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Optimization Review
Carson River Mercury Superfund Site

Carson City, Nevada

Optimization Review

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Report of the Optimization Review
Site Visit Conducted at Carson River Mercury Superfund Site on
December 11 - 12, 2013

FINAL TECHNICAL MEMORANDUM
August 6, 2014

NOTICE AND DISCLAIMER

Work described herein, including preparation of this report, was performed by Tetra Tech Inc. for the U.S. Environmental Protection Agency under Work Assignment 2-58 of EPA contract EP-W-07-078 with Tetra Tech EM Inc., Chicago, Illinois. The report was approved for release as an EPA document, following the Agency's administrative and expert review process.

This optimization review is an independent study funded by the EPA that focuses on protectiveness, cost-effectiveness, site completion, technical improvements and green remediation. Detailed consideration of EPA policy was not part of the scope of work for this review. This report does not impose legally binding requirements, confer legal rights, impose legal obligations, implement any statutory or regulatory provisions or change or substitute for any statutory or regulatory provisions. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Recommendations are based on an independent evaluation of existing site information, represent the technical views of the optimization review team and are intended to help the site team identify opportunities for improvements in the current site remediation strategy. These recommendations do not constitute requirements for future action; rather, they are provided for consideration by the EPA Region and other site stakeholders.

While certain recommendations may provide specific details to consider during implementation, these recommendations are not meant to supersede other, more comprehensive planning documents such as work plans, sampling plans and quality assurance project plans (QAPP), nor are they intended to override applicable or relevant and appropriate requirements (ARARs). Further analysis of recommendations, including review of EPA policy, may be needed prior to implementation.

PREFACE

This report was prepared as part of a national strategy to expand Superfund optimization from remedial investigation to site completion implemented by the EPA Office of Superfund Remediation and Technology Innovation (OSRTI)[1]. The project contacts are as follows:

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1 U.S. Environmental Protection Agency. 2012. Memorandum: Transmittal of the *National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion*. From: James. E. Woolford, Director Office of Superfund Remediation and Technology Innovation. To: Superfund National Policy Managers (Regions 1 – 10). Office of Solid Waste and Emergency Response (OSWER) 9200.3-75. September 28, 2012.

ACRONYMS AND ABBREVIATIONS

µg/L	Micrograms per liter
ATSDR	Agency for Toxic Substances and Disease Registry
cfs	Cubic feet per second
COPC	Constituent of Potential Concern
CRMS	Carson River Mercury Site
CRS	Carson River System
CSM	Conceptual Site Model
EC	Environmental Covenant
EPA	U.S. Environmental Protection Agency
ESD	Explanation of Significant Differences
FDA	Food and Drug Administration
FYR	Five-Year Review
GIS	Geographic Information System
HHRA	Human Health Risk Assessment
IC	Institutional Control
LTM	Long-Term Monitoring
LTSRP	Long-Term Sampling and Response Plan
mg/kg	Milligrams per kilogram
Mcf	Million cubic feet
NDEP	Nevada Division of Environmental Protection
NDOW	Nevada Department of Wildlife
ng/L	Nanograms per liter
NOAA	National Oceanic and Atmospheric Administration
OSRTI	Office of Superfund Remediation and Technology Innovation
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
PRG	Preliminary Remediation Goal
P&T	Pump and treat
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RfD	Reference dose
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of decision
RSE	Remediation System Evaluations
RSL	Regional Screening Level
SPP	Systematic Project Planning
SQuiRT	Screening Quick Reference Tables
TCLP	Toxicity Characteristic Leaching Procedure
TIFSD	Technology Innovation and Field Services Division
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

CONTENTS

FIGURES

TABLES

APPENDICES

1.0 INTRODUCTION

The Carson River Mercury Site (CRMS) (Figure 1) is located in northwest Nevada and was designated a Superfund site in 1990 because of elevated mercury concentrations observed in surface water, sediments and biota inhabiting the site. The CRMS encompasses the 80-mile Carson River System (CRS) downstream of Carson City, numerous historical mill tailings sites along the Carson River and foothill tributaries, the Lahontan Reservoir constructed approximately 30 miles downstream from Carson City, and the lake, wetland and canal complex downstream from the reservoir. The mill sites used mercury to extract gold and silver from the ore obtained by Comstock Lode mining operations. As part of ore refining operations, mill sites imported a large quantity of mercury (estimated to be 7,500 tons [Bailey and Phoenix 1944]), much of which was released to the environment. Beginning in the 1970s, characterization studies and research projects were performed by various parties to understand the distribution, fate and transport, and risks posed by mercury contamination in the Carson River watershed.

This technical memorandum provides background on the U.S. Environmental Protection Agency's optimization program, identifies review team members and site visit participants, discusses current site status, summarizes the conceptual site model (CSM) and presents findings, conclusions and recommendations.

1.1 OPTIMIZATION STUDY BACKGROUND

During fiscal years 2000 and 2001, independent site optimization reviews called Remediation System Evaluations (RSEs) were conducted at 20 operating Fund-lead pump and treat (P&T) sites (that is, those sites with P&T systems funded and managed by Superfund and the states). In light of the opportunities for system optimization that arose from those RSEs, the U.S. Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (OSRTI) has incorporated RSEs into a larger post-construction completion strategy for Fund-lead remedies as documented in Office of Solid Waste and Emergency Response (OSWER) Directive No. 9283.1-25, *Action Plan for Ground Water Remedy Optimization*. Concurrently, the EPA developed and applied the Triad Approach to optimize site characterization and development of a CSM. The EPA has since expanded the definition of optimization to encompass investigation stage optimization using Triad Approach best management practices, optimization during design and RSEs. The EPA's definition of optimization is as follows:

> "*Efforts at any phase of the removal or remedial response to identify and implement specific actions that improve the effectiveness and cost-efficiency of that phase. Such actions may also improve the remedy's protectiveness and long-term implementation which may facilitate progress towards site completion. To identify these opportunities, regions may use a systematic site review by a team of independent technical experts, apply techniques or principles from Green Remediation or Triad, or apply other approaches to identify opportunities for greater efficiency and effectiveness.*"[2]

As stated in the definition, optimization refers to a "systematic site review," indicating that the site as a whole is often considered in the review. Optimization can be applied to a specific aspect of the remedy (for example, a focus on long-term monitoring [LTM] optimization or focus on one particular operable unit [OU]), but other components of the site or remedy are still considered to the degree that they affect the focus of the optimization. An optimization review considers the goals of the remedy, available site data, CSM, remedy performance, protectiveness, cost-effectiveness and closure strategy. A strong interest

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[2] U.S. Environmental Protection Agency. 2012. Memorandum: Transmittal of the *National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion*. From: James. E. Woolford, Director Office of Superfund Remediation and Technology Innovation. To: Superfund National Policy Managers (Regions 1 – 10), OSWER 9200.3-75. September 28, 2012.

in sustainability has also been developed in the private sector and within federal, state and municipal governments. Consistent with this interest, OSRTI has developed a Green Remediation Primer (www.cluin.org/greenremediation) and now routinely considers green remediation and environmental footprint reduction during optimization reviews.

This optimization review includes reviewing site documents, visiting the site and compiling this report, which includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site completion
- Environmental footprint reduction.

The recommendations are intended to help the site technical team identify opportunities for improvements in these areas. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed before the recommendation can be implemented. Note that the recommendations are based on an independent evaluation and represent the opinions of the optimization review team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the Region and other site stakeholders. Also note that while the recommendations may provide some details to consider during implementation, the recommendations are not meant to replace other, more comprehensive, planning documents such as work plans, sampling plans and quality assurance project plans (QAPP).

The national optimization strategy includes a system for tracking consideration and implementation of optimization review recommendations and includes a provision for follow-up technical assistance from the optimization review team as mutually agreed on by the site management team and EPA OSRTI.

1.2 Optimization Review Objectives

The objectives of this optimization review are to recommend (1) an appropriate remedial strategy for the CRMS, (2) approaches for improving remedy implementation, and (3) any additional characterization efforts. The findings and conclusions and recommendations presented in Sections 4.0 and 5.0 result from review of site documentation and data in conjunction with a site visit and systematic project planning (SPP) meeting.

1.3 Optimization Review Team

The optimization review team consisted of the following individuals:

Table 1. Optimization Review Team

Name	Affiliation	Phone	Email
Tom Kady	EPA OSRTI	732-735-5822	kady.thomas@epa.gov
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1.4 SITE VISIT PARTICIPANTS

The optimization review team and the site technical team including representatives from U.S. Environmental Protection Agency Region 9 and the Nevada Division of Environmental Protection (NDEP) participated in a site visit and preliminary SPP meeting on December 11 and 12, 2013.

Table 2. Site Visit Participants

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1.5 DOCUMENTS REVIEWED

Section 6 lists the references that were included in this optimization review. The documents were prepared by a range of organizations, principally EPA Region 9, the U.S. Geological Survey (USGS), the NDEP, the U.S. Fish and Wildlife Service (USFWS) and the Nevada Department of Wildlife (NDOW). In addition, the optimization review team also reviewed a number of reports by researchers from various academic institutions.

This optimization review included creation of a Microsoft Excel spreadsheet containing a listing of site documents for sorting and cataloging (the review documents matrix) (see Appendix A). The documents matrix classifies each of the 167 documents provided by EPA Region 9 according to geographic area (OU), environmental medium, depositional environment (river, reservoir or agricultural area), and key investigation elements such as analytical data reporting, data gap analysis and CSM discussion. Given the size of the CRMS and the volume of existing information, the review documents matrix was an important and useful tool for efficient review and evaluation of the previous investigations conducted at the site.

1.6 QUALITY ASSURANCE

This optimization review uses existing environmental data to interpret the CSM. The available data from the document database were compiled to support an evaluation of the general mass distribution of mercury in the various component subareas of the CRMS. The objective of this evaluation is to identify general trends in the mass distribution of mercury. Based on a review of the available documents, the review team and site technical team concluded the data would be of acceptable quality for this purpose.

2.0 PROJECT STATUS

This section discusses the current status of the CRMS, including a description of the site OUs, site remediation efforts completed to date and mercury concentration data in affected media. Table 3 shows available background concentration data and applicable mercury screening levels for comparison to the concentration data discussed in this section for the environmental media of concern.

Table 3. Background and Biological Effect Screening Level Concentrations

Surface Water		Sediment/Soil	
Source	**Unfiltered Total Mercury (µg/L)**	**Source**	**Total Mercury (mg/kg)**
National Primary Drinking Water Standard (EPA 2002)	2	EPA Region 9 RSL (Industrial Soil)	350
EPA National Recommended Water Quality Criteria (Criteria Maximum Concentration)[1]	1.4	EPA Region 9 RSL (Residential Soil)	23
Nevada Water Quality Criteria (State of Nevada 1994)	0.012 (aquatic life) 2 (drinking water) 10 (livestock water)	NOAA SQuiRT (Probable Effects Level)	0.486
Uncontaminated Background (Gustin et al. 1994)	0.001 – 0.003	NOAA SQuiRT (Threshold Effects Level)	0.174
Truckee Basin Alpine Creeks (Wayne et al. 1996)	0.0013 – 0.0016	Uncontaminated Background (Gustin et al., 1994)	10 – 50
Truckee Canal at Lahontan Dam (Wayne et al. 1996)	0.004 – 0.0044	Regional Bedrock (Gustin et al., 1994)	10 – 50

1.Source: water.epa.gov/scitech/swguidance/standards/criteria/current/upload/nrwqc-2009.pdf
Modified from Craft, et al. (2005).
Notes: µg/L = micrograms/liter; mg/kg = milligram/kilogram; RSL = Regional Screening Level; NOAA = National Oceanic and Atmospheric Administration; SQuiRT = Screening Quick Reference Tables.

