levels at this station (19.5 µg/L in 2015) and have remained stable since 2004. In Las Vegas Bay, there has been little variability in perchlorate concentrations through the water column, and a downward trend has occurred at the LVB4.95 station (Figure 4.5.1-5).

Perchlorate concentration data from 2003 to 2005 were available for Colorado mainstem stations and the Overton Arm. Water samples were collected at surface and 100 m at the Virgin Basin station (CR360.7) and perchlorate concentrations were generally below the 4 µg/L detection limit or did not exceed 5 µg/L. Perchlorate concentrations also never exceeded the detection limit at Temple Basin station (CR380.0), Gregg Basin (CR394.0), and Overton Arm (VR25.1) during the sampling period, indicating that Colorado River was not the main perchlorate source. Sampling was discontinued after April 2005 at these locations because of the rare detection occurrences.

Except for LVB4.15, perchlorate concentrations detected at all other stations currently meet the NDEP provisional drinking water standard (≤18 µg/L). Occasional exceedances have been observed in the spring and summer at LVB4.15 in the past 10 years, but not in the fall or winter periods (Figure 4.5.1-5).

Perchlorate concentration data were available for Lake Mohave from Willow Beach, Placer Cove, Cottonwood Cove, and Katherine's Landing stations from July 2014 to December 2015 (Figure 4.5.1-6). Concentrations were similar among all four stations and were low, ranging from 1.1 to 2.5 µg/L

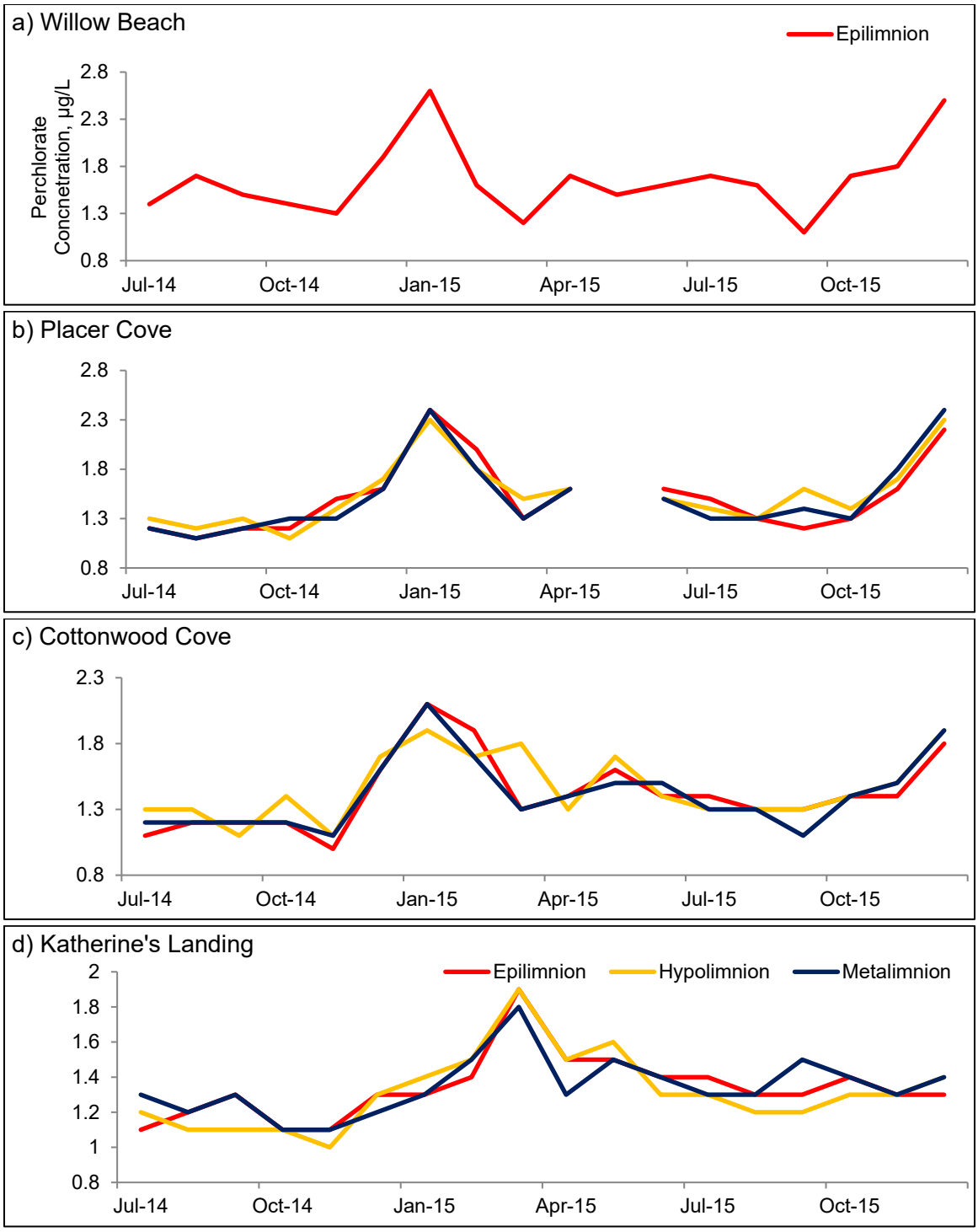


Figure 4.5.1-6. Time series (epilimnion, metalimnion, and hypoliminon) of perchlorate concentration data collected monthly between 2014 and 2015 in Lake Mohave. Stations ordered by distance from Hoover Dam discharge (closest to furthest). See Table B-1 and Figure B-3 for monitoring locations and descriptions.

Bromide (Br)

Bromide concentrations have increased from 0.068 mg/L in 2000 to 0.106 mg/L in 2004 in Boulder Basin (LaBounty and Burns, 2005). Bromide concentrations measured in Boulder Basin monitoring stations (CR346.4) also showed the same trend between 2000 and 2004 (Figure 4.5.1-7).

Bromide is oxidized and converted into carcinogenic bromate during the ozonation stage of drinking water treatment. With the observed increase of bromide concentration in source water in the early 2000s, drinking water treatment processes have since been modified to ensure that bromate concentrations do not exceed the USEPA standard of 0.010 mg/L (Table 4.1.1-6) (LaBounty & Burns, 2005). The Las Vegas Valley Water District (LVVWD) reported that bromate concentrations in drinking water averaged 0.006 mg/L in 2004.

Bromate concentrations in drinking water should decrease with decreased bromide concentrations detected in source waters. Concentrations of bromide detected at various water depths between 2000 and 2015 were generally similar (<0.01mg/L difference). These concentrations suggest that water column stratification does not seem to have an effect on the distribution of bromide. Monthly averages from all depths since 2004 have been significantly decreasing ($p<0.05$) at the Boulder Basin station (Figure 4.5.1-7). Downward trends were also observed at all Colorado River mainstem stations, as well as at the Overton Arm downgradient station (VR6.0). Bromide concentrations were relatively higher at stations closer to tributary confluences (e.g. Las Vegas Bay station LVB4.15 and Overton Arm station VR25.1) suggesting loading of bromide from Las Vegas Wash and Virgin/Muddy rivers, respectively. Concentrations observed at these stations have remained unchanged (Figure 4.5.1-7). According to the 2014 and 2015 water quality reports issued by the LVVWD, drinking water bromate concentration have averaged between 0.007 and 0.008 mg/L, and thus did not exceed the USEPA standard (LVVWD, 2016).

No bromide data were available for Lake Mohave.

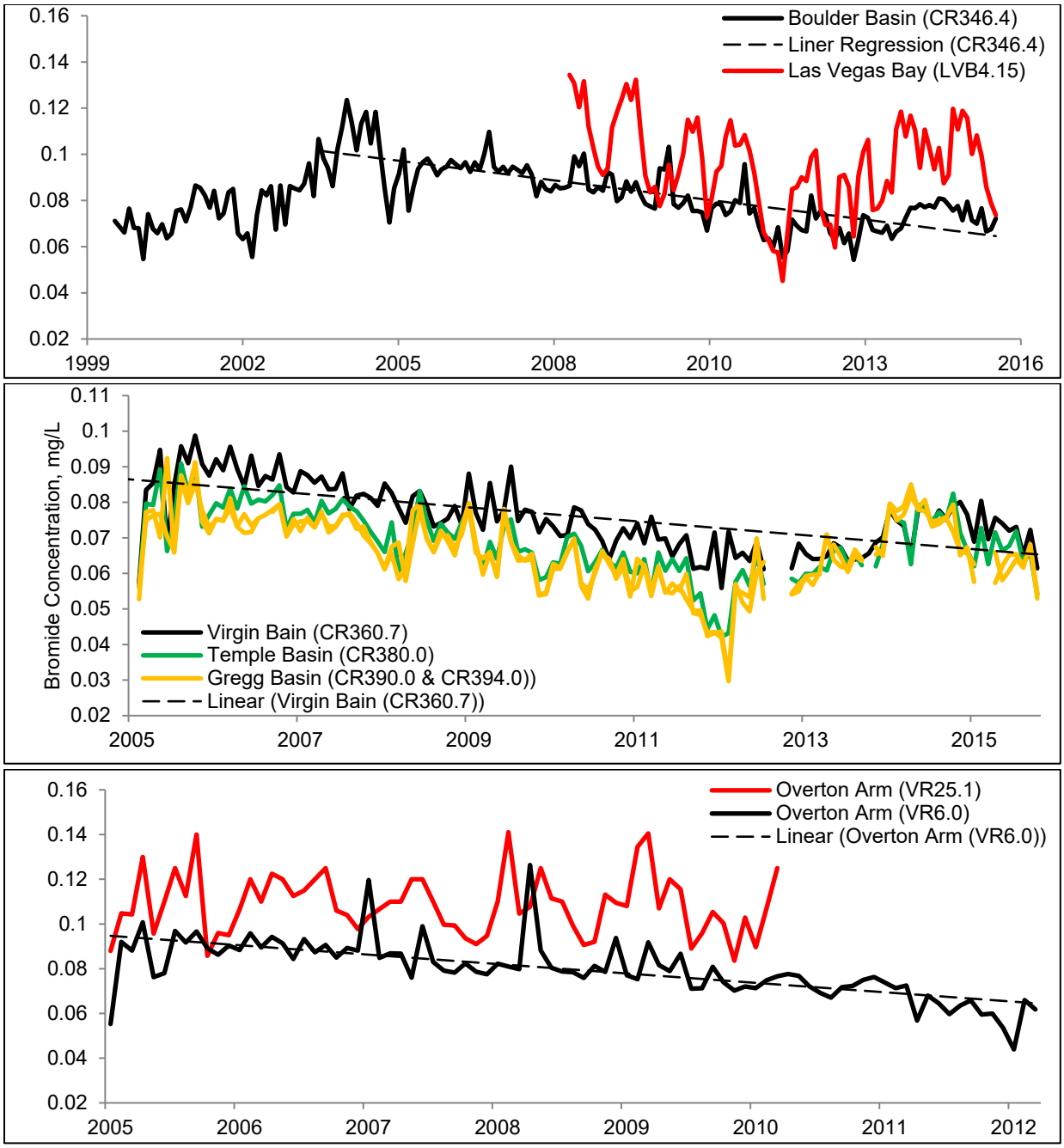


Figure 4.5.1-7. Time series (monthly averages from all depths) of bromide concentration data collected from Las Vegas Bay station (LVB4.15), Boulder Basin station (CR346.4), Colorado River main stem stations (Virgin (CR360.7), Temple (CR380.0), and Gregg (CR390.0 and CR 394.0) basins) and Overton Arm stations (VR25.1 and VR6.0). Bromate concentration in the drinking water does not exceed the USEPA standard of 0.010 mg/L See Table B-1 and Figure B-3 for monitoring locations and descriptions.

Assessment Confidence and Key Data Gaps

Overall assessment confidence is moderate. Current VOC concentrations data were only from one location in the Las Vegas Wash. Sites monitored by Lico and Johnson (2007) are no longer monitored, and thus no current data from marinas and public boat launches were available.

Investigation of the effects of EDCs to aquatic life in lakes Mead and Mohave are ongoing and new information will provide more insight as to the effect of EDCs to lakes Mead and Mohave ecosystems. Selenium and mercury data for Colorado River mainstem stations (Gregg, Temple, and Virgin Basins) are mostly from one year (2015) without a historical reference; thus, comparisons were made to other sites within Lake Mead with known higher historical concentrations of Selenium, potentially overestimating concentration decreases. Limited studies have been conducted regarding the effects of EDCs and PPCPs to human health at environmental exposure levels or through consumption of aquatic life exposure to these compounds. Bromide monitoring should be included in the routine water quality sampling in Lake Mohave.

Although it appears that organic chemicals regarded as contaminants of emerging 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 remain undetermined. Limited studies have been conducted regarding the effects of CECs to human health at environmental exposure levels (USEPA, 2015c). Although these compounds represent a threat to water quality and ecosystems and human health, more information is needed to assess impacts and develop mitigation plans. The National Toxicology Program has developed toxicological research programs to address these needs (U.S. Department of Health and Human Services, 2013). With a majority of EDCs and PPCPs not currently regulated in wastewater discharges or have water-quality standards, inventory and monitoring of CECs in the water column, sediment, and fish of lakes Mead and Mohave is warranted to assess the long-term effect on aquatic biota and human health.

Existing monitoring of perchlorate is likely to continue based on regulatory requirements. Coordination of this monitoring with efforts to reduce inputs to Las Vegas Wash will be beneficial to the protection of lakes Mead and Mohave.

Contaminants as Stressor

As urbanization continues to expand in watersheds near Lake Mead NRA, it also increases the potential for non-point sources of environmental contaminants. These potential effects from increased urbanization in tributary watersheds may be exacerbated by lowered lake levels and other drought-related conditions (Rosen et al., 2012).

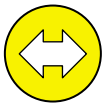
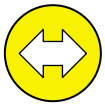
Contaminant concentrations in Las Vegas Bay are expected to increase in the coming years. Effluent and urban runoff contain a wide variety of contaminants, including mercury, PPCPs, EDCs, VOCs, perchlorate, and various pesticides. In addition, the Muddy and Virgin Rivers are likely to experience increased urban inflows if proposed development progresses along watersheds in Nevada, Utah, and Arizona. Increases in treated effluent can also be expected from proposed waste water treatment facilities upstream. Such discharge may result in channelization of the river courses and alteration of the environmental dynamics of the delta areas within Lake Mead, including potential impacts on water chemistry, nutrient load, silt deposition, water temperature, and undoubtedly increases in contaminants.

Studies have indicated that contaminants in water may bioaccumulate in quagga and zebra mussels (Mueting & Gerstenberger, 2010). Birds that feed on these mussels may be exposed to these contaminants, resulting in reduced survival and/or reproductive success (Austin, et al., 2000). To date, the impact quagga mussels have on aquatic birds at lakes Mead and Mohave is unclear. 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 (see section 4.5.1), concern for EDCs exposures to both Clark's and Western grebes, and migratory birds that feed on fish within or near Las Vegas Bay is warranted. In addition, shorebirds and other aquatic dependent species are particularly susceptible to bioaccumulation of persistent environmental contaminants (such as mercury) due to their consumption of benthic invertebrates and fish. Higher food-chain, non-migratory species, such as peregrine falcons that prey on aquatic birds and remain on lakes Mead and Mohave for longer periods, are also of great concern (Barnes & Gerstenberger, 2015).

4.5.2. Aquatic Invasive Species

A summary of the parameters used assess aquatic invasive species are shown in Table 4.5.2-1.

Table 4.5.2-1. Assessment outcome of the condition status and trend for aquatic invasive species**.**

Indicator(s)	Measurement(s)	Condition Status/Trend	Rationale
Aquatic Invasive Species Present in lakes Mead and Mohave: Quagga mussel (*Dreissena bugensis*) adult and veliger, New Zealand mudsnail, Crayfish	Density		While veliger densities have decreased, quagga mussels still persist in lakes Mead and Mohave. New Zealand mudsnail densities have increased between 2008 and 2011. The most recent crayfish study in Lake Mead was conducted in 1988. No contemporary data available for assessment of current condition and trend.
Aquatic Invasive Species as a Stressor to Essential Ecological or Management Features Examined	Qualitative discussion	–	–
Aquatic Invasive Species overall			–

Aquatic Invasive Species Present in Lakes Mead and Mohave

Description

Invasive species are any non-native species which have or may cause environmental or economic harm, or harm to human health. Aquatic invasive species (AIS) can reduce or extirpate native species populations through competition for food and habitat, predation, transmission of disease or parasites, and habitat alteration. Common AIS introduction vectors include intentional or accidental stocking, release of bait fish or pets, escape from aquaculture facilities, and discharge of ballast water and from contaminated boat hulls and fishing gear. Quagga mussels, New Zealand mudsnails, and crayfish are three major aquatic invasive species found in lakes Mead and Mohave (Rosen et al., 2012). Asian clam is another invasive species found in Lake Mead but their populations have declined substantially in recent years (see section 4.2.1).

In Lake Mead, adult quagga mussels were first detected in Boulder Basin in January 2007. It is believed that quagga mussels were introduced into Lake Mead by transport on recreational boats or other recreation equipment, potentially from the Great Lakes region. They have since spread throughout both lakes Mead and Mohave and downstream into southern California along the Colorado River aqueduct system. Quagga mussels are known to cause significant impacts through biofouling on boats and facilities, clogging watercraft engines, disrupting food web dynamics, impacting sport fishing, and littering beaches with sharp shells (Lake Mead NRA, 2010). Quagga mussel impacts on infrastructure for BOR's operations at Hoover dam and SNWA's water intakes have been significant, creating concerns for water delivery and have led to increased operational costs (Holdren & Turner, 2010). Quagga mussel abundances are typically greatest on hard substrates, with lower densities in areas of soft sediment (Wittmann, et al., 2010). Quagga mussels have a temporary planktonic phase as free-swimming veligers. Quagga mussel veligers have become part of the lakes Mead and Mohave zooplankton population since their first detection in 2007 (Rosen et al., 2012).

New Zealand mudsnail was first detected in Lake Mead in 2008 and have been abundant in certain areas of the lake bottom (Lommis et al., 2011; Rosen et al., 2012).

The red swamp crayfish (*Procambarus clarkii*) was first reported in lakes Mead and Mohave in 1978 (Peck et al., 1987). A non-native large-bodied invertebrate, the red swamp crayfish is currently established 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 (Rosen et al., 2012). The red swamp crayfish is known to be a highly aggressive, burrowing species and eat plants, other invertebrates, small fish, and dead fish of any size (Leavitt et al., 1989). It has become an important food resource for many fish within lakes Mead and Mohave, e.g. largemouth bass and striped bass (Peck et al., 1987; NPS, 2010). An understanding of the population of red swamp crayfish could provide insight to the function of the benthic food web with respect to fisheries dynamics in lakes Mead and Mohave.

Data and Methods

Table 4.5.2-2 shows the data and methods used to assesss aquatic invasive species.

Table 4.5.2-2. Indicators and measures used in the assessment of aquatic invasive species.

Indicator(s)	Measurement(s)	Scale of Analysis
• Quagga mussel adult and veliger • New Zealand mudsnail, Crayfish	Density	Lake

Quagga Mussels

A number of publications and data sources were used for the assessment of invasive quagga mussel in lakes Mead and Mohave.

Moore et al. (2009) conducted a whole Lake Mead NRA survey in 2007 to document the distribution and densities of quagga mussels after its initial detection in Boulder Basin.

Following the detection of adult quagga mussels in Lake Mead, a standardized, long-term monitoring plan was developed for Lake Mead NRA. The Interagency Management Act Plan (I-MAP) for quagga mussel focuses on the monitoring of quagga mussel adults, juveniles, and veliger densities (Wong et al., 2011). Detailed sampling schedule and protocol can be found in the I-MAP working document (Wong et al., 2011). The first comprehensive I-MAP monitoring was conducted between the fall of 2009 and 2010 (See Table B-1 and Figure B-3 for monitoring locations and descriptions). Under the I-MAP compact, SNWA and BOR technical Service Center also regularly monitored quagga mussel veligers in lakes Mead and Mohave. Both adults and veligers have been monitored at different sampling sites on a monthly, quarterly or annual interval in lakes Mead and Mohave. Data from these surveys were accessible from the Lower Colorado River Water Quality Database maintained by SNWA. Contemporary veliger monitoring data (2011–2015) for Lake Mead was downloaded from the SNWA database. Sites analyzed for veliger density were based on locations selected in Wong (2012) (See Table B-1 and Figure B-3 for monitoring locations and descriptions). Veliger monitoring data for Lake Mohave was provided by BOR (See Table B-1 and Figure B-3 for monitoring locations and descriptions).

In addition, Caldwell et al. (2015) conducted a survey of quagga mussel populations between 2010 and 2011 within three Lake Mead basins (Boulder Basin, Las Vegas Bay, and Overton Arm). Samples were collected using a petite-Ponar grab sampler during the fall and spring between 2008 and 2010 on soft substrates between 2 to 106 m depth.

New Zealand Mudsnail and Crayfish

Very few studies on the abundance and ecology of New Zealand mudsnail and crayfish have been done in lakes Mead and Mohave. For this assessment, data utilized through an unpublished benthic invertebrate study conducted on soft sediment by the University of Nevada Reno yielded New Zealand mudsnail abundance and distribution information between 2008 and 2011 (UNR Data, unpublished). The methodology used in these surveys is described in detail in the quagga mussel section above.

For crayfish, information from two published studies, Peck et al. (1987) and Leavitt et al. (1989) was used for the indicator assessment. Peck et al. (1987) conducted the first crayfish survey from inner Las Vegas Bay to Saddle Island (Figure B-1), recording baseline crayfish density and distribution using minnow traps. Leavitt et al. (1989) examined density data collected by Peck et al. (1987) in Las Vegas Bay and Overton Arm, and trapping data collected in Overton Arm in October 1988. No contemporary data were available for assessment of current condition and trend in Overton Arm.

Reference Conditions

Table 4.5.2-3 shows the reference conditions used to assess aquatic invasive species.

Table 4.5.2-3. Reference conditions for aquatic invasive species used in the assessment.

Measurment(s)	Condition Status		
	Significant Concern*	**Moderate Concern***	**Good***
Density	High or increasing density of aquatic invasive species, and/or invasive aquatic species degrading ecosystem processes	Moderate density of aquatic invasive species, and/or little to moderate impact on ecosystem processes	Low and decreasing density or absence of aquatic invasive species, and/or no impact on ecosystem processes

Condition and Trend

Quagga Mussel

Mean adult and juvenile quagga mussel density was estimated to 505 ± 667 mussels/m^2 in Lake Mead in 2007. More mussels were found on rocky, hard substrate than soft, silty substrate (Moore et al., 2009; Wong et al., 2011). Between 2009 and 2010, I-MAP surveys showed significant increases in adult and juvenile quagga mussel densities in Lake Mead. Overall, mean mussel density between 2 and 120 meters was 4,613 mussels/m^2. On hard substrates (e.g. rocky areas), the mean density was 8,078 mussels/m^2. For soft substrates (e.g. silt), the mean density was 3,014 mussels/m^2 (Lommis et al., 2011; Wong, 2012). With the assumption of Lake Mead's water level at 1100 ft, Wong (2012) estimated that there were 76 billion adult/juvenile quagga mussels in Lake Mead in 2007 and 1.5 trillion in 2010. A separate study conducted by Caldwell et al. (2015) also found an increase in adult quagga mussel density between 2008 and 2011 at all water depths (Figure 4.5.2-1). While both studies identified significant increases in adult quagga mussel densities, Wong (2012) detected much higher overall densities than Caldwell et al. (2015). This may be due to different sampling protocols and site selection used in each study. No adult and juvenile quagga mussel density data are available for Lake Mohave.

Zooplankton monitoring conducted by BOR Technical Service Center at Boulder Basin, Las Vegas Wash estuarine, Virgin Basin, Overton Arm, Muddy River and Virgin River estuaries, Temple Basin, Gregg Basin, and Colorado River detected quagga veligers and showed an increase in mean veliger abundance from peak density of 0.9 veligers/L in 2007 to peak density of 20 veligers/L in 2011. However, overall densities have decreased since 2011 to an average of 5 veligers/L (Figure 4.5.2-2).

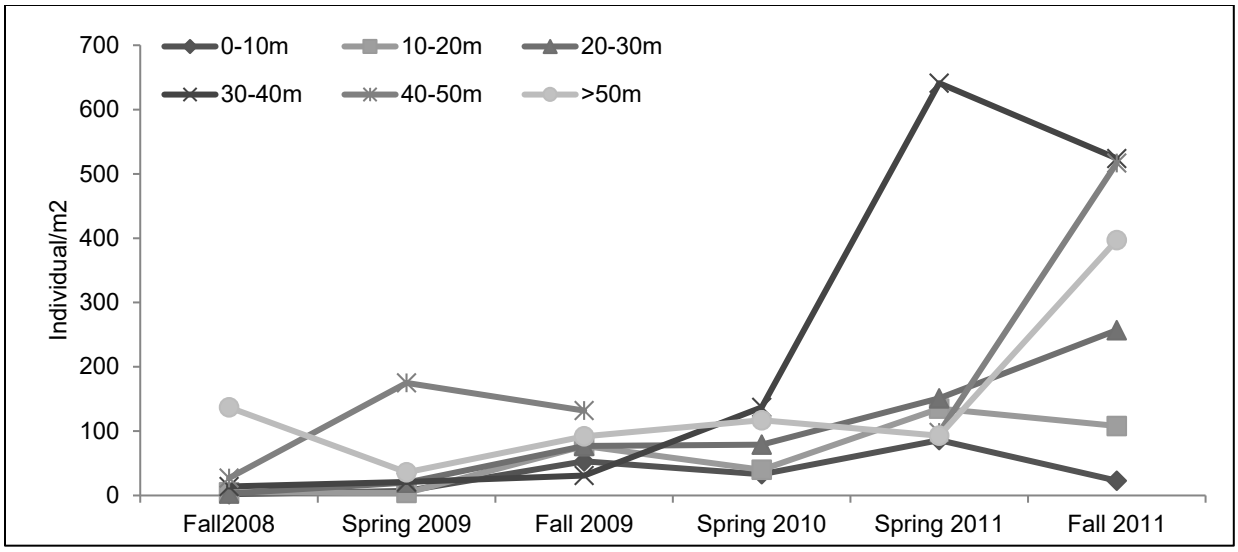


Figure 4.5.2-1. Quagga mussel adult abundance (Average among basins: Boulder Basin, Las Vegas Bay, and Overton Arm) in Lake Mead from different depth zones (m=meters). Data from Caldwell, et al., 2015.

