UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
WATER QUALITY

Criteria Support Document:

Site-specific criteria based on recalculated aquatic life water quality criteria for ammonia for a segment of Mill Creek and the Jordan River, Salt Lake County, Utah

November 21, 2018 Review Draft

Executive Summary

Mill Creek from below I-15 to the Jordan River and the Jordan River downstream to 900 South Street including the Surplus Canal (the Site) were evaluated to determine appropriate water quality for ammonia. The principle objective was to determine if mussels belonging to the Superfamily Unionoidea (unionids) are U.S. Environmental Protection Agency (USEPA) residents at the Site. The methods are recommended by USEPA as part of the update of the ammonia water quality criteria in 2013. The conclusions are:

1. Unionid mussels historically were present upstream in the Jordan and Utah Lake, tributaries to Jordan River and were also likely present at the Site.

2. Unionid mussels are not currently present at the Site or in the nearby waters that were surveyed because of degraded conditions. Not all nearby waters were surveyed.

3. Non-pulmonate snails are present, or were recently present at the Site and are residents.

4. The Jordan River is physically, biologically and chemically degraded at the Site. Efforts to restore the Jordan River are ongoing but are unlikely to be sufficient to support the potential reintroduction of unionid mussels within the reasonable planning horizon of the next 30 years, if ever.

Contents

Introduction

The United States Environmental Protection Agency (USEPA) published updated Clean Water Act Section 304(a) water quality criteria for ammonia in 2013. The updated criteria are based in-part on new toxicity data for mussels from the Superfamily Unionoidea, herein referred to as unionid mussels, and non-pulmonate snails. Non-pulmonate snails have gills but the presence of gills is not discriminating for snail taxonomy. The unionid mussels species native to the eastern United States were the most sensitive species tested, and when present, the USEPA (2013) ammonia criteria are substantially more stringent than the existing Utah ammonia criteria. Although not as sensitive to the toxic effects of ammonia as the unionid mussels, non-pulmonate snail species were the 10th most sensitive taxa for acute toxicity and 5th most sensitive for chronic toxicity (Tables 3 and 4, USEPA, 2013).

Data characterizing the specific sensitivity of the two potential unionid mussel species native to Utah (*Anodonta californiensis/nutaliana* and *Margaritifera falcata*) are unavailable. As recommended by USEPA (1984), toxicity data from species within the same family are assumed to be representative of untested species from the same family. Specifically, other species of unionid mussels for which toxicity data are available are considered appropriate surrogates for the Utah unionid mussel species.

In response to the updates of the 2013 EPA ammonia criteria, OreoHelix Consulting, on behalf of the Central Valley Water Reclamation Facility (CVWRF), conducted several physical surveys to determine what mollusks were present in the Jordan River and adjacent waterbodies beginning in 2014. The results of these surveys are documented in a series of reports discussed in more detail later in this document. Initially, the purpose was to determine if ammonia-sensitive mollusks were present in the entire Jordan River watershed. Subsequently, the efforts were focused on Mill Creek upstream of the CVWRF and downstream in the Jordan River (Figure 1). The quantity and quality of these surveys are sufficient to conclude absence of the target mussels if they were not observed. These specific segments, hereafter referred to as the Site, are the focus of this document:

> Mill Creek from I-15 downstream to the confluence with the Jordan River. The Jordan River from the confluence with Mill Creek downstream to 900 South Street and the Surplus Canal downstream to 900 South Street.

Figure 1 shows the Site boundaries and the location of the Central Valley Water Reclamation Facility. The downstream boundary for the Site is based on the modelled extent of the Central Valley Waste Water Treatment Facility’s potential ammonia influence; i.e., based on a chronic ammonia concentration of 3.7 mg/L in the CVWRF effluent, ammonia concentrations in the Jordan River downstream of 900 South would meet the USEPA (2013a)

water quality criteria protective of unionid mussels (DWQ, 2017). The upstream boundary is based primarily on a change in the designated beneficial uses. Mill Creek upstream of I-15 is classified as Class 3A: protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain. Mill Creek downstream of I-15 to the Jordan River confluence is Class 3C: protected for nongame fish and other aquatic life, including the necessary aquatic organisms in their food chain. Moving downstream, the Jordan River to 900 South is Class 3B: protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain. The Surplus Canal (begins at approximately 2100 South) is Class 3C and also Class 3D: protected for waterfowl, shore birds and other water-oriented wildlife not included in Classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain.

Site Setting

The Jordan River is approximately 50 miles long, originating at Utah Lake and ending at Great Salt Lake. The surrounding land use is urban. The majority of tributaries to the Jordan River originate in the Wasatch Mountains to the east and a few from the Oquirrh Mountains to the west. The Jordan River and its tributaries are physically biologically and chemically altered primarily from urban influences.

