Determination of a Safe Level of Ammonia that is Protective of Juvenile Colorado Pikeminnow in the Upper Colorado River, Utah

by

James F. Fairchild and Ann L. Allert
Columbia Environmental Research Center
U.S. Geological Survey
4200 New Haven Rd
Columbia, MO 65201
phone: 573-876-1871
fax: 573-876-1896
email: James_Fairchild@usgs.gov

and

Janet Mizzi, Ronnette Reisenburg, and Bruce Waddell
U.S. Fish and Wildlife Service
Ecological Services, Utah Field Office
2369 W. Orton Circle, Suite 50
West Valley City, UT 84119
801-975-3330

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Partner Agency and Region: U.S. Fish and Wildlife Service, Region 2 (Salt Lake City Office)

Principal Introduction Investigators: James F. Fairchild and Ann L. Allert

INTRODUCTION

Various sections of the un-impounded portions of the Upper Colorado River above Lake Powell have been declared critical habitat (Fed. Reg. 59:13374-13400) for four endangered fish species: Colorado pikeminnow *(Ptychocheilus lucius)*, razorback sucker *(Xyrauchen texanus)*, humpback chub *(Gila cypha)*, and bonytail chub *(Gila elegans)*. The U.S. Fish and Wildlife Service (USFWS), under the auspices of Section 7 of the Endangered Species Act, must protect these species and determine if any private, state, or federal activities could jeopardize remaining populations of these endangered species.

The abandoned Atlas Mill uranium tailings pile, located on the western bank of the Upper Colorado River near Moab, Utah, is a perceived threat to endangered fish species of the Upper Colorado River (USFWS, 1998). This tailings pile lies in the immediate vicinity of critical habitat for both the Colorado pikeminnow and the razorback sucker. The U.S. Nuclear Regulatory Commission, in cooperation with other federal and state agencies, is currently evaluating several options for long-term stabilization of the tailings pile (e.g., capping, removal, etc.) based on several environmental, economic, and legal factors.

In early 1998, the U.S. Fish and Wildlife Service requested that the Columbia Environmental Research Center (CERC), Biological Resources Division (BRD), U.S. Geological Survey (USGS), Columbia, Missouri provide research and technical assistance to determine the potential adverse impacts of the tailings pile to the endangered fish species of the Upper Colorado River. Subsequently, the Central Region of the USGS/BRD provided $20,000 in funding to the CERC via the Quick Response Program to facilitate research and technical assistance to the U.S. Fish and Wildlife Service. This final report presents the background information, research results, and conclusions derived from this Quick Response Project.

History of the Atlas Mill facility:

The Atlas Mill tailings pile is located on the west bank of the Upper Colorado River in the 100-year floodplain. The property and facilities were originally owned by the Uranium Reduction Company and regulated by the U.S. Atomic Energy Commission, precursor to the U.S. Nuclear Regulatory Commission (NRC). The mill and site were acquired by the Atlas Corporation in 1962. The Atlas Corporation ceased operation of the mill and ore milling in 1984.

Milling of ore at the Atlas site has resulted in a large tailings pile located approximately 230 m from the west bank of the Upper Colorado River and 3.7 km northwest of Moab, Utah. The pile occupies about 53 ha of land and is about 0.8 km in diameter and 27 m high. The Colorado River terrace on which the pile sits is approximately 1,210 m above mean sea level at the south side of the pile nearest the river (USFWS 1998).

Current drainage from the pile has been estimated by Oak Ridge National Laboratory (ORNL) in Grand Junction, Colorado to be between 25 and 75 L/min and could take up to 270 years to drain; similarly, it is estimated that concentrations of contaminants in the adjacent groundwater will not reach a steady state for approximately 240 years (ORNL, 1998a). The groundwater contamination plume extends beyond the Atlas property to the south and is over 1,700 m wide and 10 m deep and discharges directly into the Colorado River (ORNL, 1998b). The plume for some contaminants (ammonia, uranium, molybdenum and nitrates) is mature; these constituents have been discharging into the river since the early 1970's (ORNL, 1998c). The U.S. Fish and Wildlife Service believes that for other contaminants (e.g., selenium), the plume has not fully reached the bank of the Colorado River (USFWS, 1998).

Atlas Corporation activities at the Atlas site are currently covered by NRC Source Material License SUA-917 and regulated under the Title II Uranium Mill Tailings Radiation Control Act of 1978. The Atlas Corporation was previously involved in the process of closing and reclaiming the Atlas site. However, in 1998 the company declared bankruptcy and was not able to complete a Corrective Action Plan (CAP) for approval by the NRC. Thus, the remedial action plan for the site remains incomplete.

Significance of research to the USFWS and other management agencies:

The USFWS Utah Field Office has been assessing the proposed reclamation of the Atlas Mill tailings pile since 1983. At that time, the Utah Field Office expressed its concern in a letter to the Assistant Regional Director regarding a review of the Emergency and Remedial Response Information System Inventory and identified concerns about possible effects on Colorado pikeminnow and razorback sucker. On June 26, 1997, the Service issued a draft jeopardy biological opinion (DBO) to the Nuclear Regulatory Commission. Since issuance of the DBO, the Service, the Council of Environmental Quality (CEQ), and the Department of the Interior (DOI) have all been working with the NRC and the Trustees to resolve the issues and determine the best means of reclamation of the site. The Service issued a revised draft biological opinion (RDBO) on April 14, 1998 to the Region 6 Regional Office (RO) and is awaiting comments to finalize the opinion. The RDBO (USFWS 1998) concluded jeopardy to the four endangered Colorado River fishes from the contaminated leachate leaking into the Colorado River from the tailings pile. The RDBO (USFWS 1998) included three reasonable and prudent alternatives to avoid jeopardy: (1) expedite planning and implementation of a groundwater corrective action plan; (2) defer the decision on capping the pile until expeditiously arranged bioassay studies could be conducted to more effectively determine cleanup levels required to remove jeopardy to listed species and; (3) payment of a depletion fee to the Colorado River Recovery Program to offset the impacts of the 154.3 acre-foot water depletion identified for the proposed action (USFWS, 1998).

Data collected by ORNL further supports the Service's biological RDBO (USFWS 1998) in concluding that the Atlas Mill tailings pile is a site-specific point source of ammonia and that the proposed capping of the pile in place may jeopardize the continued existence of razorback sucker and Colorado pikeminnow due to the continued leaching of contaminated groundwater into the Colorado River (ORNL, 1998b). Additionally, the proposed action will result in the destruction or adverse modification of designated critical habitat for the Colorado pikeminnow and razorback sucker (USFWS, 1998).

The current RDBO (USFWS, 1998) jeopardy opinion has been based on the best available data and opinion of Service resource professionals. Based on the precarious existence of the Colorado River fishes and the fact that the site is located near a suspected fish nursery area, the Service has determined that the level of take anticipated under the proposed reclamation action could impact population numbers and recruitment and is sufficient to jeopardize the continued existence of these species (USFWS, 1998). All three constituent elements of designated critical habitat for Colorado pikeminnow and razorback sucker will be adversely modified: 1) water that is of good quality; 2) physical habitat potentially habitable by fish during all life stages; and 3) a biological environment capable of providing a food supply for the endangered fishes (USFWS, 1998). The Service feels that the proposed reclamation project activities could result in continued input of contaminated water into the Upper Colorado River mixing zone until an acceptable groundwater corrective action plan is approved and implemented.