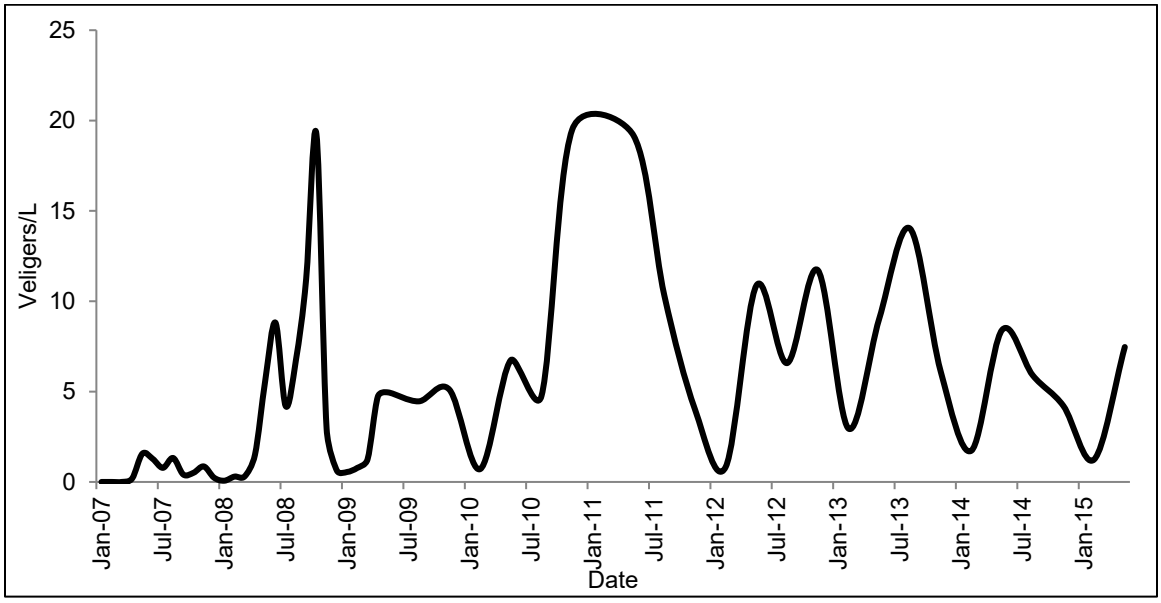


Figure 4.5.2-2. Quagga mussel veliger abundance collected by BOR and SNWA Zooplankton Monitoring program (Average among basins: Boulder Basin, Las Vegas Wash estuarine, Virgin Basin, Overton Arm, Muddy River estuarine, Virgin River estuarine, Temple Basin, Gregg Basin, and Colorado River estuarine) in Lake Mead (Data obtained from SNWA Database).

Results from the veliger-specific monitoring program conducted by BOR at Willow Beach, Placer Cove, Cottonwood Cover, and Katherine Landing in Lake Mohave are shown in Figure 4.5.2-3. Veliger densities reached a high in the summer of 2011 and have since decreased to similar densities as detected in the early invasion period in 2007 and 2008 (Figure 4.5.2-3). Note that while data presented here shows that Lake Mohave has overall higher veliger densities than Lake Mead, in

actuality, Lake Mead has higher veliger densities than Lake Mohave. The data presented here are from two different studies with different sampling protocols.

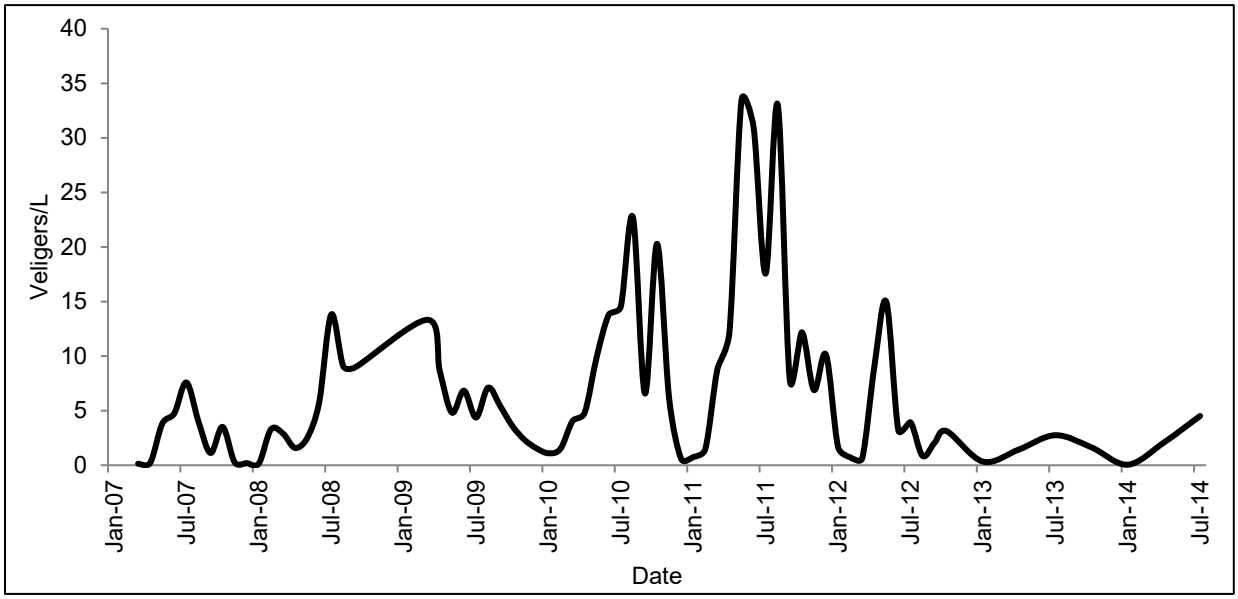


Figure 4.5.2-3. Lake Mohave quagga mussel veliger abundance (Average among sampling sites: Willow Beach, Placer Cove, Cottonwood Cove, and Katherine Landing) (Data provided by BOR).

Wong (2012) shows that veliger abundances between Lake Mead NRA Med and Lake Mohave differed significantly between 2007 and 2011 (Figure 4.5.2-4). Despite those differences, overall, summer and fall veliger counts have decreased since 2012 (Figure 4.5.2-2 and Figure 4.5.2-3). Contemporary data collected by BOR indicate that veliger densities have decreased from peak density recorded in 2011 and have since stabilized Mead.

Studies conducted in 2001–2006 (pre quagga invasion) and 2007–2009 (early invasion) showed no significant direct ecosystem impacts due to quagga mussel invasion. However, these studies were conducted at the early invasion period when quagga mussel densities were relatively low. Densities of both adult/juvenile and veliger have since changed with significant fluctuations. The ecosystem-level impacts of this invasion in lakes Mead or Mohave are not currently known.

Since 2002, Lake Mead NRA has had policies in place for inspecting large boats arriving from east of the Rocky Mountains, and currently, there are extensive inspection, certification, and boat decontamination options for recreational boaters traveling to or from Lake Mead to prevent the spread of this invasive species to other systems in the region.

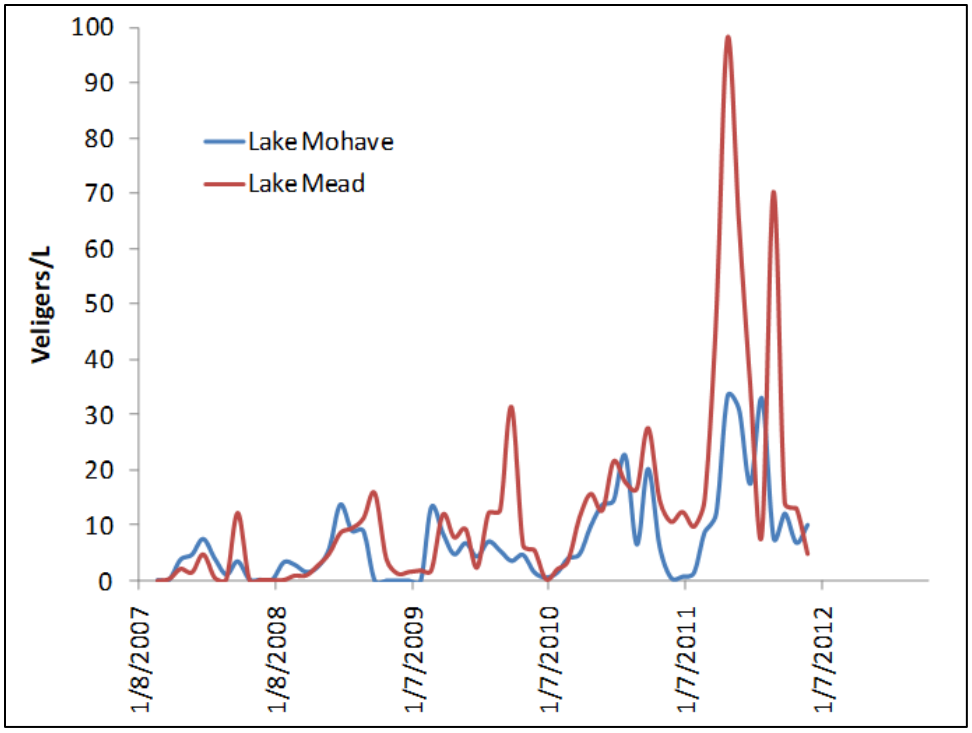


Figure 4.5.2-4. Quagga mussel veliger abundance collected by BOR's veliger monitoring program (Average among basins: Hoover Dam Deep (0-30 m) Tows, Hoover Dam Shallow (0-10 m) Tows, Echo Bay, Temple Bar, and Sandy Point in Lake Mead; Willow Beach, Placer Cove, Cottonwood Cove, and Katherine Landing in Lake Mohave.) in lakes Mead and Mohave. Excerpted from Wong, 2012.

New Zealand mudsnail

New Zealand mudsnails have been abundant in certain areas of the lake bottom. Benthic invertebrate surveys conducted by UNR found that New Zealand mudsnails are most abundant at deeper water depths (Figure 4.5.2-5). Population densities have been increasing from 2008 to 2011. New Zealand mudsnail density data were not collected after 2011, and no density data exist for Lake Mohave.

Due to the lack of New Zealand mudsnail studies at Lake Mead, the potential environmental impact of this species in lakes Mead and Mohave are unknown (Rosen et al., 2012).

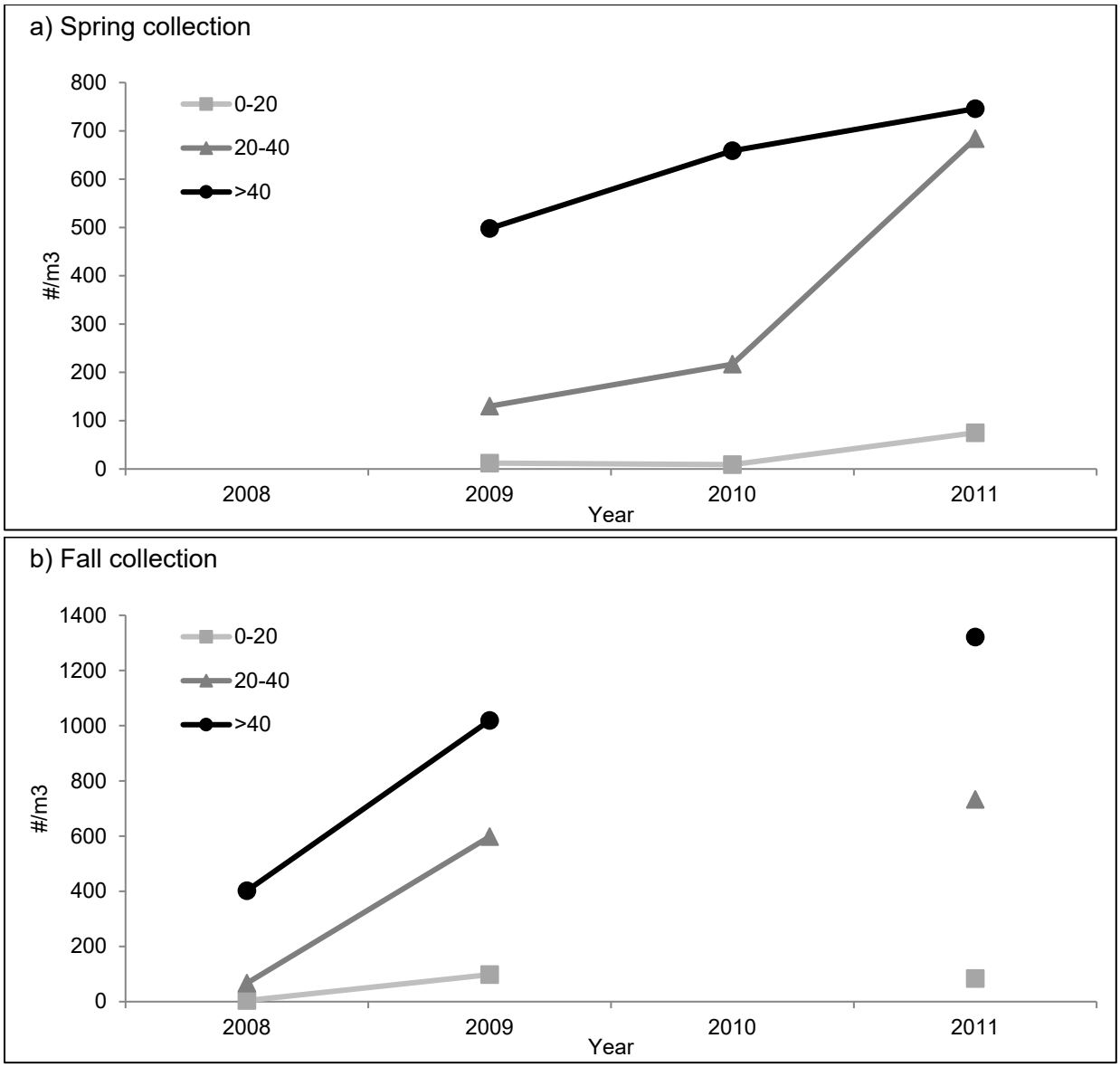


Figure 4.5.2-5. Changes in New Zealand mudsnail average abundances between 2008 and 2011 at various depth zones. (a) shows density data collected in the Spring and (b) shows data collected in the Fall. No surveys were conducted in Spring 2008 and Fall 2010 (UNR Data).

Crayfish

Trap data collected by Peck et al. (1987) indicated that red swamp crayfish abundance in Lake Mead was low in 1986 and 1987, and lake-wide relative abundances were 0.06 catch per trap day (CPTD) (Peck et al., 1987). Despite these low densities, red swamp crayfish were found in all regions of the Lake Mead NRA and were reproductively successful in the lake (Peck et al., 1987). Crayfish were present in isolated populations in the Colorado River Arm, the Overton Arm, Virgin Basin regions, as well as Las Vegas Bay. Crayfish were found to be more abundant in the presence of submerged aquatic vegetation (Peck et al., 1987). Trapping surveys conducted in 1988 in Overton Arm did not return any crayfish.

Assessment Confidence and Key Data Gaps

Assessment confidence is moderate. Limited adult quagga mussel density data has been collected in recent years, largely because monitoring efforts have mainly focused on veliger larvae. Limited information exists, regarding New Zealand mudsnails and crayfish in lakes Mead and Mohave. Baseline data collection and subsequent systematic monitoring of these invasive species are critical for understanding the long-term effects of the invasion of these species.

Aquatic Invasive Species as a Stressor to Essential Ecological or Management Features Examined

The introduction and establishment of non-native, invasive species is just one of many threats to both aquatic and terrestrial species and their habitats at Lake Mead NRA. Not only do invasive species compete with native or other desirable species in the basin, but they may also impact other important ecological and economic values such as water quantity, water quality, hydropower production and recreational uses. At present, lakes Mead and Mohave are experiencing disturbances due to a number of established invasive species, such as quagga mussel and Saltcedar, but are also threatened by future invasions from other nonindigenous species.

Lake and Riverine Ecosystem Health

Quagga mussels have potential to alter water quality and nutrient cycling (Rosen et al., 2012. Quagga mussels can reduce suspended solids in the water column, providing a general increase in water clarity (Wong et al., 2003; Binding et al., 2007; Wong et al., 2011a). As a result, shallow areas in Lake Mead may have improved habitat for both rooted aquatic plants and benthic algae. Additionally, quagga mussels can affect nutrient dynamics as they primarily use particulate nutrients for food and excrete waste nutrients (Rosen et al., 2012). The population of quagga mussels currently in the lake may potentially contribute to an increase in dissolved inorganic phosphorus and nitrogen (Wong et al., 2011a). With substantial mussel populations in benthic zones of Mead, the concentration of dissolved oxygen in the hypolimnion can be significantly reduced, especially during times of stratification (Caraco et al., 2006).

Biotic Condition

Quagga mussels feed by continuously filtering water for plankton, and the tremendous filtering capacity of large colonies of mussels can deprive other aquatic species of resources necessary for survival, causing irreversible ecosystem changes and losses of both native species and sport fisheries.

Ecosystem-wide consequences of quagga mussels might include reducing biomass and altering species community 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 (Rosen et al, 2012).

Invasion of quagga mussels may alter the food source dynamic for aquatic birds in lakes Mead and Mohave by providing a new food source and attracting aquatic bird species that can feed on quagga

mussels. In 2009, the increase in two omnivorous diving ducks known to feed on quagga mussels, the common goldeneye (*Bucephala clangula*) and lesser scaup (*Aythya affinis*), were observed at Lake Mohave (Barnes & Jaeger, 2011). Invasive riparian vegetation, such as saltcedar can reduce suitable riparian habitat for riparian-dependent aquatic birds, such as yellow-billed cuckoo. Research and monitoring are needed to determine the effects of invasive mollusks and non-native vegetation on bird habitat quality and habitat use.

Non-native crayfish have become an important food resource for many fish species within lakes Mead and Mohave. 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 have been abundant in certain areas of the lake bottom, but have not been noted to generate significant ecosystem impacts.

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

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

In addition to these aquatic invasive species, there are also riparian invaders, such as saltcedar *(Tamarisk* sp.), that are established in Lake Mead NRA region. Within the NPS alone, there are over 2.6 million acres infested with these non-native, invasive plants. These species can destroy cultural and historical sites, increase fire hazards, deplete natural resources such as water, and crowd out native vegetation.

The invasion and spread of non-native species, (i.e., saltcedar) and extended periods of water-level change can negatively impact the current population of native riparian vegetation. Tamarisk leaf beetle (*Diorhabda carinulata*) has been introduced as a biological control for saltcedar (Dudley et al., 2000).

There is a concern on the Lower Colorado River over spread of non-native aquatic vegetation, particularly given decreases in lake elevation that may increase the potential for establishment and spread by aquatic invasive plant species and associated recreational impacts to the nearshore zones of lakes Mead and Mohave. Vegetation and community inventory monitoring at Virgin and Colorado

River deltas is needed to inform management related to these habitats, and to assess restoration potential (Rosen et al., 2012).

Recreational Suitability

Invasive species such as quagga mussels have been found to enhance blue-green algae growth in the Great Lakes and mid-western US (Lake Mead NRA, 2015). It is possible that the same effect may occur at lakes Mead and Mohave. Lower water elevations can also lead to higher mortality rates of quagga mussels on above-water rocks and beach areas resulting in decomposition, which presents aesthetics and odor problems that impair recreational use of Lake Mead. Sharp shells washed up on shore can present a safety hazard to visitors. Large quantities of fecal materials produced by quagga mussels and the associated algae growth in the shallow areas can result in increased bacteria (e.g., *E. coli*) concentrations in nearby beach waters (Wong et al., 2011b).

Adult mussels colonize water intakes, marina structures, and navigation aids requiring expensive defouling and repair actions and maintenance. Shells of dead mussels are hazardous to people on beaches, and larval mussels, are drawn into boat engines and bilges where they can grow into adults and clog recreational equipment or spread to other freshwater systems via overland dispersal (Rosen et al., 2012).

Finally, lakes Mead and Mohave and the Colorado River are increasing prone to new invasions. There is a high degree of boat visitation and connectivity from the upstream Colorado River to the recreational area. Thus, it is likely that additional species would be introduced and establishing in this system if they are introduced to the region.

4.5.3. Development and Urbanization

Historically, development and urbanization have had unwanted impacts to the Lake Mead NRA and continue to pose a potentially significant threat to the area's ecological and economic resources (Batker et al. 2014). Major impacts from development and urbanization include but are not limited to increased demand on water supply, flood risk, degradation of water and air quality and negative impacts to wildlife and other ecosystem services (NPS, 2014).

Development within the Colorado River Basin, particularly in Nevada, Arizona, and southern California, has steadily increased since the expansion of water and other infrastructure projects. Major cities of the Lake Mead Basin include Las Vegas, North Las Vegas, Henderson, and Mesquite, Nevada and St. George, Utah. Since 2000, the population of Las Vegas has grown by 21 percent, Henderson, Nevada by 48 percent and in 2015 St. George Utah was ranked as the 5th fasting growing area in the country with a 3% increase per year. With population increases ranging from 16–25 percent, the major Arizonan cities in the Lake Mohave Basin (Bullhead City, Lake Havasu City, and Kingman) also have experienced similar levels of population growth (United States Census Bureau, 2015).

The population of Clark County, and particularly the greater metropolitan Las Vegas area, has grown at an exponential rate since the 1940s but has fluctuated since 2008 after the recession. United States Census Bureau estimated the population in Clark County in 2014 to be at 2.1 million people. This

was only a slight increase (6.1 percent) from 2010. In 2010, the census documented 1.95 million people in Clark County, a 38 percent increase since 2000 (United States Census Bureau, 2015).

The cities of Mesquite, NV, and St. George, UT, both along the Virgin River north of Lake Mead, also proliferated between 1990 and 2010. 11 percent and 8 percent population growth were estimated between 2010 and 2014 for Mesquite, NV and St. George, respectively (United States Census Bureau, 2015). 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 (Rosen et al., 2012).

US Census data demonstrated continued upstream development, suggesting increase challenges for future watershed management. A study conducted by Batker et al. (2014) suggested that over the next 50 years, meeting Colorado River Basin resource needs will be significantly challenged due to limitations in water supply associated with forecasted development of water supplies, increased consumptive use in the Upper Basin, and reduced volumes of water stored in system reservoirs. Lower water elevations in reservoirs also create negative impacts to hydropower production, shoreline recreation opportunities, while increasing the frequency of water delivery shortages to lower basin states and Mexico. The study estimates that decreases in flows in key river tributaries has negative implications for flow-dependent resources such as boating, recreation, and river ecology. The study emphasized that water shortage threats are most likely under scenarios of rapid population growth. As climate models continue to predict longer periods of reduced snowpack within the Colorado River Basin, as well as increasing water demands and use approaching full allocations, it would become increasingly difficult to meet current water releases and allocations requirement. BOR, the seven basin states, and a wide array of stakeholders have coordinated in the Colorado River Basin Supply and Demand Study, evaluating potential shortfalls and assessing measures to address forecasted gaps in supply and demand.

This significant population expansion and associated development and urbanization have also resulted in thousands of acres of land use change, including conversion to housing development, agriculture, and green space (Batker, et al., 2014). Structures have been built in the floodplains and impermeable surfaces have expanded, reducing natural flood control and groundwater infiltration. As a result, flooding has become a larger problem and excess dirt, debris, road oil, and other materials collect in urban and agricultural water conveyance structures, which contribute to higher peak flows, more frequent flood events, and erosion.

Increased development and urbanization also impacts water quality, which in the Lake Mead and Mohave Basin is damaged primarily by human activities that generate water contaminants such as nitrogen, phosphorus, and other soluble pollutants, as well as natural release of minerals such as selenium. Numerous waterways in both the upper and lower Colorado Basins have been designated under the Clean Water Act as threatened or impaired due to nonpoint source contamination, natural deposits resulting in selenium contamination, and in some cases disturbance from mining operations. Impaired waterway designations in Lower Basin regions specifically include issues from pesticides, metals, pathogens, mercury, organic enrichment/oxygen depletion, pH/acidity/caustic conditions, turbidity, ammonia, nutrients, toxic organics, sediment, and chlorine (NPS, 2014). Further, urban

stormwater and treated wastewater from increasing urbanization adjacent to Lake Mead NRA park lands as well as agricultural run-off, and altered riverine flow regimes in the Colorado River, Muddy River, and Virgin River are a source for a wide range of pollutants, including endocrine disrupting compounds, pesticides, fertilizers, and hydrocarbons (NPS, 2014). Naturally occurring selenium and uranium may contaminate water even in the absence of human disturbance, as occurs in some areas of the Colorado Plateau. However, these elements can be released at much higher levels through activities such as agriculture and mining, causing more widespread problems. Additionally, irrigation waters passing through salt-laden sub-soils and draining back into the Colorado generate increased salinity.

