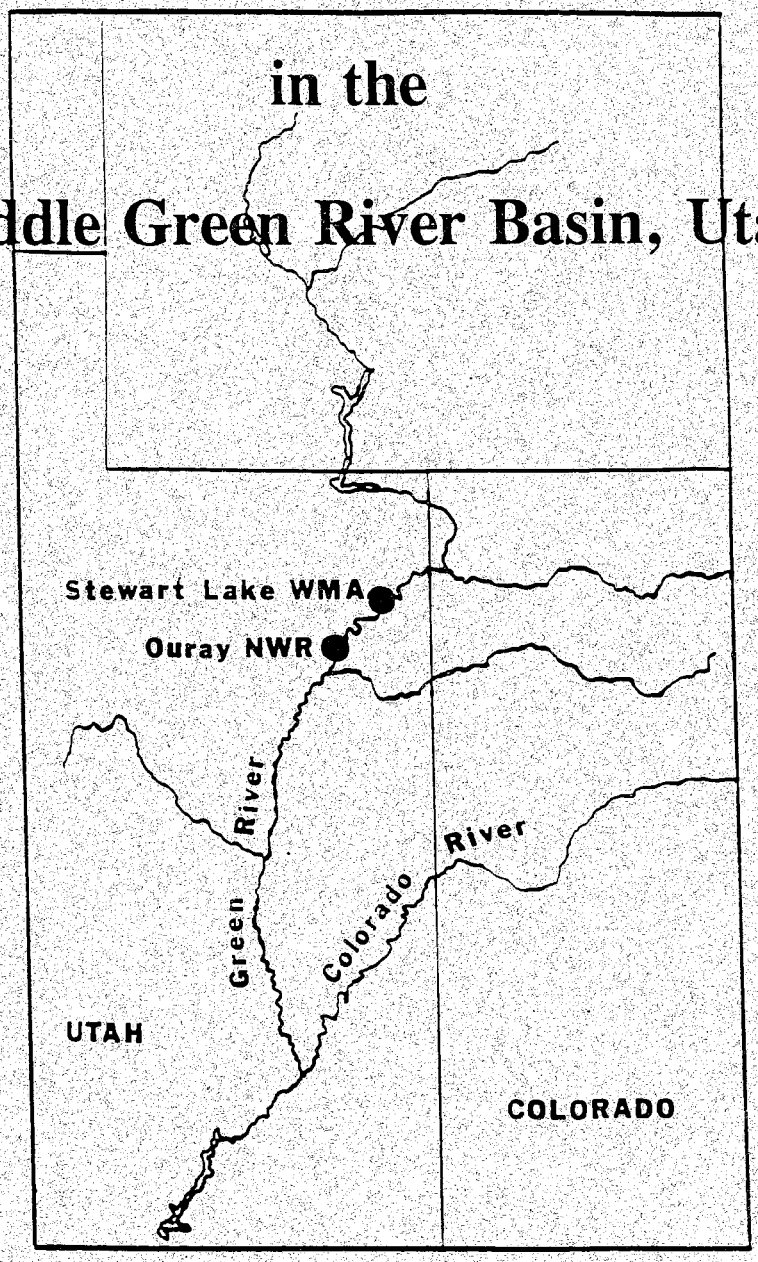
Toxicity of Irrigation Drainage and Associated Waters in the Middle Green River Basin, Utah



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National Biological Survey
National Fisheries Contaminant Research Center
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EXECUTIVE SUMMARY

The toxicity of water from twelve locations in the Middle Green River basin was evaluated in a series of on-site tests conducted for 10 days with Daphnia magna, fathead minnows, and razorback suckers. Tests included sites from the Ashley Creek drainage, the Stewart Lake Waterfowl Management Area, Ouray National Wildlife Refuge, and the Green River. In all assessments, organisms were exposed to 100% site water and dilutions of 50, 25, and 12.5%. Dilution water was reconstituted to the appropriate ionic balance for each location so that conductivity, hardness, alkalinity, pH and sulfates remained constant across all treatments. This reconstituted water was also used as a control. An additional control using contaminant free well water transported from the National Fisheries Contaminant Research Center (Columbia, MO) was also included.

