Preliminary Assessment of Impacts of Drainage from the Big Springs Mine to Aquatic Organisms in the North Fork Humboldt River, Elko County, Nevada, 1998

U.S. FISH AND WILDLIFE SERVICE
NEVADA FISH AND WILDLIFE OFFICE
DIVISION OF ENVIRONMENTAL QUALITY
RENO, NEVADA

Preliminary Assessment of Impacts of Drainage from the Big Springs Mine to Aquatic Organisms in the North Fork Humboldt River, Elko County, Nevada, 1998

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EXECUTIVE SUMMARY

The decline of water quality in the North Fork Humboldt River downstream of the Big Springs Mine, Elko County, Nevada, following the initiation of gold mining activities in the watershed raised concerns for the continued health of fish, wildlife, and their habitat. Following mining, concentrations of total dissolved solids, sulfate, and selenium in water at sites downstream of the mine have consistently exceeded Nevada water quality standards and/or levels that are potentially toxic to fish and wildlife. Concentrations of aluminum, copper, iron, manganese, nickel, and zinc in water downstream of waste rock dumps during periods of high seasonal runoff also have exceeded standards or potentially toxic levels. During high flow periods, large loads of these metals are mobilized from tributaries containing waste rock dumps. The U.S. Fish and Wildlife Service initiated a limited investigation to determine if a more detailed investigation of potential impacts to fish, wildlife, and environmental quality in the North Fork Humboldt River was warranted. Arsenic, cadmium, manganese, nickel, selenium, and zinc in bottom sediment and aquatic invertebrates downstream of the mine site were elevated. Arsenic, manganese, nickel, selenium, and zinc in sediment and arsenic and selenium in invertebrates exceeded potentially toxic concentrations. Concentrations of metals and trace elements were also elevated in Lahontan cutthroat trout. Lahontan cutthroat trout were common in suitable habitats in the North Fork Humboldt River and a reference stream. Other fish species were rare or absent in both streams. Adult trout from the North Fork Humboldt River had a lower mean condition factor. The incidence of external abnormalities, blood cell measurements, muscle lipid content, hepatosomatic index values, liver enzyme levels, bacterial and viral infection, and histology of gill, liver, kidney, heart, and testes were similar in Lahontan cutthroat trout from both streams. Differences in blood plasma protein concentrations were found between the sites. The investigation concludes that degraded water quality has the potential to adversely affect fish and wildlife in the North Fork Humboldt River, including a listed species and migratory birds. Remedial actions are needed to correct water quality concerns. Natural resource trustees should initiate meetings to discuss the need to pursue Natural Resource Damage Assessment and Restoration activities.

INTRODUCTION

Concentrations of a several inorganic contaminants in water, including a number of potentially toxic trace elements, have increased in the North Fork Humboldt River (NFHR) since initiation of gold mining in the watershed. Increased water-borne concentrations of these constituents raised concerns for adverse effects to fish and wildlife associated with this watershed. This reach of the NFHR supports Lahontan cutthroat trout (LCT; *Oncorhynchus clarki henshawi*), a federally-listed threatened species and Columbia spotted frog (*Rana pretiosa*), a candidate for listing as endangered or threatened. Additionally, at least 13 species of concern and a variety of migratory birds have been identified in the vicinity of the mine site. The NFHR watershed is a recreational site in which the Nevada Division of Wildlife manages a recreational trout fishery.

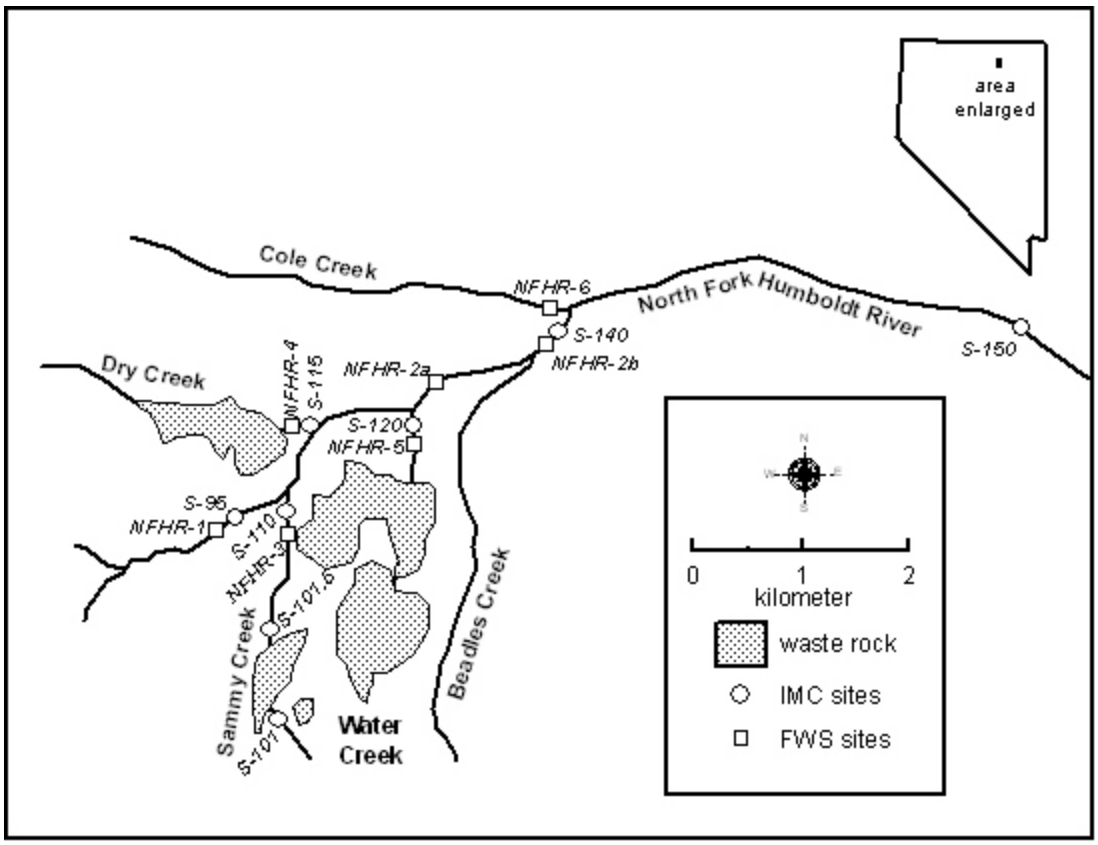

Figure 1. Map of the North Fork Humboldt River and major tributaries in the Independence Range, Elko County, Nevada. Approximate locations of Independence Mining Company (IMC) water quality monitoring sites and Fish and Wildlife Service (FWS) data collection sites are shown.

The Independence Mining Company, Inc. (IMC), Big Springs Mine, is located in the headwaters of the NFHR in the Independence Range, Elko County, Nevada (Figure 1). The mine occurs on lands administered by the U.S. Forest Service. The site occurs at elevations ranging from 2,260 to 2,800 m (7,400 to 9,200 ft). The NFHR originates from several drainages in and near the mine site. The area receives about 65 to 75 cm (25 to 30 inches) of precipitation per year, with most occurring as snow between the months of October and May. Peak flow in the river coincides with snow melt (May and June) with low river flow occurring in the late summer. The NFHR and its tributaries upstream of the Forest Service boundary have been designated as a Class A waters of the State (Nevada Administrative Code 445A.1124). Beneficial uses of Class A waters include municipal or domestic supply, aquatic life, propagation of wildlife, irrigation, livestock, and contact/non-contact recreation. Applicable standards for designated beneficial uses are provided in Table 1.

IMC initiated mining in 1987, with active mining continuing until 1994. During the life of the mine, more than 31,000,000 tons of waste rock were generated (Earman 1996). The mine is currently in a closure and reclamation phase. Remaining mine components consist of three open pits, high walls, and cross-valley fill waste rock dumps in Water Canyon, Dry Canyon, and the Sammy Creek drainages (Figure 1). All three drainages enter the NFHR.

Table 1. Regulatory standards applicable to designated waters in Nevada. Standards are from Nevada Administrative Code (NAC) 445A.119 and 445A.144.

constituent	municipal or domestic supply	propagation of aquatic life		irrigation	watering of livestock	propagation of wildlife
		1-hour avg.	96-hour avg.			
pH	5.0 -9.0	6.5 -9.0	6.5 - 9.0	4.5 - 9.0	5.0 - 9.0	7.0 - 9.2
TDS (mg/L)	500	-	-	-	3,000	-
sulfate (mg/L)	250	-	-	-	-	-
aluminum (μg/L)	-	750[a]	87[a]	-	-	-
arsenic (μg/L)	50	342[b, c]	180[b, c]	100	200	-
barium (μg/L)	1,000	-	-	-	-	-
beryllium (μg/L)	0	-	-	100	-	-
boron (μg/L)	-	-	-	750	5,000	-
cadmium (μg/L)	10	[c, d]	[c, d]	10	50	-
chromium (μg/L)	-	[c, d]	[c, d]	100	1,000	-
copper (μg/L)	-	[c, d]	[c, d]	-	-	-
fluoride (μg/L)	-	-	-	1,000	2,000	-
iron (μg/L)	-	1,000	1,000	5,000	-	-
lead (μg/L)	50	[c, d]	[c, d]	5,000	100	-
manganese (μg/L)	-	-	-	200	-	-
mercury (μg/L)	2	2[c]	0.012	-	10	-
molybdenum (μg/L)	-	19	19	-	-	-
nickel (μg/L)	13.4	[c, d]	[c, d]	200	-	-
selenium (μg/L)	10	20	5	20	50	-
silver (μg/L)	50	[c, d]	[c, d]	-	-	-
zinc (μg/L)	-	[c, d]	[c, d]	2,000	25,000	-

[a] Aquatic life criterion recommended by the U.S. Environmental Protection Agency.

[b] The arsenic standards for aquatic life are specific for As+3.

[c] The standard applies to dissolved fraction only.

[d] Standards for aquatic life are based on water hardness, which is expressed as mg/L $CaCO_3$. Formulae are as follows:

cadmium

1-hour: 0.85exp[1.128 ln(hardness)-3.828]

96-hour: 0.85exp[0.7852 ln(hardness)-3.490]

chromium(+3)

1-hour: 0.85exp[0.8190 ln(hardness)+3.688]

96-hour: 0.85exp[0.8190 ln(hardness)+1.561]

copper

1-hour: 0.85exp[0.9422 ln(hardness)-1.464]

96-hour: 0.85exp[0.8545 ln(hardness)-1.465]

lead

1-hour: 0.50exp[1.273 ln(hardness)-1.460]

96-hour: 0.25exp[1.273 ln(hardness)-4.705]

nickel

1-hour: 0.85exp[0.8460 ln(hardness)+3.3612]

96-hour: 0.85exp[0.8460 ln(hardness)+1.1645]

silver

0.85exp[1.72 ln(hardness)-6.52]

zinc

1-hour: 0.85exp[0.8473 ln(hardness)+0.8604]

96-hour: 0.85exp[0.8473 ln(hardness)+0.7614]

The Nevada Fish and Wildlife Office of the U.S. Fish and Wildlife Service (Service) is concerned that elevated inorganic contaminants contained in drainage from the Big Springs Mine have adversely affected, or have the potential to adversely affect, beneficial uses of water, sediment and food web quality, and aquatic organisms and communities in the NFHR, Elko County, Nevada (Figure 1). Such effects may impact the habitat quality and the long-term health and survival of aquatic and riparian species. Additionally, two elements identified at elevated concentrations in drainage from the mine site (mercury and selenium) have a propensity to accumulate in higher trophic level organisms. As such, these elements may represent a hazard to humans who consume fish taken from this reach of the NFHR.

In 1998, the Service, with the assistance of the California-Nevada Fish Health Center, the U.S. Environmental Protection Agency (EPA) Region IX Laboratory, the Nevada Division of Wildlife, and the U.S. Forest Service (USFS) initiated a limited investigation to determine if a more detailed investigation of potential impacts to fish, wildlife, and environmental quality in the NFHR is warranted. Specific objectives of the investigation were to: 1) Determine if water quality conditions have existed that have the potential to adversely affect aquatic organisms; 2) assess chemical concentrations in water, bottom sediment, aquatic food web organisms, and fish tissues; 3) assess the general health and condition of fish, and 4) assess relative fish population and community structure. This report presents the findings of this investigation.

METHODS

Existing water quality data were reviewed to identify constituents of concern in the water column. Reviewed data included water quality analyses reported in Riverside Technology, Inc. (1986), Earman (1996), and water quality data obtained from the IMC and the USFS. Approximate locations of sites monitored by IMC that are discussed in this report are provided in Figure 1.

The Service, Nevada Division of Wildlife, USFS, and IMC representatives collected field data and samples from July 21 to 23, 1998. Data collection activities included: measurement of water quality parameters; collection of samples of filtered and unfiltered water, bottom sediment, aquatic invertebrates, and LCT gills, livers, muscle, and whole bodies for metal and trace element residue analyses; assessment of fish assemblage; assessment of fish condition; and assessment of selected LCT health indicators.

Data Collection Activities

Water Quality

Water quality parameters were measured and water samples were collected at seven sites, including NFHR upstream of mine disturbance (NFHR-1), NFHR approximately 100 m downstream of Water Canyon Creek confluence (NFHR-2a), Sammy Creek sedimentation basin outflow (NFHR-3), Dry Canyon Creek sedimentation basin outflow (NFHR-4), Water Canyon Creek sedimentation basin outflow (NFHR-5), Cole Creek approximately 100 m upstream of the confluence with NFHR (NFHR-6), and Foreman Creek at an elevation similar to sampling sites in the NFHR. Foreman Creek is located on the east slopes of the Independence Range

approximately 8 km south of the NFHR.

Water quality parameters measured in the field included temperature, dissolved oxygen, pH, and specific conductance. Temperature was measured with a Yellow Springs Instruments (YSI) model 33 S-C-T meter. The meter temperature calibration was verified with a Fisher Scientific Company model 15-041A thermometer with a manufacturer's certification to the National Institute for Standards and Technology. Dissolved oxygen was measured with a YSI model 57 oxygen meter. The dissolved oxygen meter was calibrated to elevation and water temperature before each use each day. A Cole Parmer model 59000-25 pH meter was used to measure pH. The pH meter was calibrated using pH 4 and 7 buffers prior to use each sampling day. Specific conductance was measured with a YSI model 33 S-C-T meter. Meter calibration was checked using 1,413 microsiemens per centimeter (µS/cm) reference solution prior to use each sampling day.