The development of the corrective action plan is dependent on a determination of a criterion or safe concentration of ammonia that is protective of Colorado pikeminnow and other endangered fishes in the river. This protective concentration must then be compared to measured ammonia concentrations in the river to conduct a site-specific risk assessment. The collective results of these studies will be used by the U.S. Fish and Wildlife Service in assisting the NRC and other federal and state agencies in developing effective remedial action plans for the site which protect remaining populations of endangered fishes in the Upper Colorado River.

Objectives:

This study had three objectives:

1) Conduct spatial mapping to determine the distribution of ammonia, metal, and radiochemical concentrations in the Upper Colorado River adjacent to and below the Atlas Mill tailings pile in order to estimate exposures to endangered fishes,
2) Conduct toxicity testing with early life stages of fathead minnow and Colorado pikeminnow to determine the concentration of ammonia that is protective of endangered fishes in the Upper Colorado River, and
3) Compare the toxicity of ammonia to measured environmental concentrations to conduct a site-specific risk assessment.

METHODS

Site mapping for contaminant concentrations:

Water was collected in a regular grid framework extending from 500 m above to 1,000 m below the Moab Wash. The Moab Wash lies adjacent to the Atlas site and represents a major seasonal hydrologic input. Ammonia is the major contaminant known to be directly associated with the tailings pile and was used as a primary variable for mapping. A differentially-corrected global positioning system was used to establish a sampling grid arranged in a regularly-distributed pattern (Figure 1). Groundwater samples (i.e., water removed from a porewater pit dug in shoreline soil to 30 cm depth within a meter of the shore; measured as pore water) were collected as grab samples. Surface and bottom grab samples were collected at each grid intersection and refrigerated until analyzed for ammonia, metals, and radiochemicals. In addition, water samples were analyzed in situ for temperature, pH, dissolved oxygen and conductivity using a Hydrolab DataSonde 3 Multiparameter Water Quality Instrument. Ammonia was analyzed on-site using a Technicon Autoanalyzer II System using a salicylate/nitroprusside colorimetric reaction (detection limit 0.1 mg/L total ammonia). Ammonia concentrations were calculated based on a 5-point standard curve. Precision and accuracy were determined based on triplicate analysis of independent, certified Hach and Orion ammonia standards on each day. All samples were analyzed within 24 h of sampling. All ammonia concentrations were expressed as total ammonia as N (NH_3-N).

Water samples for analysis of dissolved metals (ICP-MS analysis of 30 metals) and radiochemicals (total alpha, total beta, and selected gamma constituents) were stored on ice (temperature < 4 ^oC) and shipped via overnight mail to the National Air and Radiation Environmental Laboratory (NAREL) in Montgomery, Alabama. Analysis of metals and radiochemicals were conducted according to NAREL's U.S. Environmental Protection Agency (USEPA) methods.

Toxicity testing:

Toxicity testing was conducted using larval fathead minnow and juvenile Colorado pikeminnow. Larval fathead minnows were purchased from Aquatic Biosystems, Fort Collins, Colorado. Larval Colorado pikeminnow were provided by Roger Hamman, Dexter National Fish Hatchery, USFWS, Dexter, New Mexico. Toxicity testing was conducted according to standard procedures as described by the USEPA Effluent Toxicity Procedures (USEPA, 1994) and the American Society for Testing and Materials (ASTM, 1997).

Ammonia was delivered as ammonium chloride (J.T. Baker Chemical Co., Phillipsburg, NJ). Seven-day static renewal studies (Colorado pikeminnow) and 72-h static renewal studies (Colorado pikeminnow and fathead minnow) were conducted. Ten juvenile Colorado pikeminnow (approximately 60 days old) were exposed in 1000-ml beakers (800 ml test volume) containing one of two water sources: 1) Colorado River water, or 2) CERC well water. This comparison was conducted to determine if the source of water (i.e., site-specific conditions) has an effect on the toxicity of ammonia. Approximately 200 L of Colorado River water was collected from above the Moab tailings pile (i.e., low in ammonia) and was shipped on ice (≤ 4 ^oC) in polyethylene carboys to the CERC. Water was stored at $\leq$ 4 ^oC until use. Four days prior to the study the 60-d old Colorado pikeminnow and larval fathead minnow were acclimated to respective test waters (i.e., either well or Colorado River water). Then, the toxicity tests were initiated. Ammonia was delivered in a 50% dilution series ranging from 0 - 64 mg/L (total ammonia) consisting of eight concentrations (e.g., 64, 32, 16, 8, 4, 2, 1, and 0 mg/L as N); each concentration was tested in triplicate. Larval fathead minnow (< 48 h old) and juvenile Colorado pikeminnow (approximately 60-d old) were tested in side-by-side experiments in well water (72-h exposure) using the same experimental design to test the effects of ammonia across species and water sources.

Exposure containers (1000-ml beakers containing 800-ml test water) were maintained at constant temperature (25 ^oC) under a 16h:8h light:dark photoperiod. Test concentrations were renewed daily by siphoning approximately 90% of water from each beaker prior to replacement with fresh solution. Total ammonia was measured daily in both newly renewed and removed test waters to determine the accuracy and precision of the ammonia exposures. Temperature (YSI Model 54 Meter), pH (Orion Model 940 Meter), and dissolved oxygen (YSI Model 54 Meter), were measured daily in the 64, 16, 1, and 0 mg/L treatments prior to renewal (i.e., 24-h old exposure water). Un-ionized ammonia, the toxic form, was calculated based on temperature and pH according to Thurston et al. (1977). Alkalinity, hardness, and conductivity were measured in the 64, 16, 1, and 0 mg/L concentrations of both source waters at the beginning and end of the test. All water quality measures were conducted using CERC Standard Operating Procedures, which are developed in accordance with methods recommended by the APHA (1995) and manufacturers' recommendations. Fish were fed brine shrimp nauplii *ad libitum* two times per day at least six hours apart. At the end of the study the fish were euthanized using tricaine methanesulfonate (MS-222) and immediately dried (60 ^oC) and weighed for final weights.

Similar testing procedures were used to determine the on-site toxicity of actual site water (e.g., containing ambient ammonia, metals, and radiochemicals) on juvenile Colorado pikeminnow. Samples from nine sites (30 L total water per site), selected across a range of measured ammonia concentrations, were sampled and placed on ice. A 7-d static renewal study (25 ^oC) was conducted in a mobile testing trailer maintained under a 16h:8h light:dark schedule. Ten Colorado pikeminnow (90 days old) were tested in each of three replicate beakers per site. Mortality, ammonia, pH, dissolved oxygen, and temperature were determined daily. Alkalinity, conductivity, and hardness were determined every other day. Radiochemicals and metals were analyzed once from each batch of site water. Fish were fed brine shrimp *ad libitum* two times per day at least six hours apart. At the end of the study the fish were euthanized with MS-222 and immediately dried (60 ^oC) and weighed for final weights.

Analytical Chemistry:

All analytical chemistry was conducted according to standardized procedures described by the USEPA (1994), ASTM (1997), or the American Public Health Association (APHA, 1995). Analysis of metals and radiochemicals was conducted by the USEPA-National Air and Radiation Environmental Laboratory (NAREL; Montgomery, AL) according to standard USEPA procedures.

Data analysis:

Data were analyzed using the Statistical Analysis System (SAS 1990) to determine means and standard deviations. Either Probit or non-linear interpolation was used to calculate LC50 values (Snedecor and Cochran 1969). Chronic incipient mortality (i.e., predicted 7, 14, 30, 60, and 90-d responses at 0.01, 0.05, 0.10, 0.50, 1.0, and 5% mortality) was calculated using the accelerated life testing procedures of Sun et al. (1995).