Several water quality impairments have been identified for the Site. The water quality of Mill Creek from the I-15 to the confluence with the Jordan River is currently impaired for benthic macroinvertebrates and microbial pathogens. The water quality of the Jordan River from the confluence with Little Cottonwood Creek to 2100 South Street is impaired for benthic macroinvertebrates, microbial pathogens and total dissolved solids. The water quality of the Jordan River from 2100 South to North Temple Street is impaired for benthic macroinvertebrates, microbial pathogens, dissolved oxygen and total phosphorus.

The Jordan River is extensively altered hydraulically. The river channel is regularly dredged in some reaches, The Surplus Canal at about 2100 South Street diverts much of the Jordan River flow for flood control. A significant amount of water is diverted upstream of the Site for potable water (upstream of Utah Lake) and by extensive diversions both upstream and along the Jordan River for secondary water.

Mollusk Surveys

Two species of indigenous unionid mussels potentially occur in Utah: *Anodonta californiensis* and *Margaritifera falcata* (Hovingh, 2004). Other bivalves include clams in the Family Sphaeriidae and non-natives *Corbicula fluminea* and the unionid *Utterbackia imbecillis*. Seven species of non-pulmonate snails are potentially present in the Jordan River watershed: *Fluminicola coloradoensis,* at least two *Pyrgulopsis* species, and two heterobranch snails: *Valvata humeralis* and *Valvata utahensis* (USU, 2017).

Existing records on the statewide occurrence of unionid mussels and non-pulmonate snails are summarized in USU (2017). The existing records for the Jordan River watershed were also reviewed by Oreohelix (2014a). Records from pre-1978 are considered historic and records after 1978 are considered recent (DWQ, 2017). Existing records document that *Anodonta* was historically present in the Jordan River (1942) and was also found in Jordan River tributaries at eight other locations including Hot Springs Lake (no longer exists), Decker Pond and Big Cottonwood Creek. Historic and recent records show unionid mussels were also present upstream in Utah Lake and some Utah Lake tributaries. The non-unionid mussel, *Sphaerium,* was historically present in the Jordan River at Utah Lake and in the Narrows. Sphaeriidae and *Anodonta* were found in Mill Pond on Spring Creek (Utah Lake tributary) in 1989 (Hovingh, 2016).

For non-pulmonate snails, records document the presence of *Fluminicola* and *Pyrgulopsis* in the Jordan River at the Site (near the Peace Gardens) post-2000.These two taxa were also reported to be recently present in the Jordan River upstream of the Site at the City of Riverdale. *Fluminicola* and *Pyrgulopsis* were also documented in Mill Pond on Spring Creek (Utah Lake tributary). No recent (after 1978) records exist for the presence of *Valvata* in Jordan River or tributaries but historic records document their presence at locations within the Jordan River (USU, 2017).

Oreohelix conducted several physical surveys for mollusks in the Jordan Basin from 2014 through 2018. The methods and results of the surveys are presented in a series of reports prepared by Oreohelix (2014a, 2015, 2017a, 2017b, 2017c). Surveys were conducted by searching shorelines for shells, benthic surveys using

aquascopes, and intrusive surveys using either a shovel, net or suction dredge. Figures 2 and 3 show the specific sample locations of the surveys for the Site. Additional survey locations are presented in the other Oreohelix reports.

The results of the Oreohelix surveys for the Site and other relevant locations are summarized below:

1. Physical surveys of the Jordan River did not find any live unionid mussels nor were any found in the surveyed segments of Mill Creek. A single *A. californiensis* shell fragment was found in the Jordan River near 11000 South and fragments were observed in a Mill Creek bank cut stratum near the confluence with the Jordan River (Figure 4). Large numbers of *Corbicula*, both living and shells were found at the Site during the surveys (Figure 5). *A. californiensis* whole shells were found in Spring Creek (Figure 6) and Currant Creek that are tributaries to Utah Lake and not part of the Site.

2. The closest known extant unionid mussels to the Jordan River are located in Salt Creek (Great Salt Lake tributary), Beaver Creek (Weber River tributary), Currant Creek (Utah Lake tributary), and as shown in Figure 7, Beer Creek (Utah Lake tributary).

   A. californienisis was found in Salt Creek. The hydraulic connectivity between Salt Creek and the Jordan River is through hypersaline portions of Great Salt Lake that is an effective barrier to migrating fish hosts.

   M*. falcata* was found in Beaver Creek. Beaver Creek is a tributary to the Weber River and to the Provo River via a diversion. The Weber River discharges to Willard Bay Reservoir on the Great Salt Lake shoreline and irrigation return flows from the Weber River eventually discharge to Great Salt Lake. The Provo River diversion from Beaver Creek is identified as a fish barrier by the Utah Division of Wildlife Resources.