Chemical Analyses

Water samples for metal analyses were collected in certified clean 500 ml polypropylene bottles. Samples for major ion analysis were collected in certified clean 250 ml bottles. Samples were collected from midstream, mid-water column depth, while facing in an upstream direction by immersing a closed bottle then opening under water. Each sample bottle was rinsed three times using the above collection technique prior to collection of the sample. Rinsate was disposed of downstream of the sample collection site. Samples for major ion and dissolved metals analyses were filtered through 0.45 µm acetate filters into appropriate bottles. These bottles were rinsed at least twice with filtered water prior to sample collection. Samples were stored on blue ice in the field and shipped to the EPA Region IX laboratory within 24-hours of collection. One field blank and one filtration blank, each consisting of deionized water exposed to sample collection and processing conditions, were collected. These blanks were treated as individual samples and submitted for metals and trace element analysis. Additionally, one duplicate water sample and one double volume sample for laboratory quality control was collected. No preservatives were added to water samples.

Sediment samples were collected from sites NFHR-1, NFHR-2a, NFHR-6, Foreman, and the NFHR approximately 100 m upstream of the Cole Creek confluence (NFHR-2b). Samples of surficial materials (i.e., top 3 cm of sediment) were collected from areas of fine sediment deposition using a Wildco model number 2422 H12 core sampler. Each sample consisted of a minimum of five subsamples collected within a 10-m reach of the stream. Subsamples were composited in a certified clean 500 ml Nalgene® jar and mixed with a stainless steel knife. Samples of composited material were placed in certified clean 125 ml glass jars with teflon-lined closures. Sediment samples were stored on blue ice in the field and transferred to a freezer within 8-hours of collection.

Sediment collecting equipment was brushed to remove sediment and rinsed with site water between collection of subsamples at each site. Collecting equipment was washed with a brush and mild detergent, rinsed with a dilute nitric acid solution, triple rinsed with deionized water, and submerged in site water for at least one minute prior to use between sampling sites. An equipment blank was collected by rinsing deionized water over the equipment after decontamination. The rinsate was collected and submitted as a water sample for analysis of metals and trace elements. Additionally, one duplicate sediment sample and one laboratory Quality Control (QC) sediment sample was collected from areas of possible contamination.

Invertebrates were collected from riffle and run habitats within the stream using kicknets. Invertebrates were placed in a clean stainless steel tray and sorted from unwanted debris and placed in certified clean 60 ml-jars with teflon-lined closures in the field. Invertebrate samples were stored on blue ice in the field and transferred to a freezer within 8-hours of collection. Samples remained frozen before and during shipment to the EPA Region IX laboratory. All collecting equipment between each sampling site was washed with a brush and mild detergent, triple rinsed with deionized water, and submerged in site water for at least one minute prior to use.

LCT were collected from NFHR-2a, NFHR-2b, and Foreman sites by electroshocking. Electroshocking methods are described in Kolz et al. (1995). Samples of liver, gill, and muscle were collected during organosomatic assays described below. Gill and liver samples were composites of tissue from five fish. Whole fish and muscle from individual fish were submitted as discrete samples. Gill, liver, and muscle samples were removed in the field with pre-cleaned stainless steel instruments and placed in certified clean 60 ml glass jars with teflon-lined closures. Whole fish were placed in plastic bags. Samples were stored on blue ice in the field and transferred to a freezer within 8-hours of collection. Samples remained frozen before and during shipment to the EPA Region IX laboratory. Instruments were cleaned with a brush and mild detergent, rinsed with a dilute nitric acid solution, and triple rinsed with deionized water prior to use on each fish.

Fish Health and Condition

All captured fish were placed temporarily in a 5-gallon bucket then transferred to a live car in the stream. All fish were identified to species level, measured, weighed, and examined for external abnormalities. Fulton's condition factor for each fish was calculated using methods described in Anderson and Gutreuter (1983). All fish, with the exception of those selected for organosomatic assays and chemical analyses, were released back to the stream from which they were collected.

Organosomatic assays were conducted on 10 adult LCT each from NFHR and Foreman Creek. The organosomatic assay is a method for ordered observation and reporting of the gross morphology of selected organs, hematological parameters, and size criteria of each individual (Geode and Barton 1987; Foott 1990). Fish of appropriate size (150-275 mm) were selected at random from fish collected by electrofishing. Captured fish were held live in containers of ambient temperature water for up to 45 minutes before being sampled for blood and tissues. Each fish was anesthetized with CO_2 (buffered Alka-seltzer) , killed by blunt force to the head, rapidly examined for external organosomatic parameters, weighed, and measured for total and fork length. Fish were dissected and evaluated for condition of skin, eyes, gill, thymus, quantity of visceral fat, and any abnormalities of the internal organs. Criteria for the visceral fat scores were as follows: 0- no visceral fat on pyloric caeca or peritoneal cavity; 1 - < 50 % coverage of caeca and/or cavity fat diameter < caeca volume; 2 - > 50 % coverage of caeca and/or cavity fat diameter = caeca volume; 3 - caeca and cavity filled with fat, organs obscured by fat.

Blood was collected from the caudal peduncle into heparinized tubes. Blood samples were used for bloodsmears (methanol fixed, Leishman-Giemsa stain) and centrifuged at 10,000 RPM for 10 minutes for measurement of hematocrit, leukocrit, and collection of plasma. Plasma was frozen on dry ice. After an internal organosomatic examination and weighing of the liver, samples of kidney were collected for *R. salmoninarum* antigen ELISA and cultured bacteria

(BHIA and TYES agars). Pooled samples of cranial bone were collected for assessment of *Myxobolus cerebalis* spores by Pepsin-trypsin digest. Pooled samples of spleen were collected for viral assay on both EPC and CHSE214 cell lines. Gill, kidney, liver, heart, and intestine tissues collected for histology were placed in Davidson's fixative and later processed for hematoxylin- and eosin-stained slides. Blocks of dorsal muscle were frozen for determination of the percent lipid using chloroform-methanol extraction and gravimetric analysis. Alanine aminotransferase and aspartate aminotransferase were tested in the plasma from four fish out each sample group using a Johnson & Johnson DTSC analyzer.

Statistical relations among TDS, sulfate, and selenium were examined using linear regression. Analysis of variance and t-tests were used to examine relationships among measures of fish assemblage, condition, and health within and between streams. Statistical significance in all tests was assigned at $p<0.050$.

Analytical Quality Assurance/Quality Control

Aluminum, barium, calcium, iron, magnesium, selenium, sodium, and zinc in the deionized water blank were detected above the absolute value of the instrument detection limit but were below the quantitation limit. All matrix spike recoveries were within the 75-125% method quality control limit. The relative percent differences for the duplicates were less than or equal to the quality control limit of 20% for all elements where the sample result was greater than or five times the quantitation limit. For elements where the sample result was less than five times the quantitation limit, the difference between the duplicates was less than the quantitation limit, as required by the method. All laboratory control recoveries were within the 80-120% method quality control limits. All other quality control criteria for water were met.

The matrix spike recoveries for antimony (49.1%), lead (65.5%), mercury (62.7%), selenium (<74.5%), and thallium (37.2%) in a sediment control sample were outside of the 75-125% method quality control limit. The matrix spike recoveries for arsenic in a tissue control sample was outside of the 75-125% method quality control limit. The duplicate relative percent differences for barium (20.7%), iron (24.7%), manganese (34%), and nickel (23.6%) for a sediment sample were outside of the quality control limit of 20%. The duplicate relative percent differences for arsenic (22.8%) for a tissue sample were outside of the quality control limit of 20%. Analytical spike recoveries for arsenic (84%), selenium (<81%), and thallium (<67%) for one or more sediment samples and arsenic (<84%), lead (<82%), selenium (58%), and thallium (<82%) in one or more tissue samples were outside of the 85-112% quality control limit

RESULTS

Existing Water Quality Data

Total Dissolved Solids

Limited data were available on total dissolved solids (TDS) from 1986 while more comprehensive data were obtained from 1994 to 1998. Specific conductance measurements were available for a broader time period at most locations. Specific conductance, which is a measure of the ability of water to conduct an electrical current, provides a relative measure of total dissolved solids in water. In the NFHR, specific conductance was positively correlated with TDS concentrations ($p<0.001$, $r^2=0.958$, $n=92$). Specific conductance (Table 2) and TDS (Table 3) in two tributaries containing waste rock dumps, Sammy Creek (site S-110) and Water Canyon Creek (S-120), have increased since the initiation of mining in the headwaters of the NFHR.

Table 2. Mean specific conductance (microsiemens per centimeter; µS/cm), number of samples (no.), and range in water at seven sites near the headwaters of the North Fork Humboldt River (NFHR), Elko County, Nevada, 1986-1998. Site locations are shown in Figure 1.

		Location						
Year		S-95	S-101	S-110	S-115	S-120	S-140	S-150
1986	mean (no.)	-[b]	-	109 (2)	-	77 (2)	91 (2)	151 (2)
	range			65-152		63-91	57-124	105-197
1987	mean (no.)	-	-	213 (7)	-	89 (7)	129 (7)	195 (8)
	range			67-435		64-111	66-190	88-270
1988	mean (no.)	-	-	257 (8)	-	105 (8)	145 (13)	214 (12)
	range			105-490		77-175	88-320	110-340
1989	mean (no.)	-	-	295 (8)	-	121 (9)	180 (7)	198 (11)
	range			150-440		95-150	109-225	122-300
1990	mean (no.)	-	-	398 (8)	-	199 (7)	217 (11)	215 (11)
	range			345-470		115-340	170-275	130-300
1991	mean (no.)	-	-	540 (10)	625 (5)	342 (10)	328 (12)	280 (9)
	range			260-1022	266-870	149-780	230-510	158-500
1992	mean (no.)	78 (5)	-	200 (1)	696 (7)	200 (1)	370 (11)	-
	range	60-90		-	155-1,230	-	240-640	
1993	mean (no.)	75 (11)	-	-	1,133 (16)	-	483 (21)	-
	range	40-110			500-1,950		290-921	
1994	mean (no.)	68 (5)	69 (2)	659 (11)	1,052 (5)	876 (14)	650 (13)	451 (12)
	range	51-82	64-74	430-855	660-1,550	536-1,390	427-851	251-740
1995	mean (no.)	65 (6)	149 (4)	694(9)	1,820 (7)	752 (7)	647 (10)	413 (4)
	range	41-84	88-208	335-838	759-3,030	440-1,109	230-819	308-554
1996	mean (no.)	53 (4)	102 (2)	1251 (7)	2,177 (3)	719 (4)	759 (8)	485 (6)
	range	44-65	59-145	449-3,100	1,050-3,450	376-960	376-1,000	273-680
1997	mean (no.)	69 (7)	176 (6)	955 (9)	2,200 (9)	1,256 (9)	-	528 (10)
	range	43-91	55-233	419-1,370	774-3,510	960-1,993		326-723
1998	mean (no.)	64 (4)	117 (3)	727 (5)	1,946 (5)	1,500 (2)	-	520 (8)
	range	45-92	52-199	430-1,070	1,060-3,130	1,320-1,860		267-771

[a] U.S. Forest Service

[b] - data were not available.

Table 3. Mean total dissolved solids (mg/L), number of samples (no.), and range of concentrations in water at seven sites near the headwaters of the North Fork Humboldt River (NFHR), Elko County, Nevada, 1986 and 1994-1998. Site locations are shown in Figure 1.

Year		Location						
		Upper NFHR (S-95)	Sammy Creek above waste rock (S-101)	Sammy Creek below waste rock (S-110)	Dry Canyon (S-115)	Water Canyon (S-120)	NFHR upstream of Cole Creek (S-140)	NFHR near USFS[a] boundary (S-150)
1986	mean (no.)	-[b]	-	64 (2)	-	29 (2)	41 (2)	84 (4)
	range			38-90		20-38	40-42	62-136
1994	mean (no.)	35 (5)	50 (2)	491 (11)	-	702 (12)	465 (13)	272 (12)
	range	10-47	-	309-655		350-1,140	286-619	149-380
1995	mean (no.)	41 (6)	87 (4)	526 (9)	2,150 (3)	745 (3)	486 (10)	268 (4)
	range	18-51	50-122	227-658	1,320-3,660	525-1,010	131-668	195-385
1996	mean (no.)	45 (4)	65 (2)	763 (7)	2,070 (3)	930 (4)	580 (8)	343 (5)
	range	32-58	48-82	360-1,330	916-3,513	652-1,470	168-766	164-483
1997	mean (no.)	36 (7)	109 (6)	748 (9)	2,176 (9)	1,084 (9)	-	363 (10)
	range	26-48	42-182	285-1,150	529-3,560	860-1,827		186-492
1998	mean (no.)	46 (4)	67 (3)	668 (5)	1,857 (5)	1,348 (5)	-	355 (8)
	range	34-56	49-102	367-882	943-3,290	1,090-1,760		166-531

[a] U.S. Forest Service

[b] - data were not available.

We were unable to locate pre-mining data in the third tributary, Dry Canyon Creek (S-115). Consistent with these increases, specific conductance and TDS concentrations have increased in the NFHR downstream of the mine site (Tables 2 and 3 and Figure 2). Pre-mining data for the upstream NFHR site (S-95) and Sammy Creek upstream of the waste rock dump (S-101) were not available. From 1994-98, TDS concentrations at S-95 were similar to pre-mining (1986) concentrations at the NFHR site downstream of mining disturbance (S-140). Similarly, TDS concentrations at site S-101 from 1994-1998 were generally within the range of the pre-mining concentrations at site S-110. Data for water quality changes from upstream to downstream of waste rock dumps was only available for Sammy Creek. TDS increased by about an order of magnitude between site S-101 immediately upstream of the Sammy Creek waste rock dump and S-101.5 immediately downstream of the dump and site S-110 further downstream (Table 3 and Figure 3). Monitoring at S-101.5 was discontinued in 1997.