Water from Sadler Draw in the Ashley Creek drainage was the most toxic to all three species (Table 1). Mortality began within 48 h of exposure and a dose response relationship was evident across treatments after 10 days. Reproductive success of Daphnia magna was also severely affected at this location even in treatments that did not exhibit mortality. All sites in the Stewart Lake Wildlife Management Area were moderately toxic to one or more species. Negative effects on reproductive success in daphnids were evident at all SLWMA sites, with effects in water

from Drain J234 most severe. Contrastingly, no appreciable mortality of any species occurred in water from South Roadside Pond or Leota Pond #6 at the Ouray National Wildlife Refuge (NWR). Reproductive success of daphnids was not impaired in any Ouray NWR location.

In contrast to other western irrigation projects such as Stillwater Wildlife Management Area (NV) and Kesterson National Wildlife Refuge (CA), no dramatic daily fluctuations in water chemistry occurred at any location during the test period (Table 2). In general, test waters were hard, well buffered, and high in sulfate with pH ranging from 7.3 to 9.4. Levels of unionized ammonia and nitrate in water did not exceed acutely toxic levels at any location. Water quality characteristics during this study were very similar to those measured in reconnaissance surveys of the Middle Green River Basin between 1982 and 1989 (Stephens et al. 1988, Peltz and Waddell 1991, Stephens et al. 1992). The consistency of water quality conditions across years suggests that existing knowledge of water quality and contaminants in drains and tributaries of the Basin will be useful in formulating management decisions related to remediation efforts in the region.

Concentrations of selenium, boron, cobalt, copper, lithium and strontium in the water were highest at the Sadler Draw location where mortality was highest. These values were not as high as some documented in 1988 samples from other locations in the Ashley Creek drainage (Peltz and Waddell 1991), however, they

were high enough to warrant concern. Although no single contaminant was present at acutely toxic concentrations, a strong relationship existed between the concentration of selenium and the mortality observed for razorback suckers and fathead minnows during the 10-day exposure. Similarly, a strong relationship was demonstrated between increased concentrations of selenium and decreased reproductive success in Daphnia magna, providing evidence to implicate selenium as an important toxic component of the drainwater.

No other single element identified in the drainwater mixture exhibited a statistically significant relationship with either reproduction or mortality. Although elements including titanium, uranium, and zinc were present in all water samples, they were not correlated with mortality or with the presence of other major elements in the drainwaters. However, for all locations, a strong relationship did exist between the combined presence of 6 elements that commonly occur in drainwater of the Middle Green River Basin -- selenium, boron, cobalt, copper, lithium, and strontium -- and the mortality observed in the on-site tests. In addition, conductivity was strongly related to the combined presence of those six elements (r=0.96) as well as to the presence of selenium alone (r=0.90). Results from this study suggest that conductivity may provide a valuable tool for assessing the quality of water discharged into the Green River.

Concentrations of selenium consistently exceeded the national water quality criterion for the protection of aquatic

life (5 μg/L) at 4 of the 5 sites in the Ashley Creek Drainage and at 2 of the 3 sites in the Stewart Lake Waterfowl Management Area. This water quality criterion was never exceeded in sites at Ouray National Wildlife Refuge or in the Green River during our study. No national water quality criteria exist for boron, cobalt, or lithium.

Although national acute and chronic water quality criteria for selenium were exceeded at numerous sites, the mortality and reproductive impairment observed during our studies could not have been predicted based on laboratory toxicity tests with individual elements. It is apparent from this study, that the toxic responses observed were influenced by, but did not result exclusively from selenium; other constituents of the drainwater interacted either additively or synergistically to cause toxic responses in the test organisms. This study clearly indicates that exposure to agricultural irrigation drainwater in the Middle Green River Basin can result in adverse effects on aquatic organisms including the endangered razorback sucker .

Table 1. Percent survival of *Daphnia magna* (n=20), fathead minnows (n=20), and razorback suckers (n=10) after 10 days of exposure to water from each site.

Location Site	Species		
	Daphnia magna	Fathead minnow	Razorback sucker
Ashley Creek Drainage			
Sadler Draw	25	40	20
South Vernal Drain	80	95	80
Drain 31A1	85	90	100
6550 Bridge	65	80	80
Ashley Creek Mouth	80	55	70
Stewart Lake Management Area			
Stewart Lake Outflow	70	90	90
Drain J234	75	50	80
Drain J1/J1A	85	70	50
Ouray National Wildlife Refuge			
Leota #6	100	100	100
North Roadside Pond	75*	95	100
South Roadside Pond	100	95	100
Green River			
Green River at Hwy 40	100	90	100

* Mortality may have resulted from low oxygen stress on day 3 of the study

Table 2. Range of concentrations of major constituents in water from all twelve locations.

