EXECUTIVE SUMMARY

Walker Lake is one of three desert terminus lakes in the United States that support a fishery. Over the past 100 years, lake levels have declined about 150 feet and the volume of the lake has decreased from about 10 million to less than 2 million acre feet. During this decline the total dissolved solids (TDS) of the lake have increased from about 2,500 mg/l to greater than 17,000 mg/l. These changes have had far reaching impacts on the health of the lake and its associated ecosystems. High TDS values have resulted in significant population declines of threatened Lahontan cutthroat trout (LCT), a subspecies that is receiving significant conservation and restoration attention.

Walker Lake is located in a watershed that supports significant agricultural activity. The source of the lake's water comes primarily from snowmelt runoff from the Sierra Nevada, which flows through several agricultural valleys before reaching the lake. There are currently no water rights for the lake, so during low water years the lake receives little or no inflow from the Walker River.

In an effort to save Walker Lake, Congress enacted a law in 2005 (i.e., H.R. 2419 Energy and Water Development Appropriations Act, 2006, Section 208), that created a program to acquire water rights from willing sellers in the Walker Basin. In order to enact an ecologically and economically sustainable program of water acquisitions, a large-scale integrated research program was established. The goal of the Walker Basin Research Project was to provide the hydrologic, ecologic, economic, and agricultural data needed to inform decisions related to water acquisitions. This report is a product of the research program that was developed in response to direction provided in this federal legislation. Specifically, Desert Research Institute and University of Nevada, Reno faculty were funded to: (1) develop a method to optimize the purchase of water rights in the Walker River Basin, (2) evaluate options for practicing alternative agricultural practices, and (3) evaluate the impacts that water removal from crop-irrigated lands will have on the spread of invasive plants, aquatic and terrestrial ecosystems, and the local economy.

Research during Phase II of the Walker Basin Research Project was supported by the National Fish and Wildlife Foundation (NFWF) and was built upon work previously conducted during Phase I of the project. The four major elements of our Phase II project include: 1) the use of alternative agriculture and irrigation scheduling technology for water conservation; 2) an evaluation of the aquatic ecosystems of the Walker River, including trout habitat; 3) the decision support tool (DST), which includes many models on surface water and groundwater flows, water rights information, and ultimately, Walker River outflows from Mason Valley at the Wabuska gauge; and 4) community economic development.

Use of Alternative Agriculture and Irrigation Scheduling Technology for Water Conservation

Water conservation and changes in water use within the Walker Basin are considered the best alternatives for the preservation of Walker Lake and its fisheries. Since agriculture along the Walker River is the largest consumer of available water resources, there has been much interest in the development of low water use alternative crops and the restoration of low profit irrigated lands back to their natural state.

Water efficient alternative crops and re-establishment of native vegetation on restoration plots that were evaluated in the Walker Phase I project had additional growing season data collected for the Walker Phase II project. These alternative crops included biomass species and alternative grain crops. Old world bluestem (*Bothrichloa ischaemum*) was the best performing biomass species across all sites and water treatments. Biomass was high, even in the lowest water treatments, and weed contamination was low. Tall wheatgrass (*Elytrigia elongata*), basin wildrye (*Leymus cinereus*), and mammoth wildrye (*Leymus racemosus)* were also strong performers, with large yields in the second year of growth. In general, cool species outperformed warm season species in the first years of growth, when warm season plots were initially contaminated by weeds. However, after three years, differences in production and weed presence between warm and cool season species disappeared. During the first year of growth, teff production was excellent, even with low water application, but weed pressure made harvests difficult in subsequent years. Amaranth produced viable crops even with low water application, but weed control remained a major challenge.

Irrigation was instrumental in establishing perennial grass species in restoration plots. An initial 75% of normal water application was effective in establishing high densities of seed, and a 25% application the second year maintained populations of most species at both sites. Restoration was most successful at the 5C site, where perennial grasses maintained populations in the 25% water treatment after four years. Western wheatgrass (*Pascopyrum smithii*), established in very high densities in the 25% water treatments. Soil properties at the Valley Vista site made water less plant available and restoration did not work as well at this site, with restored grasses essentially absent from the site two years after irrigation ceased. Some restoration plots received no irrigation. On these plots, Indian ricegrass (*Achnatherum hymenoides*), particularly the Rimrock variety, and beardless wheatgrass (*Pseudoroegneria spicata*), were best at establishing in the absence of irrigation. Sagebrush (*Artemisia tridentata* var. *wyomingensis)* and fourwing saltbrush (*Atriplex canescens*) were the best shrubs for transplanting. Most shrub death occurred immediately after transplanting or in the second year of growth, with another decline in survival after watering treatments ceased. Shrubs that survived for three years were very likely to survive into the fourth year. Shrubs that established from seeds occurring naturally at the 5C site were healthy and numerous, especially in the 25% watering treatment. Soil erosion was decreased significantly by irrigation treatments, especially in the first years of the project.

