Rationale for Site-Specific Standards for Selenium in the Lower Las Vegas Wash

R116-22

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June 2022

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Acronyms

Arcadis	Arcadis US, Inc.
BAF	bioaccumulation factor
Benchmark	Benchmark Environmental LLC
CCRFCD	Clark County Regional Flood Control District
CF	conversion factor
CFR	Code of Federal Regulations
cfs	cubic feet per second
Commission	State Environmental Commission
Division	Nevada Division of Environmental Protection
EC	effects concentration
EC10	10th percentile effects concentration
EF	enrichment factor
EPA	U.S. Environmental Protection Agency
GMCV	genus mean chronic value
L/kg	liters per kilogram
µg/L	micrograms per liter
mg/kg dw	milligrams per kilogramdry weight
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDOW	Nevada Department of Wildlife
NRS	Nevada Revised Statutes
SAP	sampling and analysis plan
TDS	total dissolved solids
TMDL	total maximum daily load
TTF	trophic transfer factor
USFWS	U.S. Fish and Wildlife Service
WWTP	Wastewater treatment plant

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RATIONALE FOR SITE-SPECIFIC STANDARDS FOR SELENIUM IN THE LOWER LAS VEGAS WASH (R116-22)

1.0 Introduction

The Clean Water Act requires that the U.S. Environmental Protection Agency (EPA) periodically update ambient water quality criteria to accurately reflect the latest scientific knowledge. In June 2016, EPA published the final report updating the criterion to protect aquatic life from the toxic effects of selenium, as "*Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater"* (EPA 2016). This criterion contains multiple components, with numeric values based on data for both fish tissue and water samples. Fish-tissue data have primacy over water-column data in most cases.[1]

Section 303 of the Clean Water Act and other Federal regulations (40 Code of Federal Regulations [CFR] Part 131) require that States and authorized tribes routinely review and, as appropriate, modify water quality standards that protect the designated uses of surface waters. Such standards also provide a basis for controlling discharges or releases of pollutants into a waterbody. The EPA has, through Section 402 of the Clean Water Act, delegated authority to Nevada to establish water quality standards for all waterbodies or segments of waterbodies within the state. Additionally, Nevada state law (Nevada Revised Statutes [NRS] 445A.520) requires the state to establish water quality standards to protect beneficial uses of surface waters of the state.

1.1 EPA's Updated Criterion for Selenium

In 1987, EPA promulgated national criteria for selenium that sought to address dietary intake (*Ambient Water Quality Criteria for Selenium – 1987*). These criteria were issued after toxicity was observed in aquatic ecosystems where selenium was present in the water column at concentrations less than the values for the 1980 criteria. The numeric criteria issued in 1987 (5 micrograms per liter [µg/L] chronic, 20 µg/L acute) were based on toxic effects observed at Belews Lake, North Carolina. This site hosted a cooling-water reservoir where water quality and fish communities had been affected by selenium loads from a coal-fired power plant. The 1987 update also provided an acute criterion of 20 µg/L, using an acute/chronic ratio derived from toxicity tests and based on dietary and water-column exposure in Belews Lake. These concentration limits were assumed to be protective of bioaccumulation via dietary intake of all forms of selenium.

The 1987 criteria recognized that "*selenium is unique among pollutants*" because of its chemistry and because it is an essential nutrient in trace amounts. Selenium is a metalloid rather than a metal, with chemical and physical property that are similar to sulfur. Selenium can replace sulfur in some minerals and biologically important compounds, and it forms organo-metallic compounds, such as selenomethionine, dimethyl selenide and dimethyl diselenide. The 1987 criteria speculated that the mode of toxicity may be related to reaction with or substitution for sulfur in biologically active compounds such as sulfur-containing amino acids. The complex geochemistry of selenium required significant research to refine the criteria to better account for bioaccumulation in aquatic vertebrates.

[1] Fish-tissue data have primacy when the waterbody is at a steady-state condition. Water-column data should be used if steady-state conditions have not yet been achieved for a waterbody. See EPA (2016) for more details.

EPA considered diet as the primary route of exposure that controls chronic toxicity to fish, and published a draft criterion document (EPA 2004). The 2004 draft criterion recommended a whole-body fish-tissue value of no more than 7.91 mg/kg, and attempted to account for different acute toxicities of selenite and selenate in the water column. The proposed acute values were 258 µg/L for selenite and a calculated value for selenate, based on sulfate concentrations. Although accounting for the different toxicities of selenite and selenate forms may be the most technically correct approach for assessing selenium, most states do not collect data for these selenium ions. A general lack of analytical data for these selenium ions in water samples presented a significant obstacle to acceptance of the criteria proposed in 2004.

In 2016, EPA published the final updated selenium criterion for freshwater aquatic life (*Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2016*) (**Table 1**). This final version considered all ecological studies published since the draft criterion was issued in 2004, in addition to all previous toxicity studies, and was refined by expert peer reviews of the drafts released in 2014 and 2015. EPA's final 2016 criterion reflects the latest scientific consensus on the effects of selenium on aquatic life and supersedes all previous aquatic-life water quality criteria for selenium. The assessment endpoint describes the survival, growth, and reproduction of aquatic life. The effects concentration (EC) used where 10 percent of test organisms exhibited effects (EC10) on offspring development and growth. Genus mean chronic values (GMCV) were established based on concentrations in the egg-ovary tissue and ranked by sensitivity of the taxa.

Table 1. EPA's ambient water-quality criterion for selenium in freshwater systems, 2016.

Medium:	**Fish Tissue (mg/kg dw)**			**Water Column (µg/L)**	
Criterion Element:	Egg-Ovary	Muscle (fillet)	Whole body	Monthly Avg	Intermittent Exposure ($WQC_{30\text{-day}}$ =)
Magnitude:	15.1	11.3	8.5	1.5 (lentic) or 3.1 (lotic)	$= (1.5 - C_{bkgd}(1 - f_{int}))/f_{int}$ or $= (3.1 - C_{bkgd}(1 - f_{int}))/f_{int}$
Duration:	Instantaneous	Instantaneous	Instantaneous	30 days	#days/month elevated
Frequency:	Not to be exceeded	Not to be exceeded	Not to be exceeded	Not more than once in 3 yrs	Not more than once in 3 yrs

1. Fish-tissue elements are expressed as steady-state.
2. All fish tissue elements are as milligrams per kilogram, dry weight.
3. Egg-ovary data supersede any whole-body, muscle, or water-column data when concentrations for fish eggs or ovaries are measured.
4. Fish whole-body or muscle tissue data supersede water-column data when concentrations of selenium in both fish tissue and water samples are measured.
5. Water-column values are based on dissolved selenium and are derived from fish-tissue values via bioaccumulation modeling. Water-column values are the applicable criterion element in the absence of steady-state conditions.
6. Where $WQC_{30\text{-day}}$ is the water-column monthly average, for either a lentic or lotic water; C_{bkgd} is the average background concentration of dissolved selenium, and f_{int} is the fraction of any 30-day period during which elevated concentrations of selenium occur, with f_{int} assigned a value ≥0.033 (corresponding to 1 day).
7. Fish-tissue data provide instantaneous point measurements that reflect integrative accumulation of selenium over time and space in fish population at a given site.