The CRMS includes the former ore mill sites located in the Comstock region of northern Nevada and mercury-contaminated sediment, surface water and biota in the 80-mile stretch of the Carson River from New Empire, just east of Carson City, to its termination points at Carson Lake, Stillwater Wildlife Refuge and the Carson Sink (Figure 1). The terms "site" and "CRMS" refer to both the Carson River Mercury Site and multiple former ore processing "mill sites" that collectively constitute the OU1 portion of the "site" (that is, CRMS). The EPA partitioned the site into two OUs as follows:

- OU1 consists of the portions of the Carson drainage and Washoe Valley in northwestern Nevada that are affected by mercury released from milling operations during the Comstock Lode mining event (EPA 1995). OU1 includes upland mercury-contaminated tailings associated with 236 known former ore processing mills (EPA 2011) located along the Carson River from New Empire (eastern Carson City area) to Dayton (Figure 1) and in the tributary canyons including Daney, Gold and Six Mile Canyon (and also Seven Mile Canyon, a tributary to Six Mile Canyon). OU1 also includes the six former mill sites located adjacent to Washoe Lake and Steamboat Creek and the tailings-contaminated sediments contained in these two water bodies. Washoe Lake and Steamboat Creek are located west and northwest of Carson City in the adjacent Truckee River watershed (Figure 1).

- OU2 consists of the mercury-contaminated sediments in the Carson River, Lahontan Reservoir, Carson Lake and the Stillwater National Wildlife Refuge. (Figure 1).

The EPA finalized a Record of Decision (ROD) for OU1 in 1995; the remedial investigation/feasibility study (RI/FS) for OU2 is ongoing (as of January 2014). The status of OU1 and OU2 is discussed in more detail below.

OU1. EPA Region 9 collected tailings samples from 42 OU1 mill sites, with an average of 10 samples collected per mill location. The average area for the 42 locations investigated was 1.5 acres (EPA 1994). The average across all locations was 298 milligrams per kilogram (mg/kg) and maximum mercury concentrations were 1,007 mg/kg (EPA 1994). Based on the results of a site human health risk assessment (HHRA, EPA 1994), the EPA developed a ROD for OU1, which included a soil cleanup goal of 80 mg/kg for total mercury and a selected remedy of surface soil removal or capping. The cleanup goal for mercury in soil (80 mg/kg) is based on the child exposure equivalent to EPA's oral reference dose (RfD) for inorganic mercury. In addition to mercury, the ROD also identifies arsenic and lead as constituents of potential concern (COPC). The ROD requires the implementation of institutional controls (ICs) consisting of characterization of COPC concentrations in surface soils suspected to be contaminated with mercury, arsenic or lead above the ROD-defined cleanup goals in areas where residential development is planned. If necessary, any soil determined to be contaminated above the cleanup levels will then be remediated by removal or capping.

The EPA applied the selected remedy within two communities where soils exceeded the 80 mg/kg cleanup goal for mercury. The selected remedy included excavating contaminated surface soil to the approximate depth of 2 feet and disposing of the excavated soils in a municipal landfill. Soils that exceeded hazardous waste standards using toxicity characteristic leaching procedure (TCLP) analysis (which considers leaching) were to be disposed of at an appropriate Resource Conservation and Recovery Act (RCRA) hazardous waste disposal facility (EPA 1995). Three OU1 areas in Dayton and one OU1 area in Silver City located approximately 3 miles up-canyon from the Carson River were remediated. Between August 1998 and December 1999, a combined area of approximately 3 acres was remediated through excavation and appropriate disposal of 9,087 cubic yards of contaminated soil (EPA 2003). EPA Region 9 has completed three Five-year reviews (FYRs) (EPA 2003, 2008 and 2013) since the remedy was completed. As documented in the FYRs, actions taken since the signing of the ROD include:

- Development of a plan governing the pre-development characterization of land proposed for residential development (the Carson River Mercury Superfund Site Draft Long-Term Sampling and Response Plan [LTSRP] [NDEP 2011]) and extension of the requirements of the LTSRP to any construction or renovation that disturbs more than 3 cubic yards of soil,
- Adoption of a 2013 Explanation of Significant Differences (ESD) that instituted a better site boundary definition (supported through the use of geographic information system [GIS]-based tools) and more stringent screening levels for arsenic and lead, and
- Establishment of measures to make ICs information more readily accessible to the public.

In general, the reviews conclude that the remedy is protective given that the planned ICs are fully implemented.

Washoe Lake and Steamboat Creek. As indicated previously, Washoe Lake and Steamboat Creek (Figure 1) are included in OU1 but are not tributaries to the Carson River. As these water bodies are located in different watersheds and sediments within each are affected by significantly different depositional processes, the optimization review team recommends that Washoe Lake and Steamboat

Creek be designated as a separate OU or OUs, distinct from OUs 1 and 2. Conditions in these two water bodies are discussed below.

Washoe Lake is located between Reno and Carson City and discharges to Steamboat Creek, a tributary to the Truckee River. Historical milling of Comstock ore has resulted in mercury contamination in Washoe Lake and Steamboat Creek surface water, sediment and biota. Blum et al. (2001) indicate that total mercury concentrations in Steamboat Creek ranged from 82 to 419 nanograms per liter (ng/L) and that 90 percent of this total is associated with suspended solids (above 0.45 microns). The maximum total mercury concentrations in surface water measured by Blum et al. (2001) were observed at the headwaters of Steamboat Creek, at the outfall from Washoe Lake. In addition, Blum et al. (2001) observed that methylmercury concentrations in samples from Steamboat Creek and Washoe Lake wetlands generally exceeded methylmercury concentrations in Steamboat Creek stream bank and stream channel samples. NDEP noted during the site visit that the Galena Creek Ditch Company (a local irrigation water purveyor) periodically spot-excavates accumulated overbank sediments where water discharges from Washoe Lake to Steamboat Creek. Lower concentrations occur in downstream channel and stream bank sediments. Rubik Environmental Consultants, Inc. (2013), measured sediment floodplain concentrations for lower Steamboat Creek that ranged from less than 1 to a maximum of 570 mg/kg and averaged 34 mg/kg in sampling to support construction of a new roadway in Reno.

Concentrations of mercury in some fish species (carp, Sacramento perch and white bass) collected from Washoe Lake have exceeded the EPA advisory level of 0.6 mg/kg and the Food and Drug Administration (FDA) level of 1.0 mg/kg. The NDOW recommends against consumption of these species from Washoe Lake and advises limited human consumption of various species from Steamboat Creek (www.ndow.org/Fish/Fish_Safety/Mercury/Health_Advisory_Status_of_Western_Nevada_Waters).

Washoe Lake and Steamboat Creek differ in several key respects from the other water bodies that make up the CRMS OUs and, as noted above, should be designated as a separate OU or OUs. In addition to their locations in different watersheds, the historical mill sites in the vicinity of Washoe Lake were generally located on the floodplain of the lake rather than along steep tributary canyons, as was the typical setting for the historical mill sites in the Carson River watershed. Sediments in the Washoe Lake mill site source areas, therefore, are subjected to sedimentary processes more typical of a low-energy lacustrine environment, whereas sediments in the Carson River watershed mill sites are subjected to sedimentary processes typical of a high-energy, fluvial environment.

OU2. OU2 encompasses the sediment (below the high water mark) portion of the CRMS from New Empire downstream to the terminal wetland areas below Lahontan Reservoir. As noted, this portion of the site is currently undergoing an RI/FS. Elevated mercury concentrations, sourced to the OU1 historical mill sites, exist in surface water, sediments and biota of the Carson River, Lahontan Reservoir and terminal wetlands.

The Carson River originates south of Lake Tahoe in the Sierra Nevada Mountains and flows 160 miles to the northeast to terminal wetlands in the Carson Sink. CRMS OU2 begins in the Carson River valley, where the large historical quantities of mercury-contaminated tailings entered the river at the OU1 former mill sites located along the river near Carson City (New Empire to Dayton [Figure 1]), and in the adjacent tributary canyons. The influx of contaminated tailings to the Carson River is believed to have begun with the beginning of Comstock mining operations in 1859 (with the most significant quantities entering the river from the beginning of mining through the early 1900s) (Miller et al. 1996); tailings influx rates varied over time. The tailings influx has dispersed tailings-contaminated sediments within the Carson River floodplain from the New Empire – Dayton vicinity downstream to the terminal wetlands. The mercury present in the floodplain sediments serves as a secondary source to surface water and biota in OU2. The Lahontan Reservoir, completed in 1915 as part of the Newlands Project for land reclamation, is located approximately 30 miles downstream from Dayton. A delta exists where the Carson River enters the Lahontan Reservoir. The delta formed through the deposition of floodplain sediments eroded by the river upstream from the reservoir. The Newlands Project also included construction of an extensive canal system to drain and irrigate the area downstream from the Lahontan Reservoir (Craft et al. 2005). A large agricultural area and system of wildlife refuges currently exist in this area. Elevated mercury concentrations exist in the soils, sediments and biota present in the Carson River basin downstream from Lahontan Reservoir as a result of pre-dam historical sediment migration and ongoing discharges from the reservoir during both normal flow and flood events.

The most significant mercury contamination in the agricultural and wetland areas downstream of the reservoir occurred during floods that predated construction of the reservoir (Tuttle et al. 2001). Most of the mercury in OU2 is inorganic mercury associated with the suspended solids in the river water and secondarily as coarse-grained channel sediments (Craft et al. 2005). Since its construction, the reservoir has functioned as a depositional sink for suspended and channel sediments from the river (Hoffman and Taylor 1998). Although mercury-contaminated surface water and sediment continue to discharge from the reservoir, the rate of downstream mercury loading has been significantly reduced since the reservoir was built (Tuttle et al. 2001).

Craft et al. (2005) compiled a summary of the available mercury and methylmercury data for surface water, sediments and biota in the Carson River System. The data were obtained from USGS databases and previous studies conducted by universities and various state and federal agencies. Figure 2, based on data obtained from Craft et al. (2005), compares total mercury and total methylmercury concentrations in Carson River headwaters with results for samples collected from the river between Dayton and the Lahontan Reservoir (Upper Carson River), the Lahontan Reservoir itself, and the wetlands and canals downstream from Lahontan Dam (Below Dam). Figure 3 compares the ranges of total mercury and methylmercury concentrations in sediment for Carson River headwaters, Upper Carson River, Lahontan Reservoir and the wetlands and canals below the dam.

Upstream from OU2, total mercury levels in surface water and sediment of Carson River are slightly above uncontaminated background concentrations, which reflects the native volcanic geology of the region and, to some extent, minor anthropogenic sourcing (Craft et al. 2005). Mercury inputs to the Carson River headwaters have been documented from the Leviathan Superfund Site, an abandoned open-pit sulfur mine located near the East Fork of the Carson River in Alpine County, California (Craft et al. 2005).

Large historical influxes of mercury-contaminated tailings from OU1 have affected the Carson River downstream from OU1. Mercury-contaminated tailings continue to enter the Carson River from OU1, but at a very low rate relative to historical levels. As a result of the influx of tailings-contaminated sediments from OU1, concentrations of total mercury in water and sediment downstream increase exponentially, as shown by a comparison of the upstream Carson River mercury concentrations in surface water and sediment to those measured in the Upper Carson River downstream from OU1 (Figures 2 and 3). Erosion of the contaminated floodplain sediments occurs annually during high flow spring runoff events. The total methylmercury concentrations in sediment and surface water exhibit a more gradual increase downstream from the OU1 source areas and reflect lower flow conditions, which are more favorable for methylation processes. Although elevated, methylmercury concentrations in the surface water discharging from the reservoir show a nearly fivefold concentration decrease from the inflow concentrations. Craft et al. (2005) note that some studies report that higher exit concentrations can occur. Overall, as noted above, the reservoir acts as a sink for incoming mercury in sediment and surface water. Hoffman and Taylor (1998) estimate that the reservoir retains up to 90 percent of the mercury entering from the Carson River. Downstream from Lahontan Reservoir, total mercury concentrations in surface water are comparable to the reservoir, while methylated mercury exhibits an increase to levels comparable to the Carson River above the reservoir. These results indicate that mercury methylation is occurring in the below-reservoir canals and wetlands.