Location Site	Conductivity (µS/cm)	pH	Selenium (mg/L)	Boron (mg/L)
Ashley Creek				
Sadler Draw	4500-5800	8.1-8.3	.940-1.150	1.9-2.1
6550 Bridge	1750-2100	8.1-8.3	.041-.063	.51-.96
S. Vernal Drain	1000-1250	8.0-8.2	.001-.002	.27-.31
Drain 31A1	1790-2550	7.3-7.8	.006-.007	.59-.68
Ashley Creek (Mouth)	1970-2400	7.9-8.1	.031-.052	.49-.64
Stewart Lake				
Drain J1/J1A	1400-1610	7.5-7.7	.022-.028	.42-.49
Drain J234	1900-2050	7.9-8.1	.028-.034	.65-.90
S.L. Outflow	1690-1920	7.6-7.8	.003-.005	.57-.63
Ouray NWR				
N. Roadside Pond	950-1120	8.9-9.4	.002-.003	.26-.31
S. Roadside Pond	710-1050	7.9-8.5	.001-.003	.24-.27
Leota # 6	550-700	7.5-8.6	.001	.13-.15
Green River				
at US 40	500-580	8.3-8.5	<.001	.08-.09

Location Site	Cobalt (mg/L)	Copper (mg/L)	Lithium (mg/L)	Strontium (mg/L)
Ashley Creek				
Sadler Draw	.046-.051	.22-.24	.62-.68	4.3-4.6
6550 Bridge	.018-.023	.10-.11	.17-.20	3.4-3.9
S. Vernal Drain	.014-.017	.07-.08	.09-.10	2.6-2.9
Drain 31A1	.024-.026	.12-.13	.17-.21	4.9-5.3
Ashley Creek (Mouth)	.020-.025	.07-.12	.14-.22	3.3-4.0
Stewart Lake				
Drain J1/J1A	.016-.018	.08-.16	.11-.12	2.4-2.7
Drain J234	.018-.020	.09-.10	.11-.12	3.2-3.4
S.L. Outflow	.018-.020	.09-.10	.10-.12	2.5-2.8
Ouray NWR				
N. Roadside Pond	.004-.007	.02	.07-.08	.69-.72
S. Roadside Pond	.007-.008	.03	.06	.76-1.04
Leota # 6	.006-.007	.02-.03	.03	.54-.60
Green River				
at US 40	.003-.006	.02	.02	.46-.54

INTRODUCTION

A recently completed U.S.Geological Survey open file report summarized the physical and chemical characterization of biotic and abiotic components of the Middle Green River Basin, Utah (Peltz and Waddell 1991). This report focused on irrigation projects near Jensen, and Vernal, Utah that supply water to Stewart Lake Waterfowl Management Area (SLWMA) and Ouray National Wildlife Refuge (SLWMA) (Figure 1). Both areas are used extensively by migratory waterfowl. Although management of fisheries is not of primary interest within these units, water from these areas enters the Green River which provides habitat for four endangered fish species: razorback sucker (*Xyrauchen texanus*), Colorado squawfish (*Ptychocheilus lucius*), humpback chub (*Gila cyphon*), and bonytail (*Gila eleganis*). In addition, irrigation water also enters the Green River from Ashley Creek and its tributaries. Areas in the Green River adjacent to these discharges provide spawning and nursery habitat for the razorback sucker and Colorado squawfish (Tyus and Karp 1990). Although little information is available defining habitat requirements for bonytail (Tyus and Karp 1989), spawning areas for both razorback suckers and Colorado squawfish are known to be limited in the Middle Green River system (Tyus 1990, Tyus and Karp 1990). Use of spawning habitat in lower Ashley Creek and the Stewart Lake Outflow where irrigation return flows are concentrated represents a potential hazard to these species. Analysis of water, sediment, and biological tissues from the Green River Basin has