   A. californiensis was reported to be present recently in the Burraston Ponds (Mock 2004) and Currant Creek (Richards 2016c) but were recently not found in the ponds by Richards (2016c). The Provo River, Burraston Ponds (via Currant Creek) and Beer Creek (via Benjamin Slough) are tributaries to Utah Lake.

3. Shells and live bivalves from the Family Sphaeriidae were observed in the Jordan River (Oreohelix, 2014). USEPA (2013a) indicates that these taxa are more closely related to the non-unionid fingernail clam *Musculium* than to unionid mussels.

4. Oreohelix found no live non-pulmonate snails in the main stem Jordan River, except for the invasive New Zealand mudsnail. Oreohelix (2014) reports that empty shells of *Fluminicola coloradoensis*, *Pyrgulopsis sp*., *Valvata humeralis*, and *V. utahensis* were found in the main stem but their age and origin are unknown. “It is likely that empty non-pulmonate shells found in the Jordan River samples were either deposited from tributaries where extant populations exist or from relatively recently extirpated (> 10-20 ybp) main stem Jordan River populations.” Oreohelix was unable to verify the presence of non-pulmonate snails at the locations where they were found in 2004 (USU, 2017). Oreohelix notes that snail population abundances can fluctuate yearly and may naturally have greater abundances in the future and therefore may be more detectable. Snail shells were also observed in the cut-bank stratum shown in Figure 3.

USEPA (2013) “Residents” Tests

Are usually present at the site.

The surveys conducted by Oreohelix (2017) support that *A. californiensis and M. falcata* are not currently present at the Site. Observed bivalves include *Corbicula* and *Sphaerium* from these surveys.

Oreohelix did not observe any non-pulmonate snails at the site but they were observed in tributaries and recently at the Site during other surveys (see USU, 2017).

Are present at the site only seasonally due to migration.

The unionid mussels do not migrate seasonally although their obligate fish hosts may migrate; nor do non-pulmonate snails migrate seasonally.

Are present at the site intermittently because they periodically return to or extend their ranges into the site.

No mussels were observed during the surveys. Adult mussels are sessile, and if present, would be present permanently. Non-pulmonate snails were recently observed at the Site but were not observed in the later surveys conducted by Oreohelix. This may represent an intermittent presence.

Were present at the site in the past (a), are not currently present at the site due to degraded conditions (b), but are expected to return to the site when conditions improve (c);

Are present in nearby bodies of water (a), are not currently present at the site due to degraded conditions (b), but are expected to be present at the site when conditions improve (c).

Were once present at the site (a), but cannot exist at the site now due to permanent (physical) alterations of the habitat or other conditions (b), that are not likely to change within reasonable planning horizons (c).

(a) Historical records document that unionid mussels were previously present in the Jordan River, the Jordan River watershed in Big Cottonwood Creek and Utah Lake. No specific records document past presence of unionid mussels at the Site. However, indirect evidence consisting of unionid shells was observed in a cutbank stratum in Mill Creek near the confluence with the Jordan River and shell fragments were found in the Jordan River near 11000 South. The origin or age of these shells is unknown.

The closest known extant unionid mussels to the Jordan River are located in Beer Creek shown in Figure 7 and Currant Creek (*A. californiensis*), tributaries to Utah Lake; and Beaver Creek (*M. falcata*), a tributary to the Weber River that discharges to Great Salt Lake. Oreohelix found *A. californiensis* shells in the Jordan River upstream of the Site at about 11000 South. (Mock et al., (2010; 2014) recently found live *A. californiensis* in Currant and Spring Creeks (tributaries to Utah Lake). Anecdotal historical records indicate that unionid mussels were common in Utah Lake.

Limited reconnaissance surveys were conducted on some of the tributaries to the Jordan River and upstream in Utah Lake and tributaries. No evidence of unionid mussels was observed but not all waters were surveyed or surveyed comprehensively.

Historical and recent records document the presence of non-pulmonate snails at the Site (e.g., see USU, 2017).

(b)(c) The surveys conducted by Oreohelix support that *A. californiensis and M. falcata* are not currently present at the Site. Observed bivalves include *Corbicula* and *Sphaerium* from these surveys. The Jordan River is degraded physically, biologically and chemically and there are likely additional factors that have contributed to the extirpation of unionid mussels.

Several water quality impairments have been identified for the Site. The water quality of Mill Creek from the confluence with the Jordan River to I-15 is currently impaired for benthic macroinvertebrates and microbial pathogens. The water quality of the Jordan River from 2100 South to the confluence with Little Cottonwood Creek is impaired for benthic macroinvertebrates, microbial pathogens and total dissolved solids. The water quality of the Jordan River from North Temple Street to 2100 South is impaired for benthic macroinvertebrates, microbial pathogens, dissolved oxygen and total phosphorus.