With regard to mercury concentrations in biota, data compiled by Craft et al. (2005) indicate that some mercury bioaccumulation is occurring in the Carson River upstream from the OU1 source areas, but the observed concentrations are within background levels. Downstream from OU1, mercury concentrations in natural vegetation and in fish and waterfowl tissue increase as the Carson River approaches Lahontan Reservoir. Tissue from fish inhabiting the reservoir exhibit extremely elevated mercury concentrations (Figure 4). The NDOW routinely stocks surface water bodies in the state with game fish (www.ndow.org/Fish/Stocking_Updates/). The Lahontan Reservoir is included in the fish stocking program, provided that reservoir water levels are sufficiently high to support the additional fish population. As a result of prolonged drought conditions in the southwestern U.S., the water level in the Lahontan Reservoir during the current year (2014) is too low to support stocking.

Elevated mercury concentrations in all biota persist in the canals and terminal wetlands below the reservoir. With only one exception, NDOW recommends against consumption of fish caught in the Carson River downstream from OU1, Lahontan Reservoir or the terminal canals and wetlands because fish tissue concentrations in nearly all species exceed EPA and FDA levels. The exception is the Sacramento blackfish, a forage fish harvested commercially; the NDOW approves this fish for consumption on a limited basis, as indicated on the current NDOW website www.ndow.org/Fish/Fish_Safety/Mercury/Health_Advisory_Status_of_Western_Nevada_Waters/.

The Agency for Toxic Substances and Disease Registry (ATSDR) evaluated environmental risk factors that might be linked to leukemia cases in the Fallon area, a municipality located in the agricultural area downstream from the Lahontan Reservoir (ATSDR 2003). This evaluation concluded that human consumption of mercury-contaminated waterfowl and fish is the most significant human exposure pathway to mercury and that infrequent exposure to soil, sediment and surface water was unlikely to result in adverse human health effects. ATSDR (2003), however, noted that data were limited regarding mercury bioaccumulation in local crops and livestock. Terrestrial mercury bioaccumulation has been documented in waterfowl in the Carson River terminal wetlands area (Hoffman 1996). Tuttle et al. (1998) note that livestock (cattle) in the terminal wetlands grazed on vegetation near ponds characterized by elevated trace metal concentrations that may potentially bioaccumulate in livestock. Understanding the conditions under which livestock bioaccumulate mercury is an ongoing area of research. Chilbunda and Janssen (2013) observed that livestock grazing in mercury-contaminated areas in a gold mining area in Tanzania exhibited elevated mercury concentrations in liver samples. Mercury concentrations in the muscle tissue of these animals, however, were generally within acceptable limits. Additional agricultural product sampling is, therefore, likely needed to assess what, if any, hazards exist regarding human consumption of livestock and produce from the Carson River floodplain area.

Existing Institutional Controls. The primary exposure pathways of concern regarding human health and ecological receptors are contact with and incidental ingestion of mercury-contaminated sediment and soil and consumption of mercury-contaminated biota. As noted above, NDOW has issued consumption advisories for fish caught in site surface waters. With regard to site soil and sediment, NDEP, in conjunction with EPA Region 9, developed the draft LTSRP (NDEP 2011), as previously discussed. The LTSRP is a regional risk assessment and soil management plan developed to address site-specific mercury contamination in OU1 and OU2. The plan sets forth sampling requirements to assess the mercury hazard at any location within the CRMS where site development is planned and would disturb surface soils. Below the Lahontan Dam, OU2 includes only a narrow portion of the floodplain adjacent to the Carson River and main distributary channels for the Carson River (Figure 1); the agricultural and canal areas away from the flood plain and distributary channels, therefore, are not covered by the LTSRP. As an example of implementation of the LTSRP, the optimization review team visited a subdivision (Onda Verde Subdivision in Fallon, Nevada). The required sampling after the development process had already been initiated did not identify mercury above 80 mg/kg within the top 2 feet of the subdivision soil. A number of parcels within the subdivision had been purchased by private citizens; therefore, NDEP sent letters to the property owners requesting that they record Environmental Covenants (ECs) for the properties. An EC is a durable voluntary agreement between NDEP and a property owner and is associated with a given land parcel in perpetuity (remains in effect after changes in ownership). As applied to the CRMS, an EC would provide notice to the public that a given parcel is subject to the conditions specified in the LTSRP.

3.0 CONCEPTUAL SITE MODEL

A CSM is a comprehensive description of a site and its environmental setting including contaminant sources, migration pathways and potential ecologic and human health receptors. A significant amount of data and associated analyses exist for the CRMS to understand the sources, fate and transport, and receptors of site-related mercury contamination. This section provides a brief review of mercury occurrence, toxicity and methylation processes, a summary of the CSM and associated data gaps.

Mercury Occurrence and Toxicity. Most mercury in the environment occurs in its elemental form or as inorganic mercury compounds. Mercury in liquid form readily volatilizes to the atmosphere. Elemental mercury readily combines with other metals such as gold and silver to form amalgams, the basis for the milling process used for the Comstock ore processed in the OU1 tailings source areas. A first step in generation of bioavailable mercury is methylation of inorganic mercury by microorganisms (Hsu-Kim 2013). Mercury, in both organic and inorganic forms, is a potent neurotoxin in humans. Exposure can result from direct contact and oral exposure. Neurological effects have been observed from acute to long-term chronic exposures involving relatively low concentrations (ATSDR 1999). The ecological impacts of mercury include reproductive and behavioral impairment of fish and waterfowl (Hoffman et al. 1990).

A mercury amalgamation process was used to extract gold and silver from the Comstock ores. Bailey and Phoenix (1944) estimate that approximately 7,500 tons of mercury were imported for ore processing in the Carson River watershed over the period from initial discovery of the Comstock Lode in 1859 through approximately 1900. The vast majority of mercury in the Carson River system is held within the tightly bound mercury amalgam produced by ore processing (Gandhi et al. 2007). Modeling studies suggest that slow dissolution of the amalgam may increase the fraction of dissolved inorganic mercury in the system over time (Gandhi et al. 2003). The erosion of floodplain sediments and the associated generation of fine sediment particles (suspended solids) with large concentrations of sorbed mercury, however, is a much more significant source of mercury to the system.

Microorganisms, including iron- and sulfate-reducing bacteria, can convert inorganic mercury into methylmercury. Methylmercury bioaccumulates in fish and other aquatic species. The largest predatory fish within an ecosystem typically accumulate the highest methylmercury concentrations. Human consumption of mercury-contaminated fish is a key route of exposure to human receptors at the CRMS. Mercury methylation occurs predominantly in anoxic environments and results from processes mediated by anaerobic microorganisms. These processes involve a variety of microorganisms and can both produce (methylate) and destroy (demethylate) methylmercury. Hsu-Kim et al. (2013) review the current understanding of microbial mercury methylation. They note that fundamental questions currently remain regarding mercury methylation, including the geochemical forms of inorganic mercury that persist in anoxic settings, the mode of uptake by methylating bacteria, and the biochemical pathway by which these microorganisms produce and degrade methylmercury. Additional scientific research on mercury methylation processes, therefore, is needed to improve remedy evaluations for mercury sites as large and complex as the CRMS.

Mercury Mass Balance. The optimization review team evaluated available sediment characterization data to support development of the CSM. The objective of the review was to compile a mass balance of total mercury for each component of the CRMS. The mass balance calculations are included in Appendix B. The review focused on Carson River watershed portions of OU1 and OU2 because data were not readily available to extend this analysis to Washoe Lake and Steamboat Creek. In general, the size of the CRMS, the comparative sparseness of mercury concentration measurements and the variability of the concentration data limited the quantitative results of this assessment. However, the available data were used to assess the relative distribution of mercury among the site components and identify where uncertainties exist. As noted above, an estimated 7,500 tons of mercury were imported to the OU1 area for use in processing Comstock Lode ore (Bailey and Phoenix 1944). Even without accounting for mercury released to Washoe Lake and Steamboat Creek, the existing data appear to account for only 10 percent of this total, as shown in Table 4.

Table 4. Summary of Mercury Mass Balance Estimate

Site Area	Estimated Mercury Mass (Tons)	Volume (Mcf)	Assumptions/Comments
Upper Carson River	115	127	Assumes average mercury concentration of 15 mg/kg increasing downstream from the OU1 source areas
Delta Area and Lahontan Reservoir	450	292	Assumes average mercury concentration of 20 mg/kg for the delta and 24 mg/kg for the reservoir
Terminal canals, lakes and wetlands	100	300	Assumes average mercury concentration of 1 mg/kg for an area of approximately 100 square miles (1 foot average depth)
Total Estimated Mass	665	719	Assuming that the 7,500-ton estimate (Baily and Phoenix [1944]) is accurate, 6,835 tons cannot be accounted for in OU2 sediments

Note: See Appendix A for calculation details.

Mcf: million cubic feet
mg/kg: Milligrams per kilogram

As shown in Table 4, these mass balance calculations suggest that a large amount of mercury (6,835 tons) remains at the OU1 mill sites, a significant amount of mercury was lost via unaccounted processes (for example, volatilization and bioaccumulation) or the amount of mercury believed to have been imported was overestimated.

CSM. The dynamics of Carson River discharge are an important consideration in the CSM. The discharge flow of the Carson River at the Fort Churchill stream gage is measured near the river's discharge point to the Lahontan Reservoir. Flow is very low (on average 1 to 4 cubic feet per second [cfs]) during August and September. During the spring, however, snowmelt in the Sierra Mountains causes an increase in median monthly flow rates to 1,100 cfs in May and 865 cfs in June (Craft et al. 2005). Extreme flood events can also occur. For example, as a result of a rain-on-snow event in the Sierra Nevada headwaters of the Carson River, a peak discharge of 22,300 cfs was measured at Fort Churchill in January 1997. In addition, temporal changes in the flux of tailings-sourced sediments contaminated with mercury are evaluated in Figures 5a through 5c. These figures were prepared to understand the evolution of the current distribution of mercury contamination and the applicable fate and transport processes that have operated and continue to operate at the site.

Figure 5a shows conditions in the watershed that predate mining and milling operations (pre-1859). The Carson River and the streams occupying the canyons in OU1 are in general equilibrium with runoff and sediment inputs. The profile of the Upper Carson River downstream from OU1 consists of a steeper, upstream canyon-bound reach and a flatter, downstream reach occupying a wide valley (Carroll et al. 2000).

Figure 5b shows conditions in the watershed after the start of mining and milling but before construction of the Lahontan Reservoir Dam, the period from 1859 to the early 1900s. With the discovery of the Comstock Lode in 1859 and the associated beginning of mining and milling operations, large quantities of mill tailings consisting of byproducts from the mercury amalgamation process were dumped into the steep canyons that serve as tributaries to the Carson River. A number of other mills that also discharged tailings are located on the Carson River between New Empire and Dayton. At the height of operations, approximately 544 metric tons of mill tailings were produced each day (Smith 1943). Based on an analysis of depositional patterns in the Six Mile Canyon alluvial fan, Miller et al. (1996) conclude that tailings were mostly transported during storm events. The massive influx of tailings to Carson River resulted in inundation of the pre-mining stream deposits.