Decreases in reservoir elevations, surface water flow, and vegetation alongside increases in impermeable surfaces due to development in the region are likely to be positively correlated with increases in dust and other wind-blown particulates. Recent studies have shown that present dust accumulation is five times greater than it was before major human settlement occurred in the Lake Mead NRA region. Dust in the Basin has been found to cause a variety of human health impacts, from asthma to Valley Fever, which was the second most reported disease in Arizona in 2012, with about 150,000 reported cases per year. Valley Fever claimed 170 lives between 2007–2012 (Batker et al., 2014).

Lake Mead NRA holds a great diversity of fish, wildlife, habitats, and ecosystems including wetland areas providing exceptional habitats for waterfowl and passerine bird species. Urbanization and development will potentially lead to further modification of flow regimes, dewatering and degraded water quantity and quality which can dramatically decrease the quality of habitats of fishes and other wildlife.

Increases in population often are ecosystem stressors because of the increased water use and decreased water quality often attributed to increased effluent, stormwater runoff, increased chemical use in households (personal-care products), and demands on water quality and quantity to maintain municipal and commercial needs such as lawns and golf courses (fertilizers and pesticides). All of these contaminants may potentially enter Lake Mead through treated wastewater discharge to tributary rivers, such as Las Vegas Wash or the Virgin River (Rosen et al., 2012). Surrounding municipal wastewater treatment facilities have improved processes and quality of effluent entering the lake and consequently reduced algae blooms and other problems. However, some non-point source discharges, as well as non-compliance from individual facilities, can occur. Potential growth of upstream communities may increase effluent load and stormwater runoff entering Lake Mead NRA as current urban infrastructures may not be sufficient for potential increase loading (NPS, 2014).

4.5.4. Climate Change

Although precise impacts are difficult to predict, climate change is expected to threaten Basin water resources with extended drought periods, stronger heat waves, and more intense storm events (NPS, 2014). As greenhouse gases and other human effects on the climate continue to increase, the Rocky Mountains region, the source of the Colorado River, is expected to warm even more by the mid-21st century, pushing temperatures outside of the range of the past century (Lukas et al., 2014). The future

warming is projected to generally reduce Colorado's spring snowpack, cause earlier snowmelt and runoff, and increase the water use by crops, landscaping, and natural vegetation.

Changes to snow processes in the Rockies will affect all reservoirs along the Colorado, including lakes Mead and Mohave. Warmer temperatures may create significant water supply shortages in the Colorado River, increase water temperatures and modify regional patterns of precipitation which can have direct effects on water quality (Lettermaier et al., 2008). An increase in mean annual air temperature projected for the region would also likely increase surface water temperatures in lakes Mead and Mohave and could increase the potential for water-borne pathogens and aquatic invasive species (NPS, 2014). Specific impacts to lakes Mead and Mohave ecosystems would likely result from changes in water quantity within the Colorado River system. This may correspond to higher probabilities of lowering lake levels, increases in surface water temperatures resulting in changes in plankton/biota and lake mixing, increases in urban runoff from increased probability of flash floods, and changes to shoreline vegetation and animal resources.

Increased storm intensity and frequency as a result of climate change has been projected for the Lake Mead and Mohave region (NPS, 2014). Flood damage and increased pollution associated with local runoff has increased in the last two decades and has been blamed on the rising number of large storm events (Batker et al., 2014). After days of heavy rain in August of 2008, the Redlands Dam located on Havasu Creek in northwestern Arizona burst, causing flooding in side canyons, which are home to roughly 400 members of the Havasupai tribe. Roughly 300 tribe members and tourists were evacuated. This, and other flooding events, caused millions of dollars in damages (Batker, et al., 2014). Further, climate change not only impacts the current residents or visitors of the region but could also impact the cultural landscape and historic structures and archeological sites through a projected increase in mean annual temperature and increase in storm intensity and frequency (e.g., changes in vegetation, flooding and erosion) (NPS, 2014).

Drought and climate conditions in the region have lowered lake levels more than 100 ft, which may be correlated with increases in contaminant concentrations in some locations (NPS, 2014). Drought conditions have the potential to increase the concentrations of these pollutants in Las Vegas Bay and other locations.

Future climate projections with increase in mean annual temperature and historic drought conditions could exacerbate conditions that degrade water quantity, thus recreation suitability of lakes Mead and Mohave. The declining lake levels observed between 2000 and 2016 affected public access to Lake Mead and created infrastructure modification and operational demands on the NPS and its concessioners. At an elevation of 1,082 ft in October 2010, the lake is almost 140 ft below full pool elevation. Boat launch ramps at Pearce Ferry, Government Wash, Las Vegas Bay, and Overton Beach have been closed as lake waters have receded such that those ramps no longer provide reasonable access. Low water levels forced closure of marina operations at Las Vegas Bay, Boulder Harbor, and Overton Beach. All lake access points have been dramatically impacted. Concessioners are having difficulty moving the marinas and extending utilities to keep the marinas operational at current water levels, and water levels continue to drop. At each of the public launch ramps, the NPS and its concessioners continue to chase water depths compatible with boating recreation; falling lake

levels adversely impact recreational lake access and, in turn, visitor use at Lake Mead. Low water levels can make many existing shoreline facilities unusable in their current design and location. Increase in storm intensity or frequency projected for the region may increase pollution from local runoff (e.g., urban stormwater) and occurrence of pathogens and other illness-causing organisms by re-suspending bacteria from sediments.

Climate changes predicted for the area are also expected to reduce aquifer recharge as a result of an increase in mean annual temperature and historic drought conditions, which will reduce precipitation amounts. These important groundwater supplies and spring discharge (e.g., Northshore Road spring complex, Black Canyon area, and other smaller springs) could be negatively impacted as a result (NPS, 2014). Discharges from smaller springs in the park may be the most sensitive to climate change effects, as these springs tend to have more localized flow systems sourced from local precipitation. However, these smaller springs are less likely to be impacted by regional groundwater pumping, due to their localized flow systems that tend to be isolated from regional flow systems and pumping.

Climate change is likely to be a threat to all park habitats, particularly changing precipitation patterns, including the seasonality, frequency, and intensity of precipitation events, which directly affects germination, recruitment, reproduction, and persistence of plant communities and species. Such impacts are most profound on riparian systems and high elevation woodlands. Climate change may decrease cryptobiotic crusts and allow more airborne dust to occur. These climate-related effects likely threaten many ecosystems within the park, though such impacts are not well understood at this time.

Lowered surface-water levels likely will eliminate some shallow-lake areas and cause loss of habitat. Razorback suckers traditionally have used 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 (Rosen et al., 2012).

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 et al., 2010). The potential, future influence of increased water temperature on the occurrence of algal blooms and associated, reduced oxygen levels in the lake (Poff et al., 2002) is another climate-induced ecosystem concern at Lake Mead NRA.

The sustained drought has already caused significant changes to the confluences and deltas in Lake Mead. Climate models developed for the Southwestern United States and for the Colorado River watershed indicate high probability for longer periods of low water levels in Lake Mead. This could result in further growth of delta area at the confluences. New delta areas provide potential for riparian habitats with native plant species as part of the composition (see section 4.3.1). On the other hand, while deltas are a sink for contaminants and can prevent contaminants from entering Lake Mead when unsubmerged, exposed sediments have the potential to be re-suspended when they become inundated, transporting sediments and bound contaminants into lakes Mead and Mohave.

NPS has taken a number of steps to mitigate some of the effects of climate change, as climate change and regional water demand are the primary threats for water decline. For example, NPS has developed low water planning as part of the general management plan (GMP). Low water (below 1080 feet MSL elevation) makes many existing shoreline facilities unusable in their current design and location. Low water also exacerbates conditions that degrade water quality, increases the potential for invasion by aquatic invasive plant species, and may increase potential for water-borne human pathogens. Previous low water planning efforts have provided comprehensive management and visitor access direction for lake level scenarios below 1050 feet and for fluctuations over the long-term, beyond current projections. As climate conditions are expected to continue to change, it is important that park managers have access to the latest predictions of future climate scenarios and are enabled to proposed amendments to the GMP to continue recreational access to the Lake Mead NRA, but also to better plan for the ecological needs of the system.

4.5.5. Human Use

The landscape at Lake Mead NRA has evidence of unwanted impacts related to human use of the park's resources. In the eight wilderness areas, signs of inappropriate use include trash; unofficial, user-created trails; and campsites. Additonal use impacts include a number of areas with invasive plants, diminishing populations of threatened, endangered, and extirpated plants and animals, compacted soils, trash piles, and artificial fire regimes (NPS, 2014). Further, activities such as grazing, mining, and off-road vehicle recreation can all contribute erosion, increased dust, and damage to biological soil crusts (composed of moss, lichen, bacteria, and algae). These crusts, when intact, slow water runoff, and help capture and percolate water into deeper soils and groundwater (Batker, et al., 2014).

More than 8 million people visit the Lake Mead NRA per year, making it amongst the top ten in the United States for most visited national parks. Approximately 50 percent of visitors travel from Southern California and the remaining visitors are primarily from Nevada, Arizona, Utah, and other western states. The recreational activities on the Lake Mead NRA are abundant. The NRA offers year-round recreational opportunities for boating, fishing, hiking, photography, picnicking and sightseeing. Recreational boating is one of the most popular activities at the NRA. As established by the 2005 Lake Mead National Recreation Area Lake Management Plan, 3,357 slips and an additional 460 boats are available for rent from concessions. The daily public launch capacity was set at 3,000 boats, and the boating capacity for Lake Mead was set at 3,295 boats on the water at any one time. In addition to the recreational visitors, according to the Arizona Department of Transportation, about 4.5 million vehicles traveled through the park on U.S. Highway 93 in 2012 (Cui et al., 2013). Twenty-three miles of the highway that spans from Boulder City to 17 miles south of the Hoover Dam are located in the recreation area. There are many site-seeing turnouts and trailheads along the highway.

Recreational and transportation activities on the Lake Mead NRA can create disturbances to birds in the form of noise, waves and wakes, and habitat degradation. Such impacts can cause birds to avoid otherwise suitable areas when establishing territories or selecting roosting or nesting sites. During the breeding season, disturbance can result in nest abandonment at any stage of the nesting process. For

example, rock climbing near peregrine falcons can cause nest abandonment (Olsen & Olsen, 1980) and human disturbance near nesting colonial waterbirds can have significant negative effects (Camey & Sydeman, 1999).

In addition to the vast surface water use opportunities provided by lakes Mead and Mohave proper, there is an extensive spring network within the park. The larger, regionally or subregionally sourced springs occur at two locations in the park: Northshore Road spring complex and springs in the Black Canyon area below Hoover Dam. Long-term ecological monitoring of these springs is the subject of the Mojave Network I&M Program Selected Large Springs Monitoring Protocol, which is currently under development. In the Black Canyon, several warm and cold springs are present that discharge water in varying amounts. Numerous smaller, more localized springs occur elsewhere in the park. Long-term ecological monitoring of a subset of these springs is the subject of the Mojave Network I&M Program Aridland Springs Monitoring Protocol, which is currently under development.

Native aquatic organisms, including rare and endemic aquatic invertebrates, have been identified in many of these springs, though inventories are incomplete and long-term monitoring has not been established. Human use of springs for recreational purposes is a long-standing visitor activity within the park, with particular interest in soaking in natural hot or warm springs. In many locations, visitors alter the spring morphology by constructing impoundments to hold the water and deepen the pool. Such actions also increase human health risks due to creation of more hospitable conditions for pathogens such as the *Naegleria fowlerii* amoeba for which the park routinely posts warning signs at popular soaking springs (NPS, 2014).

Increased use of the park's resources is likely to increase the impacts of these and other unwanted human use impacts. Further, lake surface elevations have dropped by about 131 ft since 1999 due to extended drought and increasing water demands brought about by population growth (Holdren 2010). This elevation change impacted water quality and recreation and is just one of many management challenges facing the lake.

It is recommended that Lake Mead NRA is managed for the use and enjoyment of visitors in a manner that will leave the areas unimpaired for future use and enjoyment. Human use should be managed so visitors will have opportunities to experience solitude, remoteness, challenge, self-sufficiency, and discovery. The determination of appropriate protection, research, education, monitoring, and treatment methods and techniques is key to the successful management of human use at Lake Mead NRA and to foster a better understanding and awareness of wilderness preservation issues and goals, NPS managers should work with other agencies, institutions, governments, tribal governments, and the public. Increased understanding of the recreational uses of the lake will help park managers better provide for the short and long-term recreational as well as land stewardship needs of the Lake Mead NRA.

4.5.6. Literature Cited

Alvarez, D., Rosen, M., Perkins, S., Cranor, W., Schroeder, V., & Jones-Lepp, T. (2012). Bottom Sediment as a Source of Organic Contaminants in Lake Mead, Nevada, USA. Chemosphere, 88:605–611.

Barnes, J., & Gerstenberger, S. (2015). Using Feathers to Determine Mercury Contamination in Peregrine Falcons and Their Prey. Journal of Raptor Research, 49:43–58.

Barnes, J., & Jaeger, J. (2011). Inventory and Monitoring of Shoreline and Aquatic Bird Species on Lakes Mead and Mohave: 2004–2009. University of Nevada, Las Vegas, Public Lands Institute. Boulder City, NV: Lake Mead National Recreation Area, National Park Service.

Batker, D., Christian, Z., Cooley, C., Graf, W., Jones, K., Loomis, J., & Pittman, J. (2014). Nature's Value in the Colorado River Basin. Earth Economics, 104p.

Benotti, M., Standford, B., & Snyder, S. (2010). Impact of Drought on Wastewater Contaminants in an Urban Water Supply. Journal of Environmental Quality, 39:1196–1200.

Bevans, H., Goodbred, S., Miesner, J., Watkins, S., Gross, T., Denslow, N., & Schoeb, T. (1996). Synthetic Organic Compounds and Carp Endocrinology and Histology in Las Vegas Wash, and LAs Vegas and Callville Bays of Lake Mead, Nevada, 1992 and 1995. U.S. Geological Survey Water-Resources Investigations Report 96-4266. Retrieved from http://pubs.er.usgs.gov/publication/wri964266

Binding, C., Jerome, J., Bukata, R., & Botty, W. (2007). Trends in Water Clarity of the Lower Great Lakes from Remotely sensed Aquatic Color. Journal of Great lakes Research, 33:828–841.

Boralessa, M. (2001). Transport of Perchlorate in the Las Vegas Wash and Lake Mead. Las Vegas, NV: University of Nevada Las Vegas, M.S. Thesis.

Boyd, R., & Furlong, E. (2002). Human-health Pharmaceutical Compounds in Lake Mead, Nevada and Arizona, and Las Vegas Wash, Nevada, October 2000-August 2001. U.S. Geological Survey Open-File Report 2002-385. Retrieved from http://pubs.usgs.gov/of/2002/ofr02385/ofr02385.pdf

Caldwell, T., Rosen, M., Chandra, S., Acharya, K., Caires, A., Davis, C., Thaw, M., and Webster, D. (2015). Temporal and Basin-Specific Population Trends of Quagga Mussels on Soft Sediment of a Multibasin Reservoir. In W. Wong, & S. Gerstenberger (Eds.), Biology and Management of Invasive Quagga and Zebra Mussels in the Western United States (pp. 566–587). Boca Raton, FL: CRC Press.

Camey, K., & Sydeman, W. (1999). A Review of Human Disturbance Effects on Nesting Colonial Waterbirds. Waterbirds, 22:68–79.

Caraco, N., Cole, J., Findlay, S., & Wigand, C. (2006). Vascular Plants as Engineers of Oxygen in Aquatic Systems. Bioscience, 56:219–225.

Carter, B. (2000). An Examination of Gasoline Pollutants from Two-cycle Marine Engines within Lake Mead Recreational Area. Las Vegas, NV: UNLV Theses/Dissertations/Professional Papers/Capstones. Paper 199.

Cizdziel, J., & Zhou, X. (2005). Sources and Concentrations of Mercury and Selenium in Compartments within the Las Vegas Wash During a Period of Rapid Change. Environmental Monitoring and Assessment, 107:81–99.

Covay, K., & Leiker, T. (1998). Synthetic Organic Compounds in Water and Bottom Sediment from Streams, detention Basins, and Sewage-treatment Plant Outfalls in Las Vegas Valley, Nevada, 1997. U.S. Geological Survey Open-File Rep. 98-633. Retrieved from https://pubs.er.usgs.gov/publication/ofr98633

Cui, Y., Mahoney, E., Herbowicz, T. (2013). Economic benefits to local communities from national park visitation, 2011. Natural Resource Report NPS/NRSS/EQD/NRTR-2013/631. National Park Service, Fort Collins, Colorado.

Dudley, T., DeLoach, C., Lovich, J., & Carruthers, R. (2000). Saltcedar Invasion of Western Riparian Areas: Impacts and New Prospects for Control. Transactions of the 65th North American Wildlife and Natural Resources Conference (pp. 345–381). Chicago: Wildlife Management Institute.

Goodbred, S. L., Patino, R., Jenkins, J., Denslow, N., Orsak, E., & and Rosen, M. (2007). Organic Chemical Concentrations and Reproductive Biomarkers in common carp (*Cyprinus carpio*) collected from Two Areas in Lake Mead, Nevada, May 1999–2000. U.S. Geological Survey Data Series 286. Retrieved from http://pubs.er.usgs.gov/publication/ds286

Hamilton, S. (2004). Review of Selenium Toxicity in the Aquatic Food Chain. Science of the Total Environment, 326:1-31.

Hamilton, S., Holley, K., & Buhl, K. (2002). Hazard Assessment of Selenium to Endangered Razorback Suckers (Xyrauchen texanus). Science of the Total Environment, 291:111–121.

Hinck, J., Blazer, V., Denslow, N., Gross, T., Echols, K., Davis, A., May, T., W., Orazio, C. E., Coyle, J. J., Tillitt, D. (2006). Biomonitoring of Environmental Status and Trends (BEST) program – Environmental Contaminants, Health Indicators, and Reproductive Biomarkers in Fish from the Colorado River Basin. U.S. Geological Survey Scientific Investigation Report 2006–5163.

Holdren, C. (2010). Overview of Lake Mead. National Park Service website: https://www.nps.gov/lake/learn/nature/overview-of-lake-mead.htm

Holdren, G., & Turner, K. (2010). Characteristics of Lake Mead, Arizona-Nevada. Lake Mead NRA and Reservoir management, 26 (4): 230–239.

Kime, D. (1998). Endocrine Disruption in Fish. Boston, MA: Kluwer Academic Publishers.

LaBounty, J., & Burns, N. (2005). Characterization of Boulder Basin, Lake Mead, Nevada-Arizona, USA-Based on analysis of 34 Limnological Parameters. Lake and Reservoir Management, 21:277–307.

Lake Mead National Recreation Area. (2002). Lake Mead NRA Management Plan. National Park Services, 328p.

Lake Mead NRA. (2010). Long-term Limnology and Aquatic Resources Monitoring and Research Plan for Lakes Mead and Mohave: Boulder City, NV. Lake Mead National Recreation Area and University of Nevada, Las Vegas. Retrieved from http://www.nps.gov/Lake Mead NRA/learn/nature/upload/Eco_Monitoring_Plan_for_Lakes_Mead_and_Mohave_4-27_update.pdf

Lake Mead NRA. (2015). Lake Mead National Recreation Area Resource Suitability Guidelines. Lake Mead National Recreation Area, NV, AZ: National Park Service, Pacific West Region.

Leavitt, S., Haley, J., Hager, M., Baepler, D., & Nevada Department of Wildlife. (1989). Red Swamp Crayfish Ecology in Lake Mead. Las Vegas, NV: University of Nevada, Environmental Research Center.

Leiker, T., Abney, S., Goodbred, S., & Rosen, M. (2009). Identification of Methyl Triclosan and Halogentated Analogues in Both Male Common Carp (*Cyprinus carpio*) form Las Vegas Bay and Semipermeable Membrane Devices from Las Vegas Wash, Nevada. *Science of Total Environment*, 407: 2102–2114.

Lico, M., & Johnson, B. (2007). Gasoline-related Compounds in Lakes Mead and Mohave, Nevada, 2004–2006. U.S. Geological Survey Scientific Investigations Report 2007-5144. Retrieved from http://pubs.er.usgs.gov/publication/sir20075144

Linder, G., & Little, E. (2009). Competing Risks and the Development of Adaptive Management Plans for Water Resources – Field Reconnaissance Investigation of Risks to Fishes and Other Aquatic Biota Exposed to Endocrine Disrupting Chemicals (EDCs) in Lake Mead, Nevada USA. Proceedings of World Environmental and Water Resources Congress 2009, (pp. 342:5577–5601). Great Rivers.

Lettermaier, D., Major, D., Poff, L., & Running, S. (2008). Water Resources. In the Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States. Washington, D.C.: The U.S. Climate Change Science Program and the Subcommittee on Global Change Research.

Lukas, J., Barsugli, J., Doesken, N., Rangwala, I., & Wolter, K. (2014). Climate Change in Colorado – A Synthesis to Support Water Resources Management and Adaption. Colorado Water Conservation Board, State of Colorado. Retrieved from http://wwa.colorado.edu/climate/co2014report/Climate_Change_CO_Report_2014_FINAL.pdf

LVVWD. (2016). Water Quality Reports. Retrieved from Las Vegas Valley Water District: https://www.lvvwd.com/wq/reports.html

Marr, C. (2007). Endocrine Disruption in Razorback Sucker and Common Carp on National Wildlife Refuges along the Lower Colorado River – Environmental Contaminants Program Final Report. Phoenix, AZ: U.S. Fish and Wildlife Service Region 2.

Moore, B., Gerstenberger, S., & Wong, W. (2009). Quagga Mussel Invasion into Lakes Mead and Mohave in 2007: Abundance, Distribution, and Size Frequency. Lake Mead Science Symposium. Las Vegas, NV: University of Nevada, Las Vegas.

Mueting, S., & Gerstenberger, S. (2010). Mercury Concentration in quagga Mussels, *Dreissena bugensis*, from Lakes Mead, Mohave, and Havasu. Bulletin of Environmental Contamination and Toxicology, 84:497–501.

National Research Council Committee on Minerals and Toxic Substances in Diets and Water for Animals. (2005). Mineral Tolerance of Animals (2nd revised ed.). Washington, D.C.: National Academies Press.

NDEP. (2015, September 1). Defining a Perchlorate Drinking Water Standard. Retrieved from Nevada Division of Environmental Protection, Bureau of Corrective Actions: http://ndep.nv.gov/bca/perchlorate02_05.htm

Newell, A., Johnson, D., & Allen, L. (1987). Niagara River Biota Contamination Project Fish Flesh Criteria for Piscivorous Wildlife – Technical Report. New York State Department of Environmental Conservation, Division of Fish and Wildlife, Bureau of Environmental Protection.

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region

Olsen, J., & Olsen, P. (1980). Alleviating and Impact of Human Disturbance on the Breeding Peregrine Falcon II. Public and Recreation Lands, 4:54–57.

Osemwengie, L., & Gerstenberger, S. (2004). Levels of Synthetic Musk Compounds in Municipal Wastewater for Potential Estimation of Biota Exposure in Receiving Waters. Journal of Environmental Monitoring, 6:533–539.

Peck, S., Pratt, W., Pollard, J., Paulson, L., & Baepler, D. (1987). Benthic invertebrates and crayfish of Lake Mead. Las Vegas, NV: Lake Mead Limnological research center, Environmental Research Center, University of Nevada Las Vegas.

Poff, N., Brinson, M., & Day, J. (2002). Aquatic Ecosystems and Global Climate Change – Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States. Arlington, VA: Pew Center on Global Climate Change.

Rosen, M., & Van Metre, P. (2009). Assessment of Multiple Sources of Anthropogenic and Natural Chemical Inputs to a Morphologically Complex Basin, Lake Mead, USA. Paleogeography, Paleoclimatology, Paleoecology.

Rosen, M., Alvarez, D., Goodbred, S., Leiker, T., & Patino, R. (2010). Sources and Distribution of Organic Compounds using Passive Samplers in Lake Mead National Recreation Area, Nevada and Arizona, and Their Implications for Potential Effects on Aquatic Biota. Journal of Environmental Quality, 39:1161–1172.

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

Seiler, R., Shorupa, J., Naftz, D., & Nolan, T. (2003). Irrigation-induced Contamination of Water, Sediment, and Biota in the Western United States-Synthesis of Data from the National Irrigation Water Quality Program. U.S. Geological Survey Professional Paper 1655. Retrieved from http://pubs.er.usgs.gov/publication/pp1655

Snyder, S., Keith, T., Verbrugge, D., Snyder, E., Gross, T., Kannan, K., & Geisy, J. (1999). Analytical Methods for Detection of Selected Estrogenic Compounds in Aqueous Mixtures. Environmental Science and Technology, 33:2814–2830.

Snyder, S., Kelly, K., Grange, A., Sovocool, G., Snyder, E., & Giesy, J. (2001). Pharmaceuticals and Personal Care Products in the Waters of Lake Mead, Nevada. In C. Daughton, & T. Johne-Lepp (Eds.), Pharmaceuticals and Personal Care Products in the Environment (pp. 116–139). Washington, D.C.: American Chemical Society, ACS Symposium Series 791.

Urbansky, E. (1998). Perchlorate Chemistry – Implications for Analysis and Remediation. Bioremediation Journal, 2:81–95.