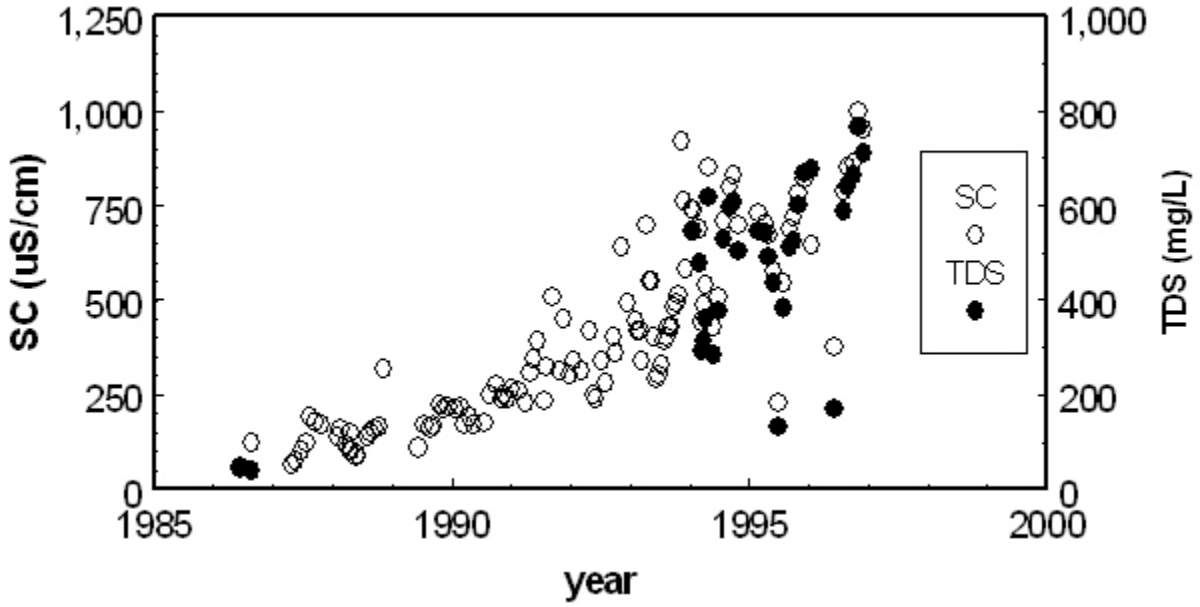

Figure 2. Specific conductance (SC; microsiemens per centimeter; uS/cm) and total dissolved solids (TDS; mg/L) in the North Fork Humboldt River between Water Canyon and Cole Creek (site S-140), Elko County, Nevada.

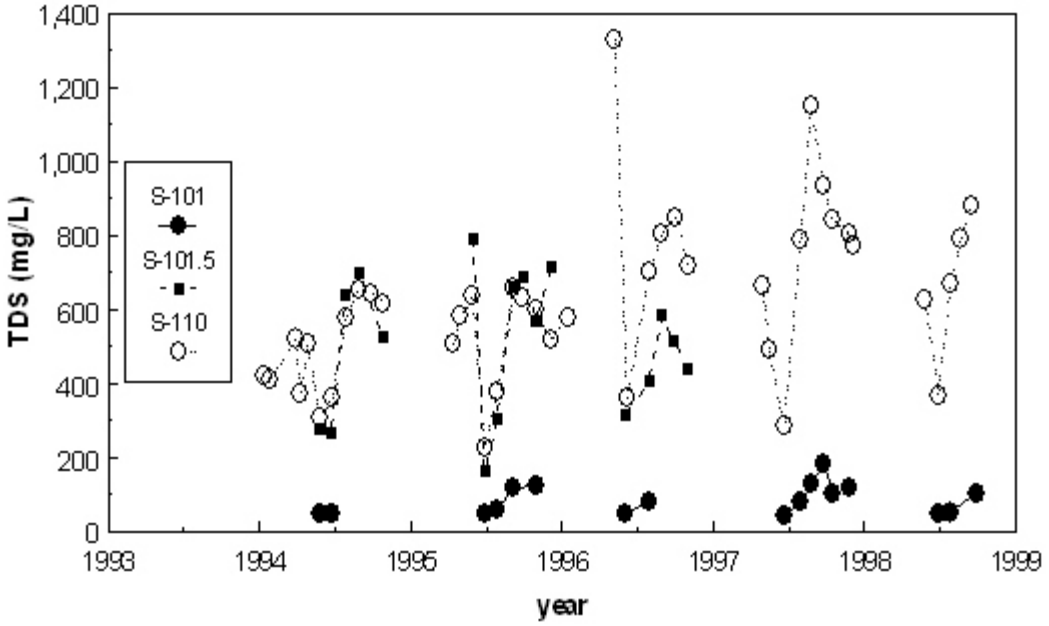

Figure 3. Total dissolved solids (TDS; mg/L) at sites upstream (S-101) and downstream (S-101.5 and S-110) of a waste rock dump in Sammy Creek, Elko County, Nevada.

Sulfate

Sulfate concentrations in the NFHR were positively correlated with TDS ($p<0.001$; $r^2=0.975$, n=99). Like TDS, sulfate concentrations have increased since initiation of mining in tributaries containing waste rock dumps (Table 4) and the NFHR downstream of the mine site (Figure 4). Again, notable increases occurred between sites S-101 and S-110 in Sammy Creek.

Table 4. Mean sulfate concentrations (mg/L), number of samples (no.), and range of concentrations in water from seven sites near the headwaters of the North Fork Humboldt River (NFHR), Elko County, Nevada, 1986-1998. Site locations are shown in Figure 1.

		Location						
Year		Upper NFHR (S-95)	Sammy Creek above waste rock (S-101)	Sammy Creek below waste rock (S-110)	Dry Canyon (S-115)	Water Canyon (S-120)	NFHR upstream of Cole Creek (S-140)	NFHR near USFS[a] boundary (S-150)
1986	mean (no.)	-[b]	-	9 (2)	-	4 (2)	5 (2)	8 (2)
	range			3-14		3-4	3-6	3-13
1987	mean (no.)	-	-	23 (8)	-	6 (8)	10 (8)	11 (9)
	range			5-50		5-8	4-19	4-15
1988	mean (no.)	-	-	20 (8)	-	6 (8)	14 (13)	13 (12)
	range			12-36		4-9	5-30	7-27
1989	mean (no.)	-	-	53 (8)	-	18 (9)	17 (7)	13 (11)
	range			31-100		10-28	11-24	2-19
1990	mean (no.)	-	-	88 (7)	-	39 (7)	32 (11)	22 (11)
	range			35-143		25-52	13-47	14-30
1991	mean (no.)	-	-	212 (10)	243 (5)	110 (10)	76 (13)	61 (9)
	range			71-539	75-408	27-322	22-154	23-157
1992	mean (no.)	8 (4)	-	190 (1)	460 (6)	45 (1)	108 (10)	-
	range	5-14		-	150-945	-	41-284	
1993	mean (no.)	6 (12)	-	-	605 (16)	-	177 (21)	-
	range	3-9			253-1,210		104-438	
1994	mean (no.)	5 (5)	7 (2)	267 (11)	577 (5)	428 (12)	268 (13)	132 (12)
	range	1-7	6-8	185-370	331-1,000	188-805	151-420	57-171
1995	mean (no.)	4 (6)	16 (4)	302 (9)	1,425 (3)	473 (3)	283 (10)	128 (4)
	range	2-10	7-24	124-394	840-2,500	324-643	72-394	93-172
1996	mean (no.)	6 (4)	11 (2)	439 (7)	1,366 (3)	560 (4)	369 (8)	166 (6)
	range	5-7	6-15	191-694	538-2,400	388-844	130-510	68-250
1997	mean (no.)	5 (7)	18 (6)	458 (9)	1,502 (9)	697 (9)	-	187 (10)
	range	2-9	5-24	170-674	440-2,440	548-1,100		100-255
1998	mean (no.)	4 (4)	12 (3)	389 (5)	1,203 (5)	824 (5)	-	180 (8)
	range	2-6	5-21	172-516	565-2,140	666-1,100		79-274

[a] U.S. Forest Service
[b] - data were not available.

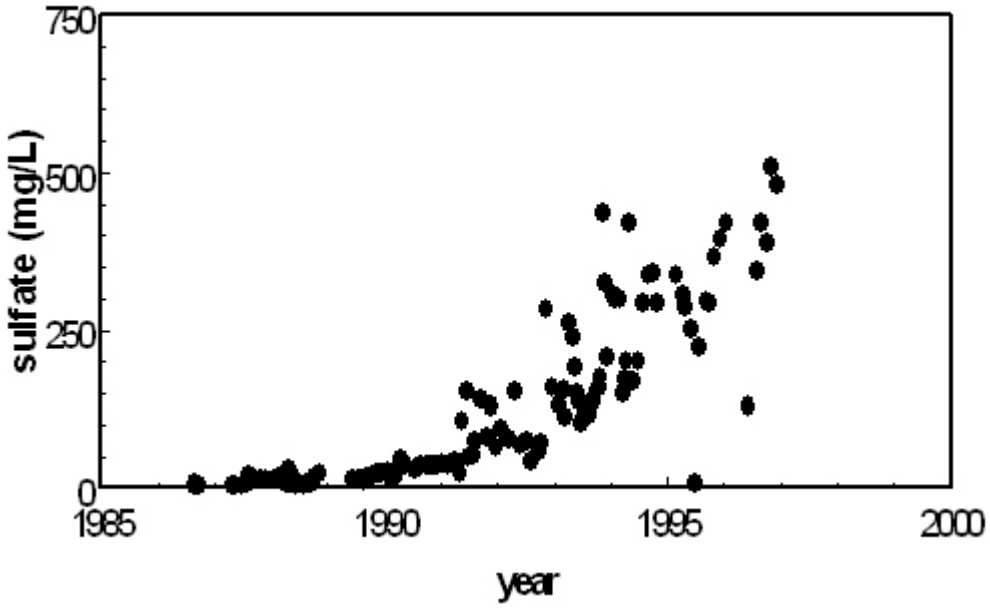

Figure 4. Sulfate concentrations (mg/L) in the North Fork Humboldt River between Water Canyon and Cole Creek (site S-140), Elko County, Nevada.

pH and Alkalinity

Available data indicate that mean pH in the NFHR and the tributaries near the confluence with the NFHR has not changed substantially over time (Table 5). One exception is Dry Canyon Creek where the pH appears to have increased since 1991.

The pH in the NFHR and the tributaries fluctuates seasonally. Fluctuations appeared to be inversely related to flow, in that the minimum pH was typically associated with peak discharge during Spring snow melt and runoff (Figure 5). During peak runoff, alkalinity was also decreased (Figure 6). Seasonal fluctuations of pH and alkalinity likely reflect characteristics of atmospheric precipitation and associated snow pack runoff. However, monitoring data from the site immediately downstream of the Sammy Creek waste rock dump (site S-101.5) in 1994-96 indicate seasonal declines of pH and alkalinity beyond levels noted at other sites. During the initial spring runoff, the alkalinity declined to < 1 mg/L as $CaCO_3$ in samples collected during spring runoff (Figure 7). The drop in alkalinity was accompanied by a drop in pH. In the initial sample in 1995, the pH at this site fell below 6.0. At the site immediately upstream of the waste rock dump, pH remained above 7.0 and alkalinity remained above 20 mg/L as $CaCO_3$. At site S-110 downstream, the pH had rebounded to 7 or greater (Table 5) and alkalinity had rebounded to 10 or greater. Monitoring at site S-101.5 was discontinued in 1997. Similar consumption of alkalinity and decrease in pH below the aquatic life standard were not observed in drainage from Dry Canyon Creek or Water Canyon Creek.

Table 5. Mean pH, number of samples (no.), and range of concentrations in water from seven sites near the headwaters of the North Fork Humboldt River (NFHR), Elko County, Nevada, 1986-1998. Site locations are shown in Figure 1.

		Location						
Year		Upper NFHR (S-95)	Sammy Creek above waste rock (S-101)	Sammy Creek below waste rock (S-110)	Dry Canyon (S-115)	Water Canyon (S-120)	NFHR upstream of Cole Creek (S-140)	NFHR near USFS[a] boundary (S-150)
1986	mean (no.)	-[b]	-	7.9 (5)	-	7.5 (2)	7.6 (2)	8.0 (2)
	range			7.6-8.2		7.1-7.8	7.1-8.0	7.2-8.5
1987	mean (no.)	-	-	7.9 (8)	-	7.6 (8)	7.8 (8)	8.2 (9)
	range			7.5-8.3		7.2-7.8	7.4-8.0	7.9-8.4
1988	mean (no.)	-	-	7.7 (8)	-	7.2 (8)	7.6 (13)	8.0 (12)
	range			7.3-8.0		7.0-7.6	7.1-7.8	7.5-8.4
1989	mean (no.)	-	-	7.4 (8)	-	7.3 (9)	7.4 (7)	7.6 (11)
	range			6.6-8.1		6.6-7.9	6.9-7.9	6.7-8.2
1990	mean (no.)	-	-	7.6 (8)	-	7.3 (7)	7.6 (11)	7.8 (11)
	range			7.1-8.3		6.8-7.8	7.2-8.3	7.4-8.7
1991	mean (no.)	-	-	6.9 (10)	7.2 (5)	6.9 (7)	-	7.4 (9)
	range			4.5-8.0	7.0-7.4	6.5-7.3		6.8-8.0
1992	mean (no.)	-	-	-	-	-	-	-
	range							
1993	mean (no.)	-	-	-	-	-	-	-
	range							
1994	mean (no.)	7.5 (5)	7.8 (2)	7.9 (11)	-	8.0 (12)	7.9 (13)	8.1 (12)
	range	7.3-7.7	7.5-8.0	7.3-8.2		7.8-8.3	7.7-8.1	7.7-8.5
1995	mean (no.)	7.5 (6)	7.8 (4)	7.7 (9)	7.7 (8	7.5 (8)	7.7 (10)	8.3 (4)
	range	7.3-7.8	7.3-8.1	7.0-8.1	6.9-8.8	7.0-7.9	7.5-7.8	8.2-8.6
1996	mean (no.)	7.5 (4)	7.8 (2)	7.8 (7)	7.6 (3)	7.7 (2)	7.9 (8)	8.2 (6)
	range	7.2-7.7	7.5-8.0	7.3-8.4	6.8-8.8	7.6-7.8	7.7-8.4	7.6-8.7
1997	mean (no.)	7.2 (3)	7.9 (3)	7.8 (9)	8.3 (3)	7.6 (3)	8.0 (3)	8.0 (4)
	range	6.5-7.7	7.7-8.0	7.3-8.1	6.9-9.2	7.5-7.8	7.8-8.1	7.7-8.3
1998	mean (no.)	7.1 (2)	7.6 (3)	7.7 (2)	8.1 (2)	7.7 (2)	7.6 (2)	7.9 (2)
	range	6.9-7.3	7.6	7.4-8.0	7.5-8.7	7.6-7.8	7.5-7.8	7.6-8.2

[a] U.S. Forest Service
[b] - indicates that data were not available.