Mining operations ceased in the early 1900s. From that time on, erosion primarily associated with storm events continued to release mercury-contaminated tailings into the Carson River. Before the Lahontan Reservoir was built, high spring runoff and flood events transported tailings-contaminated sediments downstream as coarser-grained channel bed deposits and a finer suspended silt and clay size fraction. Downstream from OU1, this transport occurred throughout the entire river valley, including the terminal lake and wetland area. The finer-grained suspended load was deposited as overbank sediments in the lower-gradient portion of the Upper Carson River Valley and in the terminal lake and wetland area. As the river eroded its banks, it continuously changed course, resulting in the formation of numerous (up to 100) meanders that were later cut and abandoned. Extreme flood events result in significant rerouting and channel modification (Hoffman et al. 1998). The resulting deposits range from overbank sediments of variable thickness to a complex of cross-cutting paleochannels (Miller et al. 1998). The cross-section shown in Figure 6 illustrates the complexity of the floodplain sediments and the extreme variability of total mercury concentrations that typically exists in these deposits. Miller et al. (1998) conclude that this extreme variability and the extent of the area of impact would complicate any efforts to adequately characterize the distribution of mercury in these sediments.

During periods of reduced river flow, mercury present in the stream bank sediments undergoes methylation and contributes to the total mercury load in the river. Carroll et al. (2000) estimate that conditions in the river banks are conducive for mercury methylation during river flows below the high end of the typical spring runoff range (1,000 cfs). Before the reservoir was constructed in 1915, methylation likely also occurred in the Carson Sink terminal lakes and wetlands.

Figure 5c shows conditions in the watershed after mining ceased and the Lahontan Reservoir was built in 1915. Tailings continue to be eroded from the former OU1 mill sites during storm events, but at a much reduced rate compared with pre-1900 levels. For example, Miller et al. (1996) indicate that, although erosion processes will continue to act on the Six Mile Canyon fan and an unquantified amount of mercury-contaminated sediment will be discharged to the Carson River, the current and future rates these sediments will move to the river is expected to be very slow. With the disappearance of the dams supporting the mills on Carson River between New Empire and Dayton, the accumulated tailings were washed downstream from the steeper portion of the Upper Carson River to the low-gradient reach upstream from Lahontan Reservoir. During the spring flooding season, a large flux of total mercury continues to be transported downstream through bank erosion in the lower-gradient reaches of the Carson River. With completion of Lahontan Dam and Reservoir, however, approximately 90 percent of sediments transported by fluvial processes are retained in the reservoir.

Both methylation and demethylation occur in sediments in the reservoir (Kuwabara 2002), resulting in decreased, but still elevated, methylmercury concentration in the reservoir outflow. Seasonally, the reservoir water level is typically drawn down to accommodate irrigation needs. This seasonal water level rising and lowering may enhance the bioavailability of mercury in the reservoir (Craft et al. 2005). Bioaccumulation of methylmercury in the reservoir ecological system may also be a significant sink for methylmercury (Gandhi 2007). As noted previously, an extensive network of canals was constructed below the reservoir when the reservoir was developed. Methylation of mercury in the Upper Carson River stream bank deposits and in the canals and wetlands below the dam is ongoing during low flow periods.

Figures 5a, b and c focus on temporal changes in mercury fate and transport in the CRMS. With respect to Washoe Lake and Steamboat Creek, historical milling sites also operated along these water bodies and resulted in discharge of large quantities of mercury-contaminated tailings. Historically, contaminated sediments have been flushed down Steamboat Creek to the Truckee River floodplain during periods of high runoff. The discharge of these tailings into Washoe Lake and Steamboat Creek has resulted in mercury-contaminated sediments, generation of methylmercury, and bioaccumulation of methylmercury in the ecological systems of these water bodies. Although a comprehensive document base describing Washoe Lake and Steamboat Creek was unavailable for this optimization review, it is likely that elevated mercury concentrations associated with these water bodies are present and exhibit significant variability. In addition, the area of impact is much smaller compared with the area of impact associated with Carson River because there are only six known historical ore processing mills in the Washoe Lake area.

CSM Data Gaps. The existing level of characterization provides a working understanding of the processes that resulted in the current distribution of mercury contamination observed at CRMS. Significant data gaps remain that should be considered during development of characterization and remediation strategies for the site:

- OU1 source area storm flow data for sediment and surface water are needed to verify current low-level total mercury loading rates to Carson River and lower Steamboat Creek.
- The order of magnitude discrepancy between the initial estimate of mercury mass imported to the OU1 source area (Baily and Phoenix 1944) and the mercury mass that can be accounted for based on available sampling results from Carson River floodplain, Lahontan Reservoir and terminal wetlands sediments should be investigated.
- Any residual tailings concentrations in the Carson River Valley portion of OU1 that may be especially vulnerable to erosion by the river during extreme flood events should be inventoried.
- An inventory of residual zones of source area tailings that are especially vulnerable to erosion in the OU1 tributary valleys in the vicinity of the former mill sites should be developed.
- A more complete understanding of the environmental conditions that influence methylation and demethylation rates in Lahontan Reservoir is needed.
- A more complete understanding of the distribution of mercury-contaminated sediments in the Upper Carson River floodplain and in the canals, soils and sediments in the area downstream from the Lahontan Reservoir is needed.
- Data regarding mercury bioaccumulation in livestock and produce from the agricultural area are needed to assess the potential for human exposure to mercury from ingestion of contaminated agricultural products.

4.0 FINDINGS AND CONCLUSIONS

The following are the primary findings and conclusions resulting from this optimization review.

- Elevated mercury concentrations exist in OU1 tailings piles and in sediments derived from the erosion, transport and deposition of tailings-contaminated sediments in OU2. Contaminated sediments are present throughout CRMS OU2 downstream from OU1.
- Elevated mercury concentrations are present in Washoe Lake sediments and the sediments contained in the Steamboat Creek floodplain downstream from Washoe Lake.
- During storm events, there is a potential for low-level releases of total mercury from the remaining mercury-contaminated tailings in the OU1 source areas. Releases of these tailings have most likely diminished substantially as the drainages have readjusted to more normal sediment loads in recent decades. As a result, current mercury release rates from OU1 are likely low.
- Using approximate averages for mercury concentrations in sediment and order-of-magnitude estimates for sediment volume for the flood plain, reservoir and terminal wetlands, the estimated total mass of mercury present in OU2 sediments is an order of magnitude less than the estimated initial mercury mass imported to the OU1 source area.
- Given the size of the area involved (80 miles of floodplain) and the random occurrence of zones of elevated mercury concentration in the OU2 area, both above and below the Lahontan Reservoir, comprehensive sampling to identify mercury hotspots would be extremely challenging logistically and scientifically and would be cost-prohibitive.
- Areas at the site where conditions are most conducive for mercury methylation include the Carson River stream bank deposits and the wetlands below the Lahontan Reservoir.
- Most of the mercury loading (sediment and surface water) to Lahontan Reservoir consists of inorganic mercury associated with suspended particles, and 90 percent of suspended particle load is retained in the reservoir as deposited sediment.
- Methylmercury concentrations are greater in the inflow to the Lahontan Reservoir from the Carson River than are concentrations in the water exiting the reservoir. Some of the reduction is the result of demethylation processes and some is the result of fish uptake. Modeling suggests that fish may be an important sink for methylmercury in the reservoir.
- Fish tissue levels exceed the EPA mercury advisory level and the FDA action level; fish advisories recommend not consuming fish from the river, with one exception: the Sacramento blackfish is a forage fish that inhabits the lake and is commercially harvested for human consumption, with advisories warning to limit consumption (one 8-ounce serving per month for an adult).
- Based on the HHRA completed with the CRMS RI (EPA 1994), the human health exposure pathways of concern are ingestion of residential soils and consumption of mercury-contaminated wildlife, especially fish and waterfowl.
- Other hypothetical exposure pathways that may pose a concern include ingestion of products from the agricultural area downstream from Lahontan Dam and incidental ingestion of surface water.

5.0 RECOMMENDATIONS

The remedy components that are recommended to be the focus of CRMS remedy evaluations are presented in this section. Recommendations for improving these components are then discussed in Sections 5.1 through 5.5.

Consistent with EPA Region 9 and NDEP consensus, the results of more than 20 years of characterization investigations, and the impracticality of meaningfully addressing data gaps in sediment characterization, this optimization review recommends that the most reasonable approach to ensure protectiveness for the CRMS should emphasize ICs. Given the scale of the site (80 miles of floodplain) and the random and temporal distribution of zones with elevated mercury concentrations, extensive soil and sediment characterization efforts are not recommended, except to support remedy implementation, as necessary. Similarly, other active remedial options such as excavation or stabilization should be considered only for limited implementation and within the context of enhancing the IC strategy. Elements of the IC remedy for sediment and soil and for tissue are discussed below.

The following recommendations are based on the primary optimization review and do not consider the application and results from the potential use of these technologies.

Sediment and Soil. The anticipated remedial alternatives analysis will emphasize ICs. This remedy approach provides controls that help to prevent exposure while allowing natural processes that are already at work transporting the contaminated sediment downstream to continue. Over time, contaminated sediments will be buried by more recent clean sediments that are generated naturally within the watershed.

The ICs would consist of the soil management protocols defined in the LTRSP — specifically, soil sampling conducted on an “as-needed” basis. As the term is used here, “soil” refers to both surface soils affected by current and historical overbank deposition of mercury-contaminated sediment and to subsurface soil consisting of buried, mercury-contaminated floodplain deposits. Mercury concentrations would be characterized at a specific location where development is contemplated and the threat of mercury exposure requires direct assessment. Site-specific spot excavations or capping remedies should then be implemented, as needed, based on site-specific analytical findings. ICs should include the establishment of ECs for CRMS properties subjected to development.

Fish and Waterfowl Tissue. Exposure to contaminated fish and waterfowl tissue is a significant human health and ecologic issue at the CRMS. Elevated mercury levels in tissue are a direct result of the introduction of mercury-contaminated sediments to the river and the reservoir. No reductions in tissue concentrations can likely be achieved until the sediment contamination is addressed. Active sediment remediation would be impractical for CRMS because of the large scale of the site, the relatively random distribution of elevated mercury and the ability to control most potential exposure pathways using ICs. ICs in the form of signage warning of the mercury contamination present in fish and waterfowl and vigorous public awareness efforts are, therefore, key elements of the anticipated approach to limiting human exposure from consumption of contaminated fish tissue. In addition to ICs, routine monitoring of fish tissue would continue. The EPA would also encourage additional research to improve the understanding of the processes that control the bioavailability of mercury at the site.

As stated in Section 1.2, the objectives of this review are to recommend an appropriate remedial strategy for the CRMS and to recommend approaches for improving remedial and additional characterization efforts. The following sections discuss recommendations to optimize the implementation of ICs at the CRMS. As indicated in the following sections, suggestions for additional characterization sampling are also offered, but only within the context of implementing the IC strategy.

5.1 IMPROVING EFFECTIVENESS

Recommendations to improve remedy effectiveness include the following. The applicability of each recommendation to OU1, OU2 or both OUs is noted for each recommendation.