1.2 Nevada Adopted a Modified Version of EPA's 2016 Criterion for Selenium

EPA's calculation of criterion concentrations for all elements of the 2016 selenium criterion used data from the four most-sensitive taxa identified from results of toxicity tests. Fish were determined to be the most-sensitive group and white sturgeon was determined to be the most-sensitive fish. After the Nevada Department of Wildlife (NDOW) confirmed that there are no sturgeon in Nevada's waterbodies, EPA's recalculation procedure (EPA 2013) was used to recalculate criterion values by "deleting" a nonresident species and using data from the four most-sensitive taxa that do occur in Nevada.

Absent the sturgeon, data from the four most-sensitive taxa were obtained from EPA (2016) and used to recalculate the criterion values for egg-ovary, whole-body and muscle tissues. The taxa used include *Micropterus* (largemouth bass), *Oncorhynchus* (rainbow or cutthroat trout), *Salmo* (brown trout) and *Lepomis* (bluegill or green sunfish). The GMCVs on an egg-ovary basis were 20.6 milligrams per kilogram, dry weight (mg/kg dw) (*Lepomis*), 21.0 mg/kg dw (*Salmo*), 25.3 mg/kg dw (*Oncorhynchus*) and 26.3 mg/kg dw (*Micropterus*). Deleting the sturgeon from the calculations yielded an egg-ovary value of 19.0 mg/kg dw, a muscle value (filet) of 13.1 mg/kg dw, and a whole-body value of 9.5 mg/kg dw selenium (**Table 2**).

Table 2. NAC 445A.1237. Nevada's selenium water quality criterion adopted in December 2019.

TYPE OF STANDARD/CRITERION	Nevada Statewide Standards for Selenium	UNITS
FISH TISSUE (FRESHWATER)		
Fish egg/ovary tissue	**19.0**	mg/kg dw
Fish whole body	**9.5**	mg/kg dw
Fish muscle (skinless, boneless fillet)	**13.1**	mg/kg dw
WATER COLUMN		
30-day average, lentic systems	**1.9**	µg/L
30-day average, lotic systems	**3.9**	µg/L
Intermittent (>1 every 3 yrs), lentic	$(1.9 - C_{bkgd}(1 - f_{int}))/f_{int}$	µg/L
Intermittent (>1 every 3 yrs), lotic	$(3.9 - C_{bkgd}(1 - f_{int}))/f_{int}$	µg/L

µg/L = micrograms per liter
mg/kg dw = milligrams per kilogram, dry weight
The following equation is used for calculating the "average background" for a 30-day period (see Equation 20, EPA 2016):
$C_{30\text{-}day} = C_{int}*f_{int} + C_{bkgd}(1 - f_{int})$
C_{int} = the intermittent spike concentration, in µg/L
f_{int} = the fraction of any 30-day period during which there are elevated concentrations of selenium
C_{bkgd} = the average daily ambient (background) concentration, integrated over 30 days

In December 2019, the State Environmental Commission (Commission) adopted this modified version of EPA's 2016 "*Ambient Water Quality Criterion for Selenium*" into Nevada Administrative Code (NAC) 445A.1236, the "toxics table." Four beneficial uses are contained in NAC 445A.1236, including aquatic life, municipal or domestic supply, irrigation, and watering of livestock. However, the complexity of the updated criterion for selenium required that a new section be added to the NAC for protection of aquatic life from selenium, hence NAC 445A.1237. In addition, a delayed effective date of January 1, 2023 was specified for the Las Vegas Wash. This delay meant that the old water quality standards for aquatic life remained in place until January 1, 2023 or when site-specific values were developed, as allowed under NAC 445A.1237(2)(b).

2.0 Developing Site-Specific Criterion Values for Selenium

As noted in Section 1.2, the updated criterion for selenium facilitates the development of site-specific standards. The values derived for the water-column component are based on dissolved selenium (or total selenium, if total and dissolved are essentially equal in water, and are derived from fish-tissue data using either the mechanistic modeling or a bioaccumulation factor (BAF) approach, as described in Appendix K of EPA's criterion document (EPA 2016). In addition, one may apply the "recalculation procedure" (EPA 2013) to generate new criteria values for a specific site, based on a site-specific species assemblage. These three options for developing site-specific values are briefly described in the following sections.

2.1 Mechanistic Modeling Approach

The mechanistic bioaccumulation modeling approach uses knowledge of the chemical and physical processes of bioaccumulation to establish a relationship between the concentration of selenium in the water column and in the tissues of aquatic organisms (EPA 2016). The model allows for consideration of site-specific information on trophic transfer in the aquatic food web, and the translation of a fish tissue criterion to a water column criterion. Equation K-1 in EPA 2016 outlines the necessary parameters to calculate an appropriate water-column concentration of selenium based on the following factors:

- concentration of selenium in the eggs or ovaries of fish, muscle tissue, or whole body
- trophic transfer factor (TTF),
- enrichment factor (EF), and
- conversion factor (CF).

A TTF is a single value that represents the steady-state concentration of selenium in the tissue of an organism, relative to the concentration of selenium in the food it consumes (EPA 2016). Different species metabolize selenium in different ways, and therefore, each species has a specific TTF. An EF quantifies the bioconcentration of selenium in aquatic organisms at the base of the food web (e.g., plankton, periphyton), thus its bioavailability in the system (EPA 2016). A CF quantifies the relationship between the concentration of selenium in fish eggs or ovaries and the average concentration of selenium in fish whole-body or muscle tissue. Each species of fish has its own specific CF.

EPA (2016) notes the mechanistic model approach has the benefit of not requiring extensive sampling of fish tissue; however, there is potential for increased uncertainty when selecting model parameters, particularly the EF, which can vary by orders of magnitude across aquatic systems.

2.2 Bioaccumulation Factor Approach

A BAF is the ratio of the concentration of a chemical in the tissue of an aquatic organism to the concentration of the chemical in ambient water at the sampling site (EPA 2016). BAFs are used in aquatic ecosystems where both the organism and its food are exposed and sufficient co-located (spatiotemporal) measurements are available. To calculate a site-specific BAF value, selenium concentrations in both surface water and fish tissue need to be measured. The main advantage of using the BAF approach is that it directly relates selenium concentrations in ambient water to selenium concentrations in fish tissue, without introducing the uncertainties that are inherent in the mechanistic model. Empirical BAFs provide the most direct measure of site-specific bioaccumulation (EPA 2009).

2.3 *Species Recalculation Procedure*

As previously described, the recalculation procedure requires only an understanding of the fish species present in a waterbody; no water quality or fish-tissue data are required. EPA (2013) states:

> "*The Recalculation Procedure involves editing the composition of a Species Sensitivity Distribution of tested species used to derive a site-specific aquatic life criterion in order to allow it to better reflect the taxonomy of species that reside at the site*."

3.0 Development of Site-Specific Criterion Values for Las Vegas Wash

As allowed by EPA (2016), and in subsection 2(b) of NAC 445A.1237, site-specific criterion values have been developed for selenium in the Las Vegas Wash, using a Nevada Division of Environmental Protection (Division) approved sampling and analysis plan (Arcadis and Benchmark 2021), and following EPA guidance (EPA 2016). The Clark County Regional Flood Control District (CCRFCD) and other Las Vegas stakeholders contracted with ecotoxicologists (Arcadis U.S., Inc [Arcadis] and Benchmark Environmental LLC [Benchmark]) to prepare a sampling and analysis plan (SAP) and develop site-specific criterion values for selenium in the wash.