RESULTS

Review of historical water quality information:

Previous water quality measurements performed by the Utah Department of Environmental Quality (UDEQ) have identified a site-specific source of contaminated groundwater entering the Colorado River from beneath the tailings pile. The primary source was identified as the Moab Wash located at the northernmost area of the tailings pile. This source exceeds Water Quality Standards for at least five parameters, including total ammonia, dissolved manganese, dissolved molybdenum, and dissolved vanadium (Table 1) (UDEQ, 1996). In addition, levels of gross alpha and total uranium levels in groundwater below the Atlas Mill tailings site exceed those measured upstream (Table 1). These data were used to select the spatial mapping locations described below.

Spatial mapping of contaminants:

Field assessments of the distribution of ammonia concentrations in the Upper Colorado River adjacent to the Atlas Mill tailings pile were conducted over a 10-d period during August 1998. Discharge during this period was approximately 3,000 cfs, which is typical of the post snowmelt period when post-larval and juvenile Colorado pikeminnow are most likely to use shallow backwater areas such as the area adjacent to Moab Wash. For sampling locations refer to Figure 1.

Samples of groundwater adjacent to the river exceeded Utah State Water Quality Standards (UDEQ, 1999) for total ammonia by a factor of up to 500 under worst-case conditions. Groundwater measured at the immediate confluence of Moab Wash with the Upper Colorado River contained 477 mg/L total ammonia (Figure 2). Total ammonia concentrations in shoreline groundwater (i.e., porewater) samples increased downstream of Moab Wash and were measured at 685 mg/L (100 m downstream) and 771 mg/L (200 m downstream), respectively (Figure 2). Note that these are undiluted groundwaters immediately adjacent to the stream.

Concentrations of total ammonia measured at near-shore areas (i.e., in the river at the bank-water interface) were measured at concentrations up to 224 mg/L at a station located 100 m downstream of Moab Wash (Table 2; Figure 3); this site was strongly influenced by groundwater entering the river directly from soil fissures located at the tamarisk root line. Concentrations of total ammonia at the bank interface decreased at downstream locations (e.g., 200 m downstream, 35 mg/L; 300 m downstream, 19 mg/L; and 400 m downstream, 5 mg/L). Concentrations of total ammonia were also elevated at the 1-m (i.e., lateral distance from bank) locations (Figures 2 and 3). For example, concentrations of 33, 21, 14, 4, and < 1 mg/L total ammonia were measured at 100, 200, 300, 400, and > 500 m downstream, respectively (Figure 3). Measurements taken at the 10-m lateral location exceeded 0.5 mg/L total ammonia at only one location (100 m downstream) (Figure 3). Thus, it was evident that ammonia concentrations greatly exceeded State Water Quality Standards (4-d chronic level of 0.32 mg/L total ammonia assuming pH = 8.5 and temperature of 25 ^{o}C) during the sampling period but were confined to a zone of less than 10 m from the western shore (Atlas side of river). Ammonia concentrations upstream of the Moab Wash were below detection limits. However, a shore porewater sample was measured at 117 mg/L at a site 100 m above the Moab Wash (Figure 2), which may reflect some influence of groundwater due to lateral migration across the alluvial plain.

Total ammonia, un-ionized ammonia, metals, and radiochemicals are presented from a subset of the survey sites in Tables 3 and 4. Total ammonia concentrations in surface waters adjacent to Moab Wash greatly exceeded the 4-d chronic Utah State Water Quality Criterion for total ammonia (0.32 mg/L total ammonia at pH = 8.5 and T = 25 ^{o}C) and exceeded concentrations known to be toxic to Colorado pikeminnow (see below). Copper exceeded water quality criterion concentrations in shore pore water at two sites: Moab Wash; and the site located approximately 100 m below Moab Wash (Table 3). Manganese was measured at one surface water site near Moab Wash and at several porewater sites at levels exceeding the 40 µg/L criterion value (Table 3). Selected radiochemicals were elevated above background levels in both surface and groundwater at two sites: Moab Wash and 100 m downstream of the Moab Wash (Table 4).

Near-shore water samples indicated that total ammonia concentrations were highly correlated (r^2 = 0.98, p = 0.01) with conductivity (Table 2). Temperature and dissolved oxygen remained within levels suitable for survival of Colorado pikeminnow. The levels of pH reached 8.69 in two areas near Moab Wash, and were measured at up to pH = 9 in some backwaters during late evening. An increase of pH from 8.5 to 9 (at 25 ^{o}C) would result in a doubling of the percentage of un-ionized ammonia (the toxic form) under these conditions (Thurston et al., 1977).

Toxicity testing:

Ammonia was toxic to Colorado pikeminnow in well water at 18 mg/L total ammonia (72-h LC50) (Table 5) or 1.17 mg/L un-ionized ammonia (72-h LC50 adjusted for pH and temperature) (Table 6). The standard surrogate species, the fathead minnow, was twice as sensitive as pikeminnow to total ammonia (9 mg/L 72-h LC50) (Table 5) and to un-ionized ammonia (0.61 mg/L; 72-h LC50 corrected for temperature and pH) (Table 6). Ammonia was toxic to both species within one hour at the high concentration of 64 mg/L total ammonia and within 12 hr at 32 mg/L total ammonia. The 16-mg/L concentration resulted in 20% mortality. The data further indicated that Colorado pikeminnow were only half as sensitive to ammonia (adjusted for pH and temperature) in Colorado River water (2.21 mg/L un-ionized ammonia; 72-h LC50) compared to fish tested in CERC well water (1.17 mg/L un-ionized ammonia; 72-h LC50) (Table 6).

Accelerated life testing procedures (Sun et al., 1995) were used with the data to predict the concentration of ammonia lethal to 0.01, 0.05, 0.10, 0.5, 1, and 5% of Colorado pikeminnow at various chronic exposure intervals (Table 7). The chronic 90-d minimal effect level for mortality (i.e., projected 0.01% population mortality) was calculated to be 2.66 mg/L and 0.17 mg/L for total and un-ionized ammonia, respectively, in Colorado River water. These concentrations are frequently exceeded in the Moab Wash area (Tables 2 and 3; Figures 2 and 3). However, note that the current water quality criterion for ammonia for Class 3B waters of Utah (e.g., 0.32 mg/L total ammonia; 0.05 mg/L un-ionized ammonia at pH 8.5 and 25 ^{o}C) appear to be protective of Colorado pikeminnow (Table 3).

On-site tests with environmental samples indicated that groundwater samples from below Moab Wash resulted in toxicity within 30 minutes due to the high level of ammonia (e.g., > 500 mg/L total ammonia). Dilutions of these test waters were acutely toxic at 12.5% dilution which was the lowest dilution tested (Figure 4).

No surface waters were toxic to Colorado pikeminnow in the on-site test under the conditions tested. However, surface waters from four field locations between Moab Wash and 100 m downstream (i.e., Moab Wash Surface 1; Moab Wash Surface 2; Downstream 1-50 m; and Downstream 2-100 m) contained between 1.4 and 1.7 mg/L un-ionized ammonia (Figure 4), which approaches the threshold for mortality determined in laboratory toxicity tests (2.21 mg/L 72-h LC50 in Colorado River water). Many of the fish exhibited altered, punctuated swimming behavior during the test which indeed indicates that water from these sites was approaching levels inducing acute toxicity. Other areas containing higher concentrations of ammonia were located but not until after the tests were initiated (e.g., site 100 m downstream of Moab Wash; Tables 2 and 3).