United States Census Bureau. (2015, December 2). State and County Quick Facts. Retrieved from United States Census Bureau: http://quickfacts.census.gov/qfd/states/32/32003.html

U.S. Department of Health and Human Services. (2013, June 18). Endocrine Disrupting Chemicals in Drinking Water: Risks to Human Health and the Environment. Retrieved from Testimony before Committee and Energy and Commerce, Subcommittee on Energy and Environment, and United States House of Representatives: http://www.hhs.gov/asl/testify/2010/02/t20100225a.html

USEPA. (2015a, August 8). Table of Regulated Drinking Water Contaminants. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/your-drinking-water/table-regulated-drinking-water-contaminants#one

USEPA. (2015b, November 15). Contaminants of Emerging Concern including Pharmaceuticals and Personal Care Products. Retrieved from Water Quality Criteria: http://www.epa.gov/wqc/contaminants-emerging-concern-including-pharmaceuticals-and-personal-care-products

USEPA. (2015c, September 29). Endocrine Disruption. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/endocrine-disruption/what-endocrine-disruption

USEPA. (2015d, October 19). Basic Information about Mercury. Retrieved from United States environmental protection Agency: http://www.epa.gov/mercury/basic-information-about-mercury

USEPA. (2015e, November 23). Perchlorate. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/dwstandardsregulations/perchlorate

USEPA. (2015f, November 15). Basic Information about Your Drinking Water. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/your-drinking-water/basic-information-about-your-drinking-water

USEPA. (2015g, January 23). $2 Billion in Funds Headed for Cleanups in Nevada and on the Navajo Nation from Historic Anadarko Settlement with U.S. EPA, States. Retrieved from USEPA Newsroom: https://yosemite.epa.gov/opa/admpress.nsf/0/2E47E97C62ACF44385257DD6007428C5

USEPA. (2016a, February 5). Human Health Water Quality Criteria. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/wqc/human-health-water-quality-criteria

USEPA. (2016b, January 15). Aquatic Life Criterion-Selenium. Retrieved from United States Environmental Protection Agency: http://www.epa.gov/wqc/aquatic-life-criterion-selenium

USEPA. (2016c, February 5). National Recommended Water Quality Criteria – Human Health Criteria Table. Retrieved from Water Quality Criteria: http://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table

USEPA. (2016d, June). Fact Sheet – Final Aquatic Life Ambient Water Quality Criterion for Selenium (Freshwater) 2016. Retrieved from Aquatic Life Criterion – Selenium Documents: https://www.epa.gov/sites/production/files/2016-06/documents/se_2016_fact_sheet_final.pdf

USEPA. (2016d, February 8). Dioxin (2,3,7,8-TCDD). Retrieved from United States Environmental Protection Agency: https://safewater.zendesk.com/hc/en-us/sections/202346377

Wittmann, M., Chandra, S., Caires, A., Denton, M., Rosen, M., Wong, W., Tietjen, T., Turner, K., Roefer, P., and Holdren, G. (2010). Early Invasion Population Structure of Quagga Mussel and Associated Benthic Invertebrate Community Composition on Soft Sediment in a Large Reservoir. Lake Mead NRA and Reservoir Management, 26: 316–327

Wong, D. (2012). Report: Quagga Mussel Monitoring in Lake Mead and Lake Mohave. Las Vegas, NV: University of Nevada, Las Vegas, Department of Environmental and Environmental Health, and Public Lands Institute.

Wong, W., Gerstenberger, S., Miller, J., Palmer, C., & Moore, B. (2011a). A Standardized Design for Quagga Mussel Monitoring in Lake Mead, Nevada-Arizona. Aquatic Invasions, 6:205–215.

Wong, W., Levinton, J., Twining, B., & Fisher, N. (2003). Assimilation of Micro- and Mesozooplankton by Zebra Mussels- A Demonstration of the Food Web Link Between Zooplankton and Benthic Suspension Feeders. Limnology and Ocenography, 48: 308–312.

Wong, D., Turner, K., Gerstenberger, S., & Miller, J. (2011b). Interagency Monitoring Action Plan (I-MAP): quagga Mussels in Lakes Mead and Mohave – Approved Working Document. Lake Mead National Recreation Area: National Park Service.

Zhou, X., Roefer, P., Zikmund, K., & LaBounty, J. (2004). Selenium Concentrations in the Las Vegas Wash and its Tributary Waters. Proceedings of the American Water Works Association 2004 Water Resources Conference and Exposition, (pp. 1–13). Austin, TX.

5. Discussion

5.1. Introduction

Lakes Mead and Mohave, the centerpieces of Lake Mead National Recreation Area (Lake Mead NRA), provide 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. While these reservoirs and others have modified the original, free-flowing Colorado River ecosystem, lakes Mead and Mohave still provide important or critical habitat for a variety of fish and wildlife species including the federally listed endangered razorback sucker (*Xyrauchen texanus*) and 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*). Lake Mead NRA also is a regionally important habitat for many birds, including peregrine falcons (*Falco peregrinus*) and 92 documented species of water-dependent birds.

Due to the importance of Lake Mead to the southwest, and regulatory monitoring related to discharge permits, there is a wealth of monitoring information routinely available for Lake Mead. We were able to access data from: SNWA data archive for SNWA, BOR and local wastewater discharge districts; USGS standard limnological data taken on continuous read-out platforms; USGS, FWS, and NPS EDC studies; and NPS recreational bacterial monitoring data. While much less data are available for Lake Mohave, SNWA, BOR, and NPS, Lake Mohave data collected from 2013 through 2015 were accessible.

A number of interagency scoping reviews for aquatic resource issues, key resources, objectives, target conditions, and suggested monitoring programs have been developed within the past few years. These include: the 2015 Foundation Document for Lake Mead NRA (NPS, 2015), the 2014 Lake Mead NRA Resource Stewardship Strategy (NPS, 2014), the 2010 Long-Term Limnological and Aquatic Resource Monitoring and Research Plan (LTAP) for lakes Mead and Mohave (Lake Mead NRA, 2010), the USGS 2012 A Synthesis of Aquatic Science for Management of lakes Mead and Mohave (USGS Circular 1381; Rosen et al., 2012), and the 2015 Lake Mead NRA Recreation Suitability Guide (Lake Mead NRA, 2015). The LTAP and USGS Circular 1381 in particular, were interagency documents involving agencies with water resource authorities on lakes Mead and Mohave. Both of those documents reflected interagency scoping that resulted in an interagency purpose statements and water quality objectives for the interagency Lake Mead Ecosystem Monitoring Work Group (LaMEM). See chapter 2 for further description of these guiding documents.

Beginning with the EPA SAB framework as a guide and checklist, the various water resource objectives, attributes, and targets from the above-listed planning documents were reviewed to develop the essential environmental and management features, attributes and indicators for the Lake Mead and Lake Mohave aquatic environments. Table 2.3.1-1 lists those features, attributes, indicators, and measures. The condition status for each indicator was presented in chapter 4. Those analyses provide the information for the key findings and ecosystem context presented below.

5.2. Key Findings

In this section, we summarize analysis findings in the context of five essential ecological or management features. For each major feature category, we summarize the scientific findings resulting from the analyses and review presented in the previous chapters, the management implications of these findings, and the relevancy to items related to the public's use and interest of Lake Mead NRA. Based on these items, we provide recommendations for data and information needs to best serve the sustainable use of the Lake Mead NRA for the benefit of its managers, stewards, and users.

5.2.1. Essential Ecological or Management Features Summary

The summary table below presents aggregated conditions and trends for the five essential ecological and management features examined in chapter 4 (Table 5.2.1–1). Conditions and trends were assigned based on the assessments of respective resource attributes and indicators. The table also provides brief descriptions of the rationales for the overall conditions and trends assigned, as well as identifies issues, emerging concerns, and data needs for each feature discussed in this section.

Table 5.2.1. Aggregated conditions and trends for the five essential ecological and management features examined in chapter 4.

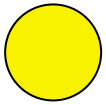
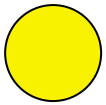
Essential Ecological or Management Features	Condition/ Trend	Rationale	Concerns
Lake and Riverine Ecosystem Health		The key lake and ecosystem health parameters for lakes Mead and Mohave are within good ranges of state standards and Environmental Protection Agency (EPA) Ecoregional Nutrient and Aquatic Life Criteria for Lakes and Reservoirs. Potential problems with nutrient balance, algae, and dissolved oxygen can occur at times and in some areas of Lake Mead and Lake Mohave.	Maintaining funding to carry out the existing (2015) level of Lake Mead-wide monitoring of physical and biological parameters, which are essential to assess trends and evaluate conditions. Monitoring is the foundation to assess impacts from ecosystem stressors, urbanization within watersheds, and potential climate change impacts. Data for important physical and biological parameters in Lake Mohave are sparse. Increasing the spatial and temporal sampling for nutrient concentrations, trophic status monitoring, and other physical characteristics of surface and water column properties is warranted in Lake Mohave.
Biotic Condition		The overall assessment included multiple taxonomic groupings, each of which indicated varied condition statuses dependent on a number of factors, including water quantity and quality parameters, population dynamics, and sampling regimes. Sport fish populations were found to be sufficient to support the recreational fishery. However, neither lake was found to support native fish populations of sufficient size to be self-sustaining in the long-term. Lake ecosystems have potential to provide significant regional habitats for water-dependent birds and native riparian vegetation; however, a lack of monitoring and management capabilities hinders the potential for restoration.	Quagga mussels and the introduced gizzard shad (*D. cepedianum*), and wastewater treatment technologies may impact native fish populations and broad biological dynamics in the lake. Monitoring status of spawning, survival, use areas and population dynamics for razorback suckers and other native populations are necessary activities to understand the health and sustainability of fish populations in the Lake Mead NRA. Increase in cyanbacterial (blue-green) algae and interactions with changing lake physical dynamics, introduced veligers, and zooplankton dynamics are a concern. Early detection monitoring is needed to identify littoral and aquatic vegetation communities, particularly those with aquatic invasive species present. Vegetation and community inventory and monitoring at Virgin River and Colorado River deltas is needed to assess invasive species control or native habitat restoration potential. Increased monitoring of all biological populations is strongly recommended for Lake Mohave.

Table 5.2.1 (continued). Aggregated conditions and trends for the five essential ecological and management features examined in chapter 4.

Essential Ecological or Management Features	Condition/ Trend	Rationale	Concerns
Ecological Processes		This attribute ranking is driven by the indicator hydrologic regime, which warrants significant concern. Drought, or drought-like conditions along the Colorado River system, are persistent in this region. In every year since 2000, Colorado River inflows have been lower than the 1990–1999 average. Declining lake levels have necessitated costly infrastructure adjustments to fulfill the purposes of the reservoir and recreation use.	Climate models project changes in rainfall patterns with less overall precipitation, but greater probabilities for higher intensities and frequencies of rainfall, flashfloods, and storm events in the Colorado River Basin. The continuation of long-term monitoring by regional interagency collaborations is important for managing the Colorado River watershed and protecting park resources. Newly exposed sediments as a result of persistent drought may also have the potential to increase sediment and contaminant transport into lakes Mead and Mohave. Monitoring delta deposition in response to lowering lake levels to assess habitat potential and alteration of reservoir hydrology is critical to inform managerial decision and strategic planning for Lake Mead NRA.
Recreation Suitability		Based on standard limnological trophic indices, the U.S. Environmental Protection Agency's (USEPA) National Lake Assessment Standards, 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. While not warranting concern, however, in the last five years lakes Mead and Mohave have seen increases in the number of isolated exceedances of bacterial standards, and in 2015 the presence of algal toxins warranting a swimming advisory.	Future climate projections forecast increases in mean annual temperature and drought conditions could exacerbate conditions that degrade water quality, and thus recreation suitability of lakes Mead and Mohave. Fish consumption advisories based on tissue concentrations of Mercury remain in place despite that no concentrations of Mercury in fish tissues from lakes Mead and Mohave have been collected since 2008. No routine chlorophyll *a* concentration data for Lake Mohave were available at this time of this assessment. Additional monitoring is needed to assess which contaminants or pathogens may pose a human health risk.

Table 5.2.1 (continued). Aggregated conditions and trends for the five essential ecological and management features examined in chapter 4.

Essential Ecological or Management Features	Condition/ Trend	Rationale	Concerns
Stressors and Disturbance Regimes		Endocrine disrupting compounds and other emerging contaminants of concern are not seen at levels currently known to pose a threat to human health for drinking water or recreation, but have been documented as causal in health effects to individual fish. The establishment of invasive species, such as quagga mussel and Saltcedar have already caused economic and ecological damage to the Lake Mead NRA, impacting water quality, quantity, recreation and water conveyance. However, the NPS currently has a rigorous containment program in place to minimize the spread of quagga mussels through recreational watercraft. Climate models indicate that there is a high probability for longer periods of low water levels in Lake Mead. This would increase water temperatures and alter water circulation patterns, nutrient cycling, and food-web dynamics. Higher water surface temperatures could raise productivity, alter algae production and composition, and also raise the risk of pathogenic organisms to thrive.	Existing monitoring of perchlorate, selenium and other contaminants is likely to continue based on regulatory requirements. While inventories for VOCs in lakes Mead and Mohave from the mid-2000s exist and provide a one-time assessment of the relative extent of VOCs, limited information is available to develop a trend. Increased coordination of monitoring efforts is recommended, particularly with efforts to leverage this information in order to identify means to reduce inputs to Las Vegas Wash. Preventing the introduction of other potentially harmful nonindigenous species, as well as preventing the spread of these species from within the NRA to locations outside the NRA is an important management implication. Climate change related information is needed for lakes Mead and Mohave particularly as it 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.

5.2.2. Lake and Riverine Ecosystem Health



Scientific Findings

The overall assessment outcome of Lake and Riverine Ecosystem Health for lakes Mead and Mohave is of Good Condition. This assessment was based on two major assessment categories: Lake Health and Tributary Condition. Lake Health is a reflection of the biological and chemical properties of the water quality, water quantity, and the effect these properties have on the ecological and recreational functioning of the overall ecosystem. Lake Health was assessed using the following three indicators: (1) trophic level, (2) hydrologic function, and (3) surface water quality conditions. Tributary Condition was largely evaluated using the following six indicators: (1) Physical Characteristics, (2) Nutrient Conditions, (3) Inflows, (4) Contaminants, (5) Sedimentation, and (6) Land Use within the Watershed.

The basic water-quality parameters are within good ranges of state standards and Environmental Protection Agency (EPA) lake criteria. However, potential problems with nutrient balance, algae, and dissolved oxygen can occur at times and in some areas of Lake Mead and Lake Mohave. Willow Beach and Las Vegas Bay had the lowest water clarity in the Lakes Mohave and Mead, respectively, and a downward trend in water clarity has been observed in Las Vegas Bay. In Las Vegas Bay, total nitrogen and total phosphorus concentrations warranted moderate concern. This can be attributed to higher sediment and nutrient loading from wastewater upstream of these locations, resulting in higher turbidity and algal production and biomass. Further, salinity concentrations in Lake Mead have been increasing over time and warrant moderate concern. In all locations, water clarity improves with distance from the tributary discharge.

The water budget for Lake Mead and Lake Mohave is highly regulated and depends primarily on releases from Lake Powell through Glen Canyon Dam and downstream releases through Hoover Dam and Davis Dam. Retention time in Lake Mead averages about 2.6 years, depending on reservoir operations for Lakes Mead and Powell. Assessment of the future hydrologic function was based on simulations of future climate in the Southwest. These simulations projected significant declines in overall precipitation and flow in the Colorado River basin. Overall, Lake Mead has a consistent downward trend of water level due to persistent drought, increasing water demands, and over-allocation of water on the Colorado River. Releases through Hoover Dam are the only significant inflow to Lake Mohave. Release volumes are variable as water is released as needed to meet water deliveries stipulated by the Colorado River Compact.

Nutrient concentrations along the Colorado and Virgin rivers inflows are within the EPA's eutrophic criteria for protection against nutrient over-enrichment in rivers and streams for the Xeric West Ecoregion. The Las Vegas Wash has been a site of concern with respect to elevated nutrient conditions and in 2015; nutrient conditions significantly exceeded the EPA threshold. Despite this exceedance, there has been a decreasing trend since the mid-2000's in Las Vegas Wash in nutrient concentrations, in large part due to nutrient (e.g., phosphorus) removal efforts by wastewater dischargers. Additionally, phosphorus concentrations in Colorado River, Virgin River, and Las

Vegas Wash have decreased in the last decade and average concentrations detected in recent years (2010–2015) were significantly lower relative to 2002–2009 average at all inflows. Recent pH levels measured at the four tributaries are in general within the historical range of variability calculated based on long-term annual mean (2001–2009). The pH levels in the water from the Colorado and Virgin rivers have increased since 2001.

Since construction of Glen Canyon Dam, there has been low sediment and nutrient load from tributaries into lakes Mead and Mohave. All tributaries to Lake Mead carry relatively heavy sediment loads, and inflows are colder (Colorado River), saltier (Las Vegas Wash), or both (Virgin and Muddy rivers) than the receiving waters of Lake Mead. This affects the flow regime and tends to limit mixing and nutrient load as the majority of nutrients enter Lake Mead at the hypolimnion or lower part of the epilimnion making them unavailable to support algal growth. Little sediment has accumulated in Lake Mohave since its impoundment in 1953 by closure of the Davis Dam as the sediment load from Hoover Dam discharge is minimal. In Lake Mead, since impoundment of Lake Powell deposits are mainly comprised of fine-grained sediment which tends to accumulate in the deepest parts of the sheltered areas along the edges of the Colorado River Channel.

Public lands mostly surround lake Mead NRA, and most land ownership zoning types are compatible with park purposes (e.g. conservation, undeveloped). Drainage entering Lake Mead via the Las Vegas Wash includes both non-point source urban runoff and permitted discharges from four municipal wastewater treatment plants. The majority of the Las Vegas Wash within Duck Creek watershed is urbanized, and the Muddy River within the Lower Muddy River watershed is about 65% urbanized while all tributary miles of the Virgin River within Halfway Wash watershed are not urbanized. Increasing urbanization in the watershed will likely add additional pressure to the hydrologic dynamics of the Lake Mead NRA.

Management Implications

In Lake Mead, trophic status has improved since 2001 as a result of improved wastewater treatment processes for effluent streams entering the park via Las Vegas Wash. Despite these improvements, Las Vegas Bay is a site of concern that continues to have high nutrient and chlorophyll a concentrations and associated declines in water clarity an annual basis. It is important to consider that water volume and hydrodynamic properties of the system play an important role the health of the Lakes as nutrient and chlorophyll a concentrations have generally been observed to be higher at the stations located closer to tributary confluences (e.g., the main source of nutrient to Lake Mead). Tributary inflows provide the highest productivity, but also the greatest potential to cause nutrient related issues. Continued investment in wastewater treatment processes will be a key factor in reducing the eutrophic nature of Las Vegas Bay. Further, as water quantity is estimated to decrease due to drought conditions or other structural deficits in the Colorado River System, the trophic status of Las Vegas Bay will likely degrade and the frequency of occasional algal blooms (e.g., such as those observed in 2001 and 2015) may potentially increase.

Public Relevancy

Water clarity, chlorophyll *a* concentrations, and the overall trophic nature of the lake are important factors of concern relative to the public's interaction with freshwater systems. Recreational users will

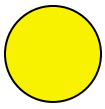
tend to select for waters with higher environmental quality when choosing trip destinations, and in particular, water clarity has shown to be a preferred condition for the valuation of interaction with freshwater systems (Poor et al. 2001).

The clear and "blue" nature of Lake Mead and Mohave's water, clarity and water quality is undoubtedly an attractant for visitors to the park. That the lakes ecosystems are of consistently good health, in accordance with EPA and state environmental standards can be of assurance to users who are selecting recreational destinations based on the abiotic and biotic properties of the aquatic ecosystem. Since the mid-2000's in the Colorado River, Virgin River and Las Vegas Wash nutrient concentrations decreased. Decreases in the Las Vegas wash and Virgin Rivers are due in large part due to nutrient (e.g., phosphorus) removal efforts by wastewater dischargers. Lake Mead has benefitted recently from enhanced wastewater treatment as well as monitoring and research resulting from coordinated efforts by the NPS and resource management agencies in the region to improve the use of the Lake Mead NRA water resources.

Recommendations for data and information needs

The recent Lake Mead-wide scope of monitoring has provided a solid baseline to characterize water quality; however, more information is needed for Lake Mohave. Maintaining the existing (2015) level of Lake Mead-wide monitoring of physical and biological parameters essential to assess trends and evaluate conditions. However, while a number of variables have been monitored in Lake Mohave over multi-decadal periods, relative to Lake Mead, data availability for important physical and biological parameters in Lake Mohave is limited. Increasing the spatial and temporal sampling for nutrient concentrations, trophic status monitoring and other physical characteristics of surface and water column properties is warranted in Lake Mohave. Monitoring is the foundation to assess impacts from ecosystem stressors, urbanization within the watersheds, and potential climate change impacts.

5.2.3. Biotic Condition



Scientific Findings

The overall biotic condition of lakes Mead and Mohave warrants concern. The overall assessment included multiple taxonomic groupings, each of which indicated varied condition statuses dependent on a number of factors including water quantity and quality parameters, population dynamics and sampling regimes.

Sport fish populations were found to be sufficient to support an important recreational fishery. Recent angler catch rates in 2014 and 2015 were consistent and also higher than historical catch rates, suggesting that that recreational harvesting is stable and sustained by the current sportfish population observed in lakes Mead and Mohave. Striped bass declined recently in catch rate (CPUE), and percent of overall harvest in the creel surveys as well as declines in CPUE in the gillnet surveys. Interest in catching striped bass have also decreased. However, in 2014, it was the most abundant

sportfish species captured. The establishment of quagga mussels has impacted some of the littoral zone sportfish species dynamics, and will likely continue to impact food web interactions.

Native fish populations warrant significant concern, with neither lake supporting native fish populations of sufficient size to appear self-sustaining in the long-term. Native fish populations in Lake Mead are small, in the low hundreds of fish, but significant in the Colorado Basin overall as a self-recruiting (no management augmentation) population. In Lake Mohave, spawning from a large remnant population (recruitment pre-Davis Dam in 1951) has been documented for recent decades. However, recent estimates indicate that the population size is less than 5000 individuals, as compared to 60,000 in the late 1980s. Adult razorback suckers are present throughout Lake Mohave; however, natural recruitment and survival of wild fish to adulthood has not been documented for many years. The existing population is a result of intensive rearing and augmentation programs, with native fish populations in Lake Mohave continueing to decline. The condition of benthic macroinvertebrates warrants concern due largely to the presence of non-native invertebrates and the potentially associated absence of native invertebrates which accounts for the majority of the dissimilarity between historical and contemporary invertebrate assemblages in Lake Mead. No qualitative benthic macroinvertebrate data or monitoring program exists for Lake Mohave and little or no data are available to assess the condition of these taxa.

A number of bird species of conservation interest utilize lakes Mead and Mohave year-round or seasonally. Therefore, Lake Mead NRA can play a critical role in the conservation of these species. However, availability of seasonal resources for a number of these species is unstable due to fluctuating water quantities. At this time there are insufficient data available to understand the population dynamics of the avian populations in the Lake Mead NRA and the potential implications of contaminant concentrations (e.g. Hg in falcons) on the influence of nesting success and production.

Riparian vegetation warrants moderate concern in both lakes Mead and Mohave, as the composition and occurrence adjusted to reservoir conditions, with a mixture of desired and non-native plant species. While some of these riparian areas are encountering significant degradation risk through receding shorelines on Lake Mead, the presence of non-native phreatophytes (e.g. Saltcedar), and human activities, such as livestock grazing, unauthorized firewood gathering, and shoreline use, lowered water levels as a result of persistent drought conditions have also exposed new acreages of riparian habitat. Aquatic vegetation has received minimal inventory or monitoring to date.

Management Implications

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 and may also impact native fish populations present in the lake. Monitoring status of spawning, survival, use areas and population dynamics for razorback suckers and other native populations are necessary activities to understand the health and sustainability of fish populations in the Lake Mead NRA.

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. Aquatic dependent bird condition warrants concern, largely due to a lack of information and variability in water supply. The initial 5-year (2004–2009) IMAP shoreline and aquatic bird inventory provided useful baseline information regarding the current condition in lakes Mead and Mohave and for future assessments.

As climate and water availability conditions are likely to change, the development of new deltas within the Lake Mead NRA provide the potential for new riparian habitats. In addition, newly exposed shoreline habitats have potential to spread non-native species such as saltcedar. In particular, the nearshore band of riparian habitat of Lake Mohave may benefit from active management due to the relatively stable shoreline. Newly exposed tributary deltas and upper terraces about retreating shorelines of Lake Mead have potential for increased numbers of native riparian species.

Public Relevancy

Those who visit the Lake Mead NRA for recreational purposes do so for a variety of reasons. Anglers make up a large proportion of the recreational users at the Park. Natural resource, and in particular, fisheries managers are often tasked with providing the best recreational experience possible which includes the conservation and improvement of fish stocks, which encompass the enhancement of environmental quality and eco-system services within fishery catchments (Curtis and Breen 2016). Eden and Bear (2011) found that anglers selectively interpret what constitutes the 'balance of nature' and favor management measures which promote ecosystems that benefit catch rates.

Through the evaluations put forth in this assessment, anglers that utilize the Lake Mead NRA may find that the sports fishery is of good condition and able to support the sustainable harvest of many recreational fishes. However, the native fishery of the Lake Mead NRA is undoubtedly undergoing changes to its population dynamics, which may potentially be attributed to a number of environmental stressors concerning the abiotic and biotic properties of the system.

The invasion of quagga mussel has been shown to impact nearshore dynamics and the abundances of forage fishes in the system (Umek et al. 2010), and will likely have impacts on both native and sports fishes of Lake Mead in the future. Certainly, the quagga mussel invasion has impacted the recreational user’s experience to at the Lake Mead NRA to date. The States of Nevada and Arizona, in cooperation with LMNRA, have implemented new boating management and education programs to prevent the spread of quagga mussels into other water bodies.