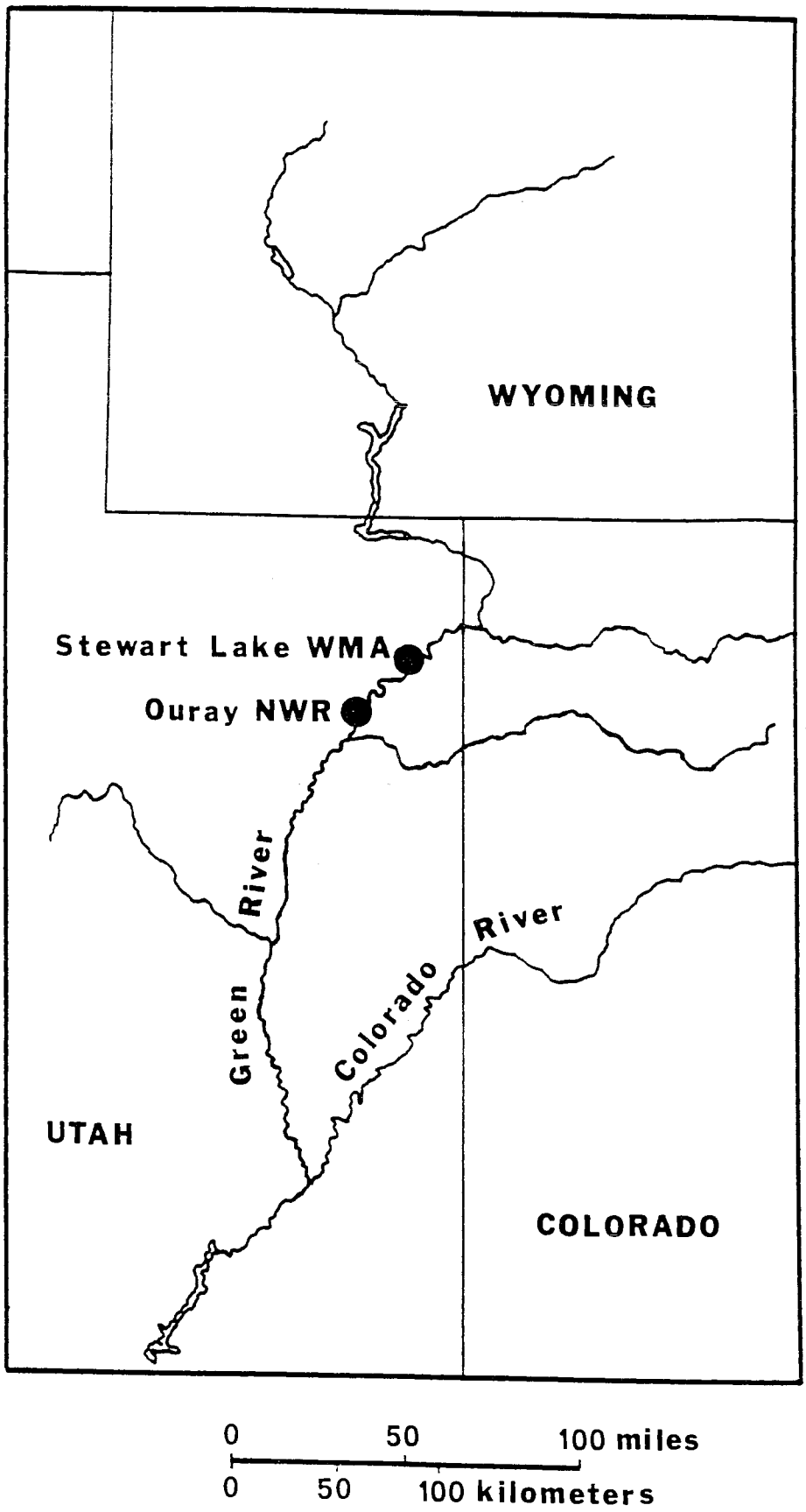


Figure 1. Map of the Middle Green River Basin where toxicity tests were conducted.

confirmed the presence of boron and selenium as well as other water quality conditions that may influence survival and reproduction of fish and aquatic invertebrates (Stephens et al. 1988, Peltz and Waddell 1991). Furthermore, selenium concentrations in water entering SLWMA and Ashley Creek were at levels above those recommended for the protection of aquatic organisms (USEPA 1987). Recent laboratory research to determine the toxicity of individual inorganic contaminants in water quality similar to that of the Green River also suggests that concentrations of certain constituents common to irrigation drainwater in the Green River system represent a moderate to high environmental hazard to critical life stages of the endangered species (Hamilton, in review).