Comparisons of the standard laboratory and on-site field tests revealed that fish were sensitive at the same approximate concentrations of ammonia and that ammonia is the primary contaminant of concern. Other contaminants (e.g., copper, zinc, and radiochemicals) were not present at individually toxic concentrations and did not contribute to any apparent additive or synergistic activity of the site waters.

DISCUSSION

Ammonia appears to be the major contaminant of concern in the vicinity of the Atlas Mill tailings site. Ammonia primarily exists in two forms: un-ionized (NH_3) and the ionized ammonium ion (NH_4). The relative distribution of the two forms is controlled by pH and temperature. It is the un-ionized form of ammonia that is most toxic (USEPA 1999).

Acute exposure of fish to un-ionized ammonia can cause loss of equilibrium, hyper-excitability, and increased respiration in fishes (WHO, 1986). Chronic exposure of fish to un-ionized ammonia has been shown to reduce egg hatching, growth, and development, and can cause pathological changes in gills, liver, and kidney (WHO, 1986). Chronic data for the effects of un-ionized ammonia on razorback suckers and Colorado pikeminnow are not available. However, Mayes et al. (1986) determined that un-ionized ammonia decreased hatching and survival of larval fathead minnows at 0.26 mg/L. Thurston et al. (1986) determined that chronic exposure to 0.91 mg/L un-ionized ammonia resulted in decreased survival, growth, and reproduction of fathead minnows, and that at 0.21 mg/L exposure, adult fatheads commonly exhibited brain lesions. Further, Le Ruyet-Person et al. (1997) determined that 28-d exposure of juvenile turbot (*Psetta maeotica*) to un-ionized ammonia resulted in significantly decreased growth at concentrations as low as 0.1 mg/L due to decreased food intake. Pathological changes (e.g., gill hyperplasia; necrosis; and tissue disintegration) have been observed at un-ionized ammonia concentrations $\leq$ 0.1 mg/L (Flis, 1963; Smith and Piper, 1974).

The results of this study indicated that Colorado pikeminnow were sensitive to un-ionized ammonia at 1.17 mg/L (measured 72-h LC50). These data are similar to the results of Dwyer (1998) that indicated that un-ionized ammonia was toxic to juvenile razorback suckers, Colorado pikeminnow, and the standard surrogate test species the fathead minnow at concentrations as low as 1.040, 0.229, and 0.227 mg/L, respectively (7-d LC50, un-ionized ammonia) (Table 8). Calculated projections indicate that pikeminnow could be sensitive to un-ionized ammonia at concentrations as low as 0.17 µg/L (90-d LC0.01; calculated according to Sun et al., 1995). A comparison of these effects levels to measured exposure data in the immediate vicinity of the Atlas Mill tailings pile indicates that endangered fish populations are at risk due to the effects of ammonia. However, existing water quality criteria for ammonia, if enforced, should be protective of Colorado pikeminnow.

Several dissolved inorganic constituents, including molybdenum and vanadium, have previously been measured at levels that exceed published State or National Water Quality Standards near the Moab Wash (UDEQ, 1999; Table 1). However, concentrations of these constituents do not approach levels that have been demonstrated in the laboratory as acutely toxic to razorback suckers or Colorado pikeminnow. For example, Hamilton and Buhl (1997) studied the effects of vanadium on Colorado pikeminnow and razorback sucker and determined 96-h LC50s of 7.8 and 8.8 mg/L, respectively, indicating a margin of safety of well over 100. Molybdenum is toxic to fathead minnows at 360 mg/L (Eisler, 1989) and acute toxicities of other dissolved inorganics including uranium, boron, arsenate, and zinc generally exceed 10 mg/L (Hamilton, 1997; Hamilton and Buhl, 1997). However, data on chronic toxicity of these elements to Colorado pikeminnow and razorback suckers are not available. Although others have suggested that synergistic effects may be possible (Hamilton and Buhl 1997; Irwin et al., 1997), there was no apparent additive or synergistic activity in the on-site studies that we conducted.

Selenium concentrations in water adjacent to the Atlas Mill tailings pile range from 1-4 µg/L as total selenium, which approaches the Water Quality Criterion of 5 µg/L (USEPA 1987). Selenium is of particular concern in the western United States due to its propensity to undergo organic transformations which lead to biomagnification in aquatic food webs (Hamilton, 1998). Concentrations of selenium above 5 µg/L have been shown to result in reproductive failure and developmental abnormalities in fish and birds (Hermanutz et al., 1992; Lemly et al., 1993). However, our data provides no indication that selenium from the Atlas Mill tailings pile is elevated to levels of localized concern.

Colorado pikeminnow populations now only occupy a portion of historical habitats in the Upper Colorado River Basin in Colorado, New Mexico, Utah and Wyoming (USFWS, 1996). The most important rearing area in the Colorado River for young-of-year Colorado pikeminnow is between Moab, Utah and the confluence with the Green River (USFWS, 1996). In a mark-recapture study of Colorado pikeminnow, 21 of 51 (41%) fish in this sampling reach were caught in the Moab Valley area between River Miles 57 and 65 (Osmundson et al., 1997).

The Atlas Mill tailings pile site is located in upper Moab Valley at River Mile 64. The Colorado River Fisheries Project implemented an Interagency Standardized Monitoring Program in 1986 to monitor population trends of the Colorado pikeminnow and humpback chub *(Gila cypha)* in the Colorado River Basin. Low numbers of Colorado pikeminnow (between 1 and 28 fish) were consistently collected between 1986 and 1996 near the Atlas site between River Miles 49 and 68. Both adults and subadults were collected in Moab Wash and directly below the tailings pile. Young-of-year Colorado pikeminnow sampling between River Miles 48 and 84 collected anywhere from 0 to 53 pikeminnow at any one site (Osmondson et al., 1997).

A potential spawning site for Colorado pikeminnow exists upstream of the Atlas site above Westwater Canyon. Larval Colorado pikeminnow are consistently found from above Moab to the confluence of the Colorado River with the Green River. This includes the Upper Colorado River section in the vicinity of the Atlas Mill tailings pile. The geomorphological and hydrological characteristics of the Upper Colorado River significantly change in the Moab Valley and produce shallow, low velocity nursery habitat for larval and young-of-year Colorado pikeminnow and significant numbers have been observed in this section of the river (UDWR, 1998). Further, the standardized monitoring data has shown that the average size of larval and young-of-year Colorado pikeminnow collected below the Atlas site is smaller than larval and young-of-year fish collected in the Green River system; however, at this time these differences cannot be attributed to the influence of ammonia from the Atlas Mill tailings pile (USFWS 1998).

SUMMARY AND RECOMMENDATIONS

Acute toxicity testing indicated that Colorado pikeminnow were sensitive to ammonia in Colorado River water at concentrations of 33 mg/L total ammonia and 1.17 mg/L un-ionized ammonia (72-h LC50), respectively. Accelerated life testing procedures indicated that Colorado pikeminnow could be sensitive to 90-d chronic exposures as low as 2.66 mg/L total ammonia or 0.17 mg/L un-ionized ammonia. Therefore, the current Utah Water Quality Criteria for ammonia (e.g., 0.32 mg/L total ammonia or 0.05 mg/L un-ionized ammonia at pH = 8.5 and temperature of 25 ^{o}C) appear to be protective of Colorado pikeminnow populations based on the limited data in existence. However, ammonia criteria concentrations and ammonia concentrations causing mortality of Colorado pikeminnow are exceeded in near-shore surface and pore waters for a distance of over 300 m downstream from the Atlas Mill tailings site. Levels of other constituents, including copper, manganese, and zinc are elevated in some areas but do not appear to approach levels of concern.