Existing data for fish tissue and water quality were supplemented with additional data for fish tissue collected in 2021. Arcadis and Benchmark (2022) used these data to derive site-specific criterion values for selenium in the Las Vegas Wash and Nature Preserve ponds, following EPA's BAF approach. The two segments of lower Las Vegas Wash (**Figure 1**), described in NAC 445A.2156 and NAC 445A.2158, represent lotic (flowing) water. The Nature Park ponds associated with the Las Vegas Wash are lentic (still) waters. Details of the calculations are provided in the Arcadis and Benchmark report (2022), which is attached here as **Appendix A** to this rationale document, and summarized below.

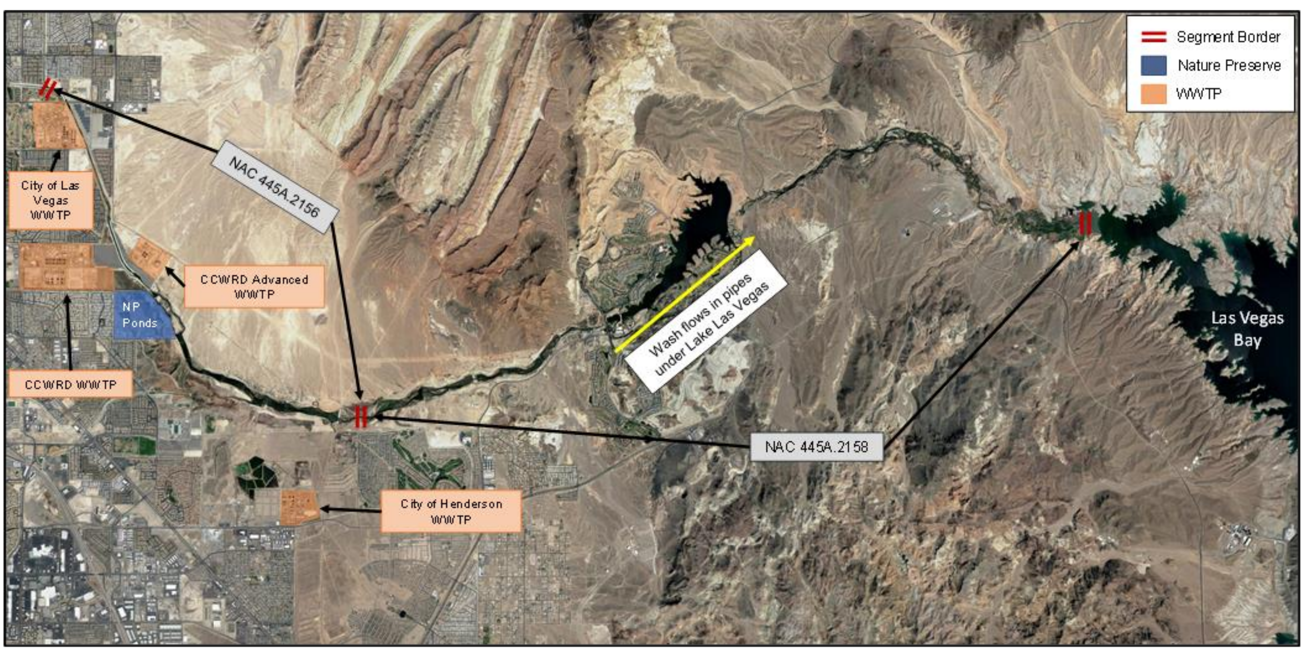

Figure 1. Segments of Las Vegas Wash to which the site-specific standards (lotic) apply (NAC 445A.2156 and NAC445A.2158)

Data for samples of water and fish tissue collected from the Las Vegas Wash from 2002 through 2021 were used in the calculations of BAFs for two fish species (carp and sunfish). Nomenclature for surface-water sampling sites consists of an alpha-numeric code that reflects the waterbody name and distance along the river channel of the Lower Las Vegas Wash. The large number of water-quality samples provided sufficient data and showed years of consistent concentrations of selenium in Las Vegas Wash below the wastewater treatment plant (WWTP) discharges. The discharge of treated effluent also provides consistent flow that has made the Las Vegas Wash a perennial river flowing into Lake Mead. The reference line for the Lower Las Vegas Wash (acronym = LW) begins at the high-pool elevation of Lake Mead (1,221 feet above mean sea level [amsl]) and follows the channel upstream to where it terminates. For example, sampling site LW6.05 is located at Lower Las Vegas Wash river mile 6.05. Locations of samples collected between 2002 and 2021 from various locations on the Las Vegas Wash and in the adjacent Nature Preserve ponds are shown in Figure 2.

Figure 2. Map of the surface water and fish tissue sampling locations in the Lower Las Vegas Wash

3.1 Evaluation of the Water Data for Las Vegas Wash

The high concentrations of selenium in the upper reach of the Las Vegas Wash above the WWTP discharges (and within other channels tributary to the Las Vegas Wash), are significantly diluted by the WWTP discharges. As demonstrated in the study report (Arcadis and Benchmark 2022), and summarize below, selenium concentrations downstream of the dischargers have remained consistent over time in the lower wash. A summary of samples sizes is given in **Table 3**.

Sampling locations in the Lower Las Vegas Wash downstream of the WWTP discharges (LW9.3 through LW0.8) had an overall average concentration of selenium of 2.95 µg/L (n = 1,841) from 2002 through 2021 (Arcadis and Benchmark 2022).

Table 3. Summary of surface water samples collected from the Las Vegas Wash and analyzed for selenium. (Table from Arcadis and Benchmark 2022).

Location Name	Latitude	Longitude	Sampling Agency	Sample Dates	Number of Samples
LW11.5	36.139476	-115.043213	SNWA, USBR	2011-2021	131
LW11.1	36.13608	-115.03775	SNWA, USBR	2008-2021	134
LW10.75	36.130997	-115.034878	SNWA	2002-2011	99
LW9.3	36.112767	-115.027166	SNWA, USBR	2011-2021	118
LW8.85	36.10794	-115.02196	SNWA, USBR	2006-2021	169
LW7.2	36.09096	-115.000299	SNWA	2011-2021	119
LW6.85	36.090504	-114.999434	SNWA	2006-2021	159
LW6.05	36.08894	-114.98543	SNWA, USBR	2002-2021	191
LW5.9	36.087811	-114.983521	SNWA	2002-2011	100
LW5.5	36.08956	-114.97512	SNWA, USBR	2002-2021	247
LW5.3	36.089827	-114.973029	SNWA	2002-2008	63
LW4.95	36.09186	-114.96633	SNWA	2006-2011	40
LW3.85	36.096015	-114.947531	SNWA, USBR	2002-2008	62
LW3.75	36.096652	-114.946317	SNWA	2002-2007	61
LW3.4	36.100491	-114.942616	CCRFCD, SNWA, USBR	2010-2021	187
LW3.1	36.10173	-114.937481	NDEP, SNWA	2001-2011	42
LW0.9	36.119942	-114.908989	City of Henderson, SNWA, USBR	2007-2021	158
LW0.8	36.12087	-114.907706	SNWA	2000-2011	99

As noted above, concentrations of selenium in the wash are markedly different upstream and downstream of the WWTP discharges, as is the flow rate in the channel. Sampling locations in the upper Wash that are upstream of any wastewater effluent discharges (LW11.5, LW11.1, and LW10.75) exhibit elevated concentrations of selenium compared to locations downstream of these discharges. The average concentration of selenium for these three sites from 2002 through 2021 was 14.2 µg/L (n = 364).