Prior to research presented herein, no studies had been conducted to determine the toxicity of drainwater entering Ashley Creek, SLWMA, or ONWR. Whole effluent toxicity tests are routinely used to evaluate point and non-point source contamination and provide information on survival, reproduction, and growth of organisms exposed to an effluent and dilutions of that effluent. These tests are now a requirement for all National Pollutant Discharge Elimination System permits and have been included as an integral component of many recently developed state and federal monitoring programs. Information from these tests can assist in ecological interpretation of existing chemical residue information. In addition, repeated use of these tests provides information useful in evaluating the success of

remedial measures. In this report, we present the results of on-site whole effluent toxicity tests conducted at twelve locations in the Middle Green River Basin and discuss the ecological implications of our findings.

METHODS

Sample Collection

Four areas in the Middle Green River Basin of northeastern Utah were evaluated using whole effluent toxicity tests. Water samples from these areas were collected from twelve different sites: 1) the Ashley Creek drainage including two sites in the creek (ACGR, 6550), two irrigation drains flowing into the creek (SVD, 31A1) and a tributary to the creek (S); 2) three sites on SLWMA (SLO, J234, J1J1A) near Jensen, UT; 3) the Green River (GR) at US Highway 40, and 4) three sites (NRS, SRS, L) at ONWR (Table 3).

Two consecutive sets of 10-d toxicity tests were conducted. The first 10-day test (July 17-28) included water samples from the SLWMA group, Sadler Draw, the mouth of Ashley Creek and the Green River (Table 3). The second test (July 31- August 11) was run with water from ONWR and the two irrigation drains near the city of Vernal.

Water was collected daily from each site as either a 24-h composite or grab sample (Table 3). For collection of composite

Table 3. Site Locations and Sampling Technique for Green River Irrigation Drainwater Study, 1992. SLWMA = Stewart Lake Waterfowl Management Area. ONWR = Ouray National Wildlife Refuge.

Site	Site Code	Location	Type of Sample
Test 1: July 17- July 28, 1992			
Green River at Hwy 40	GR	reference site	grab
Sadler Draw	S	SE Naples, UT	composite
Ashley Creek at County Road 6550 Bridge	6550	below Sadler Draw	grab
Mouth of Ashley Creek at Green River	ACGR	confluence	composite
J1/J1A Drain	J1J1A	SLWMA	composite
Composite of Drains J2, J3. and J4	J234	SLWMA	composite
Stewart Lake Outflow	SLO	SLWMA outflow to Green River	grab
Test 2: July 31- August 11, 1992			
Leota Bottom #6	Leota	ONWR	grab
North Roadside Pond	NRS	ONWR	grab
South Roadside Pond	SRS	ONWR	grab
South Vernal Drain	SVD	SE Vernal, UT	composite
31A1 Drain	31A1	SE Vernal, UT	composite

samples, automated samplers (ISCO INC., Lincoln, NE) collected water at 15-min intervals throughout the 10-day study. Water was pumped from each site through 0.48-cm Teflon tubing into 19-L acid-washed glass containers. Twenty-four hour composite water samples were held in ice baths to maintain temperatures at 4°C during collection. At sites where automated samplers were not used, a single grab sample was collected and stored on ice in acid-washed 19-L glass containers. Composite and grab samples were transported to a mobile laboratory.

On-site measurements of air and water temperature, pH, dissolved oxygen, salinity, and conductivity were recorded before transferring the samples to the mobile laboratory. Hardness, alkalinity, pH, conductivity, and turbidity of sample water were measured daily at the mobile laboratory (APHA 1989). Calcium, chloride, sulfate, nitrate, and unionized ammonia were measured on alternate days during the study (APHA 1989).

Contaminant Analysis

A subsample (1000-ml) from each 24-h composite or grab sample was collected daily from each site for inorganic analysis. Samples were filtered through 0.4 μm polycarbonate filters and preserved with 2 μL of ultrapure hydrochloric acid. These samples were stored in 1-L acid-washed linear polyethylene containers. Spiked samples, blanks, and replicates prepared on site were included as measures of quality assurance.