These results suggest additional studies are needed. An off-refuge proposal, based on the results of this Quick Response Study, was submitted to the U.S. Fish and Wildlife Service and was successfully funded to continue studies for an additional two years. Ammonia levels in interstitial pore waters are suspected of being higher than surface waters. Studies planned for 1999 and 2000 are examining the significance of interstitial ammonia exposures (e.g., Ankley et al., 1990) due to the intimate contact of Colorado pikeminnow with the substrate following larval drift and deposition. In addition, chronic effects of ammonia on growth, mortality, and behavior of Colorado pikeminnow are being determined to refine the risk assessment and determine concentrations of ammonia that are protective at the individual level of population organization. The collective results of these studies will be used by the U.S. Fish and Wildlife Service in assisting the NRC and other federal and state agencies in developing effective remedial action plans for the site which will protect remaining populations of endangered fishes in the Upper Colorado River.

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Table 1. Metals and radiation measurements taken in the vicinity of the Moab, UT, Atlas Mill tailings pile by the Utah Department of Environmental Quality on April 11, 1996[1] (UDEQ 1996).

Site	**Total Ammonia (mg/L as N)**	**Un-ionized Ammonia (µg/L as N)**	**Molybdenum (µg/L)**	**Manganese (µg/L)**	**Vanadium (µg/L)**	**Gross Alpha (pCi/L)**	**Total Uranium (pCi/L)**
CR[2] Hwy 191	0.132	0.01	8	8	<40	12	3
Atlas Seep	219.00	5.85	1550	3470	96	720	825
CR 0.0 mi BS[3]	3.57	0.09	10	14	<40	50	5
CR 0.25 mi BS	0.00	0.00	7	<5	<40	20	5
CR 0.5 mi BS	0.14	0.01	7	9	<40	19	3
CR 1.0 mi. BS	0.13	0.01	3	50	<40	19	5
Criteria value[4]	**1.29**	**0.02**	**40**	**40**	**60**	**15**	**20**

[1]Data from Nov. 8, 1996 letter from Utah Department of Environmental Quality to Mr. Myron Fliegel, Uranium Recovery Branch, NRC, Washington, D.C.

[2]CR refers to within Colorado River.

[3]BS refers to distance below entry of seep into river.

[4]Criteria from various sources obtained from Utah Department of Environmental Quality (1999). Ammonia criteria for 4-d average concentration based on pH of 8.0 and temperature of 15 °C for Class 3B river. Criteria do not exist for fish and wildlife for all constituents; thus, sources and resource categories may vary. Data are for comparison purposes only.

Table 2. Water quality of nearshore samples (at shallow bank/water interface) at various locations during 1998 Quick Response Study. Refer to Figure 1 for station locations.

Site	Lateral Location (m from shore)	Total ammonia (mg/L as N)	Un-ionized ammonia (mg/L as N)[1]	pH	Temp (°C)	Conductivity (µmhos)	Dissolved Oxygen (mg/L)
Island	nearshore	0	0	8.54	24.2	1057	6.74
East Side 1	nearshore	0	0	8.47	26.6	1097	8.2
East Side 2	nearshore	0	0	8.38	23.8	1067	7.41
Upstream 100 m	nearshore	0	0	8.58	25.0	1190	8.7
Upstream 200 m	nearshore	0	0	8.69	25.5	1200	8.3
Moab Wash	nearshore	21	4.7	8.69	25.5	1200	8.3
Downstream 100 m	nearshore	224	18.9	8.03	31	7100	4.8
Downstream 200 m	nearshore	35	2.84	8.12	28	2150	9.8
Downstream 300 m	nearshore	19	1.75	8.22	26	1700	8.5
Downstream 400 m	nearshore	5	0.58	8.38	24.5	1288	8.3
Downstream 500 m	nearshore	1	0.15	8.51	24.3	1230	7.04
Downstream 700 m	nearshore	1	0.13	8.47	23.9	1101	7.81
Downstream 800 m	nearshore	0	0	8.48	23.59	1103	7.23
Downstream 900 m	nearshore	0	0	8.35	24.5	1100	7.19
Downstream 1000 m	nearshore	0	0	8.49	24.4	1009	7.6

[1]Calculated based on pH and temperature (Thurston et al., 1977).

Table 3. Ammonia and metals measurements taken in the vicinity of the Atlas Mill tailings pile during the August 1998 Quick Response Study. Criteria are 4-d averages for wildlife in Class 3B waters.

Site	Total Ammonia (mg/L as N)	Un-ionized Ammonia (mg/L as N)	Manganese (µg/L)	Copper (µg/L)	Zinc (µg/L)
Surface Waters					
CERC well water reference	0.3	0.05	15	2	8
Colorado River Hwy 191 reference	0.2	0.03	22	4	8
Courthouse Wash reference	0.4	0.01	28	5	5
Center Island reference	0.0	0	1	3	40
East side river reference site 1	0.0	0	6	6	4
East side river reference site 2	0.0	0	7	4	3
Moab Wash site 1	21	2.9	53	6	8
Moab Wash site 2	224	42	24	5	25
Pore Waters					
Courthouse Wash pore	0.5	0.06	145	8	48
Center Island pore reference	0.0	0	38	4	18
East side river reference pore 1	0.0	0	6	4	18
East side river reference pore 2	0.0	0	8	5	8
Moab Wash pore	477	19.43	28	77	12
Moab Wash pore 100 m downstream	685	58.20	42	286	71
Criteria value[1]	**0.32[2]**	**0.05**	**40**	**12**	**110**

[1]Criteria from Utah Department of Environmental Quality (1999) for Class 3B river and personal communications with Loren Morton (UDEQ). Criteria do not exist for fish and wildlife for all constituents; sources and resource categories may vary. Data are for comparison purposes only.

[2]4-d chronic average ammonia criteria based on pH of 8.5 and temperature of 25 °C for Class 3B river.

Table 4. Radiochemical measurements taken in the vicinity of the Atlas Mill tailings pile during the August 1998 Quick Response Study. All units listed are as pCi/L.

Site	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	U234 (pCi/L)	U235 (pCi/L)	U238 (pCi/L)	Th227 (pCi/L)	Th238 (pCi/L)	Th230 (pCi/L)	Th232 (pCi/L)
Surface Waters									
Col. Riv. Hwy 191 reference	7	0	2.64	0.1	1.44	0	0	0	0
Courthouse Wash reference	0	40	3.21	0.1	0.2	0	0	0	0
Center Island reference	0	15	0.6	0	0.3	0	0	0	0
East side river reference site 1	0	18	3.2	0.2	1.9	0	0	0	0
East side river reference site 2	5.6	0	3.4	0.1	2.0	0	0	0	0
Moab Wash site 1	54	12	0.3	1.8	0.3	0	0	0	0
Moab Wash site 2	21	0	0.2	1.0	0.2	0	0	0	0
Pore Waters									
Courthouse Wash pore	7	0	1.0	0	0.6	0	0	0	0
Center Island pore reference	8	0	1.0	0	0.7	0	0	0	0
East side river reference pore 1	0	8	4.1	0.1	2.9	0	0.1	0.2	0.1
East side river reference pore 2	0	28	7.7	0.4	6.7	0	0.1	4.5	0.1
Moab Wash pore	905	601	0	0.3	0	0.1	0	0.3	0.1
Moab Wash pore 100 m downstream	170	116	0.1	0.5	0.1	0	0	0.1	0
Criteria value[1]	**15**	**50**	NA[2]	NA	NA	NA	NA	NA	NA

[1]Criteria from Utah Department of Environmental Quality (1999).