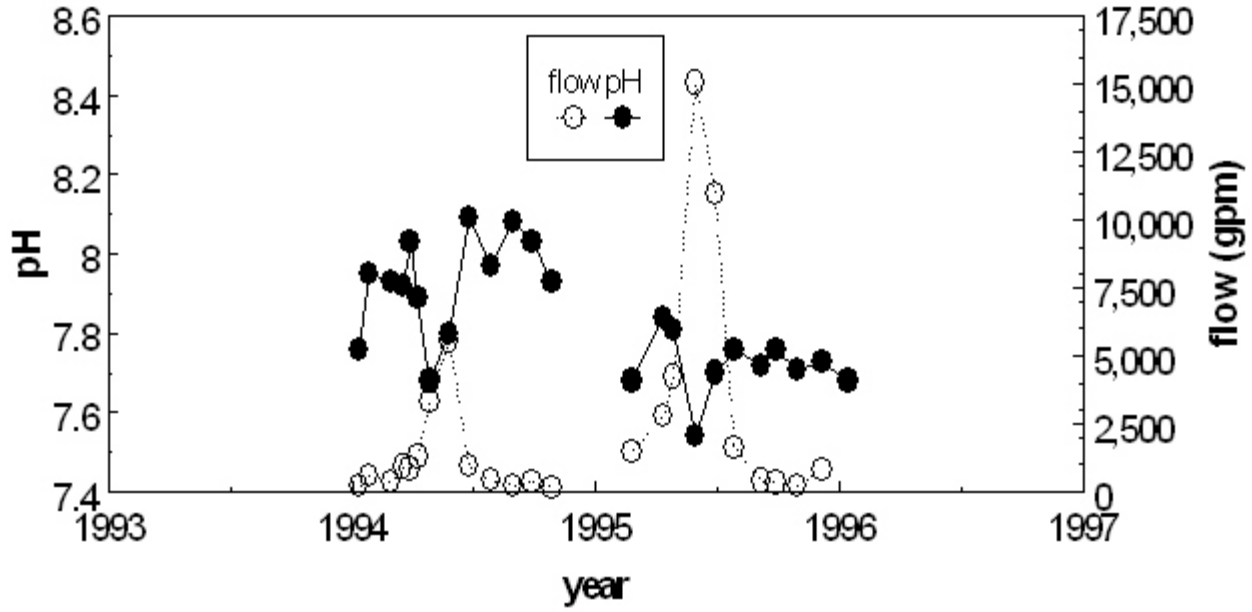

Figure 5. Flow and pH in the North Fork Humboldt River between Water Canyon and Cole Canyon (site S-140), Elko County, Nevada.

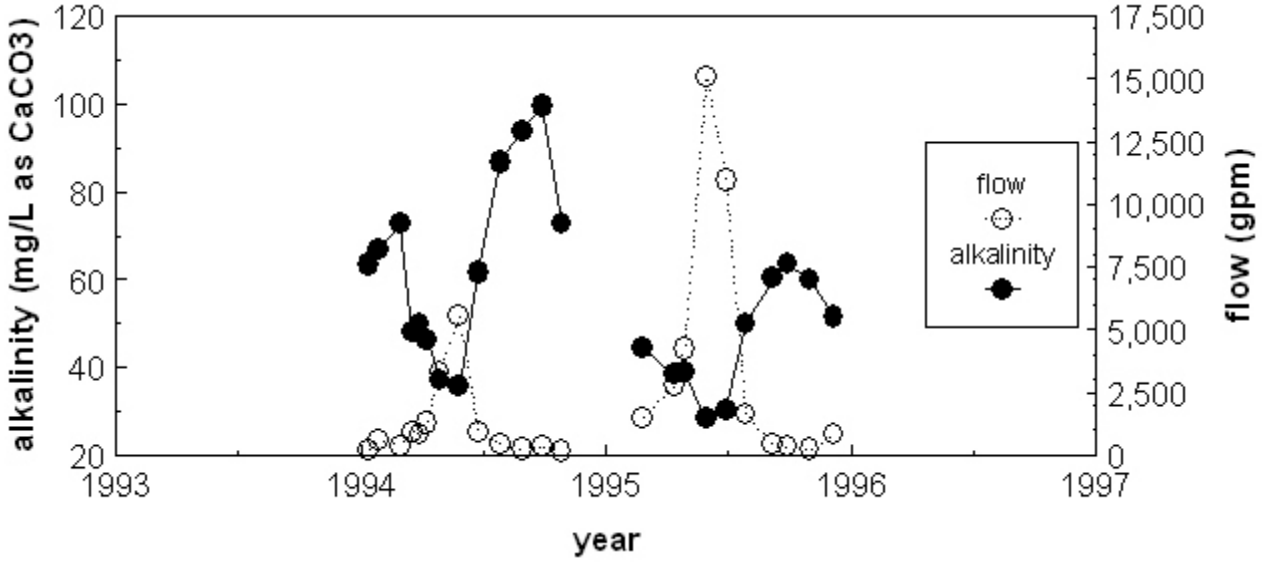

Figure 6. Flow and alkalinity in the North Fork Humboldt River between Water Canyon and Cole Canyon (site S-140), Elko County, Nevada

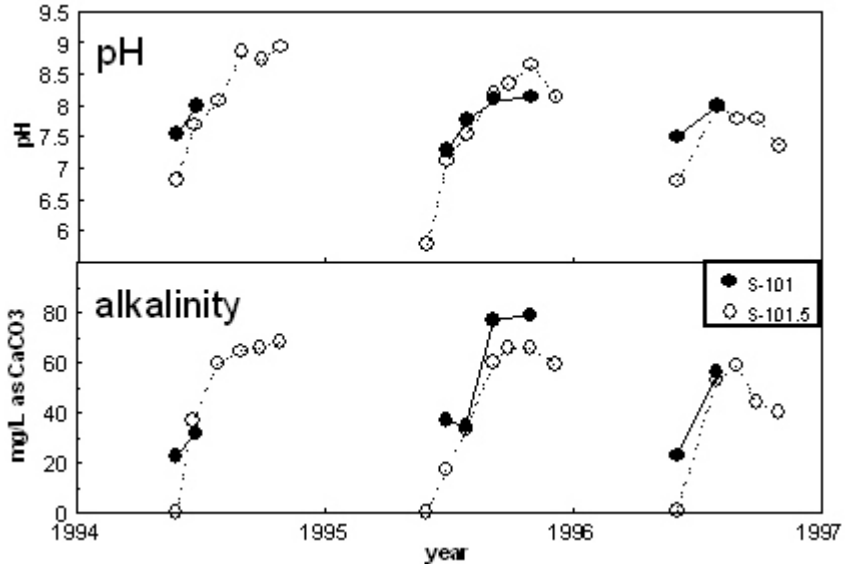

Figure 7. Relationship between pH and alkalinity in water collected from Sammy Creek upstream and downstream of the Sammy Creek waste rock dump (sites S-101 and S-101.5, respectively), Elko County, Nevada.

Trace Elements

Although we were able to locate limited data from 1986, the most comprehensive data set extends from 1994-98. Based on a review of available data, concerns were identified with aluminum, arsenic, beryllium, copper, lead, iron, manganese, mercury, silver, selenium, and zinc. Although the frequency of detection in water samples is mentioned for certain constituents in this section, it should be noted that detection limits for several of the constituents varied. Additionally, prior to 1997, IMC monitored total concentrations of trace elements in water. Since 1997, only dissolved concentrations are reported for aluminum, iron, magnesium, and zinc.

Beryllium, lead, and silver were infrequently detected in water samples. Beryllium was detected in 6 of 230 samples from the NFHR and its tributaries for which we had data. Five of these samples were from Sammy Creek in May and June, 1994. The highest detected concentration was 0.002 mg/L. Lead was detected in 12 of 236 samples. Ten of the samples with detected concentrations were collected during the May and June, 1996, sampling events. During these sampling events, lead was detected in samples collected from most sites, including those unaffected by mining. Silver was detected in 13 of 235 samples. More than half of the samples with detectable concentrations of silver were collected during the May and June, 1996, sampling events. The highest reported silver concentration was 0.171 mg/L. The next highest concentration was 0.014 mg/L. The reason for elevated lead and silver concentrations in samples collected during May and June 1996 is uncertain.

Mercury was detected in 15 of 237 samples collected from 1994-98. The maximum concentration was 0.0008 mg/L. Mercury was also detected in 2 samples collected prior to mining activity. The maximum concentration in these samples was 0.004 mg/L.

Aluminum, iron, manganese, and zinc were commonly detected in water samples, but appeared elevated in samples collected from Sammy Creek downstream of the waste rock dump during periods of Spring snowmelt and runoff (Figure 8). Copper was also detected in samples

from these locations and time periods. As indicated previously, pH was generally lower during periods of Spring snowmelt and runoff, but appeared to be particularly decreased in Sammy Creek downstream of the waste rock dump. Aluminum concentrations in 14 samples met or exceeded 1 mg/L, with the maximum concentration exceeding 4 mg/L. Of these, 11 were collected from Sammy Creek below the waste rock dump during periods of Spring runoff.

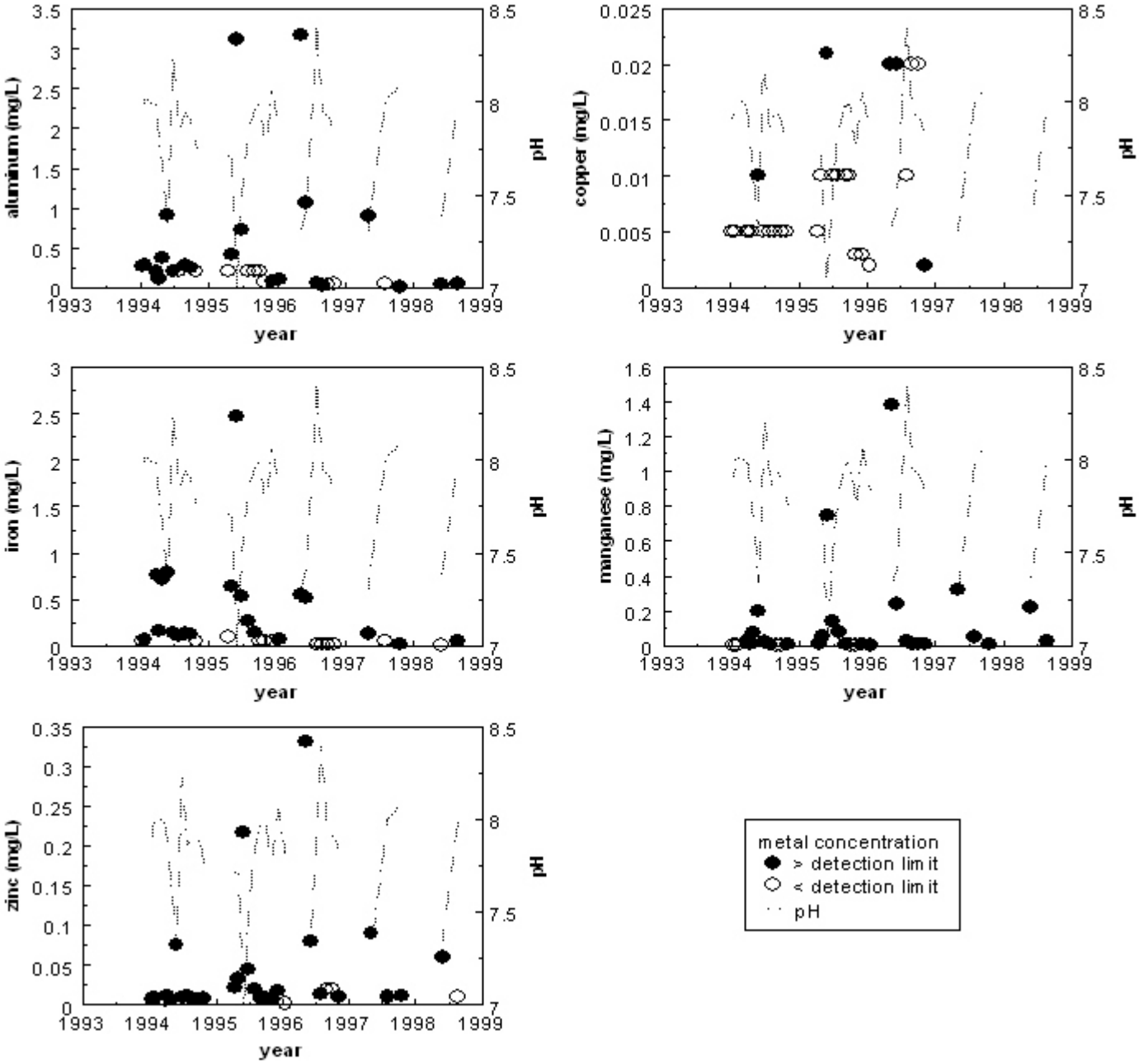

Figure 8. Relationship between pH and concentrations of aluminum, copper, iron, manganese, and zinc in water collected from Sammy Creek near the confluence wit the North Fork Humboldt River (site S-110), Elko County, Nevada. Pre-1997 samples are reported as total concentrations. Samples collected between 1997-99 are reported as dissolved fraction.

Copper concentrations in 14 samples met or exceeded 0.01 mg/L, of which 10 were collected from lower Sammy Creek. Of the remaining four samples, three were collected in May and June, 1996, when lead and silver were also elevated. Eleven samples contained iron concentrations exceeding 1 mg/L, of which 6 were collected from lower Sammy Creek during Spring runoff. The maximum concentration, 3.65 mg/L, was collected from the NFHR downstream of the mine site (S-140) in June, 1995. Twenty-eight samples had concentrations of manganese meeting or exceeding 0.2 mg/L, of which 14 were from lower Sammy Creek. The maximum concentration exceeded 1.5 mg/L. Zinc concentrations exceeded 0.1 mg/L in 8 samples. All were collected from lower Sammy Creek during spring runoff.

Prior to mining, selenium was not detected in water samples from four sites (sites S-110, S-120, S-140, and S-150; Table 6). From 1994-98, this element was not detected in the NFHR upstream of mining activity (site S-95) but was detected in 2 of 16 samples collected in Sammy Creek upstream of mining activities (site S-101). The maximum concentration at site S-101 was 0.003 mg/L (Table 6). Conversely, from 1994-98, selenium was detected in more than 90 percent of the samples collected from sites in the tributaries downstream of waste rock dumps (sites S-110, S-115, and S-120) and in about two-thirds of the samples collected from the NFHR immediately down stream of mining activity (sites S-140 and S-150). The mean concentrations in affected tributaries generally exceeded 0.01 mg/L, with the maximum concentration exceeding 0.1 mg/L. When 1994-96 data from the tributaries (sites S-110, S-115, and S-120) were examined, selenium concentrations were positively correlated with sulfate concentrations ($p<0.001$; $r^2=0.518$, $n=71$).