Distributed temperature sensing (DTS) was used to assess soil temperature, bulk soil thermal properties, and soil moisture in an irrigated agricultural setting. The need to accurately predict soil moisture in the shallow subsurface is becoming more urgent throughout the world as increasingly serious shortages of water in agricultural regions continue to emerge. These water issues make it imperative to improve the efficiency of irrigation and other water use practices. Fiber-optic temperature sensing of soil temperatures was shown to be an efficient and effective tool for monitoring seed bed conditions**.** Alternative agriculture practices in the presence of deficit irrigation can increase soil temperatures which, in turn, can lead to diminished production. DTS measurements provide continuous monitoring of soil temperatures and can be used to schedule irrigation inputs and timing. However, progression to soil moisture estimation remains challenging due to the non-uniqueness of the relation between soil thermal diffusivity and soil moisture content. For a more quantitative analysis of soil moisture content, a combination of active and passive DTS will be necessary to achieve measurement of the full range of anticipated agricultural soil moisture content.

Results from the Walker Phase I study of three species (basin wild rye, buckwheat, tall fescue) of alternative crops compared to alfalfa indicated that ET of these species differed significantly, with the three alternative species having less evapotranspiration than alfalfa. Building on the Walker Phase I study, with additional data collected in Phase II, showed that while crop ET represents the majority of growing season and yearly cropland water budgets, metering irrigation water more carefully could lower crop water use. This could be achieved by stopping irrigation once soil water saturation of the root zone has been achieved, but would require the electronic tracking of soil water content and installing sprinkler valves that shut off irrigation in feedback to soil moisture sensors. The amount of salvaged water could range from 0.4 acre-feet (123 mm) to 1.7 acre-feet (512 mm) of water per growing season. Crop species differ dramatically in the amount of water they transpire. One way to reduce crop water use is to shorten the annual irrigation period by growing non-traditional crop species that use significantly less water and produce as much yield as traditional crops.

Crop canopies were found generally effective at keeping air humidity levels high enough during the growing season to allow leaf stomata to remain open during the day and actively photosynthesizing. This allows plants to grow throughout the period of irrigation. However, low humidity levels occurring at the beginning of the growing season, when plant canopies are sparse and leaf area index is low, can inhibit photosynthesis, growth, and the ability of crop plants to compete against weeds. Thus weed suppression, through soil cultivation practices or via herbicide application, in combination with frequent short-duration irrigation in early spring, is needed on low fertility sites to keep atmospheric humidity sufficiently high and weed pressure low, allowing more rapid early growth of crop species and more rapid attainment of closed crop canopies. Differing sensitivities of crop species to atmospheric humidity, and a moderate correlation of photosynthetic water use efficiency with crop biomass yield, indicate the usefulness of screening alternative crops for potential success by measuring leaf gas exchange of carbon dioxide and water vapor.

Evaluation of the Aquatic Ecosystems of the Walker River

a. Restoration and Effects of the Walker River Environment on Biological Integrity and Secondary Production

During Walker Phase I studies, BMIs, and physicochemical characteristics of the Walker River were sampled during spring, summer, and autumn to determine environmental factors that are most influential to ecological health and structuring the composition of communities. Runoff during these years was less than 50 percent of normal, which biased observations toward drought conditions and prevented assessment of biological and environmental characteristics of the river along a precipitation gradient from drought to wet years. The narrow range of drought environments during these years did not include a gradient of biotic/environmental relationships that is necessary for an unbiased assessment of biotic/environment relationships. Phase I studies documented that BMI communities change along the gradient of environments from the base of the Sierra Nevada to Walker Lake, and that they are most influenced by low discharge, high temperatures, substrate size, and elevated nutrients. Biotic indices showed a similar pattern where tolerance values for the community were highest downstream and generally decreased along an increasing elevation gradient toward the Sierra Nevada. Communities associated with cooler temperatures, higher discharge, large substrates, and lower nutrient concentrations (low tolerance values) were more similar to those occupying healthy aquatic systems than communities in degraded systems. Higher tolerance communities were associated with areas that are most impacted by agriculture and diversion, but the absence of baseline environmental and biological information describing historical (reference) conditions in this portion of the river make it difficult to discern the relative influence of natural and human factors on these communities.