[2]Not available at time of report; pending from Utah Department of Environmental Quality.

Table 5. Sensitivity of Colorado pikeminnow and fathead minnows to total ammonia (mg/L as N) at various time intervals of exposure.

		LC50 (95% C.I.)			
Species	**Water Type**	**9h**	**24h**	**48h**	**72h**
Colorado pikeminnow[1]	CERC well	23 (14-37)	21 (15-31)	19 (14-28)	18 (10-31)
Fathead minnow[1]	CERC well	24 (18-32)	19 (16-24)	13 (11-16)	9 (7-12)
Colorado pikeminnow[2]	Colorado River	40 (32-64)	35 (32-64)	33 (32-64)	33 (32-64)

[1]LC50 determined using Probit Analysis.
[2]LC50 determined using non-linear interpolation.

Table 6. Sensitivity of Colorado pikeminnow and fathead minnows to un-ionized ammonia (mg/L as N) at various time intervals of exposure.

		LC50 (95% C.I.)			
Species	**Water Type**	**9h**	**24h**	**48h**	**72h**
Colorado pikeminnow[1]	CERC well	1.54 (0.96-2.50)	1.43 (1.01-2.09)	1.30 (0.92-1.88)	1.17 (0.69-2.07)
Fathead minnow[1]	CERC well	1.62 (1.23-2.17)	1.29 (1.05-1.60)	0.89 (0.73-1.08)	0.61 (0.45-0.84)
Colorado pikeminnow[2]	Colorado River	2.65 (2.14-4.27)	2.33 (2.14-4.28)	2.21 (2.14-4.28)	2.21 (2.14-4.28)

[1]LC50 determined using Probit Analysis.
[2]LC50 determined using non-linear interpolation.

Table 7. Chronic mortality of Colorado pikeminnow at various rates calculated using the method of Sun et al. (1995). Data are based on the results of 7-d static renewal studies using 90-d old fish.

Time (d) and Mortality (LC_x)	**Total Ammonia**			**Un-ionized Ammonia**		
	LCx (mg/L)	**Lower Limit (mg/L)**	**Upper Limit (mg/L)**	**LCx (mg/L)**	**Lower Limit (mg/L)**	**Upper Limit (mg/L)**
7-d						
5%	15.38	10.98	19.76	1.02	0.73	1.32
1%	10.93	6.88	14.98	0.73	0.46	1
0.50%	9.44	5.6	13.21	0.63	0.37	0.88
0.10%	6.74	3.43	10.06	0.45	0.22	0.67
0.05%	5.83	2.75	8.91	0.38	0.13	0.59
0.01%	4.163	1.69	6.77	0.27	0.1	0.44
14-d						
5%	13.62	9.34	17.91	0.91	0.62	1.19
1%	9.68	5.81	13.52	0.64	0.38	0.9
0.50%	8.36	4.77	12.01	0.55	0.31	0.8
0.10%	5.972	2.86	9.08	0.39	0.19	0.6
0.05%	5.165	2.29	8.04	0.34	0.15	0.53
0.01%	3.687	1.32	6.05	0.24	0.08	0.4
30-d						
5%	11.918	7.78	16.09	0.79	0.52	1.07
1%	8.472	4.85	12.18	0.56	0.32	0.81
0.50%	7.323	3.94	10.72	0.48	0.26	0.71
0.10%	5.226	2.32	8.19	0.34	0.15	0.54
0.05%	4.52	1.86	7.19	0.3	0.12	0.47
0.01%	3.226	1.02	5.4	0.21	0.07	0.36
60-d						
5%	10.556	6.61	14.51	0.7	0.44	0.97
1%	7.503	4.06	10.95	0.5	0.27	0.73
0.50%	6.486	3.27	9.702	0.43	0.21	0.64
0.10%	4.628	1.94	7.36	0.3	0.12	0.48
0.05%	4.003	1.51	6.44	0.26	0.1	0.43
0.01%	2.857	0.89	4.86	0.19	0.05	0.32
90-d						
5%	9.832	5.92	13.62	0.65	0.39	0.91
1%	6.989	3.69	10.38	0.46	0.24	0.68
0.50%	6.041	2.93	9.14	0.4	0.19	0.61
0.10%	4.311	1.74	6.88	0.28	0.11	0.46
0.05%	3.728	1.33	6.04	0.24	0.09	0.4
0.01%	2.662	0.76	4.57	0.17	0.04	0.3
Criteria	**0.8[1]**					

[1]Criteria and un-ionized ammonia calculations based on pH of 8.1 and temperature of 25 °C.

Table 8. Sensitivity of razorback sucker, Colorado pikeminnow, and fathead minnow to total and un-ionized ammonia determined by Dwyer (1998).

Species	**7-d LC50 Total Ammonia (mg/L as N)[1]**	**7-d LC50 Un-ionized Ammonia (mg/L as N)[2]**
Razorback sucker	12.3 - > 7	1.04
Colorado pikeminnow	4.44 – 22.6	0.229
Fathead minnow	7.34 - > 17	0.277

[1] Range of 2 or more tests.

[2] Calculated from lowest total ammonia value measured.