Table 6. Mean selenium concentrations (mg/L), number of samples (no.), and range of concentrations in water from seven sites near the headwaters of the North Fork Humboldt River (NFHR), Elko County, Nevada, 1986 and 1994-1998. Site locations are shown in Figure 1.

		Location						
Year		Upper NFHR (S-95)	Sammy Creek above waste rock (S-101)	Sammy Creek near NFHR (S-110)	Dry Canyon near NFHR (S-115)	Water Canyon near NFHR (S-120)	NFHR upstream of Cole Creek (S-140)	NFHR near USFS[a] boundary (S-150)
1986	mean (no.)	-[b]	-	-[c] (2)	-	-[c] (2)	-[c] (2)	-[c] (2)
	range			<0.005		<0.005	<0.005	<0.005
1994	mean (no.)	-[c] (5)	-[c] (5)	0.016 (11)	0.010 (5)	0.013 (12)	-[c] (13)	-[c] (12)
	range	<0.005	<0.005	0.006-0.033	0.010	<0.005-0.026	<0.005-0.020	<0.005-0.008
1995	mean (no.)	-[c] (6)	-[c] (4)	0.018 (9)	0.061 (3)	0.024 (3)	0.008 (10)	0.006 (4)
	range	<0.005	<0.005-0.003	<0.005-0.040	0.034-0.108	0.017-0.033	<0.005-0.023	<0.005-0.014
1996	mean (no.)	-[c] (4)	-[c] (2)	0.007 (7)	0.039 (3)	0.014 (4)	0.005 (8)	0.003 (6)
	range	<0.002	<0.002	0.001-0.016	<0.002-0.089	0.001-0.021	<0.002-0.010	0.001-0.005
1997	mean (no.)	-[c] (3)	-[c] (3)	0.013 (3)	0.032 (9)	0.015 (3)	0.005 (3)	0.005 (4)
	range	<0.001	<0.001-0.001	0.011-0.016	0.018-0.051	0.012-0.017	0.003-0.006	0.002-0.006
1998	mean (no.)	-[c] (2)	-[c] (2)	0.012 (2)	0.013 (2)	0.023 (2)	0.008 (2)	0.005 (3)
	range	<0.001	<0.001	0.011-0.012	0.007-0.019	0.015-0.030	0.007-0.008	0.004-0.007

[a] U.S. Forest Service
[b] - data were not available.
[c] More than 50 percent of the samples were less than analytical detection limits.

Water Quality Parameters and Trace Element Concentrations in Water, Sediment, and Biological Samples

Hardness and concentrations of TDS and selected major ions in water samples collected from six sites in the NFHR and one site in Foreman Creek from July 21-23, 1998, are given in Table 7. Total and dissolved concentrations of aluminum, arsenic, manganese, nickel, selenium, and zinc are given in Table 8. Concentrations of antimony, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, silver, thallium, and vanadium were either below or near analytical detection limits. Concentrations of aluminum, arsenic, cadmium, copper, iron, manganese, mercury, nickel, selenium, and zinc in bottom sediment are given in Table 9. Concentrations of aluminum, arsenic, cadmium, copper, iron, manganese, mercury, nickel, selenium, and zinc in aquatic invertebrates are given in Table 10. Concentrations of aluminum, arsenic, cadmium, calcium, copper, iron, manganese, mercury, nickel, potassium, sodium, selenium, and zinc in aquatic invertebrates are given in Table 11. Concentrations of other elements in sediment and biological tissues were less than levels of concern or insufficient information was available to assess biological implications.

Fish Assemblage

A total of 42 LCT, two brook trout (*Salvelinus fontinalis*) and one Paiute sculpin *(Cottus beldingi*) were captured from NFHR and 39 LCT were captured from Foreman Creek. Mean total length, weight and Fulton's condition factor values and ranges for all LCT and selected size groups from each stream system are given in Table 12. No significant differences were found among condition factor values for selected size classes within each stream system ($p>0.144$). However, Fulton's condition factor values were significantly higher ($p<0.050$) for Foreman Creek LCT overall and for all size groups except juveniles.

Fish Condition and Health

A total of 45 and 39 fish were examined from NFHR and Foreman Creek, respectively. Two fish from NFHR were found to have abnormalities. These included an irregularly-shaped head and eye deformities in a LCT and reduced operculum size in a brook trout. One Foreman Creek LCT was found to have reduced operculum size. A second Foreman Creek LCT was found to have an irregular operculum on one side. The irregularity appeared related to trauma.

Organosomatic assays were conducted on six male and four female LCT from NFHR and seven male and three female LCT from Foreman Creek. Male and female LCT from NFHR examined during organosomatic assays were morphologically similar (Table 13). Foreman Creek females were larger than the males. All Foreman Creek LCT had significant quantities of visceral fat (scores of 2 - 3). The Foreman Creek males had significantly greater condition factors than NFHR males ($p=0.016$). Liver mass was similar among the 2 site groups ($p=0.453$). Muscle lipid levels were similar in both sample site groups. Six of the 7 males collected from Foreman Creek had swollen kidneys. Two Foreman Creek fish had elevated numbers of neutrophils.

Table 7. Temperature (T), dissolved oxygen (DO), specific conductance (SPC), pH, hardness (mg/L as $CaCO_3$), and concentrations (mg/L) of total dissolved solids (TDS), sulfate (S), calcium (Ca), chloride (Cl),fluoride (F), magnesium (Mg), potassium (K), and sodium (Na) in surface water collected from the mainstem of the North Fork Humboldt River upstream and downstream of mining disturbance (NFHR-1 and NFHR-2a, respectively), Sammy Creek (NFHR-3), Dry Canyon Creek (NFHR-4), Water Canyon Creek (NFHR-5), Cole Creek (NFHR-6), and Foreman Creek, Elko County, Nevada, in July, 1998. Site locations are shown in Figure 1.

					concentration (mg/L)								
site	T (°C)	DO (mg/L)	SPC (µS/cm)	pH	hard-ness	TDS	S	Ca	Cl	F	Mg	K	Na
North Fork Humboldt River													
NFHR-1	15	6.9	49	7.0	24	48	3.4	5.5	0.2	0.04	3.1	0.9	2.3
NFHR-3	13	8.3	550	7.8	347	607	315	59	1.2	0.28	48	1.2	4.9
NFHR-4	15	11.4	1,480	9.5	975	1,660	936	97	1.5	0.09	187	2.2	4.3
NFHR-5	13	7.3	1,040	7.4	837	1,390	741	130	3.1	0.04	122	1.7	3.6
NFHR-2a	14	7.7	790	7.7	544	851	496	85	2.3	0.10	81	1.4	4.9
NFHR-6	14	7.7	93	7.1	53	82	3.8	14	0.4	0.05	3.6	1.0	3.2
Foreman Creek													
Foreman Creek	12	7.5	38	6.9	24	41	2.2	6.3	0.3	0.03	1.6	<0.6	1.7

Table 8. Total and dissolved (diss.) concentrations (mg/L) of aluminum, arsenic, manganese, nickel, selenium, and zinc in surface water collected from the mainstem of the North Fork Humboldt River upstream and downstream of mining disturbance (NFHR-1 and NFHR-2a, respectively), Sammy Creek (NFHR-3), Dry Canyon Creek (NFHR-4), Water Canyon Creek (NFHR-5), Cole Creek (NFHR-6), and Foreman Creek, Elko County, Nevada, in July, 1998. Site locations are shown in Figure 1.

	concentration (mg/L)											
	aluminum		arsenic		manganese		nickel		selenium		zinc	
site	total	diss.	total	diss.	total	diss.	total	diss.	total	diss.	total	diss.
North Fork Humboldt River												
NFHR-1	0.16	0.09	0.010	0.010	0.006	0.004	<0.015	<0.015	<0.001	<0.001	0.006	0.004
NFHR-3	0.35	0.11	0.019	0.011	0.184	0.187	0.039	0.039	0.010	0.010	0.036	0.040
NFHR-4	0.13	0.07	0.005	0.004	0.059	0.027	0.016	<0.015	0.013	0.016	0.014	0.003
NFHR-5	0.08	0.05	0.013	0.012	0.024	0.023	0.026	<0.015	0.015	0.015	0.018	0.021
NFHR-2a	0.19	0.06	0.018	0.014	0.064	0.049	<0.015	<0.015	0.009	0.008	0.009	0.008
NFHR-6	0.14	0.07	<0.001	<0.001	0.010	0.010	<0.015	<0.015	<0.001	<0.001	0.003	<0.002
Foreman Creek												
Foreman Creek	0.21	0.11	0.004	0.004	0.009	0.005	<0.015	<0.015	0.001	<0.001	0.006	0.002

Table 9. Concentrations (parts per million, dry weight; ppm) of aluminum (Al), arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), and zinc (Zn) in bottom sediment collected from the mainstem of the North Fork Humboldt River upstream of mining disturbance (NFHR-1), downstream of Water Canyon (NFHR-2a), upstream of Cole Canyon (NFHR-2b), Cole Canyon Creek (NFHR-6), and Foreman Creek, Elko County, Nevada, in July, 1998. Site locations are shown in Figure 1.

	concentration (ppm)									
site	Al	As	Cd	Cu	Fe	Mn	Hg	Ni	Se	Zn
North Fork Humboldt River										
NFHR-1	4,500	62	<0.4	40	24,500	284	<0.12	30	0.4	105
NFHR-2a	8,220	207	1.2	40	25,200	1,030	0.16	75	2.5	171
NFHR-2a	5,900	126	0.8	30	17,700	1,100	<0.15	68	1.2	138
NFHR-2b	7,810	130	1.0	30	19,100	640	0.22	52	2.2	135
NFHR-6	7,150	10	<0.3	42	24,900	262	<0.11	35	0.3	100
Foreman Creek										
Foreman Creek	10,900	29	0.5	29	24,500	288	0.19	37	0.4	95

Table 10. Concentrations (parts per million, dry weight; ppm) of aluminum (Al), arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), and zinc (Zn) in benthic invertebrates collected from the mainstem of the North Fork Humboldt River upstream of mining disturbance (NFHR-1), downstream of Water Canyon (NFHR-2a), upstream of Cole Canyon (NFHR-2b), Cole Creek (NFHR-6), and Foreman Creek, Elko County, Nevada, in July, 1998. Site locations are shown in Figure 1.

		concentration (ppm)									
site	dominant taxa	Al	As	Cd	Cu	Fe	Mn	Hg	Ni	Se	Zn
North Fork Humboldt River											
NFHR-1	caddis fly	552	4	<1.7	25	402	94	<0.6	<18	3.9	164
NFHR-2a	caddis fly	3,650	59	3.7	30	2,950	507	<0.6	24	14.0	353
NFHR-2b	caddis fly	2,170	27	2.7	49	2,150	636	<0.4	25	8.0	413
NFHR-6	caddis fly	3,130	2	2	69	3,330	297	<0.5	<18	4.6	262
Foreman Creek											
Foreman Creek	stone fly	870	3	<1.4	41	1,100	63	<0.5	<16	4.1	219

Table 11. Concentrations (parts per million, dry weight; ppm) of aluminum (Al), arsenic (As), cadmium (Cd), calcium (Ca), copper (Cu), iron (Fe), manganese (Mn), mercury (Hg), nickel (Ni), potassium (K), sodium (Na), selenium (Se), and zinc (Zn) in composite samples of gills and liver and mean concentrations and sample numbers (in parentheses) in individual samples of muscle and whole bodies of Lahontan cutthroat trout collected from the mainstem of the North Fork Humboldt River downstream of Water Canyon (NFHR-2a), upstream of Cole Canyon (NFHR-2b), and from Foreman Creek, Elko County, Nevada, in July, 1998. Site locations are shown in Figure 1.

	concentration (ppm)												
site	Al	As	Ca	Cd	Cu	Fe	Mn	Hg	K	Na	Ni	Se	Zn
gill													
NFHR-2a	58	1.3	52,400	2.2	5	232	36	<0.4	9,330	8,240	<13	12	155
NFHR-2b	202	4.6	41,000	<1.2	14	440	37	<0.4	11,700	8,760	<14	16	135
Foreman	41	1.0	28,500	<1.1	3	222	13	0.5	7,630	6,980	<12	7	109
Foreman	42	1.2	36,300	1.1	6	253	17	1.7	8,510	7,560	<12	7	111
liver													
NFHR-2a	31	1.0	199	3.7	310	941	8	0.3	15,200	3,920	<12	32	109
NFHR-2b	27	8.8	231	1.6	101	681	9	0.3	14,800	4,340	<13	35	107
Foreman	25	<0.6	149	<1.0	137	600	5	1.1	12,400	3,050	<11	28	77
Foreman	28	2.1	146	2.7	122	316	7	2.5	12,700	3,150	<11	21	78
muscle													
NFHR-2a (5)	40	2.0	9,308	<1.3	6	43	10	0.5	18,240	2,770	<14	9	66
NFHR-2b (5)	42	1.6	4,624	<1.4	5	56	6	0.3	18,800	2,596	<15	12	50
Foreman (10)	30	1.4	4,881	<1.5	4	36	2	1.1	17,320	2,221	<17	2	44
whole body													
NFHR-2b (5)	107	1.9	15,384	<1.8	5	166	11	<0.4	13,680	3,972	<16	8	61

Hematocrit, leukocrit, plasma protein, and alanine aminotransferase values and differential leukocyte counts are given in Table 14. Aspartate aminotransferase (AST) values for all but one fish were above the 950 μ/L upper range of the Johnson & Johnson DTSC analyzer. One fish from NFHR had an AST value of 902 μ/L. Blood cell measurements (hematocrit, leukocrit, and differential counts) of the NFHR and Foreman Creek fish were similar and within normal ranges for salmonids. Electrophoresis of plasma protein produced 6 protein bands (albumin plus 5 globulin protein bands). Data for electrophoretic separation of globulin plasma protein are provided in Table 15. One Beta-globulin band (Globulin 4+5) was significantly higher in the NFHR fish than the Foreman group ($p<0.05$). Males in both groups had higher albumin levels than their cohort females. There was no statistically significant difference in the albumin:globulin (A/G) ratios in the NFHR and Foreman Creek fish.

Table 12. Number (no.) of Lahontan cutthroat trout, percent of total sample, mean (and range) total length, weight, and Fulton's condition factor (CF) for size groups Lahontan cutthroat trout from the North Fork Humboldt River and Foreman Creek in the Independence Mountains, Elko County, Nevada, July 1998.