The Site is affected by other forms of degradation. Lower Mill Creek and portions of the Jordan are regularly dredged for flood control. Portions of the creek and river have been channelized and hardened. Flow regimes have been altered by upstream dams, diversions, water transfers and the Central Valley Water Reclamation Facility discharge. Abundant invasive *Corbicula* and New Zealand mud snails currently inhabit the Site.

Some of the degradation is expected to be improved in the future pending the outcome and implementation of Total Maximum Daily Loads for the identified water quality impairments but these activities are not expected to ever fully restore the Jordan River. The return of unionid mussels is unexpected but not impossible. No obvious mechanisms were identified for unionid mussels to return assuming that the restoration is sufficient.

If unionid mussels are present in nearby waters, they would require one of three mechanisms to become established at the Site: 1) juvenile mussels transported downstream, 2) transport of glochidia via an infected fish host or 3) reintroduction.

1) Juvenile mussels transported downstream to the Site would require a sufficient population upstream and sufficient flow for transport for juvenile mussels to be transported downstream.
2) Alternatively, an infected fish host could reintroduce unionid mussels to the Site. The fish host species for *A. californiensis* and *M. falcata* have not been fully characterized but based on their historical presence in the area, some or all of the indigenous fish species are viable hosts.

   A. californiensis is regarded more as a generalist for fish hosts (BHreference). Xerces reports that green sunfish (even as nonindigenous) are suitable hosts (http://xerces.org/california-and-winged-floaters/). Bonneville cutthroat trout (*Oncorhynchus clarki utah*) are likely suitable hosts for *M. falcata* based on trout and salmon being suitable hosts for *M. falcata* across its range (Howard and Cuffey, 2006, etc.). The suitability of other indigenous species to serve as hosts for unionid mussels, such as the Utah chub, Utah sucker and June sucker are unconfirmed. Introduced salmonids such as rainbow and brown trout may be suitable hosts.

   Bonneville cutthroat trout have been reintroduced in to tributaries of the Jordan River including Red Butte Creek and Mill Creek. Fish species currently presumed to reproduce in the Jordan River include Utah sucker, Utah chub, Channel catfish, Black bullhead, Mosquitofish, Green sunfish, Redside shiner, Fathead minnow ,Walleye, Asian carp, and White bass (DWQ, 2016). Other species observed include Black crappie, Brown trout, Rainbow trout, , Smallmouth Bass, and Yellow Perch (DWQ, 2016). Anecdotally, law enforcement officers patrolling the Jordan River Parkway told DWQ staff that fishermen fish for large trout in Mill Creek immediately upstream of the CVWRF discharge. Reintroduction of unionid mussels by fish hosts from the known existing mussel populations is judged unlikely because of the distances and potential intervening fish barriers.

3) Unionid mussels could be intentionally reintroduced by the Utah Division of Wildlife Resources.

In summary, unionid mussels were likely historically present at the Site but as discussed further below, are unlikely to return within the reasonable planning horizon of the next 30 years.

Discussion

Based on the recent observations of non-pulmonate snails at the Site and within hydraulically connected waters, nonpulomonate snails are residents for the purpose of calculating appropriately protective ammonia water quality criteria.

The historical records support that unionid mussels were likely present in portions of the Jordan River and likely in Mill Creek but recent surveys support that they are not currently present. The unionid mussels are not expected to return within the reasonable planning horizon of the next 30 years because of degraded conditions. The degraded conditions include water quality impairments but these impairments cannot be directly linked to the

absence of unionid mussels. While restoration efforts for both the physical and chemical degradation are onging, these efforts are still in the planning stages and the achievable end state is not yet defined, i.e., the highest attainable use. Once a restoration plan is established, these efforts are expected to take decades to implement.

The Utah Division of Wildlife Resources is scoping plans for reestablishing unionid mussels in Utah but these plans do not include the Jordan River for the foreseeable future. Other higher quality habitat and stabilizing extant unionid mussel populations will be the focus of the initial recovery efforts.

The existing *E. coli* impairments throughout the Jordan River are for human health and are not expected to directly adversely affect the mussels.