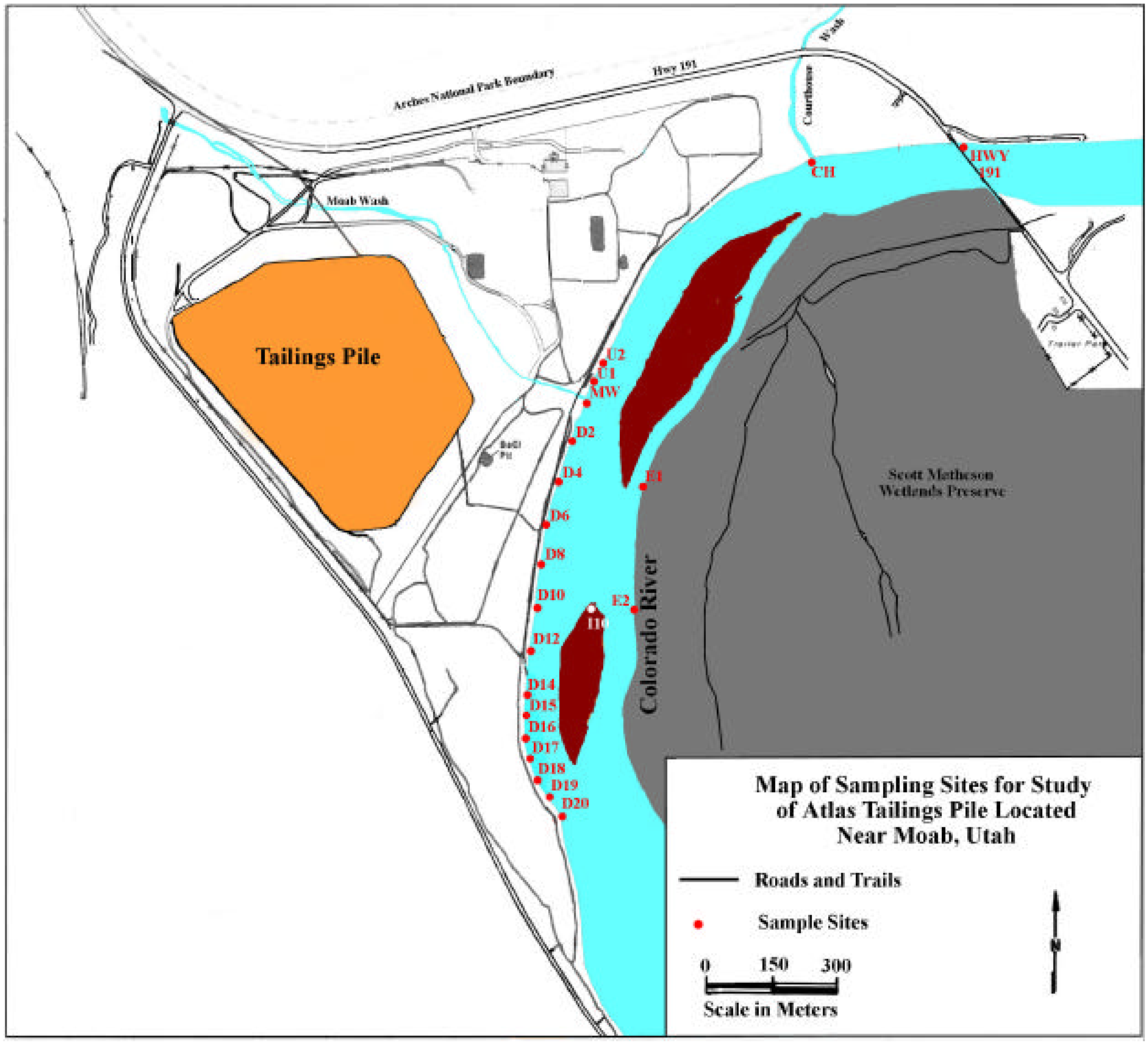

Figure 1. Map of sampling locations for 1998 Quick Response Study. Note that each sample location represents a 50-m increment upstream (U), downstream (D) of Moab Wash (MW). For example, D2 is located 100 m downstream of Moab Wash. Upstream (U) and east side of river (E) are considered reference stations.

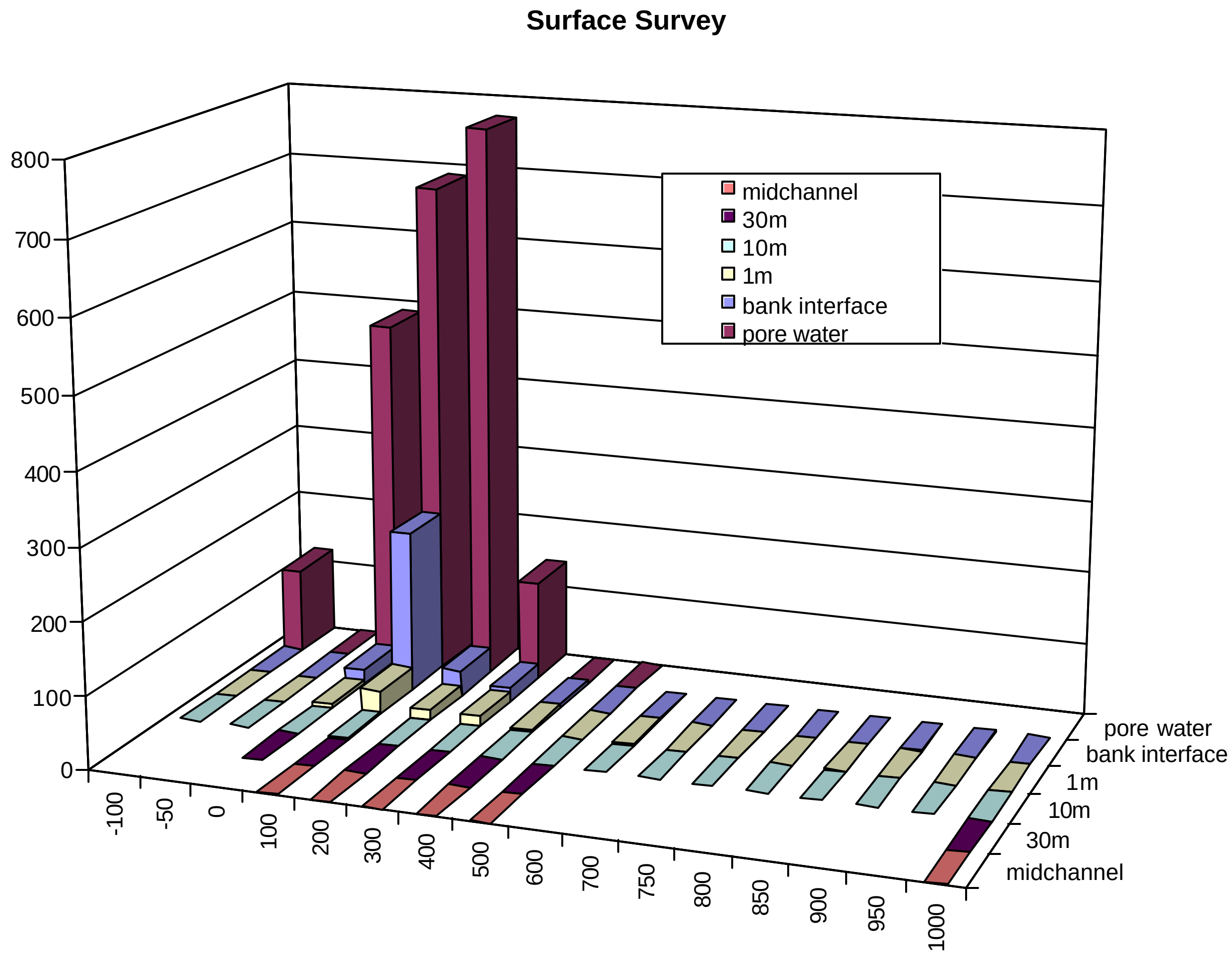

Figure 2. Spatial locations of total ammonia concentrations (mg/L as N) during 1998. Numbers on Y-axis are total ammonia concentrations. Numbers along X-axis are meters upstream or downstream of Moab Wash. Numbers on Z-axis are meters from the bank interface. Porewater samples (i.e., groundwaters) were taken from pit on bank located approximately 0.5 m from edge of river.