Recommendations for data and information needs

Continued annual sport fish, shad and forage fish population monitoring provides a key baseline to assess the impacts of major stressors of concern to the Lake Mead NRA: quagga mussels, nutrient cycling, contaminant effects, water availability, and climate change. In particular, monitoring native fish populations is critical for assessing trends and evaluating management needs for future stocking events, especially as the dynamics of major ecological stressors may be better understood with scientific or technological advancements or altered as environmental conditions change. There is also

a need for an understanding of the impacts on the plankton community resulting from quagga mussel invasion or other water quality or quantity parameters.

In order to evaluate bird responses to ecosystem changes, monitoring of population dynamics and relationship to available habitats is needed. Further, monitoring of potential contaminant impacts and quagga mussel establishment on bird population dynamics and health is warranted.

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.

Increased monitoring of all biological populations is strongly recommended for Lake Mohave.

5.2.4. Ecological Processes



Scientific Findings

The Ecological Processes of the Lake Mead NRA warrant concern and were evaluated through an assessment of three broad categories: hydrologic regime, sediment loading, and nearshore processes.

The hydrologic regime of Lake Mead NRA warrants significant concern. Droughts, or drought-like conditions along the Colorado River system, are potentially becoming the new normal for this region. In every year since 2000, Colorado River inflows have been lower than the 1990–1999 average. In 2014–2015 the average annual inflow from the Colorado River was at 81.1% of the long-term average. Between 2000 and 2015, a majority of annual flow estimates for the Virgin and Muddy Rivers were also below the long-term average. In contrast, inflow volume from Las Vegas Wash has increased in recent years. This is a result of increases in effluent discharge and urban runoff from nearby municipalities. Climate models project changes in rainfall patterns with less overall precipitation, but greater probabilities for higher intensities and frequencies of rainfall, flash floods, and storm events in the Colorado River Basin.

Sediment loading in Lake Mead was significant prior to the creation of Lake Powell. However, the Glen Canyon Dam greatly slowed and reduced the amount of sediment transport to Lake Mead. Lake Mohave's sediment profile is characterized by pre-impoundment features since almost all sediment transported by the Colorado River is trapped in Lake Mead or in other upstream reservoirs. Little sediment has accumulated in Lake Mohave since its impoundment in 1951.

Over the last 16 years, an extended drought has reduced the Lake Mead perimeter and increased exposed shoreline area. By 2011, more than 25,000 ha of formerly submerged land were exposed as a result of the drawdown. An assessment of the Lake Mead NRA alluvial delta dynamics indicates changes in size and location of confluences and deltas over time. 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 stem of the Colorado River. This may forward confluences further downstream of the tributaries, and result in growth of delta areas at the confluences. These

new delta areas provide potential for riparian habitats for native vegetation and sandflats or shallows for shoreline birds. Decreasing water volumes, however, alters habitat attributes, such as nearness to water, and may reduce overall quality of these new habitats.

While the non-native saltcedar was the most abundant species in the nearshore zones of the Lake Mead NRA, studies have shown that native perennial species richness increased with surface age (i.e., those sites with longer periods of inundation) at all nearshore sites. Additionally, density of Saltcedar decreased, and frequency of native perennial species increased with surface age. Soil properties generally appear to be little impacted by submersion, suggesting that properties of formerly submerged soil are not likely limiting native plants colonization relative to never-submerged areas.

Management Implications

Fluctuating Lake elevations can complicate the development of shoreline habitat management strategies. While Lake Mead elevation may continue to fluctuate, scientific consensus has concluded that a return to full pool elevation is unlikely within future decades. Therefore, newly exposed land will remain present along Lake Mead's shoreline.

Flash flood events in Lake Mead have caused significant damages to park infrastructure, loss of human life, and economic loss. Projected changes in climate, particularly increased summer rainfall intensities and the potential for more frequent flash floods can have widespread effect on the condition of the lakes. For example, 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. Therefore, an understanding of how flood frequency and size may change with projections of future climate is important for assisting managers to effectively plan for necessary actions needed to minimize damages and protect public health.

The sustained drought has already caused significant changes to the confluences and deltas in Lake Mead. Climate models developed for the Southwestern United States and for the Colorado River watershed indicate high probability for longer periods of low water levels in Lake Mead. This could result in further growth of delta area at the confluences. New delta areas provide potential for impacts to bird habitat or creation of new riparian habitats with native plant species as part of the composition. Newly exposed sediments may also have the potential to be re-suspended, transporting sediments and bound contaminants into lakes Mead and Mohave.

Public Relevancy

The decrease in water volume at lakes Mead and Mohave is likely the largest threat to the use of Lake Mead NRA today. The "bathtub ring" that lake users see at Lake Mead is a result of declining lake levels due to persistent drought conditions and other structural deficits associated with the Colorado River System. This dramatic ring has become more and more visible in recent years, providing a reminder to users in the park of the decrease in water supply. Declining lake levels have necessitated adjustments in infrastructure to fulfill the purposes of the reservoir. An example is the recently (2015) installed drinking water pipeline in Boulder Bay which has an intake at 860 feet above sea level--190 feet below the tallest existing intake. The NPS has also needed to adjust

facilities for recreation use. As climate and precipitation models predict that water supply along the Colorado River is likely to decrease, the public's access to Lake Mead will become increasingly difficult. The NPS has expended millions of dollars since 2000 to extend launch ramps, relocate power and water infrastructure, and maintain facilities and access in all areas of the lake. In 2015, the NPS predicted that no access points will be operable below an elevation 1060' despite additional infrastructure investment.

Recommendations for data and information needs

The last sedimentation survey in the Lake Mead NRA was conducted in 2001. Field surveys to characterize sedimentation trends in the last 15 years are needed not only to understand the volume of sediment and its impacts on water storage but also to gain a better understanding of the relationship of contaminants in sediments to food-web transfers. Characterization of the transport of sediments and potential re-suspension and flux of contaminants at the sediment-water interface would provide key information to ensure the safety of human and wildlife populations that utilize the Lake Mead NRA.

Monitor delta deposition in response to lowering lake levels to assess habitat potential and alteration of reservoir hydrology. Spatial analyses should be conducted to quantify and document changes in confluences locations of major tributaries, and the change in sizes of deltas and riparian area with lowering of Lake Mead NRA elevations. Periodic repeats of plant and soil surveys should be conducted to detect and monitor changes over time. Information collected can be used to inform managerial decisions and strategic planning for Lake Mead NRA.

Perhaps of most importance, a systematic assessment of flash flood hazard to major park facilities and cultural resources is necessary to protect these resources. NPS managers should work with partners for monitoring protocols and capacity to measure potential impacts from increasing frequency and intensity of flash floods. Such data would be critical to initiating discussions among local agencies on any potential mitigation should impacts prove significant.

5.2.5. Recreation Suitability



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.

Lake Mead has sustained a long (1999 to 2015) period of high aesthetic water quality based on the chlorophyll *a* parameter and water clarity (Secchi depth). Open water sampling stations in Lake Mead were generally within the clear water range between 2003 and 2015, and ranges considered "good" within the USEPA National Lakes Assessment. Reductions in chlorophyll *a* and increases in water clarity most likely have resulted 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. Recent trends for most limnological measurements are within ranges observed over the past 20 years, indicating a general stability in water quality.

All waters, including those within the Lake Mead NRA, 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. Lake Mead receives treated wastewater effluent and urban runoff from Las Vegas Valley via Las Vegas Wash. The wastewater discharged into the Wash is treated and disinfected, and bacterial concentrations are normally well below established limits for body-contact recreation. During periods of higher urban run-off into the Wash, indicator bacterial counts within Las Vegas Wash have been temporarily elevated above the limits recommended for body contact recreation. In multiple locations within the park sampled by NPS, including Boulder Basin, fecal coliform, and *E. coli* abundances were below established full body-contact recreation standards. A low incidence of detection of pathogens within initial survey samples from Overton Arm and Colorado inflow/upper Lake Mead NRA led to decision not to include those areas in routine pathogen monitoring after April 2005.

Water-borne human and wildlife indicator bacteria (e.g., *E. coli* and fecal coliforms) for water quality suitability for full body contact have been noted for short durations from 2001 through 2013. This is generally detected immediately following high-use weekends in the waters near popular coves. NPS continues to monitor these areas, and exceedances of the acceptable limit for full-body contact occur in a small percentage (2%) of samples. Most recently, in 2015, the highest bacterial concentrations were generally found at the Las Vegas Wash confluence. However, Las Vegas Wash is not designated as body-contact recreational waters by NDEP. Both *E. coli* and fecal coliform concentrations are considered in the "good" range for Las Vegas Bay and Boulder Basin.

Water managers at Lake Mead NRA are also concerned with a number of viruses and protozoans that can cause human illness. Water-borne pathogens, such as West Nile virus and *Naegleria fowleri*, have been detected in the park vicinity and the potential exists for occurrence in the park. Both species pose health risks to park visitors and employees). Two protozoan parasites, *Cryptosporidium* and *Giardia* have also been detected at low numbers (1–2) in the past 10 years. *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. The SNWA routinely tests for both of these organisms as a part of its drinking-water monitoring requirements. During 2014, neither organism was detected at the drinking-water intakes within Lake Mead.

While *Microcystis* sp. and other nuisance cyanobacteria are found in lakes Mead and Mohave, they do not represent a significant proportion of the overall population of phytoplankton and pose a low risk of exposure to algal toxins. The organisms of the genus *Microcystis* spp. have been noted more frequently in lakes Mead and Mohave in recent years. In March 2015, sampling in Lake Mead at the Las Vegas Boat Harbor Marina detected microcystin and localized chlorophyll *a* concentrations

exceeding hazardous levels for HAB criteria. Lake Mead NRA managers immediately issued a swimming advisory for both lakes Mead and Mohave in response and enhanced monitoring and public information for the continuing peak use period in the summer of 2015. Pockets of *Microcystis* spp. were noted in most areas of both lakes during the summer of 2015; however, aggregations of algae generally appeared and dissipated rapidly in response to wind conditions. Microcystin was present in a number of locations through the summer, and Lake Mead NRA continued its public advisory and education programs. While the park refined its protocols for managing outbreaks of *Microcystis* spp. during 2015, management did not find signficant detections of *Microcystis* spp.in the spring and summer of 2016.

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 NRA are less than the USEPA concentrations recommended to protect human health; however, individual fish samples did have concentrations that exceeded USEPA recommended for mercury. The Nevada Division of Public Health and the Department of Wildlife (NDOW) has published fish consumption advisories for lakes Mead and Mohave. The statewide fish consumption advisory issued by NDOW remains in place for sportfish harvested from lakes Mead and Mohave.

Management Implications

The purpose of Lake Mead NRA is to provide diverse public recreation, benefit and use on lakes Mead and Mohave and surrounding lands in a manner that preserves the ecological, geological, cultural, historical, scenic, scientific, and wilderness resources of the park. Agencies responsible for water-quality standards and management at lakes Mead and Mohave are concerned over the potential for human illness from microbial organisms, algal toxins, or other contaminants.

Future climate projections with increases in mean annual temperature and historical drought conditions could exacerbate conditions that degrade water quality, thus recreation suitability of lakes Mead and Mohave. Increases in storm intensity or frequency projected for the region may increase pollution from local runoff (e.g., urban stormwater) and occurrence of pathogens and other illness-causing organisms by re-suspending bacteria from sediments. Forecasted lower water levels, warmer water temperatures and re-suspension of shoreline sediments can potentially contribute to algal growth and increase the presence of algae mats and surface scums. Of concern is Golden alga (*Prymnesium parvum*), which 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. For the first time in Nevada, a toxic golden alga bloom was reported at Lake Las Vegas in 2010. This event raised concern about the potential for toxic blooms to spread into Lake Mead. The environmental factors responsible for golden algal blooms or how and when they produce toxins are not currently understood. As a result, it may be difficult to manage these blooms if they do occur or to try to prevent them from spreading to Lake Mead.

Invasive species such as quagga mussels have been found to enhance blue-green algae growth in the Great Lakes and mid-western US. It is possible that the same effect may occur at lakes Mead and Mohave. Lower water levels can also lead to higher mortality rates of quagga mussels on above-water rocks and beach areas resulting in decomposition, which presents aesthetics and odor problems

that impair recreational use of Lake Mead. Sharp shells washed up on shore can present a safety hazard to visitors. Large quantities of fecal materials produced by quagga mussels and the associated algae growth in the shallow areas can result in increased bacteria (e.g., *E. coli*) concentrations in nearby beach waters.

Public Relevancy

While this assessment has found that Lake Mead NRA is suitable for recreational uses, there have been incidents of exceedances of EPA or state standards for some contaminants including fecal coliforms, bacteria and blue-green toxins (e.g., microcystin). The March 2015 swimming advisory issued at lakes Mead and Mohave are examples of the benefits provided from the availability of monitoring resources, and the presence of the Southern Nevada Water Authority, National Park Service and other partnering agencies to conduct important public health-related monitoring and have the ability to respond immediately. While the likelihood of people being affected by contact with blue-green algae is low, federal, state, and local agencies in Southern Nevada continue to monitor algae composition levels in lakes Mead and Mohave proactively. Water treatment plants use both ozone and chlorine, which represent the two most effective treatment processes for destroying microcystin and other pathogens that may be present in freshwaters, preventing them from entering the drinking water system. Accumulations of harmful algae, pathogens and other contaminants are typically rare and sporadic in the Lake Mead NRA and will not impact swimming or other water contact activities in the lakes.

Consumption of fish containing high levels of Mercury can have impacts on reproductive, immune, and nervous systems function to all ages, affecting growth, behavior, disease susceptibility, or may even be life threatening. Mercury concentrations in surface water in lakes Mead and Mohave are relatively low and mercury concentrations in fish can vary throughout lakes Mead and Mohave, indicating different sources. In one Lake Mead study, most fish sampled for Mercury did not have flesh concentrations that exceeded USEPA tissue residue criterion and are safe for eating. However, a small percentage (<5%) of fish (mostly top predators, e.g., striped bass) studied did have concentrations that exceeded USEPA tissue residue criterion (Kramer & Gerstenberger, 2010). With individual fish samples having concentrations that exceeded USEPA recommendation for methylmercury, the State of Nevada has issued statewide fish consumption recommendations for sportfish in lakes Mead and Mohave.

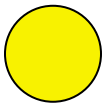
Recommendations for data and information needs

While various agencies have been collecting long-term monitoring data for some of the parameters utilized (e.g. pathogen concentrations, chlorophyll *a*, and Secchi depth), information on other parameters may be lacking (e.g. cyanobacteria abundance). In addition, different analytical methods and estimate units were used for cyanobacteria abundance and *Microcystin* spp. concentration with data obtained and what was established in the USEPA National Lakes Assessment, which made comparisons within this assessment difficult. Consistent analytical methods and estimate units should be used to document cyanobacteria abundance and *Microcystin* concentrations in the Lake Mead NRA.

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. Fish consumption advisories based on tissue concentrations of Mercury remain in place despite that no concentrations of Hg in fish tissues from lakes Mead and Mohave have been collected since 2008. No routine chlorophyll *a* concentration data for Lake Mohave were available at this time of this assessment. Additional monitoring is needed to assess which contaminants or pathogens, if any, may pose a risk to human health.

Lastly, emerging issues due to introduced species such as quagga mussel and Golden alga may pose potential unwanted impacts to the recreational value of the Lake Mead NRA. Further research to understand the role that these and other introduced species play in the proliferation of contaminants, impacts to lake aesthetics or other ecosystem functioning that may affect the management or use of the Lake Mead NRA is warranted.

5.2.6. Stressors and Disturbance Regimes



Scientific Findings

Five broad categories were reviewed to assess the impact of disturbance on the Lake Mead NRA. These categories include: Contaminants, Aquatic Invasive Species, Development and Urbanization, Climate Change and Human Use.

Contaminants

More than 100 organic compounds have been detected in water, sediments and fish of the Lake Mead NRA. Endocrine disruptor compounds (EDCs) are compounds that alter the normal functions of hormones and can lead to reproductive effects in aquatic organisms. However, limited evidence exists regarding their effects to human health at environmental exposure levels. Between 1995 and 2008, EDCs such as PCBs, PDBEs, organochlorine pesticides, and dioxins have been consistently detected in the water, sediment, fish, and birds of Lake Mead. Results of studies in Lake Mead indicate that bioaccumulation has occurred and the endocrine system and reproduction in aquatic biota (e.g., common carp (*Cyprinus carpio*)) have been altered by some of these chemicals, particularly at Las Vegas Bay and Willow Beach. Legacy contaminants (e.g., PCB's, DDT) have been in decline in the Lake Mead NRA due to regulations and mitigation. There are insufficient data to deduce impacts to the sustainability of fish and wildlife populations, or trends about whether EDCs in Lake Mead NRA are increasing or decreasing.

Pharmaceuticals and personal care products (PPCPs) are contaminants of emerging concern (CECs). PPCPs are increasingly being detected at low levels in surface water, particularly near the Las Vegas Wash. There is concern that these compounds may have an impact of aquatic life and humans that consume these aquatic organisms. Overall, little is known regarding the toxicity of trace concentrations of PPCPs to aquatic life and human health in lakes Mead and Mohave. Currently,

PPCPs in Lake Mead NRA are not seen at levels currently known to pose a problem to human health for drinking water or recreation.

There have been no exceedances of USEPA standards for human health or elevated levels of gasoline based contaminants, Volatile Organic Compounds (VOC's) at open water locations. However, marina locations where higher VOC concentrations were detected were not examined here due to lack of data availability. Between 2004 to 2006, USGS monitoring of VOC and BTEX concentrations on both lakes Mead and Mohave found that concentrations in open water went from non-detect to minimal during months of limited boating use, and were higher during more active recreation months. VOC concentration data collected from the lower Las Vegas Wash between 2007 and 2015, a period spanning from before to after the new boating regulations were implemented, show samples from all year had BTEX concentrations less than the detection limit. No post 2006 data concerning VOC's have been collected from Lake Mohave.

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 water column, 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. 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. Results from this assessment demonstrate that remediation efforts that taken place since 1998 have significantly reduced perchlorate loading from Las Vegas Wash to Lake Mead and the Colorado River downstream of the lake, including Lake Mohave.

Concentrations of bromide detected at various depths through the water column between 2000 and 2015 were generally similar (<0.01mg/L difference). This suggests that water column stratification does not seem to have an effect on the distribution of bromide. Monthly averages from all depths since 2004 have been a downward trend ($p<0.05$) with bromide concentrations at the Boulder Basin station. Downward trends of Bromide concentrations have been observed at all Colorado River main stem stations, as well as at Overton Arm downgradient station. Bromide concentrations are relatively higher at stations closer to tributary confluences suggesting loading of bromide from Las Vegas Wash and Virgin/Muddy rivers, respectively. According to the 2014 and 2015 water quality reports issued by the LVVWD, bromate concentration in drinking water did not exceed the USEPA standard. No data are available for Lake Mohave.

Selenium occurs naturally in the environment in the Lake Mead NRA region and selenium concentrations have decreased from 2008 to 2015. Overall, selenium concentrations of all samples from all locations (pooled by collection depth) were well below the USEPA selenium criterion for safe drinking water (50 μg/L) and did not exceed the USEPA selenium criterion for protection of aquatic life from 2008 to 2009 and in 2015. However, selenium concentrations of samples from open water locations did exceed the selenium criterion for lotic waters in 2015. No recent records of

selenium concentrations in Overton Arm and Lake Mohave were available at this time of this assessment.

Lastly, mercury concentrations in surface water of Las Vegas Wash, lakes Mead and Mohave have not exceeded the USEPA safe drinking water standards. There have been very few measurements of Hg in the open water areas of lakes Mead and Mohave. For findings of mercury levels in fish tissues in lakes Mead and Mohave, see section 4.4, Recreation Suitability.

Aquatic 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 pose significant threats to infrastructure, recreation, and ecosystems in lakes Mead and Mohave.

The introduction of invasive plant species to United States water bodies has been escalating with widespread destructive consequences. Invasive plants are associated with significant habitat destruction, loss of animal communities, reduced fishing and water recreation opportunities, and large mitigation expenditures. Some potential aquatic plant invaders to lakes Mead and Mohave include the Giant Reed (*Arundo donax*), Hydrilla (*Hydrilla verticillata*), Eurasian Water Milfoil and Parrotfeather (*Myriophyllum* sp.), Alligator Weed (*Alternanthera philoxeroides*), Curly Leaf Pondweed (*Potamogeton crispus*), and Giant Salvinia (*Salvinia molesta*).

In addition to these aquatic invasive species, there are also riparian invaders, such as saltcedar *(Tamarisk* sp.), that are established in the Lake Mead NRA. Declining Lake Mead elevations since 1998 have exposed greater than 25,000 ha of formerly submerged land, creating opportunities for new invaders such as crimson fountaingrass (*Pennisetum setaceum*) and Sahara mustard (*Brassica tourneforti*).

Development and urbanization

Historically, development and urbanization have had unwanted impacts to the Lake Mead NRA and continue to pose a potentially significant threat to the area's ecological and economic resources. Major impacts from development and urbanization include but are not limited to increased demand on water supply, flood risk, degradation of water and air quality, and negative impacts to wildlife and other ecosystem services. Development within the Colorado River Basin, particularly in Nevada, Arizona, and southern California, has steadily increased since the expansion of water and other infrastructure projects. Major cities of the Lake Mead Basin include Las Vegas, North Las Vegas, Henderson, and Mesquite, Nevada and St. George, Utah. Since 2000, the population of Las Vegas has grown by 21 percent, Henderson, Nevada by 48 percent and in 2015 St. George Utah was ranked as the 5th fasting growing area in the country with a 3% increase per year. With population increases ranging from 16–25 percent, the major Arizonan cities in the Lake Mohave Basin (Bullhead City, Lake Havasu City and Kingman) also have experienced similar levels of population growth. Over the next 50 years, meeting Colorado River Basin resource needs will be significantly challenged due to limitations in water supply associated with forecasted development of water supplies, increased consumptive use in the Upper Basin, and reduced volumes of water stored in system reservoirs.

Climate Change

Climate models developed for the Colorado River watershed indicate a probability of decline in watershed snowpack and thus reduced water availability. Models point to increased potential for summer thunderstorms and flash floods. Although precise impacts are difficult to predict, climate change is expected to threaten Basin water resources with extended drought periods, stronger heat waves, and more intense storm events. As greenhouse gases and other human effects on the climate continue to increase, the Rocky Mountains, the source of the Colorado River is expected to warm even more by the mid-21st century, pushing temperatures outside of the range of the past century. The future warming is projected to generally reduce Colorado's spring snowpack, cause earlier snowmelt and runoff, and increase the water use by crops, landscaping, and natural vegetation.

Human Use

The landscape at Lake Mead NRA has evidence of unwanted impacts related to human use of the park's resources. While scenic viewsheds are generally well protected due to conservation zoning within the park, the lake shorelines as well as within the eight wilderness areas adjacent to the lakes there are noticeable impacts of human use. These impacts include trash; unofficial, user-created trails; and campsites, as well as a number of areas with invasive plants, diminishing populations of threatened, endangered, and extirpated plants and animals, compacted soils, artificial fire regimes and even trash piles. Further, activities such as grazing, mining, and recreation in off-road vehicles can all contribute erosion, increased dust and particulate matter and damage to biological soil crusts, which are composed of moss, lichen, bacteria, and algae. These crusts, when intact, slow water runoff, and help capture and percolate water into deeper soils and groundwater.

Management Implications

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. Monitoring selenium concentrations in Las Vegas Wash is important because soils in up-gradient areas in Las Vegas Valley are known to contain selenium, which may leach into the shallow groundwater that enters the Wash and flows into Lake Mead. While selenium concentration is not an issue for Lake Mead in term of meeting safe drinking water standards, concerns for elevated concentration of selenium to aquatic life and birds are warranted as selenium concentrations from open water locations did exceed the selenium criterion for protection of aquatic life in for lentic waters (1.2 µg/L) in 2015. Aquatic life may experience adverse health effects at a much lower level because selenium can bioaccumlate and biomagnify within the food web. As a result, top predators, such as bald eagle and striped bass can be exposed to higher selenium levels in their diet and may be at greater risk for selenium poisoning. Additionally, selenium has been found to bioaccumulate in quagga mussels (Wong et al., 2011). Concerns have given rise to the bioaccumulation of selenium in quagga mussels and subsequent potential impacts to aquatic birds within Lake Mead NRA which may use quagga mussels as a food source.

In 2011, the USEPA determined that perchlorate meets the criteria for regulation under the Safe Drinking Water Act. Since then, USEPA has initiated the process to develop and establish a national primary drinking water regulation, which is a legally enforceable standard that applies to public

drinking water supplies. An Interim Lifetime Drinking Water Health Advisory has been issued while the enforceable standard is in development. NDEP has issued a provisional drinking water standard for perchlorate based upon USEPA guidance.

New boating regulations were introduced in the Lake Mead NRA Management Plan (2002) for the phased elimination of two-stroke personal watercraft on lakes Mead and Mohave in hopes to reduce VOCs related to gasoline and boating traffic in the Lake Mead NRA. Those restrictions went fully into effect in 2013 with an allowance for watercraft that meet the US Environmental Protection Agency (EPA) 2006 emission standards through the use of direct-injection two-stroke or four-stroke engines.

The establishment of invasive species, such as quagga mussel and Saltcedar have already caused economic and ecological damage to the Lake Mead NRA, impacting water quality, quantity, the recreational experience and water conveyance. These species and others will continue to establish, spread and have impacts within the Park. Preventing the introduction of other potentially harmful nonindigenous species, as well as preventing the spread of these species from within the NRA to locations outside the NRA is an important management implication. The NPS currently has a rigorous containment program in place to minimize the spread of quagga mussels through recreational boaters.

The Muddy and Virgin Rivers are likely to experience increases in urban inflows if proposed development progresses along watersheds in Nevada, Utah, and Arizona. Increases in treated effluent can be expected from proposed waste water treatment facilities upstream. Such discharge may result in channelization of the river courses and alteration of the environmental dynamics of the delta areas within Lake Mead, including potential impacts on water chemistry, nutrient load, silt deposition, water temperature, and undoubtedly increases in contaminants.