The dissolved oxygen impairments could adversely affect the ability of mussels to inhabit the Site. The ongoing investigations of these impairments for the Jordan River suggest that sediment oxygen demand coupled with reduced flushing flows due to flood management and stormwater are primary contributors to the impairments (Cirrus, 2017). A less stringent, site-specific dissolved oxygen criteria for portions of the Jordan River downstream of the site were previously established to reflect these conditions. Oreohelix (2017b) reports anoxic sediments in several of the surveyed locations. The primary evidence that dissolved oxygen is not a primary cause of unionid mussel absence is the presence of abundant populations of Asian clams. Like unionid mussels, these clams are sessile and would have a similar vulnerability to low dissolved oxygen conditions. Asian clams and unionid mussels are competitors but a key difference is that Asian clams do not rely on fish hosts as do unionid mussels for reproduction. While Asian clams are likely an additional stressor for unionid mussels, they have not been demonstrated to preclude the presence of unionid mussels (see discussion and references in DWQ, 2016a).

The water quality of the Jordan River is impaired for total dissolved solids (TDS) and TDS can adversely affect mussel survival (Patnode et al., 2015). Ongoing investigations to resolve the TDS impairments suggest natural and irreversible anthropogenic conditions are responsible for the impairment. Diversions upstream of Utah Lake divert water with low TDS concentrations for use as drinking water for Salt Lake and Utah Counties. Significant secondary water diversions, such as those above the Narrows, further dewater the Jordan River. The headwater for the Jordan River is Utah Lake which is also cyclically impaired for TDS. Utah Lake is large and shallow (95,000 acres, maximum depth 14') that results in high evaporative losses relative to the volume. Groundwater with elevated TDS concentrations discharges to the Jordan River including via several springs in the Narrows. Regardless of the causes of the TDS impairments, the magnitudes of the exceedances are low compared to the applicable agricultural use criterion of 1,200 mg/L (Table 1). While salt is known to be toxic to unionid mussels, the tolerance varies between species and is inversely correlated with hardness (Gillis, 2011). The hardness of the Jordan River is about 300 mg/L $CaCO^3$ (DWQ 3/21/2017 UPDES Permit for CVWRF) which combined suggest that TDS is unlikely to be a primary cause.

Oreohelix (2016a) discusses the potential negative impacts of suspended solids on unionid mussels. The degree to which the water turbidity is man-caused versus natural conditions has not been estimated.

The specific causes of the benthic macroinvertebrate impairments and the relationships to unionid mussels are less certain but are likely correlated for some of the causes, i.e., the same factors limiting the potential for unionid mussels to be present are also adversely affecting benthic macroinvertebrates.

Current data regarding fish populations are inadequate to evaluate whether an absence of fish hosts is a major impediment to the reintroduction of mussels at the Site. Introduced fish species and a loss of native species is one of the degradations likely affecting the ability of unionid mussels to inhabit or recolonize the Jordan River. If insufficient fish populations are determined to be one of the impediments, the reasons for insufficient fish populations need to be evaluated using the same USEPA (2013) resident procedures.

Table 1 All TDS data from 1990 to 2012 from five Jordan River stations to determine 90th percent confidence interval between 1,279 and 1,585 mg/L

Jordan River Location	N	Arithmetic Mean (mg/L)	Standard Deviation (mg/L)	90th Percentile Prediction Limit (mg/L)
2100 South	100	870	246	1,279
Pedestrian Bridge	105	1,110	236	1,434

near 5400 South				

Conclusions

1. Unionid mussels historically were present upstream in the Jordan and Utah Lake, tributaries to Jordan River and were also likely present at the Site.
2. Unionid mussels are not currently present at the Site or in the nearby waters that were surveyed because of degraded conditions. Not all nearby waters were surveyed.
3. Non-pulmonate snails are present, or were recently present at the Site and are residents.
4. The Jordan River is physically, biologically and chemically degraded at the Site. Efforts to restore the Jordan River are ongoing but are unlikely to be sufficient to support the potential reintroduction of unionid mussels within the reasonable planning horizon of the next 30 years, if ever.

Recommendations

Ammonia criteria protective of the aquatic life uses at the Site does not need to be protective of unionid mussels during this current planning horizon. Unless unionid mussels are demonstrated to not be residents downstream of 900 South Street in the Jordan River and Surplus Canal, permit limits CVWRF and other dischargers must assure downstream protection for unionid mussels. Non-pulmonate snails are present and the ammonia criteria are required to be protective of these taxa. The criteria should be calculated consistent with USEPA (2013c). The underlying assumptions and conclusions supporting these recommendations should be periodically reviewed as progress is made on restoring the Jordan River.

Criteria Calculation.