Phase II studies were conducted to collect additional information to clarify results of Phase I studies, quantitatively determine secondary production, and provide benchmarks to assess restoration efficacy. Results of the phase II studies showed that reducing nutrient loading is important for the East Walker River downstream from Bridgeport Reservoir and upstream from Mason Valley. The restoration goal for this river reach is to create water quality conditions that maintain a BMI community similar to the community in the upper West Walker River and East Walker River upstream from Bridgeport.

Discharge was higher and water temperatures were lower in 2010 than in 2007 and 2008. As a consequence, characteristics of the upper Mason Valley BMI community in the Walker River resembled lower East Walker and West Walker River communities during the summer and autumn of 2010. This suggests that East and West Walker communities occurred downstream into upper Mason Valley prior to anthropogenic influences, and the restoration goal for this reach of river is to create conditions in upper Mason Valley that are similar to those of East and West Walker River.

Identifying restoration goals for the lower Walker River is difficult because reference conditions are difficult to quantify, the magnitude of human influences are greatest in this reach (which potentially limits effects of cooler conditions on the river environment), and there was little difference in BMI communities during drought and above average precipitation years. However, the lowest river reach was distinguished by the unique presence of a highly tolerant BMI species, which is not likely to occur here if conditions in this portion of river are improved. A restoration goal for this reach of river is to improve conditions whereby this species no longer occupies this reach of river.

BMI species richness, density, and biomass were determined to be inversely associated with substrate size. Therefore, it is unlikely that productivity in reaches of river with smaller substrate size, from mid-Mason Valley to Walker Lake, can reach levels in reaches of river with larger substrate found in the East and West Walker Rivers.

Baetis sp. (the most ubiquitous BMI species in the Walker River basin) biomass is negatively associated with temperature. More work is necessary, but it appears that its biomass decreases rapidly in temperatures > 12^{o}C.

b. Determining the Response of Walker River Aquatic Life to Incremental Changes in River Management and Use

The Walker watershed exhibits a gradient of environmental conditions from the headwaters to the terminal end of the basin at Walker Lake. The headwaters are cold and relatively uninfluenced by human activities and downstream reaches are increasingly impacted by anthropogenic stressors (e.g. water diversions, dams, nutrient inputs, low in-stream flows and warm stream temperatures). Walker Lake dried historically and the long-term persistence of fishes and benthic invertebrates within the lake and lower reaches in the river was likely due to the re-colonization from upstream populations. Today, much of the lower Walker River is classified as ‘Impaired’ by the Nevada Division of Environmental Protection because of stream temperatures, nutrients, sediment, and chemicals. The Walker River fish community bears little resemblance to historical conditions, and the river is no longer a refuge of species to recolonize the lake when suitable conditions are re-established.

During Phase I of the Walker Basin Project, efforts were made to characterize the basic biological and chemical condition of the river, along multiple reaches, for nutrients, algae, benthic invertebrate diversity and production, and fish compositions (Collopy and Thomas, 2009). Phase II of the Walker Basin Project built on the Phase I study with additional data collection and interpretation. In the lower and middle river, the community composition of algae, *Cladophora* and *Oedogonium* in most locations, indicates nutrient rich conditions (also known as eutrophic) which may result in oxygen depletion during certain periods of the time (day or weeks), depending on production levels. The biological composition of invertebrates, a common food source for certain fish taxa, is related to temperature and discharge of the river. Thus, activities that promote the degradation of these environmental conditions, or their improvement, may lead to changes in composition and supply of fish food for trout. Higher-level consumers, such as fishes, are unevenly distributed in the watershed. In the Upper Walker watershed, six tributaries (including Slinkard and Silver Creeks) contain trout, some of which have nonnative brook trout, a strong competitor with Lahontan cutthroat trout. Brook trout were stocked by game and fish agencies and now naturally spawn within some tributaries. Slinkard Creek contains remnant populations of cutthroat trout that have been maintained in this creek due to the relatively pristine nature of the system. Silver Creek has had active maintenance of the cutthroat populations by reducing nonnative brook trout through chemical control which occurred in 1993-94. Recently, the illegal re-introduction of brook trout has occurred which is likely influencing resident cutthroat trout. During the snapshot surveys in the late 2000s, brown trout, rainbow trout, and mountain whitefish were found in upper, middle, and lower river reaches of the Walker Basin, but not necessarily overlapping in their distribution (Collopy and Thomas, 2009). Whitefish and rainbow trout were only caught in the upper reach of the East Walker River and brown trout were only caught in the upper West Walker River. Forage fishes (sculpin, dace, and shiner) can be found in the middle and upper river reaches. The lower river contains a mixed assemblage of forage fish but also brown bullhead catfish and small mouth bass. It has been suggested that the distribution of fishes and diet may be related to the environmental gradients and production of food within the system.