Dissolved selenium has not been measured as extensively as total selenium over the past 20 years, because the previous water quality standard was based on total selenium. However, there is no significant difference between selenium concentrations in filtered and unfiltered water samples collected from the Las Vegas Wash. This is due mainly to the occurrence of selenium as an oxyanion (selenate, SeO_4^{-2}) under the oxidizing alkaline conditions, and the low affinity of selenate for sorption or complexation with organic matter and particulates. Like sulfate, selenate tends to be highly mobile under oxygenated conditions. The median ratio of paired total-to-dissolved selenium data analyzed by the same analytical laboratory from 2002 to 2021 was 0.995 (n = 476 paired measurements), indicating that the dissolved fraction represents approximately all of the selenium present in the Lower Las Vegas Wash (Arcadis and Benchmark 2022).

The speciation of selenium in the water column is one of the key factors controlling its bioaccumulation potential in aquatic systems. Selenium occurs in several bioavailable forms: selenate (Se^{6+}), selenite (Se^{4+}), and organic selenium compounds (e.g., seleno-l-methionine and selenocyanate). Selenate is the primary species mobilized into aquatic systems from weathering and oxidation of seleniferous soils, whereas selenite is more typical in certain industrial discharges (e.g., fly ash associated with coal-fired power plants and oil refineries). Speciation of selenium in the Las Vegas Wash and its tributary channels was investigated by Snyder and Quiñones (2006). The authors analyzed three species (selenate, selenite, and selenocyanate) using ion chromatography separation and inductively coupled plasma mass spectrometry. Selenate was the predominant species in the Las Vegas Wash and its tributary channels, with no selenocyanate or selenite measured above the detection limit (1 µg/L) (Arcadis and Benchmark 2022).

The selenate ion (SeO_4^{-2}) tends to dominate in oxygenated systems at neutral to alkaline pH. Arcadis and Benchmark (2022) note that "*This is important because the bioconcentration potential of selenate and its waterborne toxicity tend to be less than for selenite. In addition, increasing sulfate concentrations in water reduce the bioconcentration of selenate (DeForest et al. 2017), likely due to direct competition at the cell uptake site (Brix et al. 2001). Selenate and sulfate are structurally similar group VI oxyanions of the form* XO_4*. The average concentration of sulfate in the Lower Las Vegas Wash from 2002 to 2021 was 540 ± 100 milligrams per liter (n = 2,995), which is within the upper range shown by others to mitigate the bioaccumulation of selenium in lotic, selenate-dominated systems (DeForest et al. 2017)*."

3.2 Evaluation of the Fish-Tissue Data for Las Vegas Wash

Text in this section is excerpted from Arcadis and Benchmark (2022). The number and type of fish-tissue samples are provided below in **Table 4.**

"*Monitoring for selenium in fish tissue in the Lower Las Vegas Wash was initiated in 2003 as part of the Las Vegas Wash Monitoring and Characterization Study (Intertox 2006). The study was undertaken as a series of annual bioassessments to evaluate water quality and the bioaccumulation potential of inorganic and organic constituents in both fish and bird egg samples in the Lower Las Vegas Wash (Intertox 2006, ACT I 2011, LVWCC 2013). Whole-body fish samples were collected in fall 2003, fall 2005, fall 2007, and winter 2010 to early spring 2011 by SNWA and the U.S. Fish and Wildlife Service (USFWS). Fish sampling and analysis methods are described in detail in the Bioassessment Monitoring Plan for Las Vegas Wash and Tributaries (LVWCC 2001). SNWA performed additional fish sampling in 2021 to further support development of a selenium SSC for the Lower Las Vegas Wash. Fish were collected from the main channel and Nature Preserve Ponds (NP Ponds) by seining, traps, or trammel nets.*

From 2003 to 2021, a total of 95 individual fish have been collected from the Lower Las Vegas Wash and NP Ponds and analyzed for concentrations of selenium in whole-body tissue. Fish species sampled included the green sunfish (Lepomis cyanellus), common carp (Cyprinus carpio), black bullhead catfish (Ameiurus melas), and largemouth bass (Micropterus salmoides), although limited bullhead samples (n = 6) and bass samples (n =1) have been collected relative to carp (n = 69) and green sunfish (n = 19). Therefore, only carp and sunfish were considered for development of the selenium SSC…"

Table 4. Number of whole-body samples collected for carp and sunfish

Year	Common Carp		Green Sunfish	
	Lower Wash	NP Ponds	Lower Wash	NP Ponds
2003	9	2[a]	--	1[a]
2005	10	--	4	2
2007	3	--	4	6
2010	15	--	--	--
2021	15	15	1	--
Total	**52**	**17**	**9**	**9**

The fish-tissue sampling conducted in 2021 yielded one carp (out of 15 carp collected) with an anomalously high concentration of selenium: 26.9 mg/kg dw. This sample datum was reviewed, along with the sampling and analysis procedures, but no obvious cause to reject this datum was found. The most plausible explanation is that this fish resided in the lower portion of Duck Creek that is still accessible to fish swimming up from the Las Vegas Wash. Supporting this hypothesis, the Duck Creek BAF for the anomalous fish was calculated using water quality data for Duck Creek, and yielded a BAF of 1,730 liters per kilogram (L/kg). This falls within the range seen for carp BAFs (1,259 L/kg to 2,307 L/kg), averaging 1,655 L/kg for the Las Vegas Wash (see Table 7 in Arcadis and Benchmark 2022). Two weirs and a bridge are planned for construction in the near future; these structures will block future possible migration of fish up into the lower part of Duck Creek. Concentrations of selenium in this lower portion of Duck Creek have ranged from 2 to 20 µg/L.

4.0 Calculation of Site-Specific Values

EPA (2016) recommends using fish-tissue data from the green sunfish (*Lepomis*) for waters that do not contain sturgeon or salmonids (trout). As noted previously, both the common carp and the green sunfish were sampled in 2021, as part of developing the site-specific criterion values for the lower Las Vegas Wash (Arcadis and Benchmark 2022). Carp have been sampled most frequently in the Lower Las Vegas Wash because of their abundance and trapping success during fish monitoring (n = 51, 2003 through 2021).

After collecting fish-tissue samples following an NDEP-approved SAP, Arcadis and Benchmark used the whole-body fish-tissue data for selenium, along with water-column data for the Las Vegas Wash, to derive site-specific BAFs for two fish species (common carp and green sunfish). These site-specific BAFs were then used to derive site-specific criterion values for lotic (flowing) and lentic (still) waters of the lower Las Vegas Wash (Arcadis and Benchmark 2022).