	North Fork Humboldt River					Foreman Creek				
size group (mm)	no.	percent of sample	total length (mm)	weight (g)	Fulton's CF[1]	no.	percent of sample	total length (mm)	weight (g)	Fulton's CF[1]
< 100	4	10	92 (89-96)	8 (7-9)	1.04[a] (0.96-1.13)	12	31	72 (57-92)	4 (2-9)	1.09[a] (0.98-1.33)
100-149	9	21	131 (103-147)	23 (10-37)	0.95[a] (0.73-1.16)	6	15	123 (112-137)	21 (14-25)	1.09[b] (0.97-1.26)
150-199	17	40	168 (146-174)	47 (23-65)	0.98[a] (0.49-1.08)	12	31	168 (152-196)	56 (39-90)	1.15[b] (1.04-1.24)
200-249	12	29	213 (202-238)	96 (79-126)	0.98[a] (0.88-1.14)	8	21	211 (200-227)	104 (84-128)	1.10[b] (1.04-1.14)
> 250	0	-	-	-	-	1	2	270 (-)	199 (-)	1.01 (-)
Total	42	100	166 (84-238)	52 (7-126)	0.98[a] (0.49-1.16)	39	100	143 (57-270)	48 (2-199)	1.11[b] (0.97-1.33)

[1] Within each size group, Fulton's condition factor values with different small case letters were significantly different between sites ($p<0.05$).

Table 13. Number and mean (and standard error of the mean) fork length, weight, condition factor value, hepatosomatic index value, muscle lipid, and visceral fat for Lahontan cutthroat trout from North Fork Humboldt River and Foreman Creek, Elko County, Nevada, July 1998.

	North Fork Humboldt River			Foreman Creek		
	female	male	all fish	female	male	all fish
number	4	6	10	3	7	10
fork length (mm)	194 (17)	196 (9)	195 (8)	223 (19)	184 (7)	196 (9)
weight (g)	86 (18)	88 (10)	87 (9)	140 (31)	82 (10)	102 (15)
condition factor	0.98 (0.06)	1.00 (0.02)	0.99 (0.02)	1.09 (0.04)	1.14 (0.03)	1.12 (0.05)
hepatosomatic index	0.91 (0.31)	1.38 (0.10)	1.32 (0.08)	1.36 (0.09)	1.41 (0.03)	1.39 (0.03)
muscle lipid (%)	3.3 (0.2)	3.1 (0.3)	3.2 (0.2)	2.9 (0.1)	3.1 (0.1)	3.0 (0.1)
visceral fat score	1.3	1.0	1.1	2.3	2.1	2.2

Table 14. Number and mean (and standard error of the mean) hematocrit (percent erythrocyte volume), leukocrit (percent white blood cell volume), plasma protein (g/dL), alanine aminotransferase activity (μ/L), and differential leukocyte count data (percent lymphocyte and thrombocyte and percent neutrophil and monocyte) for Lahontan cutthroat trout from North Fork Humboldt River and Foreman Creek, Elko County, Nevada, July 1998.

	North Fork Humboldt River			Foreman Creek		
	female	male	all fish	female	male	all fish
number	4	6	10	3	7	10
hematocrit	43 (3)	49 (2)	46 (2)	44 (4)	43 (3)	43 (2)
leukocrit	1.53 (0.41)	1.52 (0.26)	1.52 (0.21)	1.34 (0.09)	1.51 (0.19)	1.46 (0.14)
plasma protein	1.8 (0.3)	2.0 (0.2)	1.8 (0.2)	3.4 (0.5)	2.4 (0.3)	2.9 (0.3)
ALT (4 fish per stream)			48 (19)			69 (38)[a]
Differential Counts						
% lymphocyte and thrombocyte			96 (0.1)			90 (4.0)
% neutrophil and monocyte			4 (0.1)			10 (4.0)[b]

[a] Large ALT activity range for Foreman Creek (2-170 μ/L) as compared with North Fork Humboldt River (20-103 U/L).
[b] Two fish from Foreman Creek with apparent neutophilia.

Table 15. Plasma protein electrophoretic data reported as percent area of band (and standard error of the mean) for adult fish from North Fork Humboldt River (n = 8) and Foreman Creek (n = 7), Elko County, Nevada, July 1998.

	North Fork Humboldt River	Foreman Creek
albumin	23.8 (0.8)	23.2 (2.4)
globulin 1	19.3 (1.4)	21.1 (2.6)
globulin 2	14.4 (1.0)	15.6 (1.3)
globulin 3	14.3 (0.8)	16.2 (1.3)
globulin 4 and 5	23.1 (0.5)	20.2 (1.1)
globulin 6	5.1 (0.6)	3.7 (0.4)
albumin/globulin ratio	0.31 (0.01)	0.31 (0.04)

Histological examination showed a number of abnormalities (glomerulonephritis, interstitial hyperplasia, and granulomatous response) in kidneys in the NFHR and Foreman Creek fish. Gill, testes, and heart sections from both groups showed no abnormalities. Marked thickening of the connective tissue surrounding the hepatic portal triad (bile duct, arteriole, vein) was observed in 30 percent of the livers in the NFHR and Foreman Creek fish.

No significant bacterial infections, *Myxobolus cerebralis* spores (whirling disease agent) or viral agents were detected in fish from either stream (Table 16). The *Micrococcus* and *Pseudomonas* isolates were from single colonies (low level infection or possible contaminant). Both populations had a high prevalence and severity of *Myxidium sp*. infection in the kidney. The Foreman Creek fish also had a high prevalence of cestode infection within the intestinal tract.

Table 16. Incidence of infection (number positive / sample number, and percent in parentheses) for *Myxobolus cerebralis* spores in pooled cranial bone digest (n = 10), virus in individual spleen samples, *Renibacterium salmoninarum* (RSAL), and cultured systemic bacteria (BACTE) of individual kidney samples from Lahontan cutthroat trout from the North Fork Humboldt River and Foreman Creek, Elko County, Nevada, July 1998.

	North Fork Humboldt River	Foreman Creek
Myxobolus cerebralis	0 / 1 (0%)	0 / 1 (0%)
RSAL		
below negative cutoff	0 / 10 (0%)	0 / 10 (0%)
low antigen (+)	10 / 10 (100%)	9 / 10 (90%)
high antigen (+)	0 / 10 (0%)	1 / 10 (10%)
BACTE		
Micrococcus sp.	1 / 10 (10%)	0 / 10 (0%)
Pseudomonas sp.	1 / 10 (10%)	1 / 10 (10%)

DISCUSSION

Water Quality Standards

Since 1995, IMC data have shown that the mean TDS in Sammy Creek, Dry Canyon Creek, and Water Canyon Creek near the confluence with NFHR has exceeded the standard for municipal or domestic water supply (500 mg/L; Table 1). Since 1994, TDS has exceeded this standard in more than half of the samples collected from the NFHR at site S-140. Monitoring of TDS at site S-140 was discontinued in 1997. One of eight samples collected at site S-150 in 1998 exceeded this standard (Table 3). In July 1998, TDS concentrations exceeded 500 mg/L in all tributaries and the NFHR between Water Canyon and Cole Canyon (Table 7).

Since 1994, IMC data have shown that the mean sulfate concentrations in tributaries containing waste rock dumps and the NFHR at site S-140 (1994-96, only) have exceeded the standard for municipal or domestic water supply (250 mg/L; Table 1). Since 1996, concentrations in at least one water sample per year collected from S-150 have met or exceeded

the sulfate standard (Table 4). In July 1998, sulfate concentrations exceeded 250 mg/L in all tributaries containing waste rock dumps and the NFHR between Water Canyon and Cole Canyon (Table 7).

IMC data indicate that, since 1994, pH was below the Nevada aquatic life standard (6.5; Table 1) on only one occasion at site S-101.5 immediately downstream of the Sammy Creek waste rock dump in May, 1995. The pH was within the acceptable range in the sample collected downstream in Sammy Creek (site S-110) on the same date. IMC data illustrate that one of three pH measurements in 1997 exceeded the Nevada aquatic life standard for pH (9.0) in Dry Canyon (Table 5). During our survey, we found that pH in the Dry Canyon Creek settling basin and the outflow ranged from 9.2 to 9.5 (Table 7). Elevated pH at this site is likely attributable to the shallow, productive nature of the Dry Canyon Creek settling basin. Photosynthetic processes may reduce the amount of CO_2 in the water column and thereby cause pH to increase (Wetzel 1983).

Aquatic life water quality standards for cadmium, chromium, copper, lead, nickel, silver, and zinc are based on water hardness and are applicable solely to the dissolved fraction in the water column. Insufficient data are available to assess historic compliance with aquatic life standards for these metals. Based on a review of historic data, it appears unlikely that cadmium, chromium, or lead exceeded aquatic life standards. Our data did not indicate exceedance of aquatic life standards for these metals in July 1998. As indicated previously, concentrations of certain metals were elevated during Spring runoff in drainage from tributaries containing waste rock dumps. Aquatic life standards for arsenic are based on chemical species (As^{+3}). Previous sampling has not determined arsenic species. However, total arsenic concentrations were well below the aquatic life standard for As^{+3}. Analytical detection limits for mercury were higher than the chronic aquatic life standard. Therefore, at least all water samples with detected concentrations of mercury exceeded this standard. However, the highest observed mercury concentration occurred prior to mining in the NFHR. IMC data indicate that selenium concentrations have exceeded 1-hour and 96-hour standards for the protection of aquatic life (Table 6). We also found selenium concentrations exceeding the 96-hour aquatic life standard (Table 8).

IMC data and our data indicate exceedances of the municipal and domestic supply standard for selenium. Our data indicate exceedance of the municipal and domestic supply standard for nickel. Historic monitoring data indicate exceedances of the irrigation water quality standards for manganese and selenium.

Nevada has not adopted a standard for aluminum. During Spring runoff in 1994-96, aluminum concentrations exceeded the criterion maximum concentration (i.e., acute criterion) recommended by EPA (750 µg/L, total recoverable). Since 1997, IMC has reported only dissolved aluminum.

Trace Element Concentrations in Water, Sediment, and Biological Samples

Our review of available data identified significant concerns with aluminum, arsenic, copper, manganese, mercury, nickel, selenium, and zinc. Concerns with each element are discussed below.

<u>Aluminum</u>

Aluminum (Al) in water has been shown to be toxic to fish. Toxicity is dependent on

chemical species. Chemical species is primarily determined by pH, although solution contact with solids, concentration of complexing ligands, and temperature will also influence speciation and toxicity (Driscoll et al., 1989). The mechanism of toxicity varies with pH. Under conditions of low pH (pH < ~ 5), the Al^{+3} ion is the dominant chemical form, although other monomeric forms also occur (Martell and Motekaitis, 1989). Toxic effects may include impaired ion and osmotic regulation, damage to gill epithelium and intracellular Al accumulation causing necrosis and apoptosis of gill ion-transporting cells (Sparling and Lowe, 1996). Under circumneutral conditions (pH 6 - 8), $Al(OH)_3$ becomes the predominant form, and will generally precipitate from solution. Within the lower end of this range (pH 5.5 - 6.5), asphyxiation becomes the predominant toxic mechanism. Asphyxiation is believed to be caused by deposition of $Al(OH)_3$ on gill surfaces causing production of excess mucus and inflammation, which may restrict O_2 and CO_2 diffusion across gill membrane (Sparling and Lowe, 1996). Observed effects may include increased gill ventilation rates, increased blood CO_2, increased blood lactate, reduced blood O_2, increased gill mucus production, and gill damage. Rapid changes in pH, such as those found in mixing zones of Al-rich acidic waters with higher pH waters, may greatly enhance fish asphyxiation (Witter et al., 1996). Enhanced toxicity may be attributed to Al deposition and polymerization on gill surfaces which form a physical barrier to gaseous exchange. Under more alkaline conditions, (pH>8), aluminate [$Al(OH)_4^-$] becomes the dominant form. Aluminate is soluble, and Al concentrations in solution again increase. The biological availability and toxicity of Al under alkaline conditions are poorly understood (Sparling and Lowe 1996).

The pH range observed in the NFHR was above levels associated with aluminum toxicity (Tables 5 and 7). A possible exception may be drainage from Sammy Creek during periods of Spring runoff where IMC data indicated that pH immediately downstream of the waste rock dump was in the range associated with asphyxiation (Figure 7). However, pH rebounded to 7 or greater prior to entering NFHR although Al remained elevated in some samples (Table 8). It is uncertain whether mixing zone effects and deposition of Al on gills would persist in the NFHR downstream of Sammy Creek. We found higher concentrations of Al in composite LCT gill samples collected from the NFHR than from Foreman Creek (Table 11). However, no abnormalities were observed upon histological examination of gills.

Arsenic

Arsenic (As) in water, sediment, and diet may be toxic to aquatic organisms. Like aluminum, the toxicity of arsenic in water is dependent on chemical species (Eisler 1994). In general, As^{+3} is considered more toxic than As^{+5}. Under oxygenated conditions, such as in the NFHR, formation of As^{+5} would be favored. Our data and IMC data indicate that arsenic concentrations in water did not exceed concentrations associated with acute toxicity to aquatic organisms.

Arsenic concentrations in all NFHR bottom sediment samples exceeded a severe effect level for aquatic sediments (33 ppm) identified by Persaud et al. (1993). The authors define the severe effect level as a concentration at which the health of sediment-dwelling organisms will likely be affected. Concentrations were highest in samples collected from the NFHR downstream of the mine site (Table 9). Sediment concentrations in the three samples collected in this reach also exceeded an effect range-median (ER-M; 85 ppm) for coastal marine or estuarine invertebrates identified by Long and Morgan (1991). The authors identify the ER-M as a sediment concentration above which effects were frequently or always observed or predicted

among most species.

Consistent with elevated As in bottom sediment, As concentrations were higher in invertebrate samples collected downstream of the mine site (Table 10). One invertebrate sample from this reach approached and the other exceeded a 30 µg/g dietary concentration associated with decreased growth and other sublethal effects in rainbow trout (*Oncorhynchus mykiss*; Oladimeji et al. 1984).

Copper

Although copper is an essential nutrient, elevated concentrations in water, sediment, or diet may be toxic. Water-borne copper tends to be more toxic to aquatic organisms under conditions of low pH and hardness. IMC data indicate that copper concentrations were elevated in drainage from Sammy Creek during Spring runoff. Concentrations in a few samples exceeded levels that may be potentially toxic to sensitive fish and aquatic invertebrates (Eisler 1997). LCT generally spawn during the Spring (Sigler and Sigler 1987) and early life stage trout tend to be more sensitive to copper (Eisler 1997). Therefore, sensitive life stage trout may be present during periods of elevated copper in the NFHR. Copper toxicity to aquatic organisms may be enhanced in the presence of zinc. Finlayson and Ashuckian (1979) concluded that safe levels of copper and zinc were 0.011 and 0.083 mg/L, respectively. IMC data indicate that copper and zinc exceeded these concentrations during Spring runoff during at least two occasions from 1994-96 (Figure 8). IMC discontinued monitoring of copper at all but one site (S-140) in 1997. At this site, only dissolved copper and zinc concentrations are reported.