Research conducted in Phase II of the study focused on integrating our understanding of the thermal attributes of the river, to improve understanding of the biological composition and production of invertebrate food sources which supply food for some fishes, and trout distribution. This effort includes modeling approaches to understand stream temperature and fish collections made during the Walker Phase II project. As mentioned previously, cutthroat trout live in the upper watershed and select tributaries. The potential re-population of lower river reaches and/or survival of re-introduced fishes by management agencies into middle to lower river reaches may have greater success if the environmental conditions within the river are optimized during the water acquisition and delivery programs.

Airborne thermal infrared remote sensing imagery was collected in fall/winter 2011 to capture high flows and cool atmospheric conditions and in summer 2012 to capture low flows and warm atmospheric conditions (see appended final reports from Watershed Sciences). These data provide a range of thermal variability spatially throughout the Walker River. Whereas, temperature loggers provide data at a fine temporal resolution (hourly), the thermal imagery provides data at a fine spatial resolution (continuous surface temperatures) for the entire length of the Walker River, and portions of the East Walker and West Walker Rivers. This thermal imagery will be used to improve the accuracy and precision of the stream temperature model, since we can now better characterize locations with groundwater seeps, return flows, or small tributaries that otherwise would not be represented in the model. In Phase III, we plan to use the thermal imagery and modeled data to identify reaches with cooler stream temperatures (which may provide thermal refuge for trout) and river reaches with poor thermal habitat conditions that may cause potential bottlenecks in trout production. By identifying thermal refugia, as well as potential thermal barriers, we can use a handheld temperature probe to better characterize and understand these reaches and to develop management strategies to preserve stream temperatures within the tolerable range for Lahontan cutthroat trout.

Decision Support Tool (DST), Including Surface Water and Groundwater Flow Models and Water Rights Information

a. DST, GIS, Mapping and Database Support

The DST GIS information developed in Phase II of the Walker River Project directly supports water rights acquisitions and the movement of additional water to Walker Lake. The spatial and tabular data acquired and developed by DRI are used as inputs for the DST, and the DST is and will be used by NFWF to evaluate the effect of water purchases and subsequent withdrawals on other users in the system. In the near term, data generated by DRI and integrated into the DST will be used in the upcoming NDWR hearings for NFWF's Change Application 80700.

The mapping and database support DRI has provided NFWF directly supports NFWF's ongoing public outreach and water rights purchases in the Walker Basin. Transaction maps are produced for potential willing sellers' properties, helping NFWF track potential willing sellers and the water rights they own. The database work DRI has provided helps NFWF track water transactions, the "colors" of water for potential willing sellers, and the amounts of water potentially available for delivery downstream to Walker Lake. The ditch/diversion reconciliation work performed by DRI directly aids NFWF and their subcontractors as they attempt to reconcile water rights, irrigated acres and actual water use for all properties serviced by ditches, river pumps, and wells.