- To increase awareness of the LTRSP and the hazards of consuming contaminated fish, ensure that the existing community involvement plan effectively defines specific approaches for outreach to city and county officials, developers and the public (both OUs).
- To understand the extent of potential remaining source areas, inventory remaining large concentrations of tailings that could erode directly into the Carson River and classify them regarding their susceptibility to erosion. Consider stabilization or removal to reduce the potential for a direct influx of additional contaminated tailings releases during major flood events (OU1) for any tailings that appear especially vulnerable to erosion.
- To better characterize the potential for human exposure through consumption of locally produced agricultural products, consider sampling livestock and produce from the agricultural area to assess the potential for human exposure from this pathway (OU2).
- Conduct alternatives analysis to identify potential engineering controls to cost-effectively reduce or eliminate the need to spot-excavate sediments at the discharge point of Washoe Lake at the headwaters of Steamboat Creek (OU1).
- To reduce human exposure through consumption of contaminated fish tissue, post effective signage warning against fish consumption from the OU2 area at all public access points (docks, boat ramps and similar locations) to the Lahontan Reservoir, Carson River, and the lakes and wetlands downstream from Lahontan Reservoir (OU2).
- To reduce human and waterfowl exposure to contaminated fish tissue, the practice of stocking the Lahontan Reservoir with game fish should end. This measure would also reinforce the health advisory against the consumption of fish caught in the reservoir (OU2).
- End the commercial harvesting of the Sacramento black fish from Lahontan Reservoir to eliminate this human exposure pathway (OU2).
- Research reservoir water level management as a potential approach to reduce mercury methylation (OU2).
- To more effectively manage site restoration efforts, Washoe Lake and Steamboat Creek should be assigned to a separate OU, distinct from OUs 1 and 2. This recommendation is put forth because Washoe Lake and Steamboat Creek are in a separate watershed and depositional processes operating to disperse contaminated sediments may differ from those that dominate sediment transport in the Carson River watershed, (OU1).

5.2 REDUCING COST

Recommendations to reduce cost include:

- The anticipated strategy emphasizing ICs will more cost-effectively manage the mercury issues at CRMS compared with other strategies that involve source control or removal measures. However, to be effective, special attention must be focused on IC implementation and monitoring to ensure protectiveness (both OUs).
- Consider ways to expedite the LTRSP process by streamlining, to extent possible, the application process. Tools such as standardized application checklists and procedures can minimize administrative application review costs (both OUs).

5.3 TECHNICAL IMPROVEMENT

Recommendations for technical improvement include:

- With respect to LTRSP implementation, expand the use of GIS tools and the use of risk boundary polygons developed by NDEP (NDEP undated). The designation of high, moderate, and low risk areas and associated LTRSP requirements tailored to each area will improve implementation of the LTRSP (both OUs).
- With regard to mercury bioavailability, encourage research organizations such as the USGS and universities to continue investigating mercury methylation and demethylation processes in the Carson River and Washoe Lake and Steamboat Creek watersheds (OU2).
- In coordination with the recommended research regarding mercury methylation, research should be encouraged to identify and evaluate potential measures to prevent or inhibit methylation processes in site water bodies (OU2).
- To help address uncertainties in the mercury mass balance, review and verify the calculations performed by Bailey and Phoenix (1944) regarding the amount of mercury imported to OU1to support ore processing operations (OU1).

5.4 SITE COMPLETION

Recommendations for site completion include:

- Conduct continued, routine monitoring of surface water and sediment quality both in the Carson River and in the OU1 tributaries so that any significant reductions in mercury concentrations can be established to assess progress toward site completion and to evaluate the effectiveness of ICs. This monitoring can also support ongoing studies regarding the factors controlling mercury bioavailability (both OUs).
- Consider a site-wide, hyperspectral aerial imaging survey to attempt to map mercury distribution. The imaging sensor system should be flown over the area during the annual period of lowest water (typically August/September). The survey will require soil and sediment sampling, combined with laboratory-based analytical and spectral signature determination, to ground-truth the mercury identified through aerial imagery. If successful, the survey could indicate areas of relatively higher mercury concentrations in soils and sediments that could be considered for more targeted institutional controls or containment or removal actions. As the survey is anticipated would be performed by EPA’s Office of Research and Development, no costs for the effort are provided.

5.5 GREEN REMEDIATION

Recommendations for green remediation:

- Consider developing and maintaining a CRMS soils database to facilitate leveraging sampling results across neighboring project sites, thus potentially minimizing the extent of characterization needed for the CRMS and conserving project resources (both OUs).

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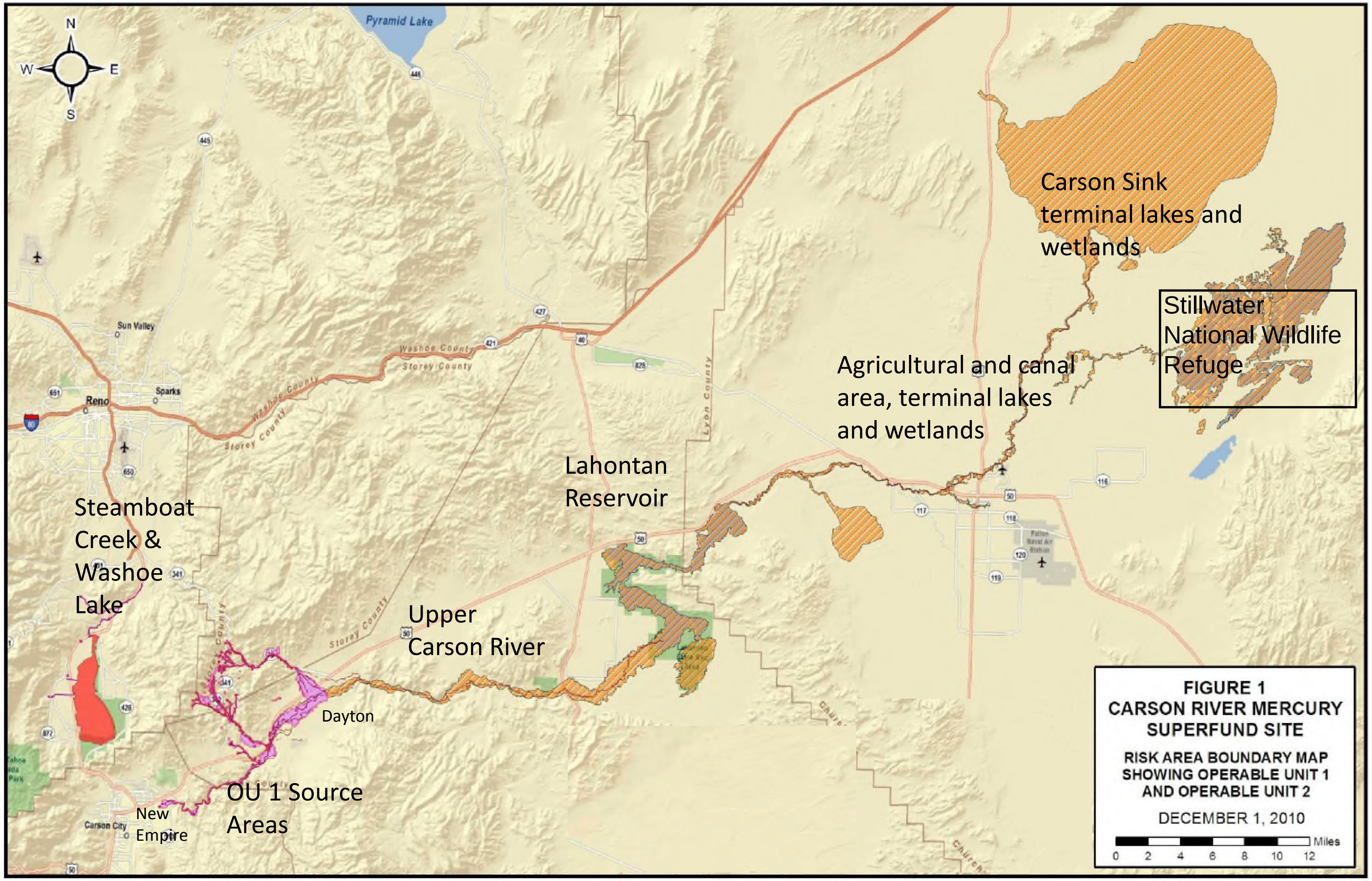
FIGURES



N
W
E
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Pyramid Lake
Carson Sink
terminal lakes and
wetlands
Stillwater
National Wildlife
Refuge
Agricultural and canal
area, terminal lakes
and wetlands
Lahontan
Reservoir
Steamboat
Creek &
Washoe
Lake
Upper
Carson River
Dayton
OU 1 Source
Areas
New
Empire
Carson City
Sun Valley
Reno
Sparks
Washoe County
Storey County
Lyon County
FIGURE 1
CARSON RIVER MERCURY
SUPERFUND SITE
RISK AREA BOUNDARY MAP
SHOWING OPERABLE UNIT 1
AND OPERABLE UNIT 2
DECEMBER 1, 2010
Miles
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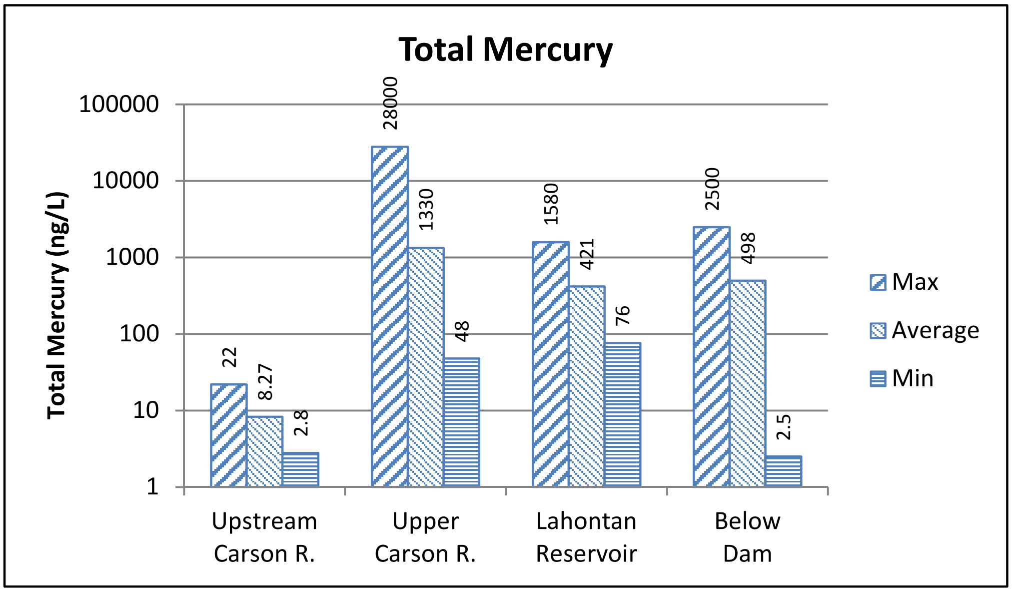

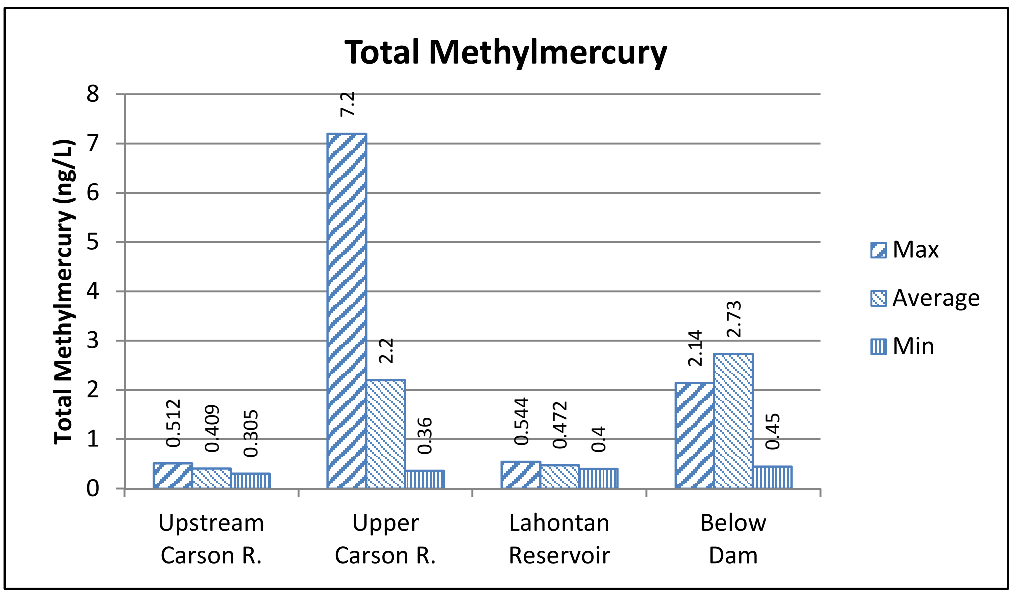

Figure 2. Comparison of Total Mecury and Methylmercury in Surface Water
(Total Mercury - logrithmic scale; Total Methhylmercury - linear scale)