4.1 Averaging by Year BAFs for Carp and Sunfish in Lotic and Lentic Waters

Arcadis and Benchmark (2022) applied the BAF equation in two ways; first taking the averages of yearly averages, by species; then these annual average BAFs were averaged to obtain an overall average BAF for each species. For Lower Las Vegas Wash, this approach yielded site-specific water column values (C_{target}) of 5.7 and 6.8 µg/L for carp and sunfish, respectively (**Table 5**). Data for the Nature Park ponds were evaluated separately using the same method (**Table 6**).

Table 5. Summary of surface water, fish tissue, site-specific BAFs, and site-specific water column values based on annual means for lower Las Vegas Wash (lotic water)

Surface Water		Whole-Body Fish Tissue (mg/kg WB dw)				Fish Bioaccumulation Factors (L/kg)	
N	Total Se (µg/L)	N	Carp	N	Sunfish	Carp BAF	Sunfish BAF
2002-2003							
83	3.381	9	6.354	--	--	1879.2	--
2004-2005							
84	3.678	10	4.63	4	4.95	1258.9	1345.9
2006-2007							
71	3.706	3	5.533	4	4.475	1493	1207.4
2009-2010							
42	2.871	15	3.835	--	--	1335.5	--
2020-2021							
85	2.286	14	5.274	1	3.79	2306.7	1657.6
					Average Fish BAF (L/kg)	1654.7	1403.7
					Carp C_{target} (µg/L)	**5.741**	--
					Sunfish C_{target} (µg/L)	--	**6.768**
					Average of Carp and Sunfish (µg/L)	**6.255**	

Table 6. Summary of surface water, fish tissue, site-specific BAFs, and site-specific water column values based on annual means for lower Nature Park ponds (lentic water).

Surface Water		Whole-Body Fish Tissue (mg/kg WB dw)				Fish Bioaccumulation Factors (L/kg)	
N	Total Se (µg/L)	N	Carp	N	Sunfish	Carp BAF	Sunfish BAF
2004-2005							
12	3.748	--	--	2	3.8	--	1013.8
2006-2007							
10	2.94	--	--	6	4.933	--	1678
2020-2021							
11	2.136	15	4.06	--	--	1900.4	--
					Average Fish BAF (L/kg)	1900.4	1345.9
					Carp C_{target} (µg/L)	**4.999**	**--**
					Sunfish C_{target} (µg/L)	**--**	**7.059**
					Average of Carp and Sunfish C_{target} (µg/L)	**6.029**	

4.2 Spatially Paired BAFs for Carp and Sunfish in Lotic and Lentic Waters

In this method, the concentration of selenium in whole-body fish tissue for each individual fish was paired with a concentration in the water column to calculate an individual BAF. All individual BAFs for each species were then averaged for Las Vegas Wash (**Table 7**) and the Nature Park Ponds (**Table 8**).

Table 7. Summary of surface water, fish tissue, site-specific BAFs, and site-specific water column values for all years for Lower Las Vegas Wash (lotic water).

Surface Water	Fish Tissue		Fish Bioaccumulation Factors (L/kg)		C_{target} (µg/L)		
N	Carp (N)	Sunfish (N)	Carp BAF	Sunfish BAF	Carp	Sunfish	Carp & Sunfish
365	51	9	1713.7	1325.5	**5.544**	**7.167**	**6.355**

Table 8. Summary of surface water, fish tissue, site-specific BAFs, and site-specific water column values for all years for Nature Park Ponds (lentic water).

Surface Water	Fish Tissue		Fish Bioaccumulation Factors (L/kg)		C_{target} (µg/L)		
N	Carp (N)	Sunfish (N)	Carp BAF	Sunfish BAF	Carp	Sunfish	Carp & Sunfish
33	15	8	1906.5	1526.2	**4.983**	**6.225**	**5.604**

4.3 Proposed Site-Specific Criterion Values

The two averaging approaches yielded similar BAFs and C_{target} values for both locations and species of fish sampled in the Lower Las Vegas Wash system (Tables 6-9). This result is consistent with the stable concentrations of selenium in surface water and fish tissue during the current study period (2002-2021). It also reflects steady-state conditions in the Las Vegas Wash system over the last two decades. While both approaches are defensible for deriving site-specific BAFs, the first approach was chosen for the proposed C_{target} values (Tables 6 and 7). This approach more explicitly incorporates any temporal variation in BAFs as a function of surface water selenium concentrations

EPA guidance recommends using sunfish as the most sensitive species when sturgeon are absent; however, when the site-specific criterion values were calculated, the sunfish-derived values were significantly higher than the carp-derived numbers. It was deemed reasonable, therefore, to include data from both fish species to derive a site-specific criterion value of 6.3 µg/L for selenium in lower Las Vegas Wash (lotic waters) and 6.0 µg/L for lentic waters (Nature Park ponds) (Arcadis and Benchmark 2022). These values for lotic and lentic waters values, along with the statewide values for fish tissue, constitute the complete site-specific criterion for selenium for the lower Las Vegas Wash and associated lentic waters (**Table 9**).

Table 9. Site-specific criterion values for selenium applicable to the lotic waterbody segments covered under NAC 445A.2156 and NAC 445A.2158

Type of Tissue Analyzed	Criterion Value (mg/kg dry weight)
Fish Egg or Ovary Tissue	19.0
Fish Whole-Body Tissue	9.5
Fish Muscle Tissue	13.1
Exposure Duration and Category of Water	Criterion Value (µg/L)
30-day average, lentic water	6.0
30-day average, lotic water	6.3
Intermittent, lentic water*	$(6.0 – C_{bkgd}(1 - f_{int}))/f_{int}$
Intermittent, lotic water	$(6.3 – C_{bkgd}(1 - f_{int}))/f_{int}$

**For purposes of this fish-centric standard, the upper end of the lotic segment covered under NAC 445A.2156 truncates at the point of discharge at the City of Las Vegas water reclamation facility due to limited water and fish habitat above this point.*

1. Fish tissue elements are expressed as steady-state.
2. Egg-ovary data supersede data for any whole-body, muscle, or water column data.
3. Fish whole-body or muscle tissue data supersede water-column data when data for both fish tissue and the water column are available.
4. Water-column values are based on dissolved selenium and were derived from fish-tissue data using bioaccumulation factors derived from co-located water and fish-tissue samples.
5. Where WQC 30-day is the water-column monthly value, for either a lentic or lotic water; C_{bkgd} is the average background concentration of selenium, and f_{int} is the fraction of any 30-day period during which selenium concentrations are elevated above background, with f_{int} assigned a value ≥0.033 (corresponding to 1 day).
6. Fish-tissue data provide instantaneous point measurements that reflect integrative accumulation of selenium in fish tissue over space and time.

5.0 Implementing Site-Specific Standards for Selenium

Water quality standards are used to evaluate whether water quality is supporting designated beneficial uses for surface waters across the State. Results of the biennial assessment of water quality data are presented in the State's "*Water Quality Integrated Report*." If the assessment finds that a surface is not meeting the water quality standards for selenium, that water would be "impaired" for selenium and it would be placed on the 303(d) list (the list of impaired waters). If verified, the impairment would place the waterbody-parameter pairing in the queue for development of a traditional total maximum daily load (TMDL) or a TMDL alternative plan.

Both water quality standards and TMDLs are implemented through the process of permitting point-source discharges. NDEP does not have regulatory authority over nonpoint (i.e., diffuse) sources of pollution, which include agricultural and urban runoff. Improvements to reduce pollution from nonpoint sources are voluntary, and NDEP provides grants for projects undertaken to limit pollution derived from nonpoint sources. Selenium in the Las Vegas Wash system is largely derived from nonpoint sources, such as groundwater seepage and urban runoff.