Summer and winter thermal image surveys were collected for the Walker River system as part of Walker Phase II. As mentioned previously, this information on the thermal properties of the river surface on a seasonal basis will be used for fish habitat modeling and groundwater seepage analysis.

b. Calibrating Basin-Scale Groundwater Models to Remotely Sensed Estimates of Groundwater Evapotranspiration

In the Walker Basin, phreatophytic and riparian vegetation consumption of groundwater is an important component of the groundwater budget needed for groundwater model calibration. Remotely sensed vegetation indices correspond to canopy vigor and cover through the ratio between red and near infrared in the electromagnetic spectrum, and have been successfully used to estimate groundwater evapotranspiration (ETg) over large spatial and temporal scales. However, these data do not provide information on depth to groundwater (dtgw) necessary for groundwater models to calculate ETg. Assuming an exponential decline in ETg with dtgw, an iterative approach is provided that calibrates MODFLOW to ETg derived from Landsat estimates of the Enhanced Vegetation Index (EVI). The approach is applied to different functional groups in Mason Valley, Nevada, over an 11-year time span and accounts for atmospheric water demand. An uncertainty analysis was done to estimate the resulting mean and 90% confidence intervals in ETg to dtgw relationships, while a first-order second moment analysis shows these relationships are almost exclusively sensitive to estimated land surface ETg despite relatively large uncertainty in extinction depths and hydraulic conductivity. Results were verified with site-specific water level data. Combining vegetation mapping, remotely sensed estimates of ETg and basin-scale groundwater models will aid researchers in deciphering eco-hydrologic responses to changing water conditions and will provide regional managers the necessary tools to make informed decisions on water resource allocations into the future.

c. Decision Support Tool

In support of H.R. 2419 Energy and Water Development Appropriations Act, 2006, Section 208, we developed, tested, and implemented a computer-based Decision Support Tool (DST) to better inform decision makers of proposed water right acquisitions in the Walker River basin. The latest version of the DST (version 2.0) captures the spatial and temporal complexity of important relationships among climate, crop demand, river flows, groundwater-surface water exchange along the river, irrigation practices, groundwater pumping, and all known existing water rights (e.g., surface decree, storage, and flood) in the Walker River system above the USGS Wabuska gaging station (i.e., Mason Valley and Smith Valley). The development of the Walker Basin DST represents a major step forward in understanding the complex hydrologic relationships within the real system. The DST allows users to track water through the complicated deliveries and returns in the heavily irrigated Smith and Mason Valleys, down to the USGS gaging station at Wabuska. Since January 2010, the DST has been applied in scenarios that are strictly focused on assessing the impacts of potential water right acquisitions (and the associated change in place of use) on the efficiency of water deliveries throughout the system. These efforts have been in close collaboration with a broad group of stakeholders that comprise the Walker Water Group (WWG).

The National Fish and Wildlife Foundation (NFWF) completed a purchase of water rights on the West Hyland ditch in December of 2010. In March of 2011, NFWF filed its first application (Application No. 80700) to the Nevada State Engineer to change these purchased water rights. The purchased rights include 7.745 cubic feet per second of Walker River Decree surface water rights with priority dates ranging from 1874 to 1906; the water is appurtenant to 646.16 acres of land. Application No. 80700, states that NFWF intends to “change the place, manner, and purpose of use of the subject water rights so that they can be administered and protected in stream to benefit the lower Walker River and Walker Lake.”

In this report, the DST is used to simulate, as closely as possible, the transfer of water rights as proposed in NFWF’s Application No. 80700 to better understand how this transfer may affect the system. Two DST modeling runs are made over calendar years 1996 through 2011: a baseline calibration run and a scenario run that simulates, as closely as possible, Application No. 80700.

The results from the two model runs are presented in this report in a comparative scenario analysis format that is used to better understand the possible impacts of the transfer on the real system, within the assumptions and limitations associated with the DST, the observed data and other information that was incorporated into the DST.

The DST was modified from the baseline model run to simulate, as closely as possible, the proposed Application No. 80700 water rights transfer scenario over calendar years 1996 through 2011. The results from the scenario model run were then compared to the results from the baseline model run. An analysis of the results indicates that, within the assumptions and limitations of the DST and the scenario method, 86% of the Application 80700 water reaches the Wabuska Gage (80700 Wabuska water) over the sixteen-year time period with an annual range between 77.3% and 92.9%. The analysis also indicates that there were no shortages in surface water delivered to the remaining areas of the West Hyland HRU but that there are occasional minor shortages and surpluses within the system that are directly related to the system responding to the changes in losses and uses of surface water and supplemental pumping on the 80700 Application area of the West Hyland HRU, changes in return flows from the West Highland HRU, and changes in stream accretions and depletions in the stream system.