USEPA (2013a) provides procedures for calculating the ammonia criteria to represent the site-specific aquatic life to be protected. As recommended by Oreohelix (2014) the criterion maximum concentration (aka, acute criterion) should be based on unionids and trout not being residents. At a pH of 7 and temperature of 20 °C, the total ammonia nitrogen is 38 mg/L. Criteria for other pH and temperature conditions are provided in Table N.4 of USEPA (2013a). The following equation can be used to calculate the criterion maximum concentration:

$$CMC = 0.7249 \times \left(\frac{0.0114}{1+10^{7.204-pH}} + \frac{1.6181}{1+10^{pH-7.204}}\right) x\ MIN(\left(51.93, \left(62.15 \times 10^{0.036\times(20-T)}\right)\right)$$

For the criterion continuous concentration (aka, chronic criterion), unionid mussels are not residents. When early life stages of fish are present, the criterion continuous ammonia criterion at a pH of 7 and temperature of 20 °C, is 6.5 mg/L total ammonia nitrogen. Table N.8 in USEPA (2013a) shows the criteria for other temperature and pH combinations that are calculated using the following equation:

$$CCC = 0.9405 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times MIN\left(6.920, \left(7.547 \times 10^{0.028\times(20-T)}\right)\right)$$

When early life-stages of fish are not present, the criterion continuous ammonia criterion at a pH of 7 and temperature of 20 °C, is 7.1 mg/L total ammonia nitrogen. Table N.9 in USEPA (2013a) shows the criteria for other temperature and pH combinations that are calculated using the following equation:

$$CCC = 0.9405 \times \left(\frac{0.0278}{1+10^{7.688-pH}} + \frac{1.1994}{1+10^{pH-7.688}}\right) \times \left(7.547 \times 10^{0.028\times(20-MAX(T,7))}\right)$$