Filtered samples to be analyzed for inorganic contaminants

were digested in 100-ml borosilicate glass beakers that had been cleaned by a 30-min concentrated nitric acid reflux cycle. About 40 ml of the sample was combined with 15 ml concentrated nitric acid and 2.5 ml concentrated perchloric acid and evaporated over low heat until 1 ml remained. This digestate was diluted to 50 ml with ultrapure water and analyzed for selenium and arsenic with hydride generation atomic absorption (AA) at the National Fisheries Contaminant Research Center's (NFCRC) Field Station in Yankton, SD. A separate digestate was analyzed for additional elements with a Jarrel-Ash 1100 Inductively Coupled Argon Plasma Spectrophotometry (ICAP) at Environmental Trace Substance Research Center, University of Missouri-Columbia. Natural uranium and its isotopes were analyzed by the University of MO-Columbia.

All results were within 20% of confidence intervals for certified or recommended concentrations for the reference materials. Of the samples analyzed, 10% were blanks and 20% were blind replicates and spiked samples. No values for blanks exceeded detection limits for any element (Table 4).

Toxicity Assessments

Toxicity tests were conducted with water collected from each site for a 10-day period in a mobile laboratory in Vernal, Utah. Test species included 40-60 d old razorback suckers (*Xyrauchen texanus*), 72-h old larval fathead minnows (*Pimephales promelas*), and 72-h old daphnids (*Daphnia magna*). Daphnids and fathead

Table 4. Detection limits for inorganic elements measured in water samples (mg/L) and in sediment samples (μg/g) from the Middle Green River Basin.

Element	Water (mg/L)	Sediment (μg/g)
Silver	0.02	20.0
Aluminum	0.03	30.0
Arsenic	0.002	0.03
Boron	0.02	20.0
Barium	0.001	1.0
Beryllium	0.001	1.0
Bismuth	0.02	20.0
Calcium	0.1	10.0
Cadmium	0.002	3.0
Cobalt	0.01	6.0
Chromium	0.002	10.0
Copper	0.002	2.0
Iron	0.01	10.0
Potassium	0.2	200.0
Tungsten	0.02	10.0
Lithium	0.001	2.0
Magnesium	0.001	30.0
Manganese	0.002	2.0
Molybdenum	0.01	10.0
Sodium	0.01	10.0
Nickel	0.01	10.0
Phosphorus	0.1	100.0
Lead	0.04	40.0
Antimony	0.05	40.0
Selenium	0.001 (.0001)	0.03
Silica	0.01	60.0
Tin	0.05	40.0
Strontium	0.001	1.0
Titanium	0.0007	0.7
Thallium	0.0003	70.0
Uranium	0.005	**
Vanadium	0.003	3.0
Zinc	0.002	2.0

** Not measured

minnows were obtained from cultures at the National Fisheries Contaminant Research Center (NFCRC), Columbia, MO. Razorback suckers, originally from Dexter National Fish Hatchery (Dexter, NM) were obtained from NFCRC-Yankton. Brood stock of razorback suckers was from Lake Mohave, Arizona-Nevada. All organisms were shipped to Vernal, UT, immediately prior to the start of each test. Organisms were held in their culture water and temperature acclimated overnight. Fathead minnow larvae and daphnids remained in NFCRC-Columbia laboratory well water prior to the test (280 mg/L hardness, 255 mg/L alkalinity, 7.8 pH). Razorback suckers remained in well water from the NFCRC-Yankton laboratory (230-330 mg/L hardness, 174-226 mg/L alkalinity, 7.7-7.9 pH).

Tests were conducted as static renewals following USEPA (1985) and ASTM (1988) protocol for toxicity testing. Razorback suckers were fed hatchery diet (Biodiet, Bioproducts Inc., Warrenton, Oregon). Fathead minnows were fed freshly hatched brine shrimp nauplli (Artemia) twice daily. Daphnids were fed the USEPA yeast-trout chow-Cerophyl (cereal leaves) formula (USEPA 1985). Tests with fathead minnows and daphnids included 2 replicates per treatment and 10 organisms per replicate. Razorback sucker exposures were run with 2 replicates per treatment and 5 organisms per replicate. Treatments included full strength sample water and dilutions of 50, 25 and 12.5 percent. Dilution water for each test was reconstituted to the appropriate hardness, alkalinity, specific conductance, and pH for individual test locations by the addition of major cations

and anions to deionized water. Consistent concentrations of major ions such as calcium, magnesium, sodium, chloride, and sulfate were maintained for all treatments for each sampling site by reconstituting dilution water to a similar ionic composition for each site. This reconstituted water was also used as control water. In addition, NFCRC well water was used as a second control to monitor organism condition during testing.