Copper did not exceed concentrations of concern in aquatic sediment, invertebrates or whole-body LCT (Ohlendorf 1998).

Manganese

Manganese toxicity to aquatic organisms is hardness-dependent. Stubbelfield et al. (1997) estimated an effect level (interpolated concentration causing adverse effects to 25 percent of a test population; IC_{25}) of 4.67 mg/L at low water hardness (30 mg/L as $CaCO_3$) for brown trout (*Salmo trutta*). The estimated toxic concentration at high water hardness (450 mg/L as $CaCO_3$) was 8.68 mg/L. The maximum concentration that we observed in July 1998 was 0.187 mg/L. The maximum concentration observed during IMC monitoring was 1.55 mg/L.

Manganese concentrations in sediment collected down stream of the mine site exceeded the lowest effect level for aquatic sediment (460 ppm) identified by Persaud et al. (1993). The lowest effect level is defined as a concentration where no effect on the majority of the sediment-dwelling organisms would be expected. Concentrations in two samples met or approached the severe effect level of 1100 ppm (Table 9).

Manganese was elevated in aquatic invertebrates collected down stream of the mine (Table 10). However, no information was found on dietary concern or effect concentrations for manganese.

Mercury

Mercury is considered highly toxic, and minor amounts in water, sediment, and diet have been associated with adverse effects to fish and aquatic invertebrates. Mercury in water may be toxic (LC_{50}) to aquatic invertebrates at concentrations as low as 0.002 mg/L for inorganic mercury or as low as 0.0009 mg/L for organic forms (U.S. EPA 1980). Concentrations below 0.001 mg/L may cause reduced growth and reproduction in salmonids (Zillioux et al. 1993). IMC sampling found that mercury exceeded the 0.0002 mg/L detection limit in approximately 6 percent of the water samples from the NFHR, including samples collected prior to mining. Mercury concentrations were less than a 0.0001 mg/L detection limit in the samples that we collected.

Mercury was detected in two bottom sediment samples from NFHR and in the sample from Foreman Creek (Table 9). Concentrations approached or exceeded the lowest effect level for aquatic sediment (0.2 ppm) identified by Persaud et al. (1993). Concentrations were well below the 2.0 ppm severe effect level identified by Persaud et al. (1993).

Mercury was not detected in aquatic invertebrates, but was detected in LCT liver, muscle, and whole-body samples from NFHR and Foreman Creek. Concentrations in these matrices were higher in samples from Foreman Creek.

Detection of mercury in samples collected prior to mining suggests that mercury is naturally occurring in the Independence Range or has been introduced through some other anthropogenic activity. It is uncertain if higher mercury concentrations in Foreman Creek are reflective of mercury from stack emissions from the Jerritt Canyon mill site, which is located approximately 9 km south.

Nickel

Like copper, nickel is an essential nutrient but may be toxic at elevated concentrations. IMC has not reported nickel concentrations in their regular monitoring. We detected nickel in unfiltered water from Sammy Creek, Dry Canyon Creek, and Water Canyon Creek and in filtered water from Sammy Creek (Table 8). The highest concentrations was 0.039 mg/L. Mortality of rainbow trout embryos (LC_{10}) may occur at concentrations as low as 0.011 mg/L (Birge et al. 1979). Eisler (1998) noted that toxic effects of nickel may be expected in salmonids at concentrations ranging from 0.03 to 0.05 mg/L, and recommended a safe level of less than 0.029 mg/L for salmonids. Water hardness is protective against nickel toxicity to aquatic organisms; therefore, elevated water hardness downstream of Big Springs Mine may reduce the potential for adverse effects. Conversely, nickel is more soluble at lower pH levels. Therefore, concentrations may be higher during Spring runoff. Additional sampling during Spring runoff in the NFHR is needed to better characterize concerns with nickel in water.

Nickel concentrations in bottom sediment collected at all sites exceeded the lowest effect level of 16 ppm identified by Persaud et al. (1993). One sample from the NFHR downstream of the mine site exceeded a severe effect level of 75 ppm identified by these researchers (Table 9). Similarly, concentrations in both sediment samples collected downstream of the mine site exceeded a ER-M for coastal marine and estuarine organisms (50 ppm) identified by Long and Morgan (1991).

Nickel was detected in aquatic invertebrates collected from the NFHR downstream of the mine site (Table 10). We were unable to locate information on dietary effect levels for aquatic species. Nickel was not detected in LCT tissues or whole bodies at detection limits ranging from

11 to 17 µg/g.

Selenium

Selenium is strongly bioaccumulated in aquatic organisms (Lemly 1996) and relatively low concentrations in water can quickly become concentrated to potentially toxic levels in aquatic organisms. Toxic endpoints commonly include histopathology, physiological effects, reduced reproduction, and reduced survival. Selenium is recognized as a powerful teratogen, and reproduction is generally considered the most sensitive and significant toxic endpoint. Waterborne concentrations in the low part per billion range can lead to reproductive failure in adult fish with little or no additional symptoms of selenium poisoning in the environment (Lemly 1996). Field cases of selenium poisoning in fish have been documented for waters averaging as little as 0.0015 mg/L selenium (Skorupa 1998). Maier and Knight (1994) summarized seven recent studies that provided estimates of waterborne thresholds for food chain-mediated toxicity to fish and wildlife. All reports concluded that toxic thresholds were less than or equal to 0.003 mg/L in water.

We found selenium concentrations ranging from 0.010 to 0.016 mg/L in drainage from tributaries containing waste rock dumps and from 0.008 to 0.009 mg/L in the NFHR downstream of the mine (Table 8). Concentrations were less than the 0.001 mg/L analytical detection limit in water samples from NFHR upstream of the mine site and Cole Creek. Selenium was detected at a concentration of 0.001 mg/L in the unfiltered sample from Foreman Creek. Comparison of total and dissolved concentrations indicate that the bulk of the selenium was in a dissolved form. Selenium in unfiltered and filtered water correlated significantly with sulfate ($p<0.001$, $r^2=0.934$ and $p=0.002$, $r^2=0.886$, respectively), however the sample size in each case (n=7) was small. As indicated previously, sulfate concentrations in water have increased since initiation of mining in the headwaters area of the NFHR. Concentrations consistently exceeded potentially toxic levels (Table 6)

Selenium concentrations were elevated in bottom sediment and aquatic invertebrates collected downstream of the mine site (Tables 9 and 10). Sediment concentrations in this reach met or approached a biological effect concentration (EC_{10}) of 2.5 ppm identified in Skorupa (1998). Concentrations in invertebrates from all sites exceeded a toxic effect threshold of 3.0 ppm identified by Lemly (1996). Concentrations at NFHR sites downstream of the mine site exceeded dietary concentrations associated with reduced juvenile salmonid survival (6.5 - 10 ppm; Lemly 1996). Hepatic concentrations were elevated in LCT from NFHR and Foreman Creek (Table 11). However, hepatic concentrations have little interpretive value for assessing ecological risks of selenium (Skorupa 1998). NFHR LCT mean muscle and whole body concentrations exceeded toxic thresholds of 8 and 4 ppm, respectively, identified by Lemly (1996).

Lemly (1995) developed a protocol for assessing the toxic threat of selenium to fish and aquatic birds that use a specific habitat known or suspected of being contaminated with selenium. The protocol provides numerical rankings for selenium concentrations in water, sediment, aquatic invertebrates, fish eggs, and avian eggs. Ranking values for individual components are added to provide an overall hazard score. Bird eggs were not collected during our assessment. However, Lemly indicated that the assessment may be performed using four evaluation criteria, although the predictive power will be weakened. Similarly, fish eggs were not collected for analysis of selenium residues in our assessment. However, Lemly indicated that whole body

concentrations may be converted to approximate egg concentration by multiplying by a factor of 3.3. Accordingly, selenium ranks as a high hazard in NFHR and low in Foreman Creek (Table 17). This high ranking indicates that birds associated with the NFHR may be at risk of adverse effects from selenium.

Table 17. Predicted selenium hazard to fish in North Fork Humboldt River and Foreman Creek, Elko County, Nevada, July 1998. Hazard ranking is based on protocol provided in Lemly (1995).

site and component	selenium concentration	hazard rank	hazard score	overall hazard rank
North Fork Humboldt River				
water (mg/L)	0.008	high	5	
sediment (µg/g)	2.0	minimal	2	
aquatic invertebrates (µg/g)	11.0	high	5	
whole fish (µg/g)	8.0	high	5	
Total			17	high
Foreman Creek				
water (mg/L)	<0.001	none	1	
sediment (µg/g)	0.4	none	1	
aquatic invertebrates (µg/g)	4.1	moderate	4	
whole fish (µg/g)	4.2	moderate	4	
Total			10	low

Selenium is a concern in fish for human consumption. California health officials have established a human consumption criterion of 2.0 µg/g, wet weight, for selenium in edible portions of fish and wildlife tissue (Fan et al. 1988). Wet weight selenium concentrations in NFHR LCT muscle samples ranged from 1.7 to 2.9 µg/g with a mean of 2.3 µg/g (Figure 9). Conversely, wet weight concentrations in trout muscle samples from Foreman Creek ranged from 0.4 to 0.7 µg/g with a mean of 0.6 µg/g. Canton and Van Derveer (1997) and Van Derveer and Canton (1997) recommended a sediment-based selenium criterion and presented a model for deriving site-specific criteria**.** In an example, the authors use the model to calculate a site-specific sediment criteria of 0.031 mg/L, using a sediment selenium toxicity threshold of 2.5 µg/g and a site specific mean sediment total organic carbon of 0.5%. However, Hamilton and Lemly (1999) identified several concerns with this approach and the derivation of standards based solely on sediment concentrations.
These researchers also provided overwhelming evidence for the establishment of a water-borne selenium criteria of 0.002 mg/L.

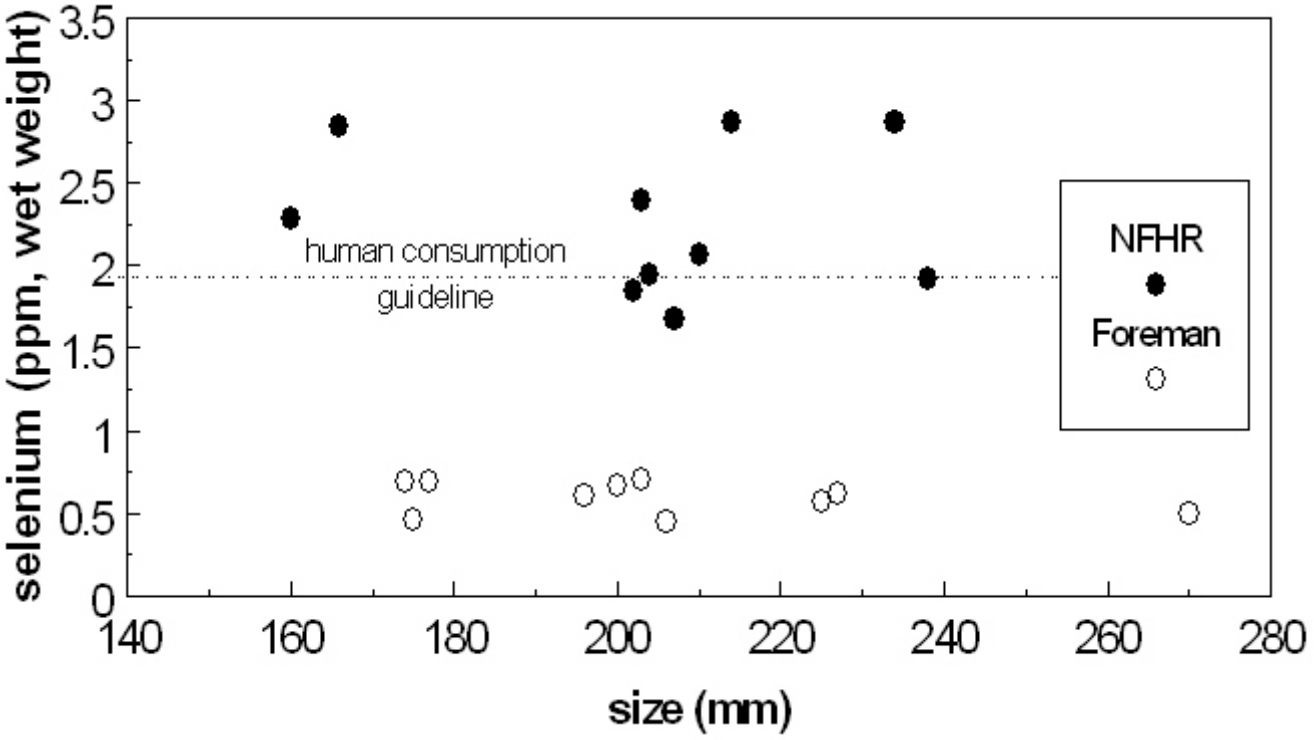

Figure 9 . Selenium concentrations in Lahontan cutthroat trout muscle samples from North Fork Humboldt River (NFHR) and Foreman Creek (Foreman) in the Independence Mountains, Elko County, Nevada, July 1998. The human consumption guideline of 2.0 ppm wet weight are based on recommendations from Fan et al. 1988.

Zinc

Zinc has been found to be acutely toxic (96-hour LC_{50}) to aquatic invertebrates at a concentration as low as 0.032 mg/L in water (U.S. EPA 1987). Lethal and sublethal effects have been found in salmonids at concentrations of less than 0.01 mg/L (Eisler 1993). Zinc concentrations in drainage from NFHR tributaries containing waste rock dumps exceeded 0.01 mg/L (Table 8). Comparison of total and dissolved concentrations indicate that the bulk of the zinc at most sites exists in a dissolved phase. IMC data indicate that zinc concentrations are generally higher during spring runoff. Like copper, early life stage trout tend to be more sensitive to zinc. Because LCT spawn in the Spring, the most sensitive LCT life stages may be present in the NFHR when zinc is most elevated .

Zinc was also elevated in bottom sediment and aquatic invertebrates collected downstream of the mine site (Tables 9 and 10). Concentrations in sediment samples collected from this reach exceeded the lower effect level for aquatic invertebrates (120 µg/g) identified by Persaud et al. (1993), but were well below the severe effect level (820 µg/g). We were unable to locate literature on fish dietary effect concentrations for zinc.