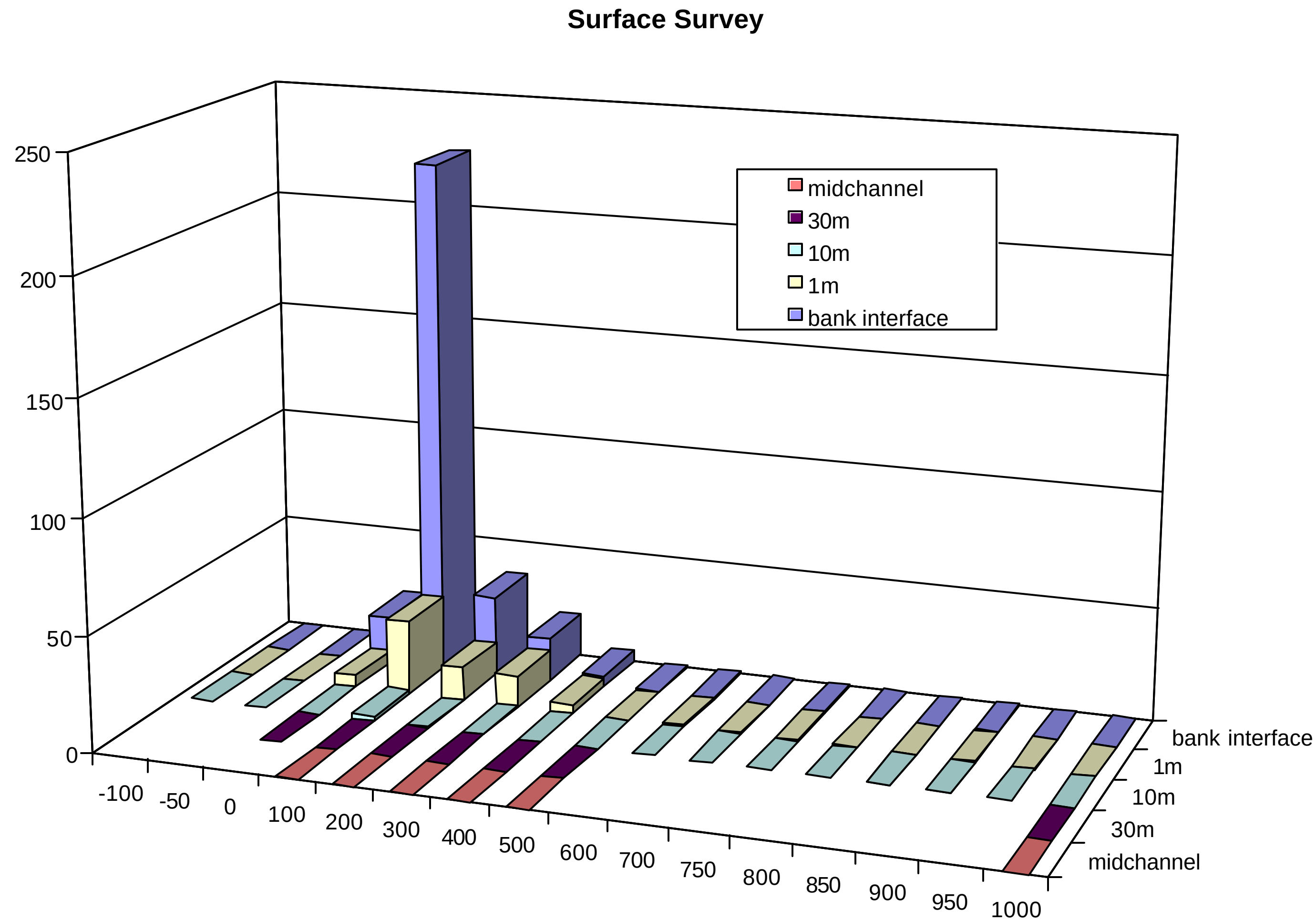

Figure 3. Spatial locations of total ammonia concentrations (mg/L as N) during 1998 with pore waters excluded. Numbers on Y-axis are total ammonia concentrations. Numbers along X-axis are meters upstream or downstream of Moab Wash. Numbers on Z-axis are meters from the bank interface.

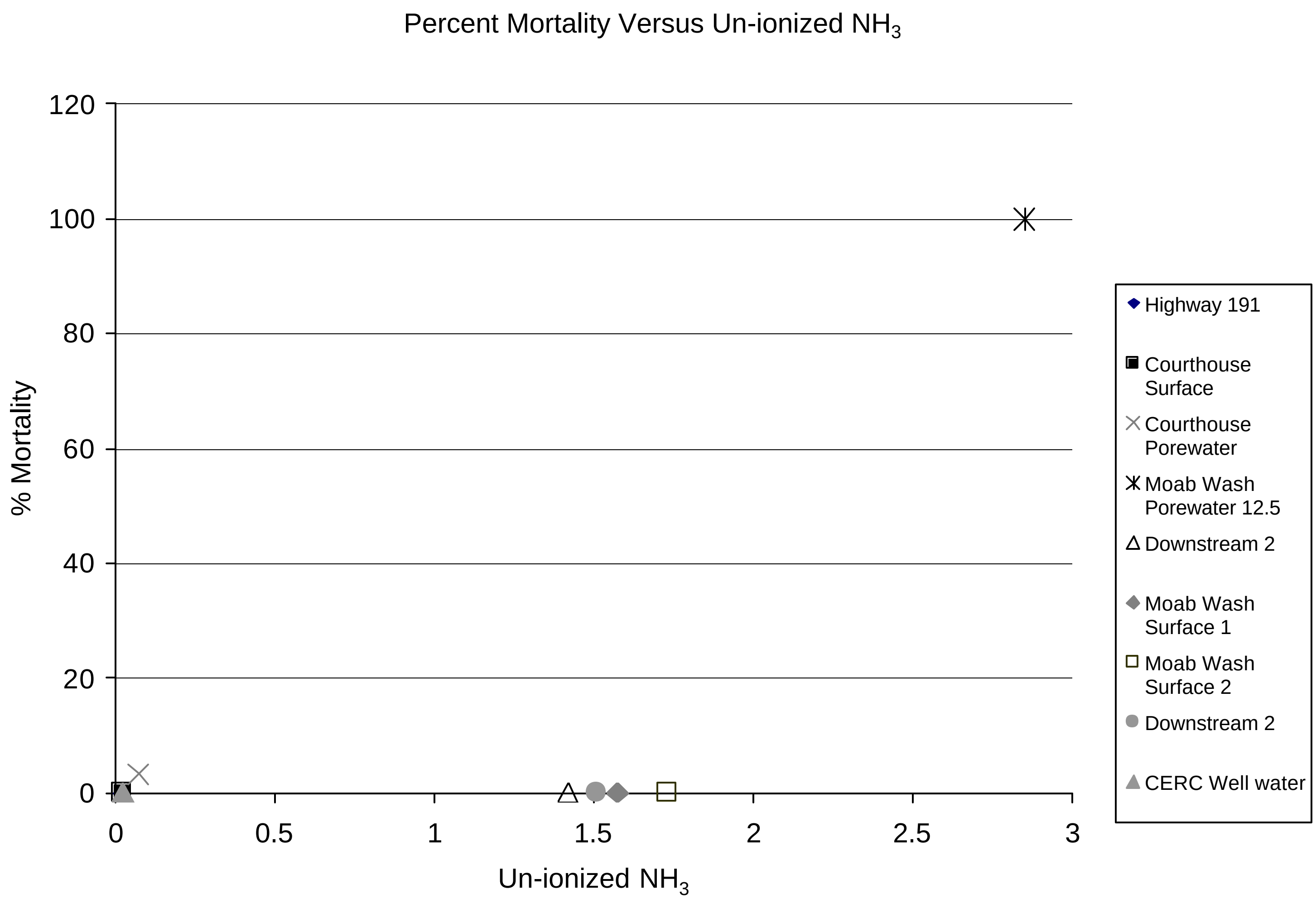

Figure 4. Response of Colorado pikeminnow over 7-d chronic exposure of field-collected water in 1998. The data indicates that un-total ammonia entering the river as groundwater was toxic to Colorado pikeminnow and that surface waters from four locations were approaching the laboratory-measured 72-h LC50 (2.21 mg/L un-ionized ammonia) of ammonia in Upper Colorado River water.