Water quality (temperature, dissolved oxygen, pH, conductivity, salinity) was measured daily in fathead minnow chambers and on Days 1, 2, and 10 in razorback suckers and daphnid chambers daily. Adequate oxygen levels (above 40% saturation) were maintained in test chambers by continual aeration during the study. Daily mortality was recorded during all tests. Daphnids and fathead minnows were preserved with 10% formalin on the final day of the tests to examine differences in growth. For daphnids, time to first brood, number of broods, and number of young were recorded as a measure of reproductive success.

RESULTS

I. Ashley Creek Drainage

Ashley Creek located near Vernal, Utah drains Ashley Valley and discharges to the Green River. Wetlands adjacent to Ashley Creek provide extensive wildlife habitat and a nearby marsh is managed as a waterfowl area. Between 1970 and 1981, the Bureau of Reclamation installed about 19 miles of subsurface drains in this area that collect water and discharge into Ashley Creek through the Ashley Central irrigation canal or through a series of eight natural tributaries to the creek.

Five locations (Sadler, South Vernal Drain, 6550 Bridge, Drain 31A1, and the mouth of Ashley Creek) were evaluated within the Ashley Creek Drainage. Overall, toxicity was higher in this drainage than in the Stewart Lake Management Area or Ouray National Wildlife Refuge. Concentrations of selenium consistently exceeded the 5 μg/L national water quality criterion for the protection of aquatic life at every location in the drainage except South Vernal Drain. As is characteristic of many western irrigation drainwater systems, water from all sites in the Ashley Creek drainage was well buffered, high in hardness, and generally high in sulfate and chloride. Specific conductance ranged from a low of 1000 μS/cm in the South Vernal Drain to a high of 5800 μS/cm in Sadler Draw. The pH ranged from 7.3 to 8.3 across all locations with no appreciable daily fluctuations.

Surface water temperatures ranged from 18 to 22 °C and remained stable throughout the study. No measurable rainfall was recorded during the test period.

Sadler Draw

Toxicity of all three species was higher in water collected from Sadler Draw than at any other location (Table 5). Mortality began within 24 to 48 h of exposure and by day 10, a dose response pattern for all species was evident across treatments. Rate of mortality was similar for all species, however, total mortality of razorback suckers was higher than that of daphnids or fathead minnows in the two highest treatments. No appreciable mortality of any species occurred in dilutions of 25% or 12.5% or the control exposures.

Exposure of daphnids to water from Sadler greatly reduced the reproductive success for these organisms. Time to first brood, total number of young produced, and mean number of young per adult were all affected by exposure to drainwater. Initiation of reproduction was delayed by exposure to drainwater. Time to production of the first brood in the three highest treatments was 24 to 48 h longer than time to first brood in either the control or the 12.5 % drainwater treatment. During the 10-d period, only 3 young were produced in the full-strength water from Sadler Draw compared to 341 young produced in the control. Production of young increased as concentration of drainwater decreased. In addition, the mean number of young

Table 5. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from Sadler Draw (S) beginning 18 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	75	100	100	100	100
Day 3	30	100	100	100	100
Day 4	30	95	100	100	100
Day 5	30	75	100	100	100
Day 6	25	75	100	100	100
Day 7	25	60	100	100	95
Day 8	25	60	100	100	95
Day 9	25	60	100	100	95
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	75	100	100	100	100
Day 3	50	75	95	100	100
Day 4	45	70	95	100	100
Day 5	40	70	95	100	100
Day 6	40	70	95	100	100
Day 7	40	70	90	100	95
Day 8	40	70	90	100	95
Day 9	40	70	90	100	95
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	70	100	100	100	100
Day 2	60	90	100	100	100
Day 3	40	70	100	100	100
Day 4	30	60	100	100	100
Day 5	30	60	100	100	100
Day 6	20	50	100	100	100
Day 7	20	50	100	100	100
Day 8	20	50	100	100	100
Day 9	20	50	100	100	100

produced per surviving adult increased from 0.5 young per adult in the full-strength drainwater to 17.1 in the control.