Climate models indicate that there is a high probability for longer periods of low water levels in Lake Mead. This would increase water temperatures and alter water circulation patterns, nutrient cycling, and food-web dynamics. Higher water surface temperatures could raise productivity, alter algae production and composition, and also raise the risk of pathogenic organisms to thrive.

Human use should be managed so visitors will have opportunities to experience the existing levels of solitude, remoteness, challenge, self-sufficiency, and discovery. The Lake Management Plan and the park's wilderness plans have documented actions to maintain natural zones and wilderness character while facilitating visitor use. The determination of appropriate protection, research, education, monitoring, and treatment methods and techniques is key to the successful management of human use at Lake Mead NRA and to foster a better understanding and awareness of visitor experience issues and goals, NPS managers should work with other agencies, institutions, governments, tribal governments, and the public.

Public Relevancy

The disturbance regimes presented above will largely impact all users of the Lake Mead NRA. Environmental pressures will likley increase in the future resulting from the introductions of

contaminants in the environment and aquatic invasive species, increased development, urbanization and other land uses in the watershed, and changes and more eradicate climate. Coordinated monitoring and management actions will ensure the ability for stewards and managers at Lake Mead NRA to be able to respond quickly to emerging water quality threats, understand the near and long-term for water availability issues and design research programs to more fully benefit activities related to NRA planning.

Recommendations for data and information needs

The multi-decadal interagency collaborations in lakes Mead and Mohave have resulted in quite possibly one of the most comprehensive and relevant set of databases in existence concerning a National Recreation Area. Sustaining these data resources through continued investment in data managers, database maintenance, upgrades and increased user-friendliness will only increase the use of these invaluable resources. Below we describe some specific data recommendations concerning contaminants, invasive species, and climate-related data collection.

Existing monitoring of perchlorate, selenium and other contaminants is likely to continue based on regulatory requirements. While inventories for VOCs in lakes Mead and Mohave from the mid-2000s exist and provide a one-time assessment of relative extent of VOCs at that time, limited information is available to develop a trend. Increased coordination of these monitoring efforts is recommended, with efforts to use this information to reduce inputs to Las Vegas Wash.

Studies on the fate and transport of EDCs and other contaminants of emerging concern (CECs) at Lake Mead began in 1996 with a study that identified the occurrence of endocrine disruption in common carp. With a majority of EDCs not currently regulated in wastewater discharges or having water-quality standards, inventory and monitoring of EDCs, including CECs in the water column, sediment, and fish of lakes Mead and Mohave, are warranted to assess the long-term effects on aquatic biota and human health. Limited studies have been conducted regarding the effects of CECs to human health at environmental exposure levels. Although these compounds represent a threat to water quality and ecosystems and human health, more information is needed to assess impacts and develop mitigation plans. The extent and nature of population-level impacts of these compounds remain undetermined and are potentially detrimental to both wildlife and human users of the Lake Mead NRA.

Current quagga mussel monitoring efforts are mainly focused on veliger larvae and limited adult quagga mussel density data have been collected in recent years. There is limited information regarding other invasive species that are likely impacting the recreational fishery, such as New Zealand mudsnails and crayfish in lakes Mead and Mohave. Baseline data collection and subsequent systematic monitoring of these invasive species is critical for understanding the long-term effect of the invasion of these species.

Climate change related 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.

5.3. Observations

Summary findings from this LRCA concur with summary findings from the USGS Circular 1381, A Synthesis of Aquatic Science for Management of lakes Mead and Mohave. We concur that Lake Mead hydrology and base limnology is well understood, based upon over twenty years of agency coordinated long-term monitoring and research. Similar to the USGS 1381, this LCRA finds that overall the water quality parameters for ecosystem health and for recreation suitability are within a "good" condition. However, it is difficult to draw long-term conclusions regarding the status of Lake Mohave, due to lack of available resource for monitoring basic environmental parameters from the lake. Based upon the data collection and utilization successes resulting from long-term monitoring interagency partnerships in Lake Mead, we recommend that increased efforts focused on Lake Mohave with comparable methods utilized at Lake Mead. Similar methods and efforts will improve our understanding and management of that resource and allow for comparisons across the system.

Given the significant 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. That interest has initiated and sustained 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; and the Lake Mead Ecosystem Monitoring Work Group (LaMEM) composed of members of Federal, State, and local agencies and organizations concerned with understanding and protecting the ecosystems of lakes Mead and Mohave. In addition, the Las Vegas Valley Watershed Advisory Committee, comprised of water and wastewater agencies in southern Nevada, works to enhance watershed management of Lake Mead and its southern Nevada tributaries primarily Las Vegas Wash. The long history of interagency cooperation has greatly enhanced protection of lake ecosystems and water quality.

Much of the information provided in this review was due to the efforts of individuals within agencies and stakeholders responsible for managing and contributing to the sustainability of this resource. The interagency effort has existed for the last 15 years and has developed partnerships with research and educational institutions to assist in understanding changes to the resource. Maintaining and supporting the interagency partnership is more important today given newly emerged challenges (e.g. invasive species, climate change, urban pollution) which may influence human and environmental health (e.g. pathogens and algal toxins). Every major resource in the country (e.g. Laurentian Great Lakes, Chesapeake Bay, Lake Tahoe, San Francisco Bay Delta, Florida Everglades) has interagency partnerships between agencies and educational institutions to guide resource management. In this respect, the National Recreational Area is well suited to move forward in quantifying future challenges and changes. All of the major resources, however, have some form or another of centralized support mechanisms that foster collaboration and support monitoring and research for each resource.

An example of a joint federal-state-city programs that may be used as a case example in the Western United States could be the Lake Tahoe watershed. In this watershed, there is a coordinated support program using federal and state (California and Nevada) dollars to tackle key issues developed in a

jointly agreed upon Environmental Improvement program. We recommend a centralized financial support system for assessment and monitoring activities for the recreation area. In addition, the National Park Service may want to consider expanding the interagency framework that has been used to address emerging issues to develop common goals and approaches for developing financial resources that help manage the resource. It may help interagency partnership to reach out to the other major interagency resource partnerships listed above to understand common issues and develop frameworks to address these issues. Utilizing the Cooperative Ecosystem Studies Unit framework may be used to engage research partners at Universities.

There is movement towards a common framework. The LaMEM has established a purpose statement of mutual interests and objectives for water-related resources and values for lakes Mead and Mohave. Tble 5.3–1 provides a comparison of the summary findings for the key features of this LRCA with corresponding interagency attribute interests documented by LaMEM.

On the ground expertise by NPS staff and NPS staff capacity to effectively work with partner agencies has allowed for the rapid response to observations of water quality related incidences such as Microcystin toxins present in the watershed, Golden alga blooms and other exceedances of USEPA standards. These responses have resulted in the continued safety for the users of the Lake Mead NRA. The NPS response to the quagga mussel invasion has also resulted in one of the largest containment and recreational boater outreach programs in the nation, which is aimed at reducing the spread of this harmful invader to other locations in the Western U.S. For decades, the NPS has worked in collaboration with multiple agencies in the assessment of water quality, water-dependent resources, and ecosystem health. In light of novel stressors to the Lake Mead NRA, there is an urgent need for resources to allow the NPS to continue to be actively involved in regional coordination and monitoring efforts.

Over $15 million worth of monitoring and research for lakes Mead and Mohave water resources was conducted from 2004 to 2011 through funding available from the Southern Nevada Public Lands Management Act. Agencies involved in implementing research plans and conducting the work 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. This partnership program, coordinated by Lake Mead NRA, led to a number of research and monitoring products, including two Lake Mead Science Symposia (2009 and 2012), the interagency development of a Lake Mead NRA Long-term Aquatic Resources Monitoring and Research Plan for lakes Mead and Mohave (National Park Service, 2010), and the 2012 USGS Circular 1381, A Synthesis of Aquatic Science for Management of lakes Mead and Mohave. In 2012 these partnerships coalesced into the interagency Lake Mead Ecosystem Monitoring Workgroup, a subcommittee of the Lake Mead Water Quality Forum coordinated by Nevada Division of Environmental Protection. These partnerships have been effective in identifying issues threatening water quality and lake resources, conducting coordinated monitoring and research, and informing the public and respective agency managers. These studies, conducted with non-recurring funds, resulted in a wealth of information and concluded that overall the lakes and lake ecosystems were well within healthy conditions.

Table 5.3–1. Summary of the findings for the key features of this LRCA.

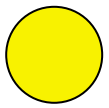
Lake Mead Ecosystem Monitoring Work Group interests: ***Water quality that:***	**Condition/ Trend**	**Rationale**	**Concerns**
Supports regional and community needs for municipal and industrial uses		Water from Lake Mead is well within state and EPA standards to be considered as high quality as a drinking water source.	Decreasing water quality and quantity as a result of persistent drought conditions will increase costs of water delivery.
Supports aquatic life: healthy populations of native fish		While the sport fishery is active, native fish populations in lakes Mead and Mohave are declining.	Forecasts of environmental conditions that may adversely affect fish health indicate that Native fish populations are at risk.
Supports aquatic life: healthy populations of sport fish		Sport fish populations were found to be sufficient to support an important recreational fishery, but potentially in decline.	Sport fishery declines may be due to decreasing water volume, aquatic invasive species, contaminants, pathogens, habitat losses or other stressors. Continued monitoring is essential to meet fishery management objectives.
Supports healthy populations of aquatic dependent wildlife: waterbirds		Many sensitive bird species utilize lakes Mead and Mohave year-round or seasonally. Availability of seasonal resources for these species is unstable due to fluctuating water quantities. At this time, there are insufficient data available to understand the potential impacts to Lake Mead NRA waterfowl.	Continued monitoring is needed to understand the status and trends of species composition, occurrence, distribution, and abundance of shorebirds and aquatic-dependent birds. Potential future climate effects on changes in water quantity, water quality, habitat and food resources for aquatic birds in Lake Mead NRA is not known and should be evaluated.
Supports foodweb and components		Phytoplankton relatively stable; Zooplankton still in range supporting healthy foodweb (at least from Beaver et al in 2016); shift in benthic, forage fish at good levels within historic ranges	Benthic shift; gizzard shad, and threat to plankton from quagga, climate, low water. Phytoplankton increase in cyanobacterial cells in part of lake a concern.
Supports healthy populations of riparian and aquatic vegetation		The composition and occurrence of riparian vegetation has historically adjusted to variable reservoir conditions, with a mixture of desired and non-native plant species. Aquatic vegetation has received minimal inventory or monitoring to date.	Monitoring and assessment of riparian and aquatic vegetation in Lake Mead NRA is sparse or nonexistent, yet important to inform the development of appropriate management strategies for controlling and limiting the spread of non-native plants along the shorelines of lakes Mead and Mohave.

Table 5.3–1 (continued). Summary of the findings for the key features of this LRCA.

Lake Mead Ecosystem Monitoring Work Group interests: ***Water quality that:***	**Condition/ Trend**	**Rationale**	**Concerns**
Supports existing high quality setting for water based recreation		Lakes Mead and Mohave generally are of high quality for recreational uses. However, in the last five years lakes Mead and Mohave have seen increases in the number of isolated exceedances of bacterial standards, and in 2015 the presence of algal toxins warranting a swimming advisory.	Future climate projections with increase in mean annual temperature and historic drought conditions could exacerbate conditions that degrade water quality, thus recreation suitability of lakes Mead and Mohave.

Lakes Mead and Mohave are now in transition, however, with new challenges for interagency water managers and park managers to face. Persistent drought conditions have been observed since 2001 which has resulted in lower water volumes, warmer air and water temperatures, potential health concerns from pathogens and contaminants, the invasion of new nonindigenous species such as quagga mussel, and other impacts to water quality which have impacted the recreational and municipal uses of the aquatic resources. The lakes and the watershed are potentially entering a new normal of climate and consumptive related stressors to the water resources. Maintaining or increasing existing levels of lake-wide monitoring of physical and biological parameters of water quality in Lake Mead is important with the anticipated threats brought forth by stressors such as contaminants, aquatic invasive species, and climate change. Establishment of a comprehensive baseline monitoring network for Lake Mohave is important as historical water quality data are sparse for Lake Mohave. Physical characteristics, such as bathymetry or water depth and the resultant associated ecosystem dynamics, of Lake Mohave may react differently than Lake Mead to impacts from various stressors. Consistent and reliable funding is critical for the maintenance and establishment of long-term monitoring effort in lakes Mead and Mohave.

Reviews indicate that water quality and limnological characteristics of Lake Powell and the Colorado River within Grand Canyon influence water quality and hydrologic processes in lakes Mead and Mohave. A predictive model analysis conducted to assess potential climate change impacts on water quality in Lake Mead found that future lower lake levels on Lake Mead will have a direct impact on water quality in Lake Mohave. Lake Mohave has only a sixty day water retention time; impacts to Lake Mohave will quickly influence the lower Colorado River and Lake Havasu. Lower Colorado River ecosystems and community water needs would benefit from greater coordination of monitoring protocols and findings among the managers within the entire Colorado River watershed.

5.4. Emerging Issues for Lakes Mead and Mohave Water Resources and Regional Implications

Data collection and monitoring efforts supported by strong partnerships have resulted in the recognition of new, emerging water-quality and environmental health issues within Lakes Mead and Mohave. This information has enabled the authors to evaluate the condition of the Lake Mead NRA. Evaluations were completed often using quantitative data to support indicators of lake and tributary health, vulnerabilities within the system, as well as key knowledge gaps.

5.4.1. Hydrologic Dynamics

While much is known about the hydrological properties of the Lake Mead NRA, there are still a number of unknowns that may have profound impacts on the management of this whole system. For example, Lake Mohave is heavily and directly influenced by waters received through Hoover Dam. Stressors to water quality in the Boulder Basin will influence water quality in Lake Mohave. Understanding the dynamics and connections between systems are not well understood.

Lower water elevations could alter the basic hydrology and water-column mixing of Lake Mead, subsequently altering algal growth and composition, sediment distribution, and dissolved oxygen concentrations. Reductions in dissolved oxygen have been noted in the Muddy and Virgin Rivers and Overton Arm during extended low-flow conditions.

Changing water management in the upper Colorado Basin that may result from implementations of the Glen Canyon Dam Long-term Experimental and Management Plan (LTEMP), affecting lower Lake Powell, which may result in altered water quality or quantity entering Lake Mead. How these potentially changing management regimes will impact downstream resources is currently unknown, and largely unidentified.

Better understanding of the hydrologic dynamics within and upstream of the Lake Mead NRA will allow for improvements in strategic management of park resources in order facilitate sustainable wildlife and habitat management and better serve Lake users under an ecologically sustainable framework.

5.4.2. Impacts of changes in climate conditions

Regional climate model predictions are largely in agreement on a number of factors such as increased air temperatures and subsequent increased mean lake temperatures, increased floods, and more variable precipitation regimes. While experiments and models have measured or forecasted the impacts of warming surface water conditions on various components of Lake Mead, the localized, the long-term, and the synergistic effects of some of these climate dependent changes on the ecosystem and associated use of Lake Mead NRA are largely unknown.

For example, potential future climate effects on changes in habitat and food resources for aquatic birds in Lake Mead NRA should be evaluated. Continued monitoring of population dynamics and relationship to available habitats is needed to assess response to low water and evaluate bird responses to changes in Lake Mead NRA ecosystems. Aquatic bird species at lakes Mead and Mohave will be affected by anthropogenic-induced changes, particularly from non-native invasive species and contaminants contained in tributary inflow. Understanding pathways of contaminants within the food web and to bird reproduction is needed to assess risks to population health. Long-term monitoring of anthropogenic activities in relation to the effect such activities have on aquatic birds is important for park managers so that they can better plan for protection of sensitive areas.

While the current climate models have indicated that these impacts could likely occur as a result of increased air and water temperatures, it is unknown how these impacts will specifically impact the abiotic processes and biota of the Lake Mead NRA, and subsequently, use of the park's resources. Further information is needed to understand the linkages between the large-scale forecasted changes in climate and the smaller scale impacts to wildlife and human populations that rely on the park.

<u>Contaminant impacts</u>

Contaminant concentrations in Las Vegas Bay are expected to increase in the coming years; however, little is understood about the impacts of various contaminants on the biota of the Lake Mead NRA, or how the physical properties of the system may impact the magnitude of this affect. Effluent and urban runoff contain a wide variety of contaminants, including mercury, PPCPs, EDCs, VOCs, perchlorate, and various pesticides. In addition, the Muddy and Virgin Rivers are likely to experience increased urban inflows if proposed development progresses along watersheds in Nevada, Utah, and Arizona. Increases in treated effluent can also be expected from proposed waste water treatment facilities upstream. Such discharge may result in channelization of the river courses and

alteration of the environmental dynamics of the delta areas within Lake Mead, including potential impacts on water chemistry, nutrient load, silt deposition, water temperature, and undoubtedly increases in contaminants. Improved understanding of the potential synergies of these processes at the individual, community and ecosystem scale will greatly improve the development and implementation of successful management strategies to protect against potential adverse effects to human health.

Invasive species

Studies on the impacts and management of invasive species have increased dramatically over the last few decades. In Lake Mead, a research and management focus has been narrowed on Dreissenid mussels, which were discovered in 2007. In lakes Mead and Mohave and other systems, quagga mussels have been found to clog water intakes and pipes and alter nutrient cycling in Lake Mead by increasing dissolved phosphorus and decreasing particulate phosphorus in the water column through filtration and excretion (Wong et al., 2011). In other systems, quagga mussels have been found to change the composition of phytoplankton communities and nutrient dynamics by lowering the nitrogen/phosphorus ratio. This can potentially favor the growth of cyanobacteria, particularly those that can produce harmful cyanotoxins. These and other kinds of ecological impacts may have series implications for the recreational and municipal water use of lakes Mead and Mohave, however, there remains information gaps related to the impacts of this and other invasive species on multiple aspects of the system, including but not limited to, food webs, water clarity, productivity, deterrence of recreational users and impacts to infrastructure.

Riparian and Aquatic Vegetation

Information concerning riparian and aquatic vegetation in lakes Mead and Mohave are sparse. Ongoing monitoring and assessment of riparian vegetation are important for assessing the effectiveness of the tamarisk leaf beetle and other control methods for regulating saltcedar and other non-native riparian plant species, as well as for understanding the health and diversity of native riparian vegetation. Data collected could inform the development of appropriate management strategies for controlling and limiting the spread of non-native plants along the shorelines of lakes Mead and Mohave.

5.5. Management Recommendations

Lake Mead 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. However, there remains the need for maintaining established coordinated monitoring within the system and expanding monitoring in areas of LMNRA that are undermonitored. For example, until 2012, Lake Mohave was not on a regular basis in space and time. In order to more fully understand the impacts to the water quality, quantity, recreational and ecological dynamics of the Lake Mead NRA system, the Lake Mohave monitoring program needs to continue and be enhanced.

Recognition that increasing stressors and influences in individual basins have affected water quality and quantity throughout Lake Mead NRA and have given rise to an even stronger effort towards the

development of holistic and effective interagency approaches. In the context of the Colorado River system, there is a need not only for increased coordination amongst agency participants specific to the Lake Mead NRA, but also in the Lower and Upper Basin states. The reservoirs of the Colorado River Basin are connected and have a significant impact on each other. Understanding this interconnectedness through enhanced monitoring and park management programs will allow for the sustainable use of the Lake Mead NRA.

To better enable the National Park Service (NPS) to address the complex resource preservation issues stemming from dam operations along the Colorado River, the National Park Service Colorado River Basin Parks Program was established. This program strives to understand river operations issues and more effectively advise fellow agencies to adjust those operations, where discretion permits, to better protect park resources. Recent drought across the Colorado River watershed has heightened awareness of all stakeholders to potential economic, social, and political tradeoffs in river management. The Colorado River Basin Parks Program includes the Steering Committee comprised of park superintendents, two NPS Regional Directors (Pacific West Region; Intermountain Region) and the Chief of the NPS Water Resources. A Technical Committee comprised of chief Colorado River park resource managers and selected subject matter specialists was also established, and a Colorado River Coordinator has been created to help coordinate communication both among parks and with other agencies and external stakeholders. Efforts like this program should be continued.

We recommend the NPS continue to participate and, in some cases, lead ongoing networks and working group. Networks and working groups which have shown successes in coordinated actions include the Las Vegas Valley Watershed Advisory Committee (LVVWAC) which was formed in October 1998 at the recommendation of the Water Quality Citizens Advisory Committee (WQCAC). The Mission of the Las Vegas Wash Coordination Committee is to evaluate all facts, issues, and concerns regarding the Las Vegas Wash in order to develop and implement a practical, comprehensive approach for managing the Wash in a timely manner. The Wash is a critical subwatershed of Lake Mead and active participation in the committee is important to maintaining lake health. Additional 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, State, and local agencies and organizations concerned with understanding and protecting the ecosystems of Lakes Mead and Mohave. The partnerships have been able to focus and identify issues that would not be possible with a single group or agency. It is also very important to maintain the ongoing efforts to bring people together to share information through a common forum. The Lake Mead Science Symposia which is now theLower Colorado River Science Sympoisum occurs every few years. This should be supported with resources to allow staff across agencies to share ideas and identify issues that need to be addressed over time. This meeting should remain open to the public so they can particate in the discussions.

Safeguarding the water supply for the 25 million-plus people who depend upon the Lower Colorado River is a long-term challenge that will require the commitment, collaboration, and contributions of local, state, and federal governments through a comprehensive management program. In systems, such as the Lake Mead NRA, that do not have a centralized funding mechanism to steward its key

resources, sustainable management depends on the partnerships and coordinated activities of multiple agencies operating under their individual missions, but toward a common goal. Long-term monitoring programs, interagency coordination, periodic review of data and adaptive management strategies are key components to the successful resource management and stewardship of these resources.

5.6. Literature Cited

Curtis, J., & Breen, B. (2016). Fisheries Management for Different Angler Types. ESRI Working Paper # WP529.

Eden, S., & Bear, C. (2011). Models of Equilibrium, Natural Agency and Environmental Change: Lay Ecologies in UK Recreational Angling. Transactions of the Institute of Bristish Geographers, 36:393–407.

Lake Mead NRA. (2010). Long-term Limnology and Aquatic Resources Monitoring and Research Plan for Lakes Mead and Mohave: Boulder City, NV. Lake Mead National Recreation Area and University of Nevada, Las Vegas. Retrieved from http://www.nps.gov/lake/learn/nature/upload/Eco_Monitoring_Plan_for_Lakes_Mead_and_Mohave_4-27_update.pdf

Lake Mead NRA. (2015). Lake Mead National Recreation Area Resource Suitability Guidelines. Lake Mead National Recreation Area, NV, AZ: National Park Service, Pacific West Region.

NPS. (2014). Resource Stewardship Strategy. Lake Mead National Recreation Area, NV: National Park Service, Pacific West Region.

NPS. (2015). Foundation Document. Lake Mead National Recreation Area, Arizona and Nevada: National Park Service, U.S. Department of the Interior.

Poor, P. J., Boyle, K. J., Taylor, L. O., & Bouchard, R. (2001). Objective Versus Subjective Measures of Water Clarity in Hedonic Property Value Models. Land Economics, 77: 482–493.

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

Appendix A. Glossary (words highlighted in text)

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.

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**.

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

Evapotranspiration: The comniations of processes by which water is transpired through a plant's leaves and is evaporated from the soil in which the plant is growing.

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

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

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

Limnological/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.

Lotic: Flowing water including creeks, streams, rivers, and springs.

Mesotrophic: Water that has a moderate amount of dissolved nutrients (moderate productivity) that are usually clear and have beds of submerged aquatic plants.

Metalimnion: See **Thermocline**.

Monomictic: Having layers of water that intermix only once per year.

Nutrient loading: Quantity of nutrient 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.

Phreatophyte: A plant with a deep root system that depends on its water supply upon ground water that lies with reach of its roots.

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

Profundal zone: A deep zone of an inland body of freestanding water located beyond the depth of effective light penetration.

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.

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

Sportfish: Fish having material value in connection with sport or recreation in the marine and/or fresh waters. Sportfish are fish sought after for sport by recreational anglers.

Thermal Stratification: Vertical temperature stratification that show the following: The upper layer of the lake (**Epilimnion**), in which the water temperature is virtually uniform; a stratum next below (**Thermocline**), in which there is a marked drop in temperature per unit of depth; and the lowermost region or stratum (**Hypolimnion**), in which the temperature from its upper limit to the bottom is nearly uniform.

Thermocline (also known as **Metalimnion):** The area of marked temperature change usually between a warm to layer of a lake (**Epilimnion**) and the cold bottom part of the lake (**Hypolimnion**). See **Thermal Stratification**.

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

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.