5.1 Las Vegas Wash

The site-specific standards for selenium calculated using site-specific data for water quality and fish tissue will be implemented in future permits issued or renewed for point-source discharges into Las Vegas Wash. The analysis shows that the site-specific lotic standard for selenium in Las Vegas Wash will be sufficiently protective of lentic waterbodies immediately downstream (i.e., Inner Las Vegas Bay and Lake Mead).

Because much of the selenium in Las Vegas Wash is derived from seeps and discharges of shallow groundwater, there is no cost-effective treatment. The selenium is naturally occurring soils in the Las Vegas Valley (and throughout the Colorado River Basin). At present, the high concentrations of selenium in the upper Las Vegas Wash (and in the channels tributary to the wash) are diluted by the discharge of approximately 300 cubic feet per second (cfs) of highly treated effluent from the WWTPs. This discharge significantly dilutes the higher concentrations of selenium and total dissolved solids (TDS) derived from shallow groundwater. The current permitted limits for selenium in the WWTP discharges are 5 µg/L (chronic) and 20 µg/L (acute). Water quality in the lower Las Vegas Wash is not impaired for selenium, according to results of the recent assessment, which used the 5 µg/L selenium standard (NDEP 2022).

Water quality standards should also be protective of downstream waters. All indications are that the Las Vegas Wash, which averages around 3 µg/L selenium and has a 95th percentile concentration of 4.6 µg/L at its mouth, is not adversely affecting the health of the razorback suckers in Lake Mead. This proposed site-specific standard for selenium in Las Vegas Wash will not alter the concentrations of selenium in the Wash. The discharges of highly treated effluent, which constitute more than 85 to 90 percent of the average flow in the wash, significantly dilute the high concentrations of selenium from groundwater seepage into the Las Vegas Wash and channels tributary to the wash (**Table 10).** The statistical summary used data from 1979 through 2020, although there were no data prior to 2006 for the tributary channels.

Table 10. Summary statistics for selenium inflow into Lake Mead and in flood-conveyance channels. All concentrations in micrograms per liter (µg/L). (Data set 1979 through 2020)

	Lake Mead	Muddy River	Virgin River	Las Vegas Wash	Duck Creek	Flamingo Wash	Las Vegas Creek	Sloan Channel	Pittman Wash
Count (N)	1,594	637	358	1,202	221	118	22	227	208
Mean	2.5	3.7	2.7	3.2	18.8	16.5	6.3	10.2	18.0
SD	0.6	4.9	1.6	1.4	4.3	2.7	2.1	8.0	4.9
Min	1.8	0.5	0.5	1.0	2.3	10.0	1.6	0.5	10.0
Max	12.0	39.0	10.0	28.0	31.9	25.0	10.0	37.4	34.4
Median	2.4	2.0	2.9	3.0	19.0	16.1	6.2	8.3	17.4
25th%	2.1	1.0	1.4	2.5	17.7	15.0	5.2	3.2	13.9
75th%	2.6	4.0	4.0	3.5	21.0	18.0	7.8	16.2	21.5
90th%	2.8	10.0	5.0	4.0	23.0	19.7	8.4	21.0	24.7
95th%	3.1	15.0	5.0	4.6	24.0	21.0	9.9	23.2	25.8
99th%	5.0	20.0	7.4	10.0	27.2	23.7	10.0	30.6	29.7

5.2 Downstream Waters

The downstream waterbodies of Lake Mead and the Colorado River also need to be considered when setting upstream standards. In the development of the site-specific criterion for the Las Vegas Wash, both the volume of water and load of selenium were considered. The Las Vegas Wash itself typically provides only about 2 percent of the total water inflow into Lake Mead, whereas the Colorado River provides about 97 percent of the water in Lake Mead. The Virgin River and Muddy River provide roughly 1 percent of the flow into Lake Mead. Elevated levels of TDS and selenium are found throughout the Colorado River Basin, and selenium is a common impairment in waters of the Colorado River Basin.

Lake Mead is the Colorado River, dammed at Hoover Dam to create four basins (Boulder, Virgin, Temple and Gregg) and the Overton Arm **(Figure 3**). Additional inputs to Lake Mead come from Las Vegas Wash, the Muddy River, and the Virgin River. The Muddy River originates in Nevada, but the Virgin and Colorado Rivers enter Nevada from upstream states, but each enters Lake Mead in Nevada. The basins of Lake Mead are shared by Nevada and Arizona, but the Overton Arm lies entirely within Nevada. Las Vegas Wash enters into the Las Vegas Bay in the Boulder Basin, which is the most downstream basin of Lake Mead. This is the only area in the Colorado River system that has recruitment of the endangered razorback sucker (US Fish and Wildlife Service [USFWS] 2018).

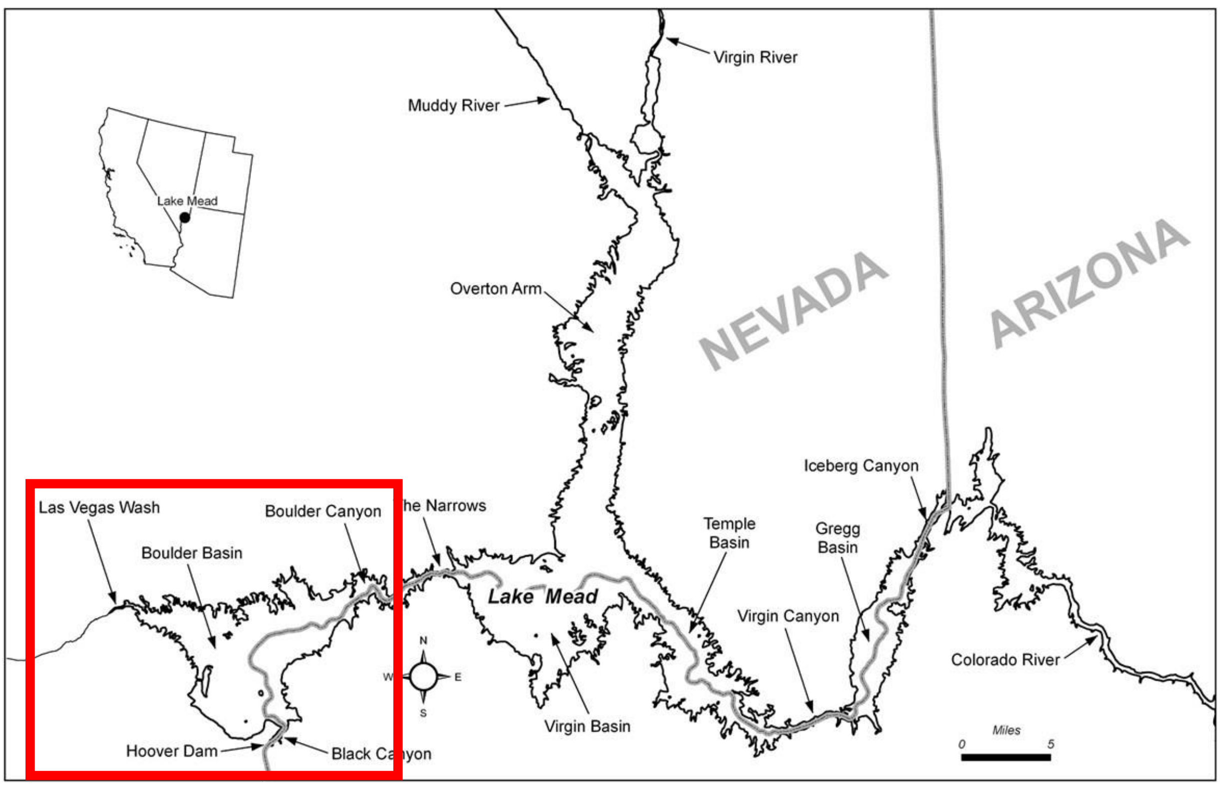

Figure 3. Overview of Lake Mead, from National Park Service website. (Las Vegas Wash, the Inner Las Vegas Bay, and the Boulder Basin are highlighted in the lower left box.)