Upstream Carson R.: upstream from Dayton
Upper Carson R.: Dayton to Lahontan Reservoir
Lahontan Reservoir: samples from the reservoir
Below Dam: terminal wetlands below Lahontan Reservoir
ng/L: nanograms per liter

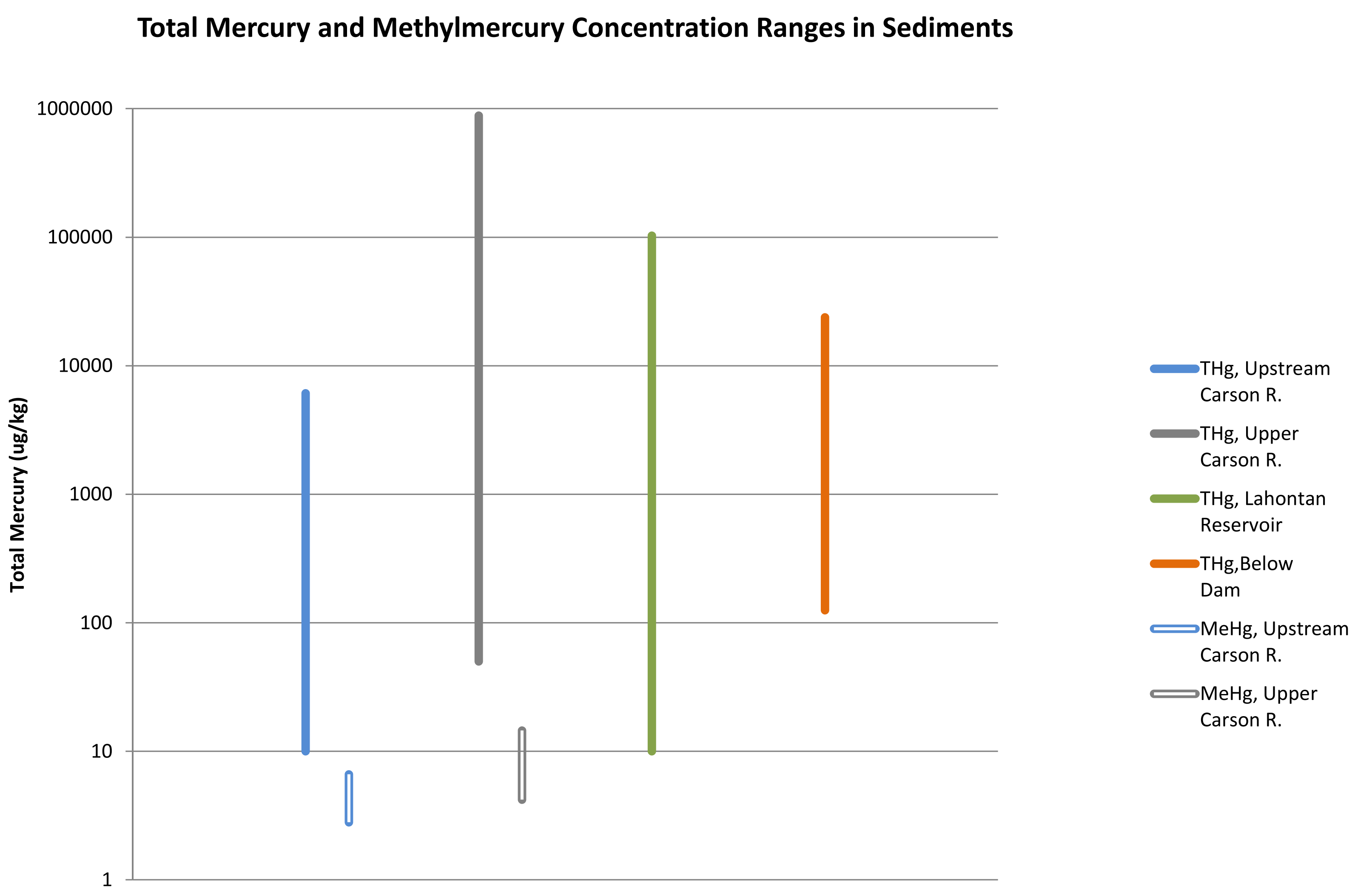

Figure 3. Total Mercury Concentration Range in Sediments

(THg: Total Mercury, MeHg: Methylmercury, ug/kg: microgram per kilogram)

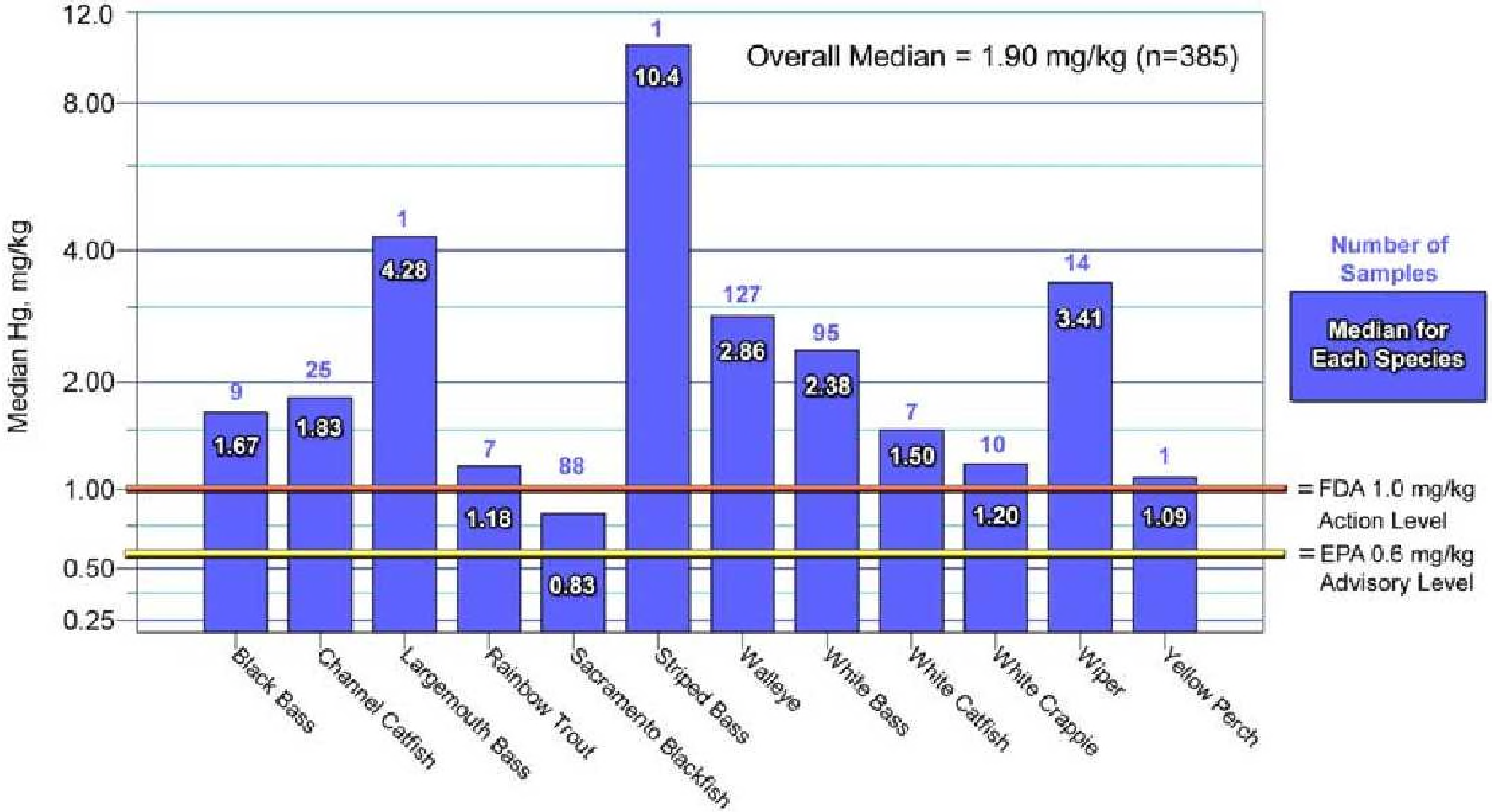

Figure 4. Median Mercury (Hg) Concentrations for Fish in Lahontan Reservoir

Modified from Craft et al. (2005)

Mg/kg: milligrams per kilogram

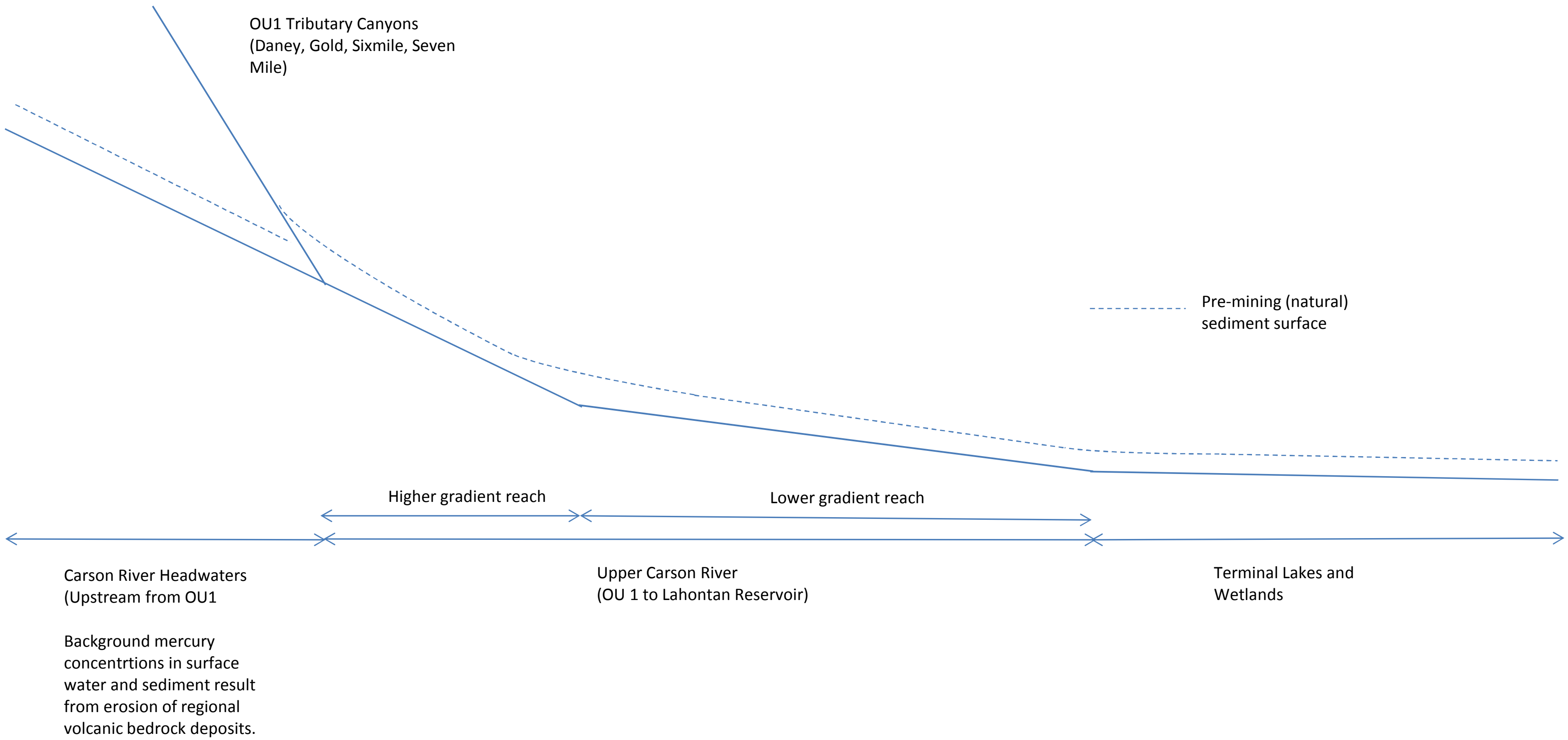

Figure 5A. Carson River CSM Schematic Profile, Pre-1859 Conditions (not to scale)

The OU1 tributaries and Carson River contain naturally-derived sediment. Stream channels are in general equilibrium with water flow and sediment input. Lahontan Reservoir has not yet been constructed. From the OU1 area downstream, the Upper Carson River includes a high gradient reach followed by a lower gradient reach extemdomg to below the future location of the reservoir.