Appendix B. Supporting tables, figures, maps, and data

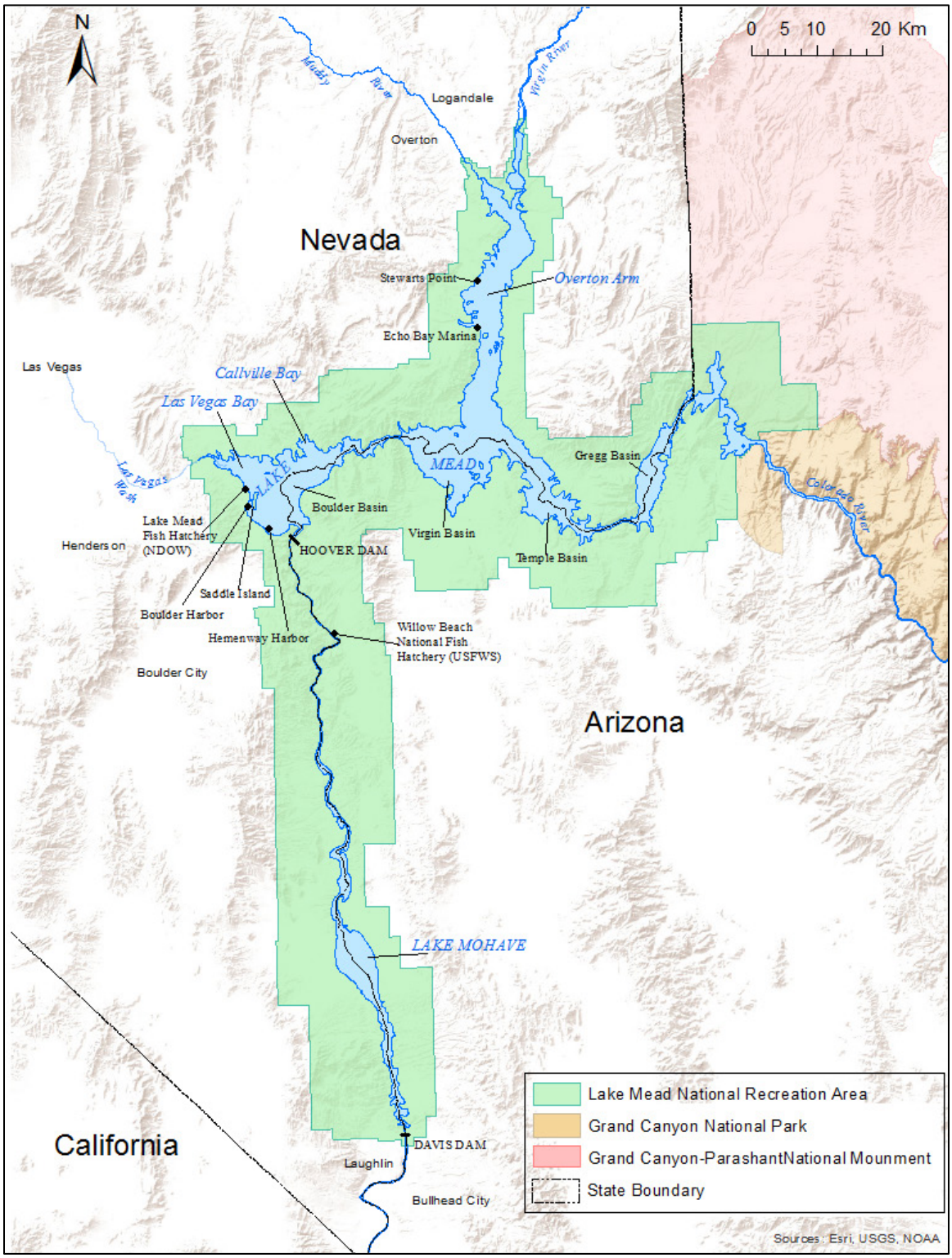


Figure B-1. Geographical setting of Lake Mead National Recreation Area (Lake Mead NRA) showing prominent features of the landscape near and within Lake Mead NRA.

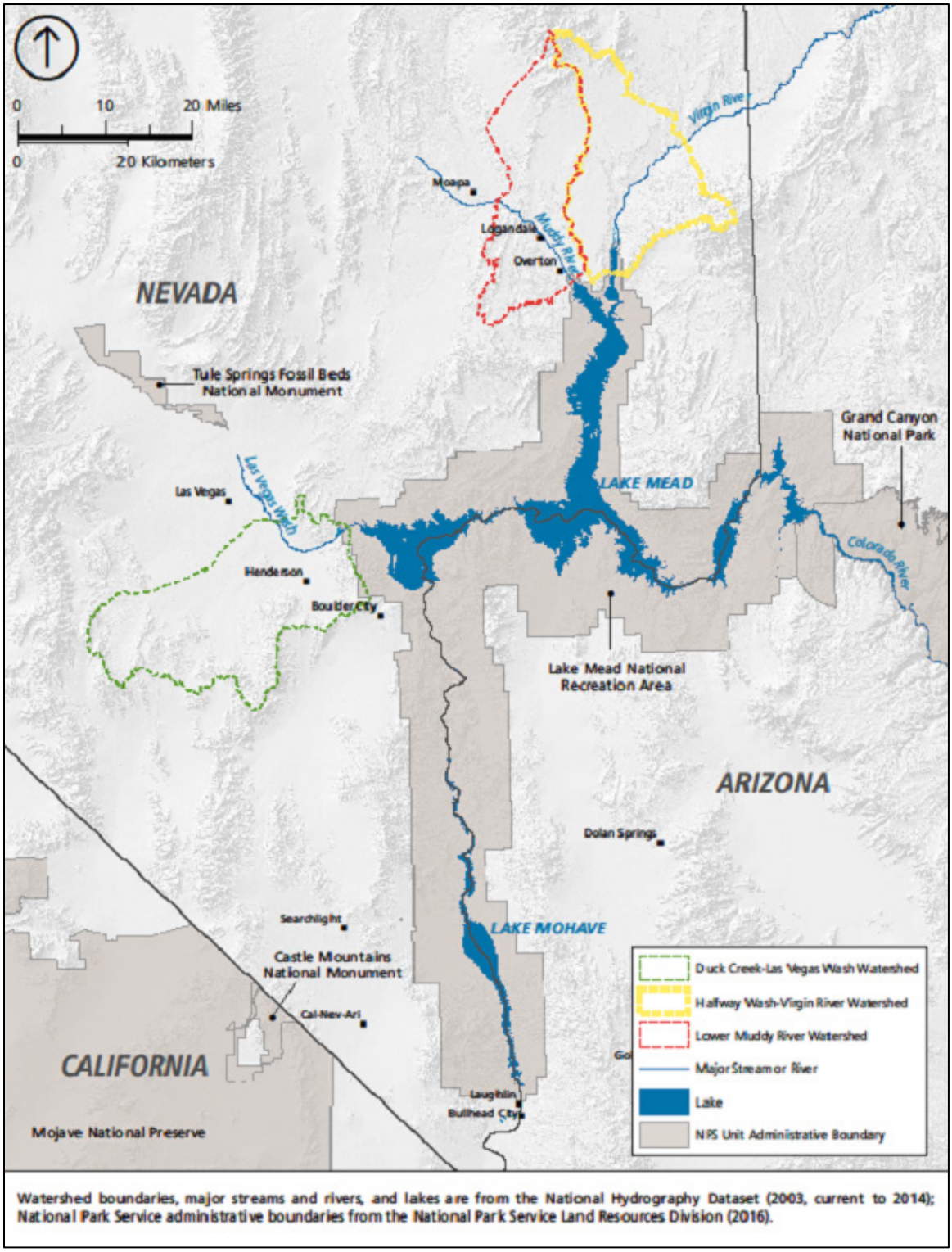


Figure B-2. Duck Creek-Las Vegas Wash (HUC: 1501001507), Halfway Wash-Virgin River (HUC: 1501001007), and Lower Muddy River (HUC: 1501001209) watershed boundaries used for indicator Land Use within Watershed assessment.

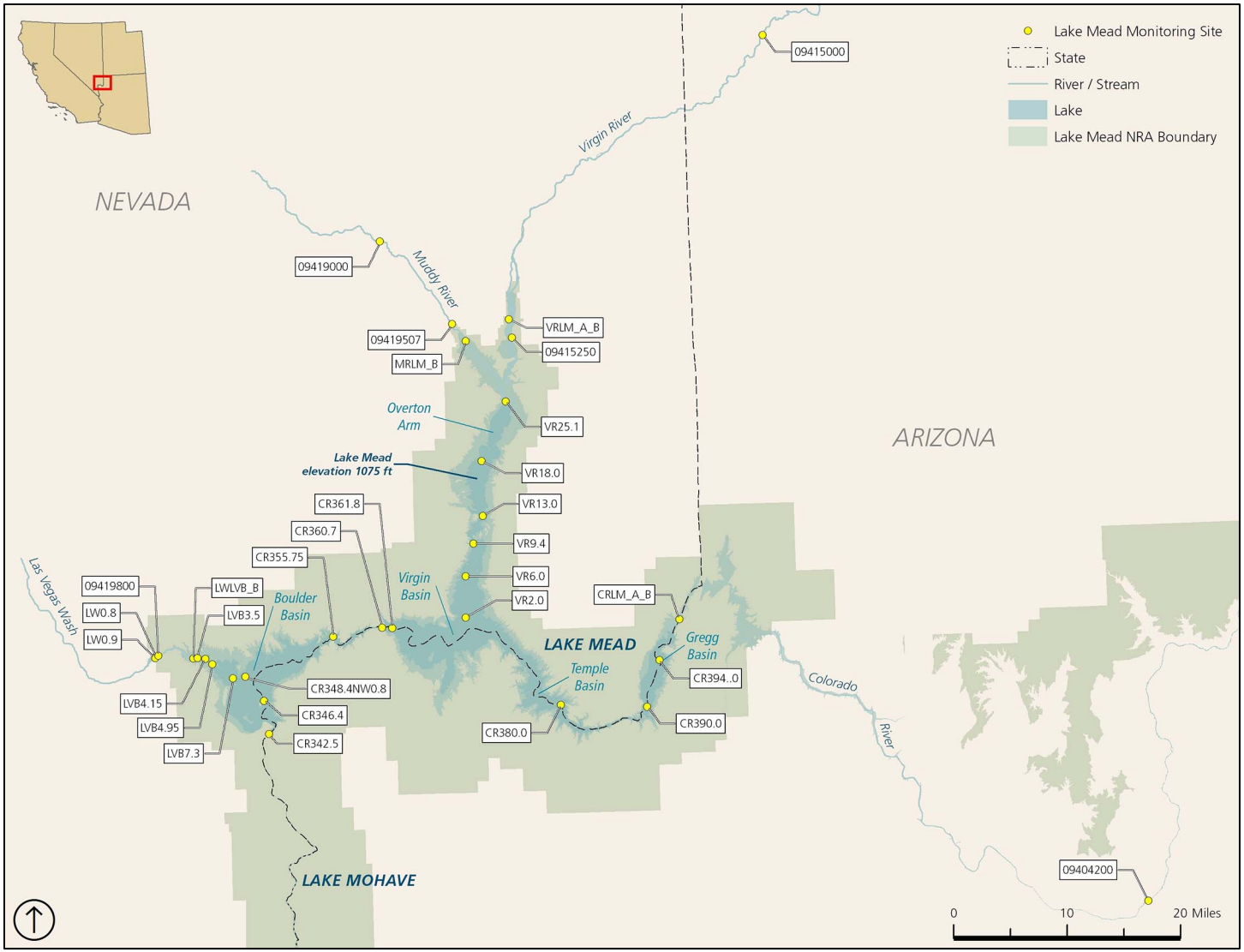


Figure B-3. Map of Lake Mead showing sites examined for various indicators and measures in this LRCA. Site names follow conventions adopted in 1999 by the Interagency Sampling Committee in Lake Mead. USGS gauging stations locations are also included in this map. Specific station descriptions and Lat/Long coordinates can be found in Table B-1. NOTE: LWLVB_B, MRLM_B, VRLM_A and B, CRLM_A and B are movable and depend on lake water levels.

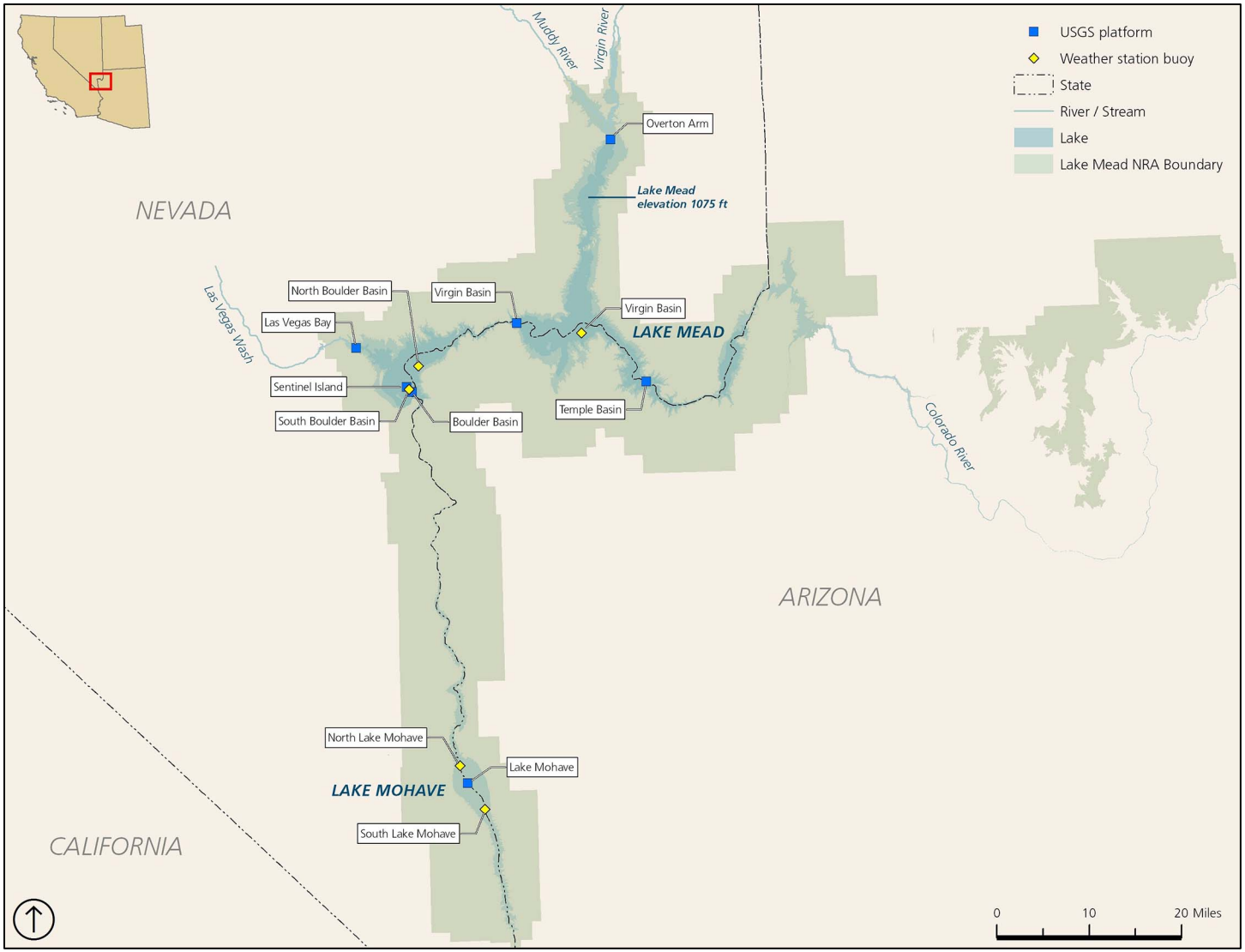


Figure B-4. Locations of U.S. Geological Survey automated water-quality stations on lakes Mead and Mohave. Specific station descriptions and Lat/Long coordinates can be found in Table B-1. NOTE: LWLVB_B, MRLM_B, VRLM_A and B, CRLM_A and B are movable and depend on lake water levels.

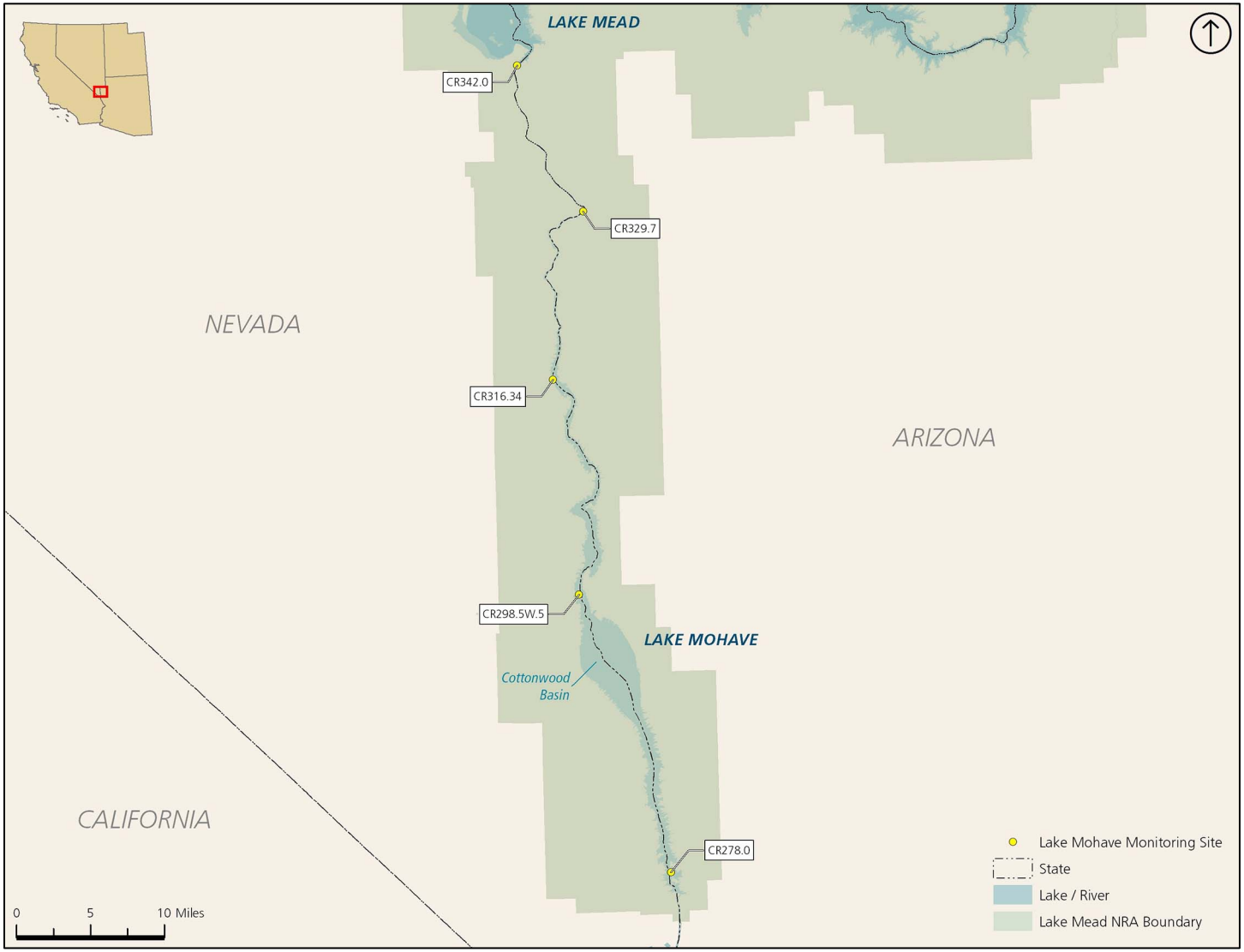


Figure B-5. Map of Lake Mohave showing sites examined for various indicators and measures in this LRCA. Specific station descriptions and Latitude/Longitude coordinates can be found in Table B-1.

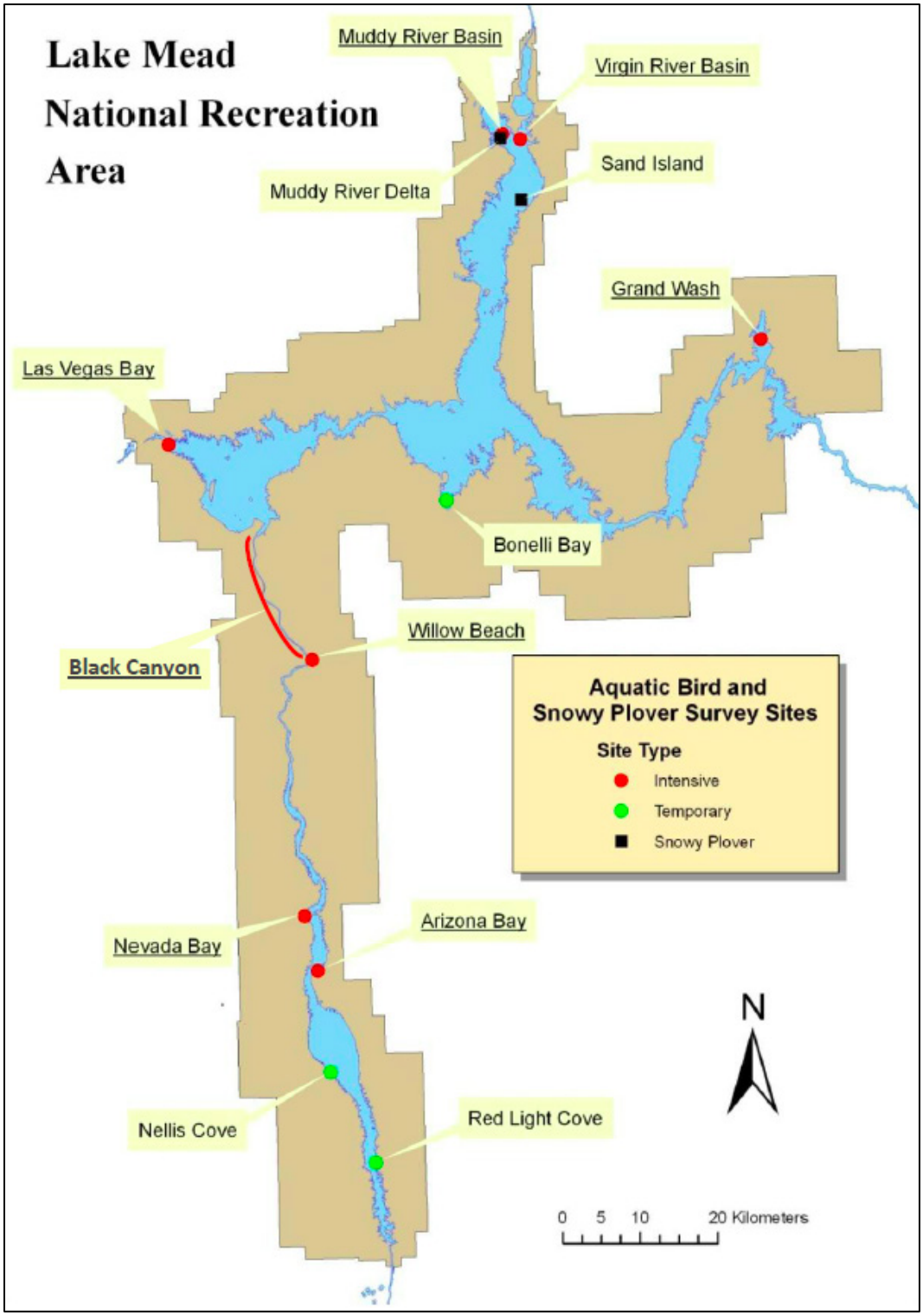


Figure B-6. Barnes and Jaeger (2011) aquatic bird surveys sites on lakes Mead and Mohave. Monthly surveys conducted from March 2004 through July 2009 for the Inventory and Monitoring Program (I&MP) of shoreline and aquatic bird species on lakes Mead and Mohave Details regarding the surveys conducted can be found in Barnes & Jaeger, 2011.

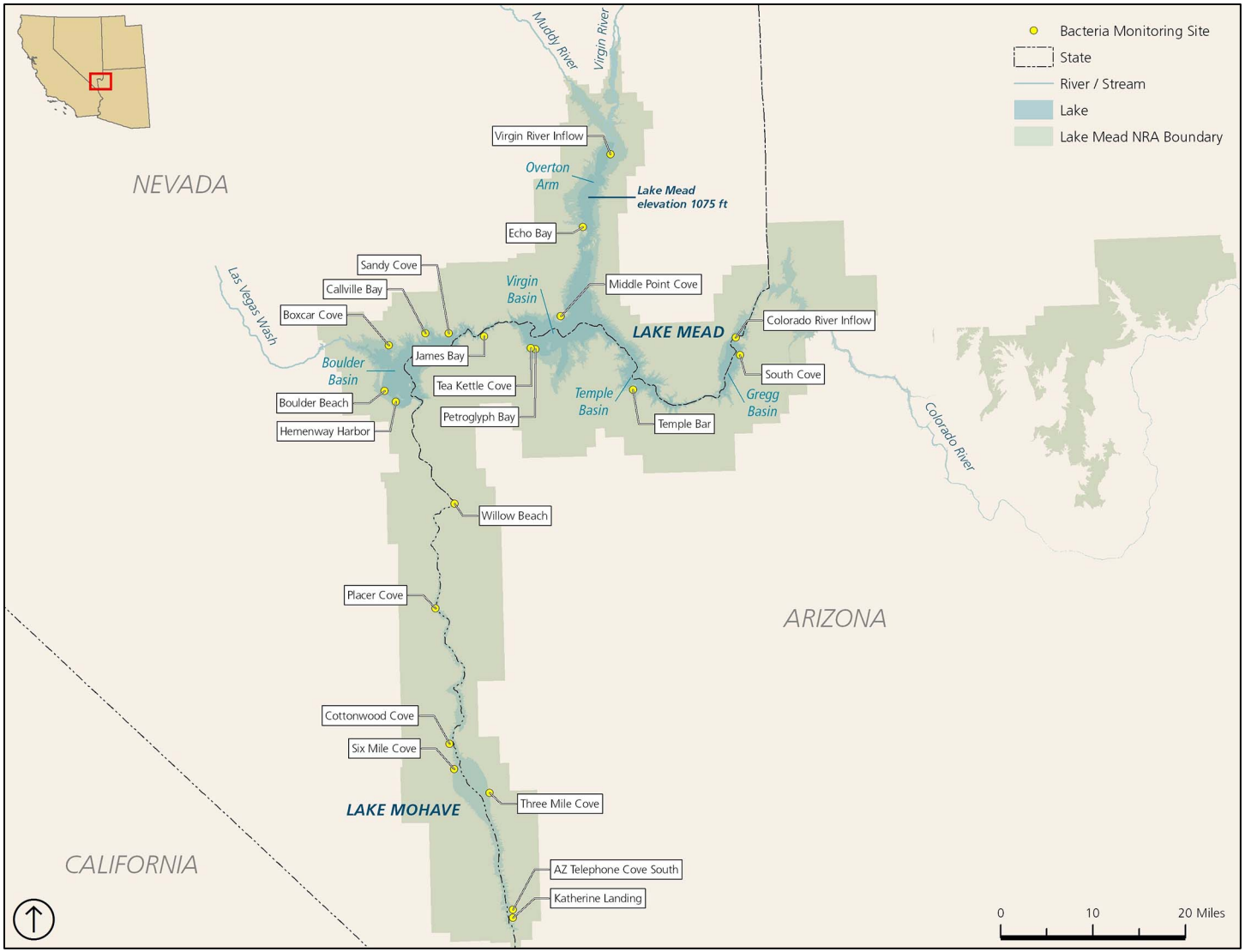


Figure B-7. Map of current bacteriological cove-monitoring sites at Lake Mead NRA.