Fish Assemblage

LCT was the dominant fish species in NFHR and was the only species observed in

Foreman Creek. Although it was not an objective of this investigation to quantify fish numbers, it was subjectively noted that LCT were common in suitable habitats within each stream. The lack of fish diversity limits the application of Index of Biological Integrity methodologies (Miller et al. 1988; Plafkin et al. 1989).

The size (i.e., total length) distribution of the observed LCT population from each stream differed (Figure 10). The NFHR assemblage was dominated by larger individuals, with total length in approximately 70 percent of the fish exceeding 150 mm. Juveniles (< 100 mm) represented less than 10 percent of the observed NFHR population. Juvenile fish in NFHR ranged from 89 to 96 mm. Conversely, juveniles in Foreman Creek accounted for approximately 30 percent and individuals exceeding 150 mm accounted for slightly more than 50 percent of the observed population. Juvenile fish in Foreman Creek ranged from 57 to 92 mm. The observed difference in LCT size distribution and juvenile fish abundance suggests a difference in recruitment rates in each stream. However, the streams were not systematically sampled and caution should be used when interpreting differences in recruitment. Subsequent sampling conducted by Anglo Gold indicated the occurrence of young of the year trout and suggested that recruitment was not compromised. Additional surveys are needed to further evaluate age and size class structure of LCT and recruitment in the NFHR and Foreman Creek.

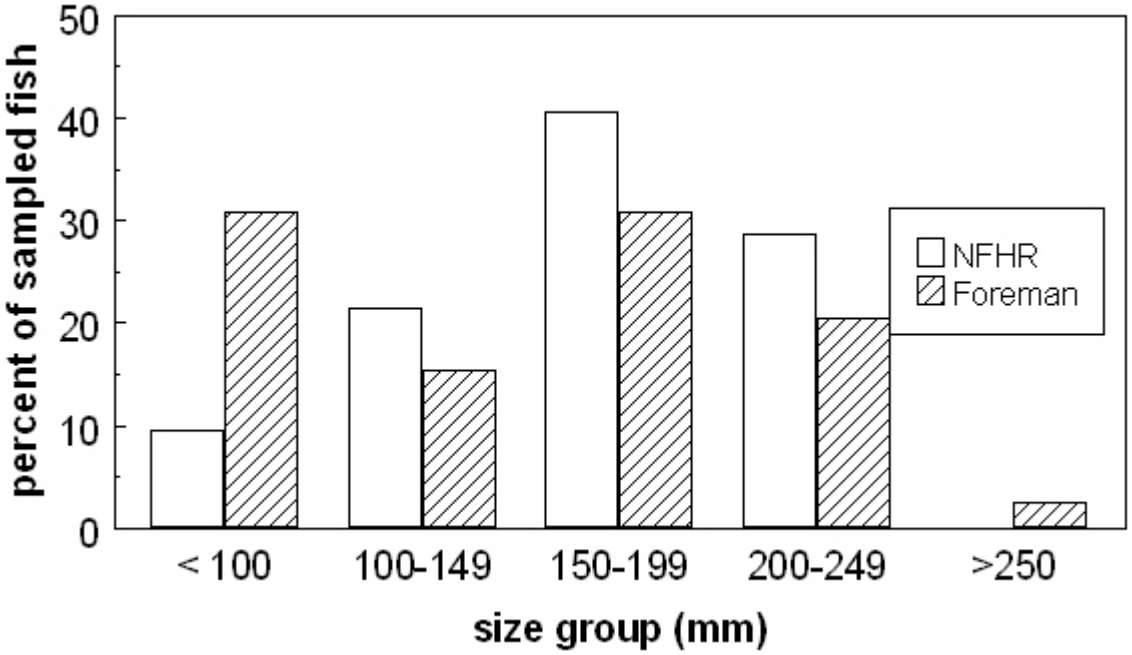

Figure 10. Size distribution of Lahontan cutthroat trout from North Fork Humboldt River (NFHR; n=42) and Foreman Creek (Foreman; n=39) in the Independence Mountains, Elko County, Nevada, July 1998.

Fish Condition

Environmental stress can affect growth rate and general condition of fish (Ney 1993). Condition factors, such as Fulton's condition factor, provide a relative measure of nutritional state or "well being" of individual fish and populations (Anderson and Gutreuter 1983). In general, a smaller condition factor value is interpreted as an indicator of a poorer relative nutritional state. Length-weight relationships, and therefore, condition factors may vary with fish age class. Therefore, we calculated Fulton's condition factor for all LCT from each stream system and for selected size classes. No significant differences were found among condition factor values for selected size classes within each stream system. However, Fulton's condition factor values were significantly higher for Foreman Creek LCT overall and for all size groups except juveniles (Table 12). Reduced condition factors have been associated with elevated selenium in warm water fishes (Lemly 1993).

As indicated previously, selenium is a powerful teratogen to fish and wildlife. Two of the 45 fish (4.4%) examined from NFHR were malformed compared to one of 39 fish (2.6%) from Foreman Creek . It is uncertain if the observed malformations were attributable to teratogenesis. A high mortality rate of teratogenic fish larvae is expected in natural populations. Persistence of deformities in juvenile and adult fish may only occur in special circumstances where natural predation has been reduced or eliminated (Lemly 1997). LCT are piscivorus (Sigler and Sigler 1987) and, therefore, may selectively remove teratogenic or otherwise impaired larval and juvenile fish from the population. Additional information is needed to adequately assess incidence of teratogenesis and potential population-level impacts in the NFHR and Foreman Creek. As recommended by Lemly (1997), additional assessment should include characterization of teratogenesis in fish larvae.

Because of its role in the biotransformation of toxins, assessment of liver structure and function may provide an indicator of exposure to environmental contaminants. The ratio of liver to body weight, or hepatosomatic index, often decreases in chronically stressed fish (Heath 1995). Although the mean hepatosomatic index was lower in NFHR LCT than Foreman Creek LCT, the difference was not significant ($p=0.453$). Certain metals and trace elements may accumulate in fish livers and cause cellular damage in liver (Heath 1995). Histological examination revealed a marked thickening of the connective tissue surrounding the hepatic portal triad in about a third of the livers from NFHR and Foreman Creek. This occurrence may be related to age. No liver abnormalities reflective of toxic insult were observed in LCT livers from either stream. Hepatic damage has been correlated with changes in the activity of certain enzymes in blood plasma. Serum alanine aminotransferase and aspartate aminotransferase activity were tested in the plasma from four fish from each stream. The mean alanine aminotransferase activity for the fish from each stream was within the range (13 to 71 μ/L) for adult trout reported by Racicot et al. (1975). Normal alanine aminotransferase levels specific for LCT were not found in our literature search. The highest alanine aminotransferase activity (170 μ/L) was found in a fish from Foreman Creek. This fish also had high numbers of neutrophils in the blood smear. However, no tissue lesions unique to this individual were seen in the histological sections. Racicot et al. (1975) noted that alanine aminotransferase activity increased with the severity of bacterial disease. The mean aspartate aminotransferase values for both groups exceeded the upper range of the analyzer (950 μ/L). Miller et al. (1983) reported a normal aspartate aminotransferase range for adult trout of 207 to 1,920 μ/L, with a mean of 680 μ/L. Racicot et al. (1975) reported a range of 103 to 508 μ/L for adult trout. Again, normal

aspartate aminotransferase levels specific for LCT were not found in the literature. The high aspartate aminotransferase values in both groups suggest some level of hepatocyte damage common to both groups, however, this observation is not supported by histological data. Due to the lack of normal enzyme level information specific for LCT and conflicting histological evidence, no conclusive diagnosis can be attributed to the plasma enzyme data.

Hematocrit, leukocrit, and blood cell differential counts were similar in fish from NFHR and Foreman Creek. Both groups were within normal ranges for salmonids. Two Foreman Creek fish had elevated numbers of neutrophils which may have been a host response to the observed parasitic infections. No bacteria were isolated from these fish. Although total plasma protein concentrations were higher in the Foreman Creek fish, fish from both sites were within normal ranges for salmonids. Globulin 4 and 5 proteins were significantly higher in the NFHR fish than the Foreman Creek fish. Previous electrophoresis work by the California-Nevada Fish Health Center demonstrated that the complement protein (C3) resides in the Globulin 4 and 5 fraction in juvenile chinook plasma. Compliment proteins are an important component of fish immune response. There was no statistically significant difference in the albumin:globulin ratios between trout from NFHR and Foreman Creek. Changes in the albumin:globulin ratio are indicators of shifts in specific protein production. Other than differences in Globulin 4 and 5 proteins, no obvious plasma protein abnormalities were seen in the NFHR fish.

No significant bacterial infections were detected in either group (Table 16). The *Micrococcus* and *Pseudomonas* isolates were from single colonies. It is quite common to isolate these aquatic bacteria from asymptomatic fish. The *R. salmoninarum* ELISA data indicates low-level infections from this bacteria (BKD agent) without disease. No *Myxobolus cerebralis* spores (whirling disease agent) or viral agents were detected in either group. Both populations had a high prevalence and severity of *Myxidium sp*. infection in the kidney. Histological examination of the kidney showed a number of abnormalities associated with this myxosporean, such as glomerulonephritis, interstitial hyperplasia, and granulomatous response to the spores. The diffuse nature of the granulomatous (scar) lesions caused the swollen kidneys seen in the Foreman Creek fish. The Foreman Creek fish also had a high prevalence of cestode infection within the intestinal tract, however, no histological lesions were associated with these parasites. Gill, testis, and heart sections from both groups showed no abnormalities. As indicated previously, histological abnormalities were found in livers of some LCT from both streams.

Elevated concentrations of metals in water and diet may affect ion regulation in salmonids. Farag et al. (1994) found significantly lower potassium concentrations in juvenile whole fish exposed to elevated concentrations of arsenic, cadmium, copper, lead, and zinc in water and diet consistent with concentrations found in invertebrates in Clark Fork River, Montana. Whole-body concentrations of calcium and sodium were not significantly different. Our findings are consistent with these observations. Potassium concentrations were significantly lower ($p=0.043$) in whole adult fish from NFHR than in fish from Foreman Creek. No significant differences were found in whole-body concentrations of calcium and sodium ($p>0.500$). Farag et al. (1994) indicate that upsets in ion regulation may affect growth and survival. Arsenic, cadmium, and zinc concentrations in aquatic invertebrates from NFHR exceeded or were within the general range of concentrations associated with decreased potassium concentrations in trout from Clark Fork River. Concentrations of copper and lead in NFHR invertebrates were lower concentrations reported by Farag et al. (1994).

SUMMARY

Concentrations of a variety of inorganic contaminants, including a number of potentially toxic metals and trace elements, have increased in the NFHR downstream of the Big Springs Mine since the initiation of mining. Increases in these constituents raised concerns for adverse effects to fish, wildlife, and their habitat in and along the NFHR. Species of concern in this area include threatened LCT, spotted frog (a candidate for listing as endangered or threatened), and a variety of migratory birds. To better assess these concerns, the Fish and Wildlife Service with assistance from EPA, Nevada Division of Wildlife, and the Forest Service reviewed existing water quality data and collected additional biological and chemical data.

A review of existing water quality data indicated that TDS, sulfate, aluminum, copper, iron, manganese, mercury, selenium, and zinc are at levels of concern to fish, wildlife, and their habitat in the NFHR. Since initiation of mining, concentrations of TDS and sulfate have increased in tributaries containing waste rock dumps and in the NFHR downstream of the mine. Data from Sammy Creek indicate that the largest increases occur downstream of the waste rock dumps. Since 1994, concentrations of TDS and sulfate in drainage from tributaries with waste rock dumps and the NFHR between Water Canyon and Cole Creek have consistently exceeded standards for applicable beneficial uses (municipal and domestic water supply). Aluminum, copper, iron, manganese, and zinc were generally most elevated during periods of high runoff during the Spring (May and June). During this period, concentrations commonly exceeded fish effect levels. We also found nickel concentrations exceeding aquatic life effect concentrations and Nevada water quality standards for municipal and domestic supply. Previous IMC monitoring had not included nickel. Since 1994, selenium concentrations in tributaries with waste rock dumps and the NFHR downstream of the mine site have consistently exceeded aquatic life and wildlife effect concentrations and Nevada water quality standards for aquatic life. Selenium concentrations commonly exceeded the standards for municipal and domestic supply and irrigation in drainage from tributaries. Selenium concentrations in water were significantly correlated with sulfate concentrations. Sulfate concentrations have increased since initiation of mining.

Effects of drainage from the Big Springs Mine to aquatic organisms in the NFHR may result from direct toxicity from water and/or from sediment-mediated toxicity. The latter includes incorporation of the contaminants in food chains and the resulting exposure of fish and wildlife to contaminants through dietary pathways. Sediment and food chain contamination associated with mine site drainage may persist extended distances in stream systems (Moore et al. 1991).

IMC data demonstrate elevated concentrations of certain metals in Spring runoff. Elevated concentrations of these metals is of particular concern during Spring because LCT spawn during this time period. Therefore, sensitive trout life stages may be subjected to potentially toxic concentrations of these metals. Also, because of high water volumes associated with snowmelt runoff, large loads of these metals are mobilized from tributaries containing waste rock dumps. These loads appear to contribute to elevated concentrations of certain constituents in sediment. We found elevated concentrations of arsenic, cadmium, manganese, nickel, selenium, and zinc in bottom sediment from the NFHR downstream of the mine site. Arsenic, manganese, nickel, selenium, and zinc in sediment exceeded potentially toxic concentrations. Concentrations of arsenic, cadmium, manganese, nickel, selenium, and zinc were elevated in

aquatic invertebrates collected from the NFHR downstream of the mine site. Concentrations of arsenic and selenium in invertebrates exceeded fish dietary effect levels. Concentrations of metals and trace elements appeared elevated in some LCT tissue samples collected from NFHR. Selenium was of particular concern. As with water, sediment, and invertebrates, selenium in fish tissues exceeded concentrations associated with adverse effects. Selenium concentrations in the majority of fish muscle samples from NFHR also exceeded a recommended criterion for human consumption.

LCT were common in suitable habitats in NFHR and Foreman Creek, which served as a reference stream. Other fish species appeared rare in NFHR and absent in Foreman Creek. As compared with Foreman Creek, fewer juvenile LCT were found in NFHR. Adult LCT from NFHR also had a lower mean condition factor. External abnormalities were found on a limited number of fish in NFHR and Foreman Creek. Blood cell measurements, muscle lipid content, hepatosomatic index values, liver enzyme levels, incidence of bacterial and viral infection, and histology of gill, liver, kidney, heart, and testes were similar in LCT from NFHR and Foreman Creek. Slight differences in blood plasma protein concentrations were found between the sites.

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