Figures

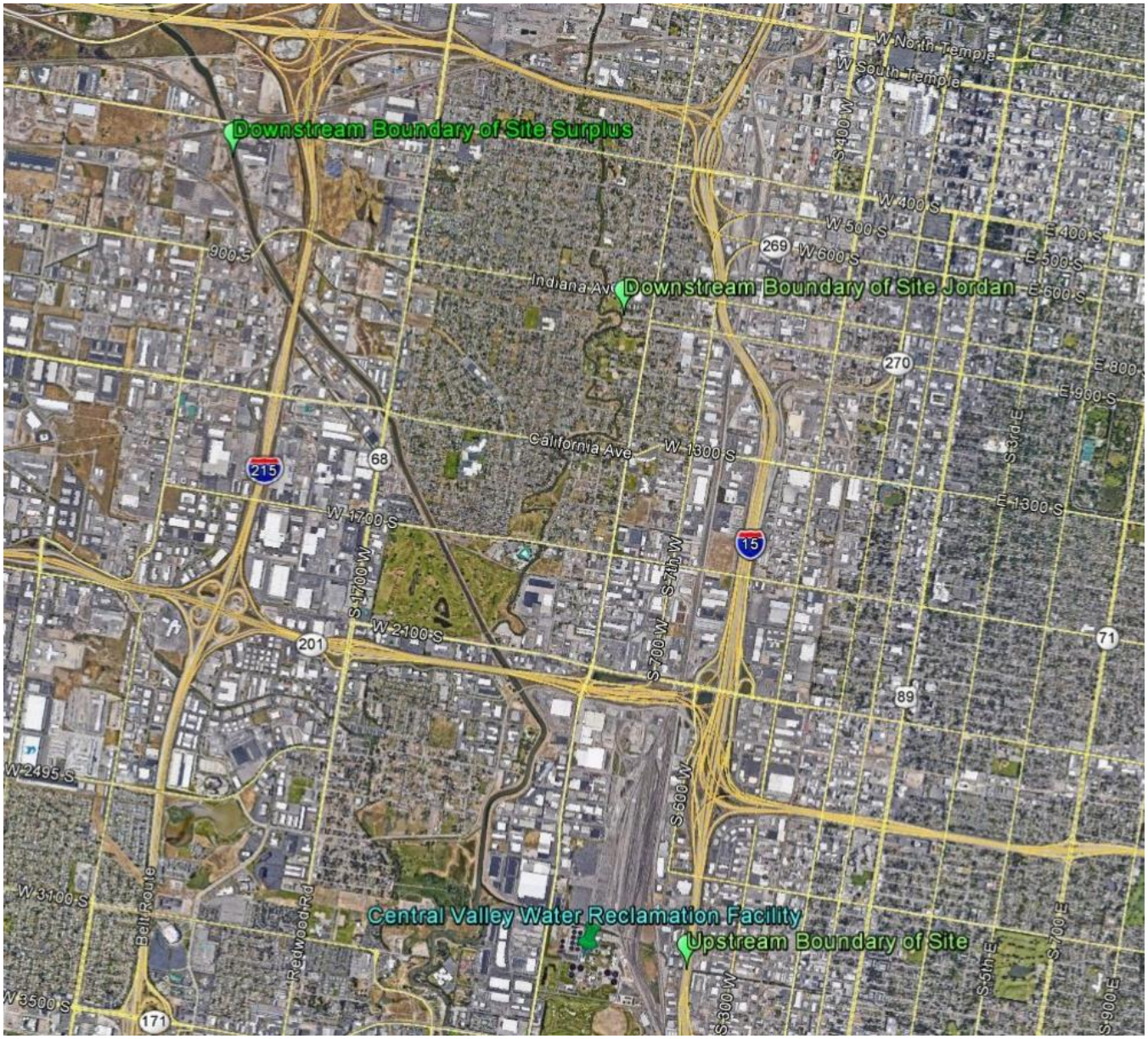

Figure 1. The Site and location of the Central Valley Water Reclamation Facility

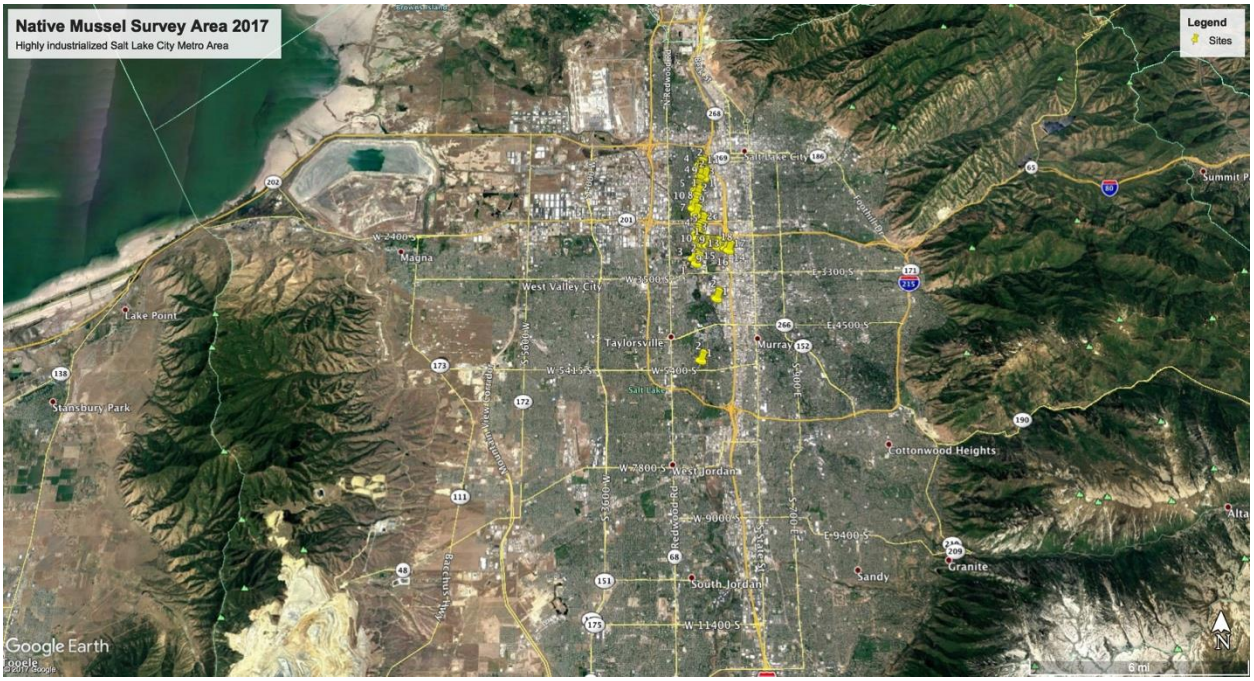

Figure 2. Overview of mussel survey locations at the Site (adapted from Figure 6, Oreohelix, 2017a).