Table B-1. List of major sampling stations within lakes Mead and Mohave. The list includes descriptions (lat/long, period of record) of LaMEM long-term monitoring stations, USGS Tributary gauging stations, and I-MAP quagga mussels monitoring stations. Data from all listed stations were used for indicators assessment in this LRCA. Stations are named for their locations along the mainstem 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 (LW). All locations are referenced to the North American datum of 1983 (NAD83). Period of record information is summarized from SNWA Lower Colorado River Water Quality database and USGS National Water Information System. Figure B-3 and Figure B-5 show the physical locations of these stations within lakes Mead and Mohave. An "X" denotes that sampling station was sampled by that entity (LaMem, USGS, I-MAP).

Basin/ Tributary	Station ID	Latitude/ Longitude	First Record	Last Record	Period of Record	Sampling Frequency	LaMEM Stations	USGS	I-MAP
Las Vegas Wash	LW0.8	36.120870/ -114.907706	8/28/2000	3/8/2011	11	Monthly	–	–	–
	LW0.9	36.119420/ -114.908989	10/5/1994	5/17/2016	22	Monthly	–	–	–
	09419800	36.1222222/ -114.904167	10/1/2007	6/23/2016	9	Continuously	–	X	–
	LWLVB, _B	36.1178306/ -114.849069	7/18/1990	5/3/2016	26	Monthly	X	–	X
	LWLVB3.5	36.101/ -114.8052	1/4/2005	5/10/2016	11	Monthly	X	–	–
Las Vegas Bay	LVB3.5	36.1180333/ -114.842617	7/19/1990	5/19/2014	24	Monthly	X	–	–
	LVB4.15	36.1168944/ -114.830417	7/18/1990	5/3/2016	26	Monthly	X	–	X
	LVB4.95	36.1095611/ -114.819628	7/19/1990	5/13/2015	25	Monthly	X	–	X
	LVB7.3	36.0914972/ -114.787433	7/19/1990	5/13/2015	25	Monthly	X	–	X
Boulder Basin	CR355.75	36.1413806/ -114.628239	5/12/2000	5/11/2015	15	Monthly	X	–	X

Table B-1 (continued). List of major sampling stations within lakes Mead and Mohave. The list includes descriptions (lat/long, period of record) of LaMEM long-term monitoring stations, USGS Tributary gauging stations, and I-MAP quagga mussels monitoring stations. Data from all listed stations were used for indicators assessment in this LRCA. Stations are named for their locations along the mainstem 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 (LW). All locations are referenced to the North American datum of 1983 (NAD83). Period of record information is summarized from SNWA Lower Colorado River Water Quality database and USGS National Water Information System. Figure B-3 and Figure B-5 show the physical locations of these stations within lakes Mead and Mohave. An "X" denotes that sampling station was sampled by that entity (LaMem, USGS, I-MAP).

Basin/ Tributary	Station ID	Latitude/ Longitude	First Record	Last Record	Period of Record	Sampling Frequency	LaMEM Stations	USGS	I-MAP
Boulder Basin (continued)	CR348.4NW0.8	36.093000/ -114.767833	3/13/2006	3/29/2012	6	Weekly (through 2010, then sporadically)	–	–	–
	CR346.4	36.0616556/ -114.739133	3/19/1974	5/3/2016	42	Twice a month	X	–	X
	CR342.5	36.0193833/ -114.732664	5/14/2001	4/12/2016	15	Monthly	X	–	X
	SNWA Intake (LMI_1_2)	NOT SHOWN	1/5/2005	6/30/2015	10	Weekly	–	–	–
Virgin Basin	CR360.7	36.1514194/ -114.550689	3/14/2001	4/13/2016	15	Monthly	X	–	X
	CR361.8	36.1501667/ -114.535	9/25/2007	3/16/2010	2	Twice a month	–	–	–
Temple Basin	CR380.0	36.04675/ -114.273358	3/14/2001	4/13/2016	15	Monthly	X	–	X
Gregg Basin	CR390.0	36.0415528/ -114.138122	11/26/2003	4/13/2016	12	Monthly	X	–	X
	CR394.0	36.1001944/ -114.116808	3/14/2001	4/13/2016	15	Monthly	X	–	X
	CR395.0	36.11508/ -114.167	11/26/2003	6/13/2012	9	Monthly	–	–	X

Table B-1 (continued). List of major sampling stations within lakes Mead and Mohave. The list includes descriptions (lat/long, period of record) of LaMEM long-term monitoring stations, USGS Tributary gauging stations, and I-MAP quagga mussels monitoring stations. Data from all listed stations were used for indicators assessment in this LRCA. Stations are named for their locations along the mainstem 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 (LW). All locations are referenced to the North American datum of 1983 (NAD83). Period of record information is summarized from SNWA Lower Colorado River Water Quality database and USGS National Water Information System. Figure B-3 and Figure B-5 show the physical locations of these stations within lakes Mead and Mohave. An "X" denotes that sampling station was sampled by that entity (LaMem, USGS, I-MAP).

Basin/ Tributary	Station ID	Latitude/ Longitude	First Record	Last Record	Period of Record	Sampling Frequency	LaMEM Stations	USGS	I-MAP
Colorado River	CRLM, _A, _B	36.1518111/ -114.083699	9/26/2001	4/13/2016	15	Quarterly (sometimes monthly)	X	–	X
	09404200	35.7736111/ -113.362778	10/1/2007	6/23/2016	9	Continuously	–	X	–
Overton Arm	VR2.0	36.1613917/ -114.419119	7/14/2004	5/4/2016	12	Monthly	X	–	X
	VR6.0	36.2139833/ -114.417578	4/12/2005	5/12/2015	10	Quarterly (sometimes monthly)	X	–	X
	VR9.4	36.2550472/ -114.403667	4/12/2005	5/12/2015	10	Quarterly (sometimes monthly)	X	–	X
	VR13.0	36.2899278/ -114.388075	4/15/2003	5/4/2016	13	Monthly	X	–	X
	VR18.0	36.360025/ -114.387542	4/12/2005	5/4/2016	11	Monthly	X	–	X
	VR25.1	36.43525/ -114.346686	1/10/2000	11/8/2011	12	Monthly	X	–	X
Muddy River	MRLM_B	36.51322/ -114.40733	2/16/2000	5/15/2014	14	Monthly	X	–	X
	09419000	36.6430556/ -114.538889	10/14/2007	6/23/2016	9	Continuously	–	X	–

Table B-1 (continued). List of major sampling stations within lakes Mead and Mohave. The list includes descriptions (lat/long, period of record) of LaMEM long-term monitoring stations, USGS Tributary gauging stations, and I-MAP quagga mussels monitoring stations. Data from all listed stations were used for indicators assessment in this LRCA. Stations are named for their locations along the mainstem 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 (LW). All locations are referenced to the North American datum of 1983 (NAD83). Period of record information is summarized from SNWA Lower Colorado River Water Quality database and USGS National Water Information System. Figure B-3 and Figure B-5 show the physical locations of these stations within lakes Mead and Mohave. An "X" denotes that sampling station was sampled by that entity (LaMem, USGS, I-MAP).

Basin/ Tributary	Station ID	Latitude/ Longitude	First Record	Last Record	Period of Record	Sampling Frequency	LaMEM Stations	USGS	I-MAP
Muddy River (continued)	09419507	36.5352778/ -114.428333	10/1/2008	6/23/2016	8	Continuously	–	X	–
Virgin River	VRLM_A, _B	36.53951/ -114.33816	1/10/2000	5/4/2016	16	Monthly	X	–	X
	09415000	36.8916667/ -113.923611	10/1/2007	6/23/2016	9	Continuously	–	X	–
	09415250	36.5161111/ -114.334167	10/1/2007	6/23/2016	9	Continuously	–	X	–
Lake Mohave	CR342.0	36.014227/ -114.739776	2/21/2002	5/25/2016	14	Monthly	X	–	–
	CR329.7	35.8694444/ -114.664722	6/28/1967	5/17/2016	49	Monthly	X	–	–
	CR316.34	35.7055556/ -114.705556	5/20/1996	5/18/2016	20	Monthly	X	–	–
	CR298.5W.5	35.4941667/ -114.680278	5/20/1996	5/18/2016	20	Monthly	X	–	–
	CR278.0	35.2202778/ -114.578611	2/19/1981	5/18/2016	35	Monthly	X	–	–

Table B-2. List of U.S. Geological Survey automated water quality stations on lakes Mead and Mohave showing site coordinates and period of record. See Figure B-4 for locations of monitoring sites.

Station ID	Basin	Latitude	Longitude	First Record	Last Record	Period of Record	Sampling Frequency	Sources
Boulder Basin	Boulder Basin	36.04611	-114.7417	2011	2016	5	Every 6 hours	http://nevada.usgs.gov/water/lmqw/map.htm
Lake Mohave	Lake Mohave	35.43056	-114.6519	2013	2016	3	Every 6 hours	http://nevada.usgs.gov/water/lmqw/map.htm
Las Vegas Bay #3	Las Vegas Bay	36.11667	-114.8475	2001	2010	9	Every 6 hours	http://nevada.usgs.gov/water/lmqw/map.htm
Overton Arm	Overton Arm	36.43372	-114.3459	2005	2009	4	Every 6 hours	http://nevada.usgs.gov/water/lmqw/map.htm
Sentinel Island	Boulder Basin	36.05403	-114.7515	2002	2012	10	Every 6 hours	http://nevada.usgs.gov/water/lmqw/map.htm
Temple Basin	Temple Basin	36.05278	-114.2897	2008	2010	2	Every 6 hours	http://nevada.usgs.gov/water/lmqw/map.htm
Virgin Basin	Virgin Basin	36.15017	-114.5361	2005	2009	4	Every 6 hours	http://nevada.usgs.gov/water/lmqw/map.htm
VBBA3	Virgin Basin	36.13188	-114.4113	2016	2016	0	Every 10 minutes	http://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=VBBA3&unit=0&timetype=LOCAL
SLMN2	Lake Mohave	35.38875	-114.6207	2016	2016	0	Every 10 minutes	http://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=SLMN2&unit=0&timetype=LOCAL
SBBN2	Boulder Basin	36.05014	-114.7475	2016	2016	0	Every 10 minutes	http://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=SBBN2&unit=0&timetype=LOCAL
NLMA3	Lake Mohave	35.45801	-114.6664	2016	2016	0	Every 10 minutes	http://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=NLMA3&unit=0&timetype=LOCAL
NBBA3	Boulder Basin	36.08649	-114.7282	2016	2016	0	Every 10 minutes	http://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=NBBA3&unit=0&timetype=LOCAL

Table B-3. List of NPS bacteriological cove-monitoring sites in Lake Mead NRA showing site coordinates and period of record. See Figure B-7 for locations of monitoring sites.

Station ID	Latitude	Longitude	First Record	Last Record	Period of Record
Callville Bay	36.137689	-114.713183	2016	2016	0
Echo Bay	36.297844	-114.403718	2016	2016	0
Petroglyph Bay	36.108380	-114.501382	2016	2016	0
South Cove	36.090398	-114.106756	2016	2016	0
Temple Bar	36.040548	-114.315135	2016	2016	0
Virgin River Inflow	36.410907	-114.346547	2016	2016	0
Cottonwood Cove	35.493082	-114.685039	2016	2016	0
Three Mile Cove	35.414395	-114.611019	2016	2016	0
Willow Beach	35.869236	-114.664428	2016	2016	0
Colorado River Inflow	36.117712	-114.114023	2015	2016	1
AZ Telephone Cove South	35.230569	-114.571800	2015	2016	1
Placer Cove	35.705559	-114.706249	2008	2016	8
James Bay	36.130175	-114.600016	2003	2015	12
Tea Kettle Cove	36.110009	-114.509834	2003	2015	12
Boulder Beach	36.048471	-114.794409	2003	2016	13
Boxcar Cove	36.119636	-114.784385	2003	2016	13
Hemenway Harbor	36.031119	-114.773258	2003	2016	13
Middle Point Cove	36.159348	-114.450416	2003	2016	13
Sandy Cove	36.136792	-114.667941	2003	2016	13
Katherine Landing	35.217682	-114.571994	2004	2016	12
Six Mile Cove	35.452891	-114.677317	2004	2016	12

Table B-4. List of fishes found in lakes Mead and Mohave and their conservation status. Sportfish are fish that have material value in connection with sport or recreation in the marine and/or fresh waters. Sportfish are generally fish sought after for sport by recreational anglers. Forage fish are any fish eaten by large predatory fish, birds, or mammals associated with an aquatic system. "√" represents fish currently found in the lakes. "E" represents fish extirpated from or not currently found in Lake Mead LRA.

Family name	Common Name (Scientific Name)	Fish Group	Native to Colorado River (Pre-impounded)	Conservation Status	Lake Mead	Lake Mohave	References
Clupeidae	Threadfin shad (*Dorosoma petenense*)	Forage	No	–	√	√	NDOW, 2015a and 2015b
	Gizzard shad (*Dorosoma cepedianum*)	Forage	No	–	√	√	NDOW, 2015a and 2015b
Salmonidae	Rainbow trout (*Oncorhynchus mykiss*)	Sport	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
Catostomidae	Bluehead sucker (*Catostomus discobolus*)	Native	Yes	–	√	–	Sjoberg, NDOW
	Flannelmouth sucker *(Catostomus latipinnis*)	Native	Yes	–	√	–	Rosen et al., 2012
	Razorback sucker *(Xyrauchen texanus*)	Native	Yes	Federally listed as endangered	√	–	Rosen et al., 2012 Sjoberg, NDOW
Cyprinidae	Common carp (Cyprinus carpio)	Sport	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
	Bonytail chub *(Gila elegans*)	Native	Yes	Federally listed as endangered	–	√	Rosen et al., 2012
	Humpback Chub (*Gila cypha*)	Native	Yes	Federally listed as endangered	√	E	Mueller & Marsh, 2002; Rosen et al., 2012
	Colorado Pikeminnow (*Ptychocheilus ucius*)	Native	Yes	Federally listed as endangered	E	E	Rosen et al., 2012
Ictaluridae	Channel Catfish (*Ictalurus punctatus*)	Sport	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
	Yellow bullhead (*Ameiurus natalis*)	Sport	No	–	–	√	Rosen et al., 2012; NDOW, 2015a and 2015b

Table B-4 (continued). List of fishes found in lakes Mead and Mohave and their conservation status. Sportfish are fish that have material value in connection with sport or recreation in the marine and/or fresh waters. Sportfish are generally fish sought after for sport by recreational anglers. Forage fish are any fish eaten by large predatory fish, birds, or mammals associated with an aquatic system. "√" represents fish currently found in the lakes. "E" represents fish extirpated from or not currently found in Lake Mead LRA.

Family name	Common Name (Scientific Name)	Fish Group	Native to Colorado River (Pre-impounded)	Conservation Status	Lake Mead	Lake Mohave	References
Serranidae	Striped bass (*Morone saxatilis*)	Sport	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
Centrarchidae	Largemouth bass (*Micropterus dolomieu*)	Sport	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
	Smallmouth bass (*Micropterus salmoides*)	Sport	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
	Black crappie (*Pomoxis nigromaculatus*)	Sport	No	–	√	–	Rosen et al., 2012; NDOW, 2015a and 2015b
	Green sunfish (*Lepomis cyanellus*)	Sport/Forage	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
	Bluegill (*Lepomis macrochirus*)	Sport/Forage	No	–	√	√	Rosen et al., 2012; NDOW, 2015a and 2015b
Cichlidae	Blue tilapia (*Oreochromis aureus*)	Sport	No	–	√	–	Rosen et al., 2012; NDOW, 2015a and 2015b

Table B-5. List of 96 species compiled from observation made during monthly aquatic bird surveys on lakes Mead and Mohave between 2004 and 2009. Excerpted from Rosen et al., 2012. **[General status of each species is listed; along with its relative abundance on each Lake Mead NRA (blanks 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 (observed frequency) on each Lake Mead NRA**: a, abundant: regularly observed, often in large numbers; c, common: regularly observed; I, common by infrequently observed: observed often but sporadically and in low numbers; r, rare: few observations; blank space, not detected.].

Bird Class	Common name	Relative abundance (observation frequency)		
		Status	Lake Mead	Lake 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	–

Table B-5 (continued). List of 96 species compiled from observation made during monthly aquatic bird surveys on lakes Mead and Mohave between 2004 and 2009. Excerpted from Rosen et al., 2012. **[General status of each species is listed; along with its relative abundance on each Lake Mead NRA (blanks 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 (observed frequency) on each Lake Mead NRA**: a, abundant: regularly observed, often in large numbers; c, common: regularly observed; I, common by infrequently observed: observed often but sporadically and in low numbers; r, rare: few observations; blank space, not detected.].

Bird Class	Common name	Relative abundance (observation frequency)		
		Status	Lake Mead	Lake Mohave
Waterfowl (continued)	Wood Duck	U	R	R
	Gadwall	W	A	R
	American Wigeon	M,W	A	R
	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	–

Table B-5 (continued). List of 96 species compiled from observation made during monthly aquatic bird surveys on lakes Mead and Mohave between 2004 and 2009. Excerpted from Rosen et al., 2012. **[General status of each species is listed; along with its relative abundance on each Lake Mead NRA (blanks 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 (observed frequency) on each Lake Mead NRA**: a, abundant: regularly observed, often in large numbers; c, common: regularly observed; I, common by infrequently observed: observed often but sporadically and in low numbers; r, rare: few observations; blank space, not detected.].

Bird Class	Common name	Relative abundance (observation frequency)		
		Status	Lake Mead	Lake Mohave
Marsh birds (continued)	Virginia Rail	W	R	–
	Sora	M,B	I	–
	Common Moorhen	U	R	R
	American Coot	M,W,B	A	A
Shorebirds	Black-bellied Plover	U	R	–
	Snowy Plover	M,S,B	1	–
	Semipalmated Plover	M	1	–
	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 Sandpoiper	U	R	–
	Baird’s Sandpiper	U	R	–
	Pectoral Sandpiper	U	R	–
	Dublin	M	R	–
	Long-billed Dowitcher	M	I	–
	Wilson’s Snipe	M	R	–
	Wilson’s Phalarope	M	I	–

Table B-5 (continued). List of 96 species compiled from observation made during monthly aquatic bird surveys on lakes Mead and Mohave between 2004 and 2009. Excerpted from Rosen et al., 2012. **[General status of each species is listed; along with its relative abundance on each Lake Mead NRA (blanks 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 (observed frequency) on each Lake Mead NRA**: a, abundant: regularly observed, often in large numbers; c, common: regularly observed; I, common by infrequently observed: observed often but sporadically and in low numbers; r, rare: few observations; blank space, not detected.].

Bird Class	Common name	Relative abundance (observation frequency)		
		Status	Lake Mead	Lake Mohave
Shorebirds (continued)	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	M	I	I

Table B-6. List of aquatic dependent birds of conservation concern based on the Great Basin Bird Observatory's Nevada Bird Conservation Plan (2010) and tailored to the bird species and habitats found within the Lake Mead National Recreation Area.

Key Birds*	Important Habitat	Main Concerns	Conservation Strategies
• Shorebirds[a] • Waterfowl[b] • Diving ducks[c] • Snowy Plover • Snowy Egret • American white pelican • Bald eagle • Franklin's gull • Black turn	Open Water	• Water levels & water quality; • Climate change (related to temperature); • Flooding	Avoid excessive fluctuation and drops of Lake levels to maintain vegetation and fish habitat in shallow areas; Manage to minimize contaminants, sediment disturbance, and stagnant conditions; Depending on foraging strategy, birds require a variety of water depths and food items; Most species need some vegetation cover at the nest site, with the exception of the Snowy Plover, which nests in very sparse vegetation cover; Island are valuable for nesting, roosting, and protection from land predators; Bald Eagles and Snowy Egrets prefer small groves of mature trees adjacent to a water body; Shorebirds require a variety of vegetation cover densities and a mosaic of different patches (emergent vegetation, mudflats, sparse grass cover, dense ground cover, and occasional groves of trees) to accommodate the greatest variety of species; Disturbance-free buffers along shorelines are important in nesting areas
• Peregrine Falcon • Prairie Falcon • Golden Eagle	Cliffs	• Human disturbance; • Adjacent habitat and prey availability; • Changes in temperature due to climate change	Potentially establish disturbance-free buffer zones of 1 km, particularly during the nesting season April 1 to July 15; Conserve surrounding habitats that support prey populations

* see Table B-5 for scientific names

[a] Willet, Marbled Godwit, Long-billed Curlew, Long-billed Dowitcher, Wilson's Phalarope, Black-necked Stilt, American Avocet, Western Sandpiper, Red-necked Phalarope

[b] Cinnamon Teal, Northern Pintail, Canvasback, Redhead, Lesser Scaup, Tundra Swan

[c] Common Loon, Eared Grebe, Western Grebe, Clark's Grebe

Table B-6 (continued). List of aquatic dependent birds of conservation concern based on the Great Basin Bird Observatory's Nevada Bird Conservation Plan (2010) and tailored to the bird species and habitats found within the Lake Mead National Recreation Area.

Key Birds*	Important Habitat	Main Concerns	Conservation Strategies
• Snowy Egret • Yellow-billed Cuckoo • Bell's Vireo • Lucy's Warbler	Mojave Lowland Riparian	• Maintaining sufficient water flows; • Climate change (change in precipitation and temperature); • Invasive weeds; • Overgrazing; • Flooding; • Increased fire frequency or intensity; • Motorized recreation	Active revegetation of native plants where saltcedar is eradicated and native vegetation can be supported; Protect areas occupied by priority bird species from fire, in the form of prevention and response planning; Maintain grazing and OHV use to not permanently impact understory and soil;
• Shorebirds[a] • Waterfowl[b] • Eared Grebe • Least Bittern • Snowy Egret • White-faced Ibis • Clapper Rail • Franklin's Gull • Black Tern • Willow Flycatcher	Marsh (Virgin and Muddy Rivers)	• Maintaining sufficient water supplies; • Climate change (change in precipitation and temperature); • Recreation; • Overgrazing on marsh vegetation	Maintain stable water levels during nesting periods (May 1 to July 15); Marshes that are >30 m of open water, riparian areas and cliffs are of increased value to birds; Islands are valuable and should be protected from disturbances during the breeding season and possibly during migration

* see Table B-5 for scientific names

[a] Willet, Marbled Godwit, Long-billed Curlew, Long-billed Dowitcher, Wilson's Phalarope, Black-necked Stilt, American Avocet, Western Sandpiper, Red-necked Phalarope

[b] Cinnamon Teal, Northern Pintail, Canvasback, Redhead, Lesser Scaup, Tundra Swan

[c] Common Loon, Eared Grebe, Western Grebe, Clark's Grebe

Table B-6 (continued). List of aquatic dependent birds of conservation concern based on the Great Basin Bird Observatory's Nevada Bird Conservation Plan (2010) and tailored to the bird species and habitats found within the Lake Mead National Recreation Area.

Key Birds*	Important Habitat	Main Concerns	Conservation Strategies
• Willow Flycatcher • Yellow-billed Cuckoo • Lucy's Warbler	Springs	• Overgrazing; • Maintaining surface water; • Invasive weeds; • Climate change (change in precipitation and temperature); • Motorized recreation	To the extent possible, maintain the water source of springs; Restoration of spring habitat may involve creating enclosures and conducting weed control; Important habitat components include dense shrub thickets with patches of mesic herbaceous cover interspersed

* see Table B-5 for scientific names

[a] Willet, Marbled Godwit, Long-billed Curlew, Long-billed Dowitcher, Wilson's Phalarope, Black-necked Stilt, American Avocet, Western Sandpiper, Red-necked Phalarope

[b] Cinnamon Teal, Northern Pintail, Canvasback, Redhead, Lesser Scaup, Tundra Swan

[c] Common Loon, Eared Grebe, Western Grebe, Clark's Grebe

Literature Cited (Appendix B)

Mueller, G., & Marsh, P. (2002). Lost, A Desert River and its Native Fishes: A Historical Perspective of the Lower Colorado River. USGS (USGS/BRD/ITR—2002—0010).

NDOW. (2015a). 2014 Federal Aid Job Progress Report, Statewide Sport Fisheries Management F-20-50 – Lake Mead. Lake Mead, Southern Region: Nevada Department of Wildlife.

NDOW. (2015b). 2014 Federal Aid Job Progress Reports, Statewide Sport Fisheries Management F-20-50 – Lake Mohave. Lake Mohave, Southern Region: Nevada Department of Wildlife.

Rosen, M., Turner, K., Goodbred, S., & Miller, J. (Eds.). (2012). A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey Circular 1381, 162 p.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 602/159930, August 2019



Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525