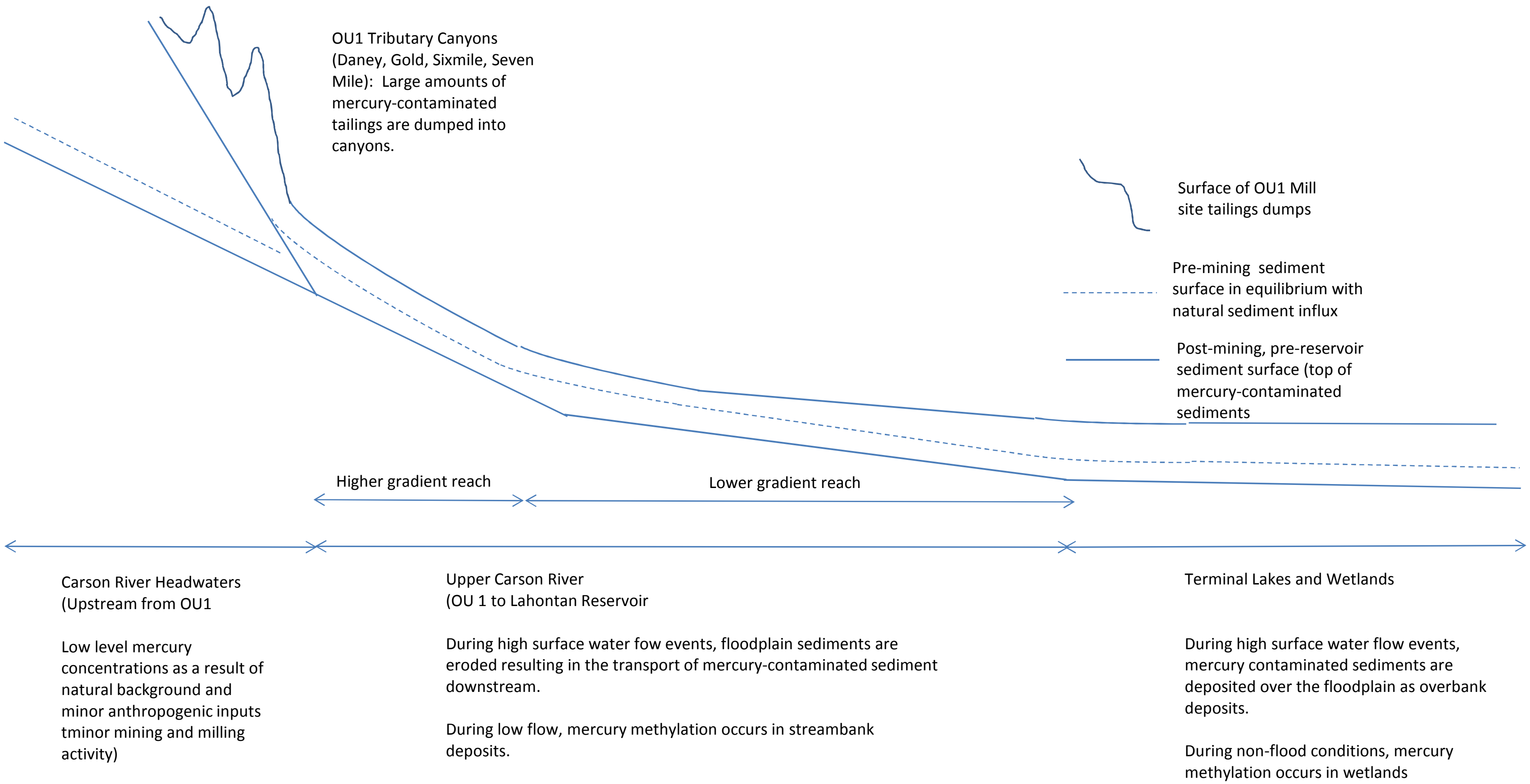

Figure 5B. Carson River CSM Schematic Profile, Post Mining and Pre-Reservoir (1859 - 1915, not to scale)

As a result of the generation of massive amounts of mercury-contaminated mill tailings in the OU1 tributary canyons, a large influx of tailings to the Carson River valley results. In the high-gradient, bedrock-controlled canyon downstream from Carson City, large amounts of tailings accumulate behind dams constructed to support milling facilities on the river. In addition, large amounts of mercury contaminated sediments are stored in the low gradient portion of the Upper Carson River and downstream in the terminal lakes and wetlands. Large amounts of total mercury are transported downstream with high sediment load during spring floods; elevated levels of methylated mecury generated in stream bank deposits during low flow are discharged to the Carson River and terminal wetlands and lakes.

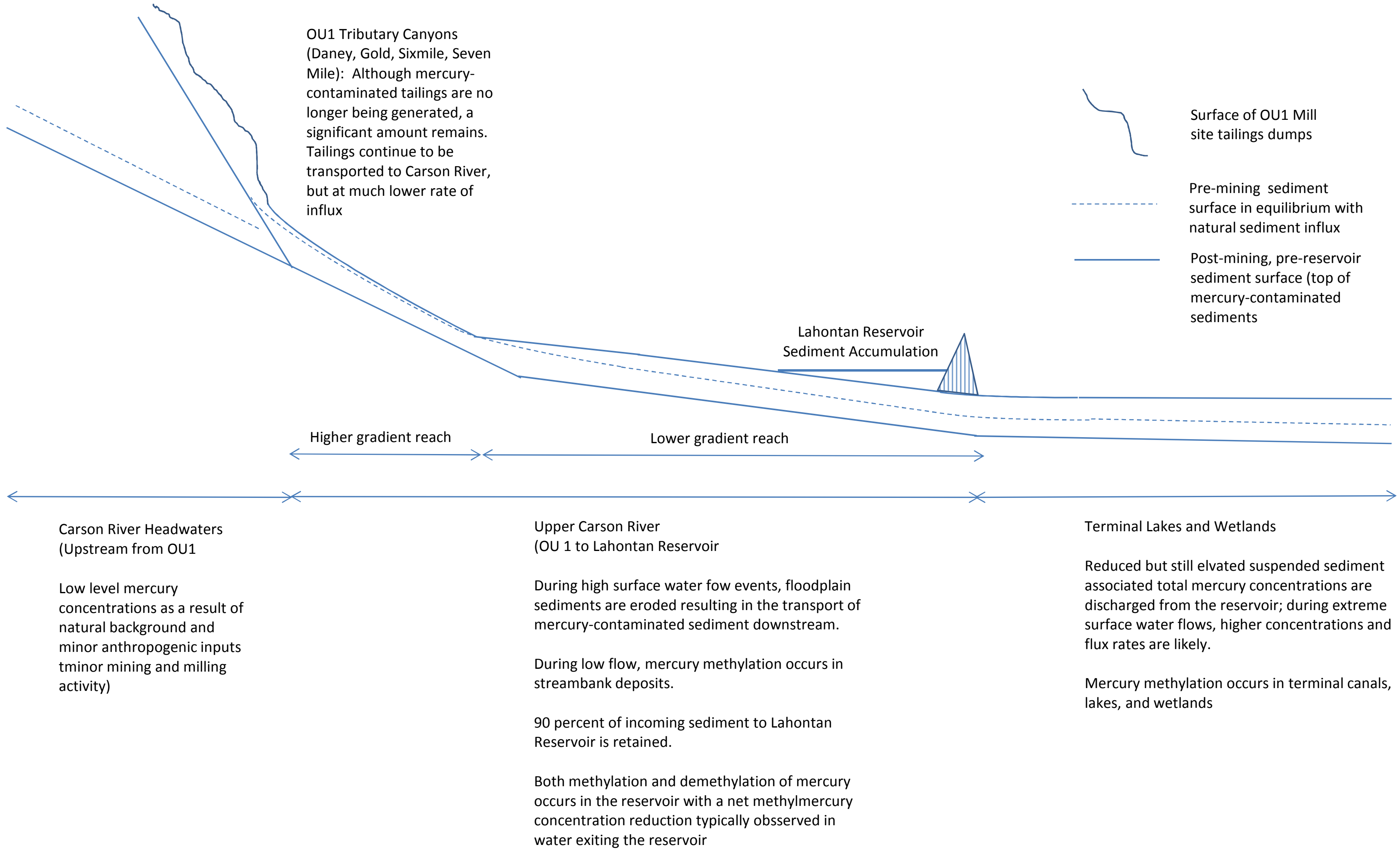

Figure 5C. Carson River CSM Schematic Profile, Post Reservoir (1915 to present, not to scale)

Large fluxes of total mercury continue to be transported downstream with high sediment load during spring floods. With the constuction of the Lahontan dam and reservoir, however, approximately 90 percent of these sediments are retained in the reservoir. Elevated levels of methylated mecury continue to be generated in stream bank deposits of the Upper Carson River. Mercury methylation and demethylation (Kuwabara 2002) occurs in the reservoir with a net reduction in surface water concentrations of methylmercury typically observed.