The Colorado River overwhelmingly controls the chemical composition of the water in Lake Mead. According to Engberg (1999) the load of selenium entering Lake Powell, upstream of Lake Mead, is nearly 30 million tons of selenium per year. In contrast, the Las Vegas Wash was estimated to provide between 1,430 pounds (Zhou et al. 2004) and 1,890 pounds (Ryan and Zhou, 2010) of selenium per year to Lake Mead. Evaluating the data for inputs to Lake Mead (Las Vegas Wash, Virgin River, Muddy River, Colorado River) helps place the selenium sources in context. The summary statistics (see Table 3) for some available data show that the 95th percentile values for Lake Mead (3.1 µg/L), Muddy River (15.0 µg/L), Virgin River (5.0 µg/L), and Las Vegas Wash (4.6 µg/L) reflect the elevated ambient levels of selenium throughout the basin. (More general information on Lake Mead is available from the U.S. National Park Service, at https://www.nps.gov/lake/learn/nature/overview-of-lake-mead.htm).

Despite the concentrations of selenium in Lake Mead, it is the only section of the Colorado River that supports a reproducing population of razorback suckers (**Figure 4**). The species status assessment conducted by the USFWS (USFWS 2018) evaluated razorback suckers in eight geographic areas including four in the Upper Colorado River Basin (Green River, Colorado River, San Juan River and Lake Powell) and four in the Lower Colorado River Basin (Lake Mead, Lake Mohave, the Colorado River between Davis and Parker dams [Lake Havasu], and the Colorado River downstream of Parker dam). That study noted that “Competition and predation from nonnative predators, which is exacerbated by lack of cover and turbidity, prevents recruitment in all populations except Lake Mead.”

Razorback suckers are not typically sampled for tissue analysis due to their status as an endangered species. However, two razorback suckers were opportunistically sampled because of mortalities that occurred during a telemetry study. An adult male between 9 and 10 years of age was collected at Blackbird Point in Las Vegas Bay, while a juvenile male of 4 to 5 years of age was collected from Echo Bay (Tuttle and Orsak 2002). Selenium concentrations in whole-body tissue were 6.2 mg/kg dw in Echo Bay and less than 0.3 mg/kg dw in Las Vegas Bay, which is at the mouth of the Las Vegas Wash.

Tuttle and Orsak (2002) found that selenium concentrations in whole-body carp in the Las Vegas Bay ranged from 2.4 to 12.6 mg/kg, with a mean of 4.9 mg/kg for all sites combined. Similarly, for the Las Vegas Wash, Arcadis and Benchmark (2022) noted that:

> *Carp have been sampled most frequently in the Lower Las Vegas Wash because of their abundance and trapping success during fish monitoring (n = 51, 2003 through 2021). Annual mean concentrations of selenium in the whole-body tissues of carp collected in the Lower Las Vegas Wash ranged from 3.8 to 6.4 mg/kg dw over the period from 2003 to 2021. Selenium concentrations in carp have not varied significantly (p > 0.05) over time. This suggests that selenium accumulation in the Lower Las Vegas Wash has remained at steady-state conditions over the past 19 years of monitoring.*

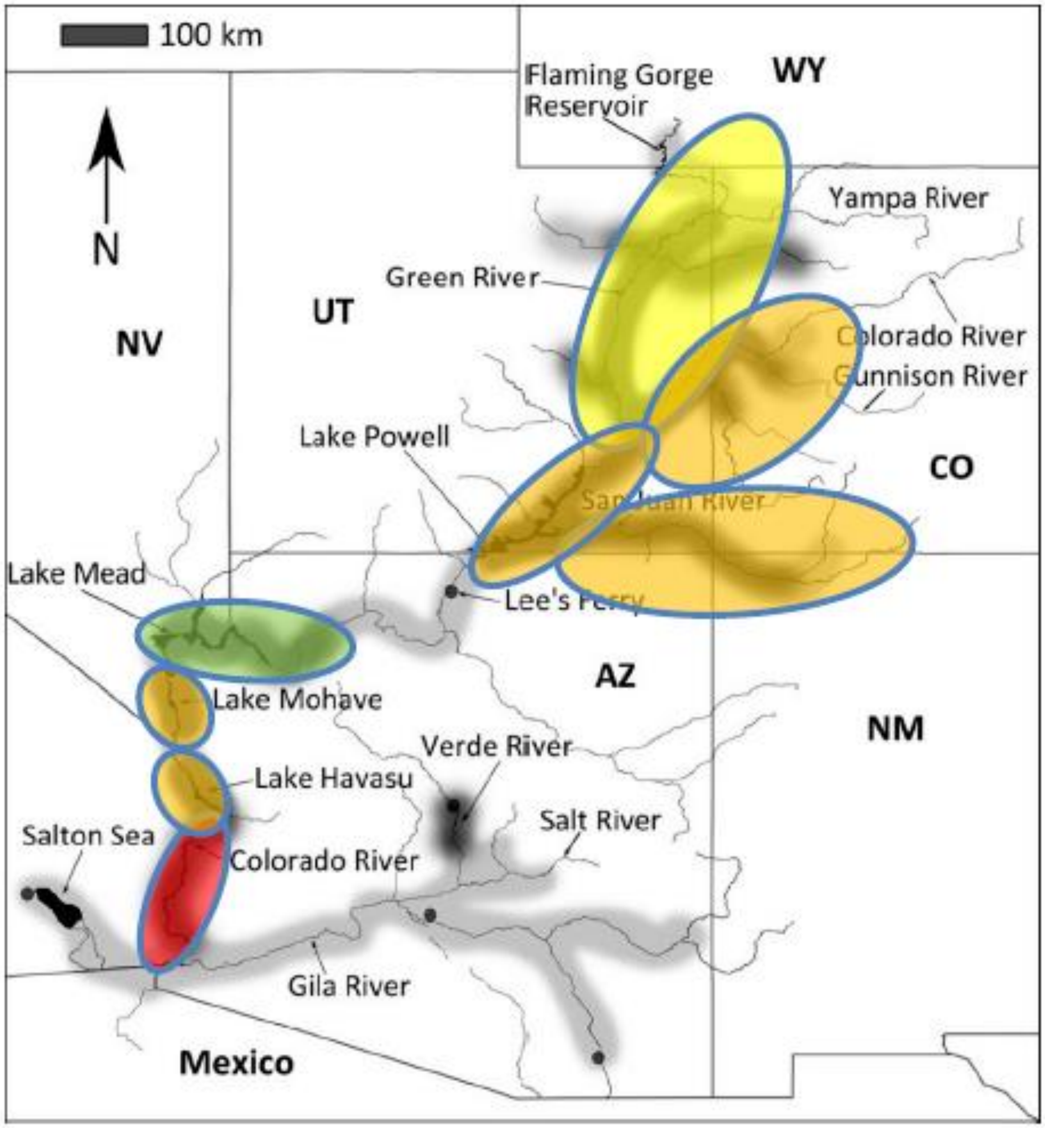

Figure 4. Color-coded assessment of razorback sucker status in the Colorado River system showing Lake Mead as the only location with active recruitment. (Figure from USFWS 2018.)