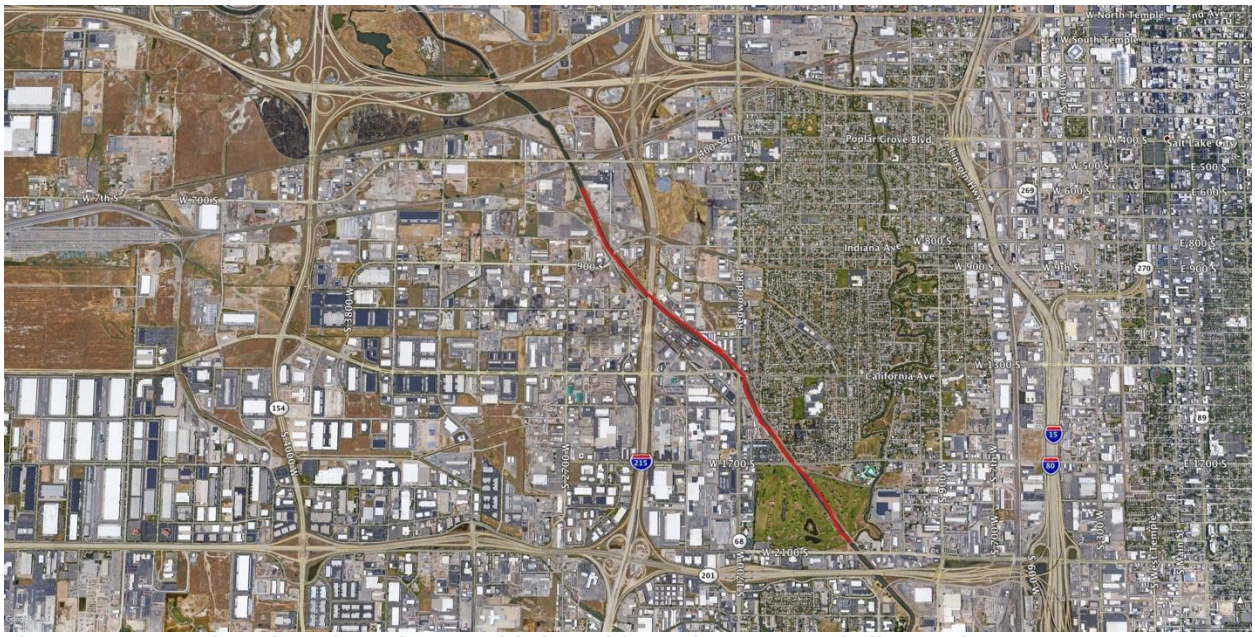

Figure 3. Surveyed portion of Surplus Canal (adapted from Figure 5, Oreohelix, 2018)

Figure 4. Soil profile of Mill Creek between the CVWRF and confluence with the Jordan River. Several easily observable soil layers can be seen. Physidae and Lymnaeidae shells typically were found in the darker layers suggesting warm water, wetland habitat conditons, whereas Fluminicola were found in slightly coarser sediment layers suggesting cold-water conditions. Potential Anodonta fragments were found somewhat in between these layers.(Figure 17, Oreohelix, 2016c)

Figure 5. Clamming on the Jordan River at 1700 South. Corbicula sp. at extreme high densities. This is also the location of the muskrat midden shown in the appendices. (Figure 38, Oreohelix, 2014)

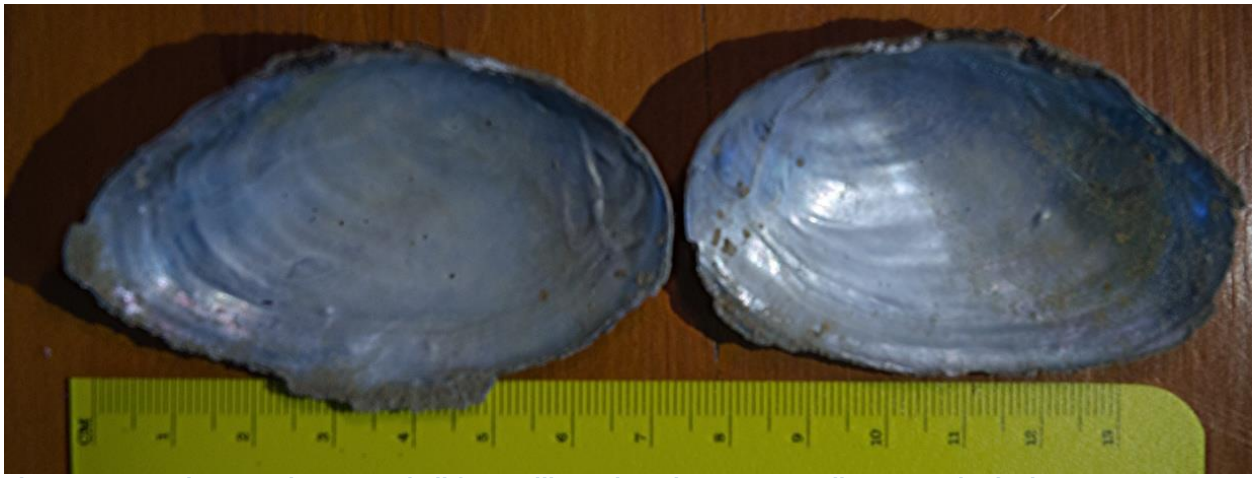

Figure 6. Complete Anodonta sp. shell from Mill Pond, Utah County, April 2014. No body tissue was present and the time since death is unknown. (Figure 27, Oreohelix, 2014)

Figure 7. Location of Beer Creek, the closest known population of Anodonta californiensis/nuttalliana to Mill Creek evaluation site and CVWRF (adapted from Oreohelix, 2016c)

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