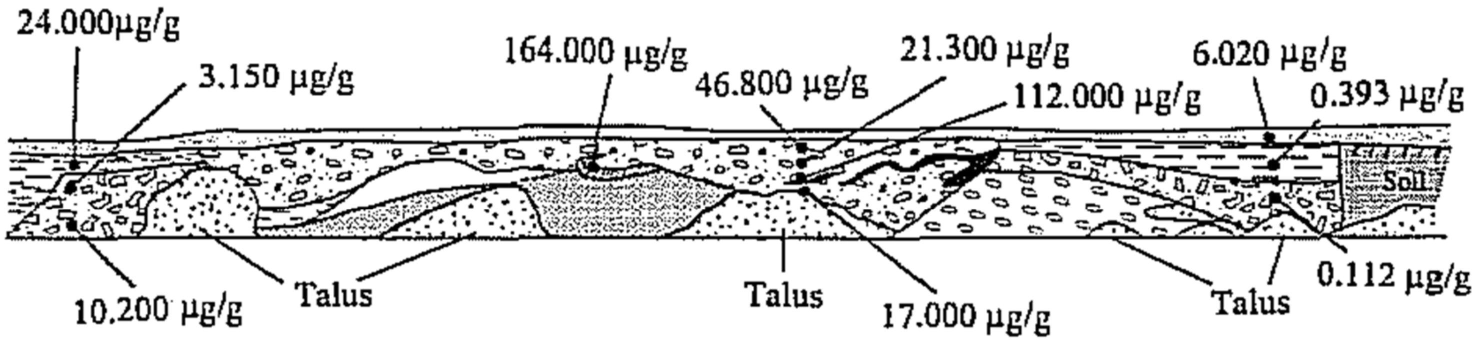

Figure 6. Stratigraphic Section (length: approximately 246 ft) of Upper Carson River Floodplain Sediments with Total Mercury Concentrations Posted Indicating the Extreme Variability in Concentrations over Short Distances (source: Miller et al., 1998)

APPENDIX A

REVIEW DOCUMENTS MATRIX

Document Title	Date	Document Filename	Site General	OU 1	OU 2	OU 2A	OU 2B	OU 2D	Sources	SW/GW	River	Oxbows	Reservoir	Ag Fields	CSM	RI / Data Gaps	FS / Remedy	Risk / Community	Mercury / Other	Analytical Data
Background Documents / Side-Wide																				
Carson River Mercury Superfund Site Site Boundary Evolution and Operable Units		Mini-Retreat (2).ppt	X						X		X		X		X					
Flux of Dissolved Forms of Mercury Across the Sediment-water Interface in Lahontan Reservoir, Nevada		07_15_2009_09_47_00_57.pdf	X										X		X					
First Five-Year Review Report for the Carson River Mercury Site, Dayton and Silver City, Lyon County, Nevada	2003-09	carsn_003227.pdf	X						X						X					
Second Five-Year Review Report For Carson River Mercury Site, Cities of Dayton and Silver City, Lyon County, Nevada	9/30/2008	carsn_003226.pdf	X						X						X					
Water Quality in the Las Vegas Valley Area and the Caron and Truckee River Basins, Nevada and California, 1992-96	1998	07_15_2009_09_47_51_4.pdf	X							X					X	X				
Initial Site Visit to the Carson River Mercury Site and Briefing by USGS on the Status of their Data.	5/1/2009	05_28_2009_16_06_10_16.pdf	X							X	X	X	X		X	X				
Mills and Dams on the Carson in Words and Pictures, The Quartz Mills, 1860	1897	carsn_003231.pdf	X						X						X	X				
Atmospheric Mercury Concentrations Associated with Geologically and Anthropogenically Enriched Sites in Central Western Nevada	1996	carsn_003511.pdf	X						X						X	X				
Carson River Chronology, A Chronological History of the Carson River and Related Water Issues	1997-04	carsn_003350.pdf	X								X				X	X				
Ground-Water-Quality Assessment of the Carson River Basin, Nevada and California: Analysis of Available Water-Quality Data through1987	1989	carsn_003234.pdf	X							X					X	X				
Hydrogeology of the Stillwater Geothermal Area, Churchill County, Nevada. Plate	1982	carsn_003273.pdf	X							X					X	X				
In Situ Bacterial Selenate Reduction in the Agricultural Drainage Systems of Western Nevada	1991-02	carsn_003523.pdf	X											X	X	X				
Mercury in the Carson and Truckee River Basins of Nevada	1973	carsn_003232.pdf	X							X	X		X		X	X				X
Mercury Results (Fish Tissue) 2005, 2006, 2007 & 2008		carsn_003359.pdf	X								X		X		X	X				X
Methyl-Mercury Degradation Pathways: A Comparison Among Three Mercury Impacted Ecosystems	3/8/2000	carsn_003264.pdf	X								X				X	X				
Methylmercury Formation and Degradation in Sediments of the Carson River System	12/17/2001	carsn_003245.pdf	X								X		X	X	X	X				

Document Title	Date	Document Filename	Site General	OU 1	OU 2	OU 2A	OU 2B	OU 2D	Sources	SW/GW	River	Oxbows	Reservoir	Ag Fields	CSM	RI / Data Gaps	FS / Remedy	Risk / Community	Mercury / Other	Analytical Data
Reconnaissance Survey of Ground-water Quality in the Carson River Basin	1988-01	carsn_003228.pdf	X							X					X	X				X
Report on Lahontan Reservoir, Churchill and Lyon Counties, Nevada	1977-09	carsn_003230.pdf	X										X		X	X				
Draft Development of Remediation-Related Hypotheses and Questions, Carson River Mercury Site	3/10/1997	carsn_003255.pdf	X							X	X		X		X		X			
Analytical Data for Soil and Well Core Samples from the Carson River Basin, Lyon and Churchill Counties, Nevada	1991	carsn_003389.pdf	X													X				X
Directory of Mining and Milling Operations	1989	carsn_003253.pdf	X						X							X				
Chemical Analyses of Ground Water in the Carson Desert near Stillwater, Churchill County, Nevada, 2005	2008	carsn_003265.pdf	X							X						X				X
Revised Draft Ecological Assessment Field Sampling Plan, Phase I Remedial Investigation/Feasibility, Carson River Mercury Site, Carson River, Nevada	1994-04	carsn_003238.pdf	X							X	X		X			X				
Washoe Lake Data (Mercury in Fish Tissue)	1987	carsn_003371.pdf	X							X						X				X
Effects of Mercury on Fish-Eating Birds Nesting along the Mid to Lower Carson River, Nevada	8/18/2000	carsn_003224.pdf	X							X	X		X			X		X		
Preliminary Health Assessment, Carson River Mercury Site, Lyon, Churchill, Storey Counties, Nevada	1990	carsn_003246.pdf	X						X	X	X		X			X		X		
Technical Memorandum, Updated (2007) Dafa Gaps Identification - Carson River Mercury Superfund Site	7/31/2007	carsn_003241.pdf	X						X	X	X	X	X	X		X				
Nevada’s Water Quality Standards and Low/High Flow Statistics (7Q10)	2004-09	carsn_003361.pdf	X							X	X		X				X			
Background Documents / OU1																				
Geologic Map and Geology of the Virginia City Quadrangle, Washoe, Storey and Lyon Counties and Carson City, Nevada	2009	carsn_003354.pdf		X					X						X	X				
Technical Memorandum, Data Gaps Identification and Remedial Alternatives Screening - Carson River Site	10/27/1999	carsn_003240.pdf	X						X	X	X	X	X	X		X				
Feasibility Study, Carson River Mercury Site	12/20/1994	carsn_003247.pdf	X						X								X			
Revised Draft Human Health Risk Assessment and Remedial Investigation Report, Carson River Mercury Site	1994-12	carsn_003277.pdf	X						X							X		X		

Document Title	Date	Document Filename	Site General	OU 1	OU 2	OU 2A	OU 2B	OU 2D	Sources	SW/GW	River	Oxbows	Reservoir	Ag Fields	CSM	RI / Data Gaps	FS / Remedy	Risk / Community	Mercury / Other	Analytical Data
Revised Draft, Human Health Risk Assessment and Remedial Investigation Report, Carson River Mercury Site. Appendix: Data Validation Reports	1994-12	carsn_003270.pdf		X					X							X		X		X
Background Documents / OU2																				
Final Technical Memorandum - Conceptual Site Model (CSM) for Carson River Mercury Site, Operable Unit 2	12/30/2011	01_05_2012_13_08_49_51.pdf			X				X	X	X		X	X	X					
Field Sampling Plan, Investigation of Mercury Loading into Lahontan Reservoir (2000 - 2001), Carson River Mercury Site, Lyon and Churchill Counties, Nevada	4/19/2000	carsn_003262.pdf	X							X	X		X			X				
Effects of the 1997 Flood on the Transport and Storage of Sediment and Mercury within the Carson River Valley, West-Central Nevada	1999	carsn_003315.pdf			X						X				X					
Mercury Contamination of the Carson River, Nevada Geology: Quarterly Newsletter of the Nevada Bureau of Mines and Geology	1992	carsn_003357.pdf			X						X		X		X					
Mercury Levels in Surface Waters of the Carson River Lahontan Reservoir System, Nevada: Influence of Historic Mining Activities	12/9/1997	carsn_003497.pdf			X					X	X		X		X					X
Modeling Erosion and Overbank Deposition During Extreme Flood Conditions on the Carson River, Nevada	2004	carsn_003327.pdf			X						X				X					
Modeling Total and Methyl Mercury in the Carson River, Nevada. Model Documentation: Detailed Output	6/1/2000	carsn_003329.pdf			X						X				X					
Simulating Sediment Transport in the Carson River and Lahontan Reservoir, Nevada, USA	1997-02	carsn_003272.pdf			X						X		X		X					
Simulating Sediment Transport in the Carson River and Lahontan Reservoir, Nevada, USA		carsn_003278.pdf			X						X		X		X					
Simulation of Mercury Transport and Fate in the Carson River, Nevada	2000	carsn_003334.pdf			X						X				X					
The Role of Geomorphic Processes in the Transport and Fate of Mercury in the Carson River Basin, West-central Nevada	1998	carsn_003332.pdf			X							X			X					
The Role of Geomorphic Processes in the Transport and Fate of Mercury in the Carson River Basin, West-Central Nevada		carsn_003492.pdf			X							X			X					
Understanding Mercury Mobility at the Carson City Superfund Site, Western Nevada, USA: Interpretation of Mercury Speciation Results from Mill Tailings, Soils, and River and Reservoir		carsn_003498.pdf			X						X		X		X					

Document Title	Date	Document Filename	Site General	OU 1	OU 2	OU 2A	OU 2B	OU 2D	Sources	SW/GW	River	Oxbows	Reservoir	Ag Fields	CSM	RI / Data Gaps	FS / Remedy	Risk / Community	Mercury / Other	Analytical Data
Dispersal of Mercury Contaminated Sediments by Geomorphic Processes, Sixmile Canyon, Nevada, USA: Implications to Site Characterization and Remediation of Fluvial Environments	1994	carsn_003254.pdf				X													X	
Nutrient Assessment Protocols for Lakes and Reservoirs in Nevada, Version 1	2008-12	carsn_003362.pdf	X																X	
Strategic Plan for the Reduction of Mercury-Related Risk in the Sacramento River Watershed		07_15_2009_09_48_24_57.pdf	X																X	

Abbreviations:

OU = Operable Unit
SW = Surface water
GW =Groundwater
Ag = Agricultural
CSM = Conceptual Site Model
RI = Remedial Investigation
FS = Feasibility Study

APPENDIX B

MASS BALANCE CALCULATION

BY Peter Rich DATE Nov 2013 PROJECT Hg Distribution in Carson River System SHEET NO. 1 OF 1

(1) Carson River from Dayton to Lahontan Delta

(2) Lahontan Delta + Reservoir

(3) Carson Sinks

(1) About 40 miles of river, width ~100' avg., bank to bank ~300' avg.
Hg Avg ~15 ppm relatively consistent increasing toward downstream
Depth based on X sections avg ~2'

40 mi × 5280 ft/mi × 2 ft × 300 ft = 127 MCF
Assume 120 lb/cf for sediment = 152.4 B lbs × 15 ppm = 2286,000 lbs
1143 tons
Say 115 tons

(2) Main contributors are Delta + Bottom Flood Plain

Delta 11.2 M m², 38 cm depth, 20.05 ppm avg Hg
11.2 × 10.76 ft²/m² × 38 cm / (2.54 cm/in × 12 in/ft) = 150.64 MCF
18076.8 M lbs sed × 20.05 ppm = 362440 lbs / 2000 lbs/ton = 181 tons

Bottom Flood Plain 6.3 M m², 64 cm depth, 23.74 ppm
6.3 × 10.76 × 64 / (2.54 × 12) = 142.4 MCF
17086 M lbs sed × 23.74 ppm = 405612 lbs / 2000 = 203 tons

+ other <10% contributors (see attached reference)

Reference: Miller et al. (1995)

Say 450 tons

(3) USGS avg conc. 1.2 ppm area ~ Lahontan 300M SF
~~avg depth~~ avg 2' depth
600 MCF × 120 lb/cf × 1.2 ppm = ~~43200~~ 86400 lbs / 2000 = 43.2 tons
Say 50 tons

HSI GEOTRANS