5.3 Relationship of the Las Vegas Wash, Las Vegas Bay, and Lake Mead

A closer view of the area (**Figure 5**) shows how the mouth of the Las Vegas Wash enters into the Inner Bay portion of Lake Mead. There is an unusual configuration of the wash, in that the Las Vegas Wash is transmitted via two large pipes beneath Lake Las Vegas. These pipes also have the effect of blocking any upstream migration of fish from Lake Mead into the segments of the wash above the outfall pipes. What this odd arrangement means, is that all the fish above the Lake Las Vegas intake were likely to be from aquarium dumping, intentionally introduced, or released as bait fish. No native Nevada fish are found in the Las Vegas Wash upstream of Lake Las Vegas.

Below the outfall pipes east of Lake Las Vegas, the length of the Las Vegas Wash from the outfall to Las Vegas Bay and Lake Mead is controlled by the lake level, which is currently (June 2022) at historically low levels. Following completion of Hoover Dam in 1936, Lake Mead began filling to 708.7 feet, and reached its highest point of 1225.4 feet in July 1983 (National Park Service 2022). The lake currently stands at an historic low level of 1047.7 feet (Bureau of Reclamation 2022).

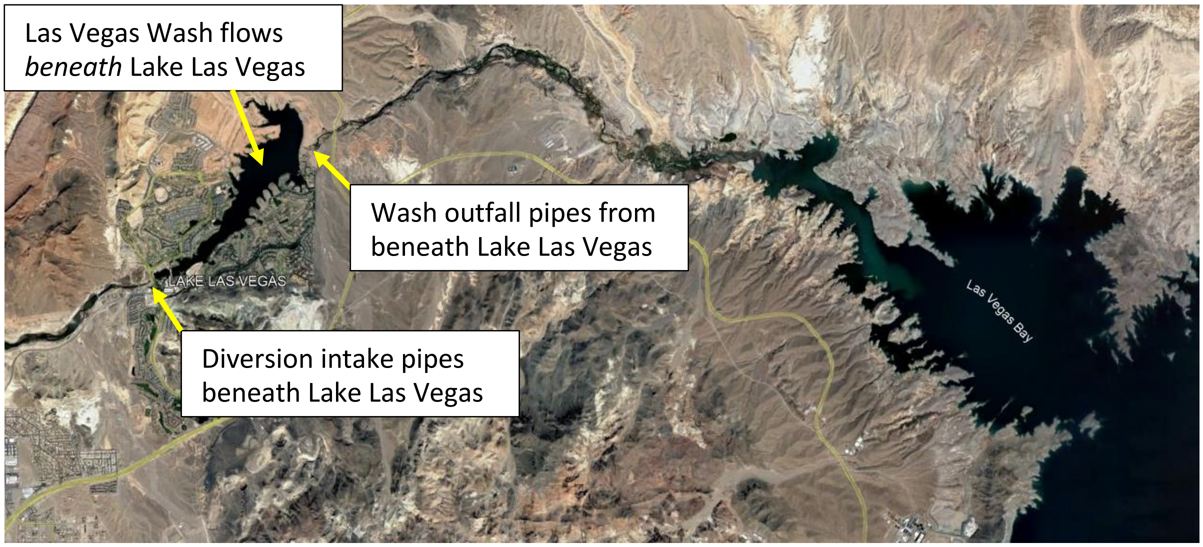

Figure 5. The outfall pipes that divert the Las Vegas Wash beneath Lake Las Vegas. The high-velocity discharge drops into the lowest part of Las Vegas Wash and presents an impassible barrier to fish coming upstream from Las Vegas Bay.

5.4 Fish Surveys for the Las Vegas Wash

Fish surveys conducted in the effluent-dependent lower Las Vegas Wash over the period from 2002 to 2019 have identified a total of eight species of fish in the wash (**Table 11**): green sunfish (*Lepomis cyanellus*), largemouth bass (*Micropterus salmoides*), red shiner (*Cyprinella lutrensis*), fathead minnow (*Pimephales promelas*), common carp (*Cyprinus carpio*), mosquito fish (*Gambusia affinis*), blue tilapia (*Oreochromis aureus*), black bullhead (*Ameiurus melas*), and suckermouth catfish (*Hypostumus plecostomus*). None of these species are native to Nevada and many are presumed to have been introduced into the Lower Wash as discarded aquaria fish. In addition, mosquito fish were intentionally introduced by the Clark County Vector Control to control mosquito populations.

Prior to 2021, fish surveys had not been conducted in the channels that are tributary to the Las Vegas Wash due to poor habitat and lowflow conditions. Arcadis and Benchmark (2021) evaluated conditions in the channels tributary to the Las Vegas Wash as part of an overall assessment of conditions in the highly modified channels. (These channels have been engineered to function as flood-conveyance channels, and are largely lined with concrete and modified to fit within the city.) More discussion on the condition of these channels is provided in report by Arcadis and Benchmark (2021), and in the rationale document (NDEP 2022) for establishing a designated water quality standards table for these channels in the NAC.

Table 11. Fish species observed in the Las Vegas Wash, 2002-2019, above Lake Las Vegas outfall pipes.*

Family	Genus	Species	Common Name	Number Observed	
				2002-03	2017-19
Centrarchidae	*Lepomis*	*L. cyanellus*	Green Sunfish	152	2
	Micropterus	*M. salmoides*	Largemouth Bass	--	251
Cyprinidae	*Cyprinella*	*C. lutrensis*	Red Shiner	3165	608
	Cyprinus	*C. carpio*	Common Carp	5	92
	Pimephales	*P. promelas*	Fathead Minnow	1	--
Poeciliidae	*Gambusia*	*G. affinis*	Mosquito Fish	879	501
Cichlidae	*Oreochromis*	*O. aureus*	Blue tilapia	--	315
Loricariidae	*Hypostomus*	*H. plecostomus*	Suckermouth Catfish	5	1008
Ictaluridae	*Ameiurus*	*A. melas*	Black Bullhead	496	--

*The outfall pipes create an impassible barrier for fish migration from the Inner Bay and Lake Mead, up into Las Vegas Wash upstream of Lake Las Vegas.

6.0 References

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Appendix A – Petition for Site-Specific Standards for Selenium in the Lower Las Vegas Wash

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Appendix B – Proposal for Site-Specific Selenium Criterion
Lower Las Vegas Wash, Clark County, Nevada

Arcadis U.S. Inc. and Benchmark Environmental, LLC
2022

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