Community Economic Development

In Phase II of the Walker Basin Project a plan was developed for the formation of a Walker Basin Development Corporation (WBDC). The commitment to a resource pool is currently on hold at NFWF and may or may not be undertaken in the future. Also, during Phase II, a community assessment was completed for Mineral County; no other areas within the Nevada portion of the Walker Basin desired to have a community assessment done.

In 2009, the Mineral County Commission and the Mineral County Economic Development Authority approached the Nevada Rural Development Council (NRDC) to arrange a Resource Team Visit. Funding was secured and NRDC assembled a team to assist Mineral County in evaluating community challenges and assets and in developing suggestions for improving its quality of life, social and economic future. All team members were trained and certified to complete the process. A four-day assessment began Monday, June 21, 2010 and ended with a Town Hall Meeting at the El Capitan Convention Center Thursday, June 24, 2010. At that meeting the resource team presented a preliminary report to the community. The report identified five themes: Community Engagement, Jobs! Jobs! Jobs!, Natural Resources, Renewable Energy, and Youth.

Following the assessment, a report was prepared which includes the major themes, recommendations and resources. A draft of this report was presented at a Town Hall Meeting on August 24, 2010 in the Conference Center at the El Capitan casino in Hawthorne. At that meeting, priorities were chosen by residents who were then given the opportunity to volunteer for work groups to carry out specific elements identified through the assessment. The priorities set at that meeting were Jobs! Jobs! Jobs!, with an emphasis on Community Development as the starting point; Youth; Community Engagement, with an emphasis on creating a community vision; Renewable Energy; and Natural Resources. NRDC will work with the community during a follow up campaign to assist in the development of strategic plans to address priority actions. The key to the success of this planning process will be its implementation. The assessment identifies the needs of the community as presented by its citizens. Only as those citizens become engaged in the process of carrying out the actions identified through this process will this plan have a lasting impact on the community.

A project on community business matching processes has been slightly altered to provide a Comprehensive Economic Development Strategy (CEDS) for Mineral County and the Yerington and Smith Valley areas within Lyon County. CEDS are needed in order for these areas to be able to qualify for U.S. Economic Development Administration (EDA) funding. Additionally, the CEDS will provide economic development roadmaps for these areas; however, additional interaction with local communities will be needed to finalize the CEDS.

A revised work plan and budget for the direct economic development assistance efforts has been developed and submitted to NFWF. As suggested by NFWF, it appears that the best way to leverage this effort and get the “biggest bang for the buck” is to partner with other entities that are working to increase farmers’ production of alternative water-efficient crops. This will include such entities as: Western Nevada College’s Specialty Crop Institute (Ann Louhela), Cooperative Extension (Jay Davison), Lattin Farms (Rick Lattin – specializing in farming/farmers’ markets/subscription farming, value-added processing and agricultural-tourism), Churchill County Economic Development Authority, Mineral County Economic Development Authority, Western Nevada Development District, and others as they are identified as providing key services and/or links to economic development resources.

Nevada SBDC business counselors and our team partners will help these entrepreneurs to: a) assess the market potential for their concepts; b) look at the competitive environment, c) identify risks; d) formulate a general marketing plan; e) determine what human resources will be required; f) determine how much initial capital might be required; and g) examine potential profitability. In short, the Nevada SBDC will help these entrepreneurs determine if their business concepts seem to be viable, as well as help explore ways that their business concepts might be modified to improve viability. As a part of this effort, the Nevada SBDC and team partners will assist community groups define and pursue such ideas as collaboratives, cooperatives, community kitchens, and similar concepts. All of the above efforts may include assistance with writing grants and/or with acquisition of capital equipment.

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ACKNOWLEDGMENTS

This project was funded as part of a grant agreement between the University of Nevada-Reno and the National Fish and Wildlife Foundation (No. 2010-0059-201) pursuant to Public Law 111-85, Section 208(b), under the Foundation's grant agreement with the U.S. Bureau of Reclamation (No. R10AP20007).

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RECOMMENDED CITATION

Collopy, M.W. and J.M. Thomas (Editors). 2013. Restoration of a Desert Lake in an Agriculturally Dominated Watershed: The Walker Lake Basin. Phase 2 Final Report to the National Fish and Wildlife Foundation, March 2013. University of Nevada, Reno and Desert Research Institute. 677 pp.