Specific conductance of water from Sadler Draw ranged from 4690 to 5800 μS/cm (Table 6) and was consistently higher than that of water from any other location. In addition, sulfate concentrations were among the highest recorded. However, because conductivity and major ion concentrations (including sulfate) were maintained at constant levels across all treatments and no reduction in survival occurred in the 25 or 12.5% treatments, the mortality observed in water from this location can not be attributed to high conductivity, atypical ionic ratios, or sulfate alone. In addition, unionized ammonia did not approach acutely toxic concentrations and although nitrate was elevated in water from Sadler Draw, it did not exceed concentrations known to be toxic in such a hard, well-buffered water.

Concentrations of selenium, boron, cobalt, copper, and lithium at this location were higher than concentrations at any other location tested (Tables 2 and 7). Although the selenium concentrations ranging from 940-1150 μg/L at Sadler Draw should be recognized as elevated, they were considerably lower than concentrations of 3800 - 8900 μg/L reported by Peltz and Waddell (1991) for another Ashley Creek tributary (Sunshine/Burns runoff north of US 40) and similar to concentrations of 1600 μg/L reported for Ashley Creek Tributary 8 north of US 40. Contrastingly, natural uranium concentrations were not elevated at this location. Similarly, silver, arsenic, beryllium,

Table 6. Water chemistry measurements on daily composite samples collected from Sadler Draw beginning 18 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	1636	280	7.1	8.29	3.9	5800
Day 2	2048	240	8.4	8.22	2.9	4900
Day 3	2048	236	8.2	8.26	3.0	4950
Day 4	2040	244	7.8	8.26	3.0	4690
Day 5	2080	238	9.5	8.26	3.5	4760
Day 6	2052	222	8.0	8.21	3.5	5000
Day 7	2200	230	9.4	8.24	3.3	4500
Day 8	2032	240	8.9	8.14	3.1	5000
Day 9	2200	240	8.8	8.08	3.0	4775

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	2.0	1530	142	0.09	14.7
Day 2	8.5		120	0.08	12.7
Day 3	14.0	1555			
Day 4	2.5		140	0.06	14.1
Day 5	7.0	1416			
Day 6	3.7		284	0.04	11.0
Day 7	4.8	1285			
Day 8	4.0		223	0.04	17.7
Day 9	2.2				

Table 7. Concentrations (mg/L) of dissolved inorganic constituents in daily composite water samples collected from Sadler Drain beginning 18 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	2.03	0.018	338.0	0.049	0.24	0.14
07-19-92	<.002	2.07	0.016	318.0	0.050	0.24	0.21
07-20-92	<.002	2.07	0.015	326.0	0.048	0.24	0.02
07-21-92	<.002	2.00	0.015	318.0	0.048	0.23	0.06
07-22-92	<.002	2.04	0.014	323.0	0.049	0.23	0.02
07-23-92	<.002	2.05	0.013	321.0	0.051	0.24	0.05
07-24-92	0.002	2.01	0.014	319.0	0.047	0.23	0.13
07-25-92	<.002	1.98	0.014	323.0	0.047	0.23	0.06
07-26-92	<.002	1.90	0.015	311.0	0.046	0.22	0.33

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.68	285.0	6.3	932.0	0.01	1.12
07-19-92	0.67	284.0	6.5	917.0	0.01	1.15
07-20-92	0.67	285.0	6.3	905.0	<.01	1.04
07-21-92	0.63	276.0	6.1	862.0	<.01	1.04
07-22-92	0.68	282.0	6.3	897.0	<.01	1.06
07-23-92	0.70	288.0	6.4	926.0	0.01	1.09
07-24-92	0.68	279.0	6.7	893.0	<.01	1.02
07-25-92	0.67	276.0	7.0	883.0	<.01	1.02
07-26-92	0.62	263.0	6.1	836.0	0.01	0.94

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	0.78	4.60	0.003	0.17	<.003	0.007
07-19-92	0.64	4.49	0.004	0.15	<.003	0.004
07-20-92	0.06	4.55	0.001	0.21	<.003	0.002
07-21-92	0.18	4.43	0.001	0.15	<.003	0.009
07-22-92	0.77	4.49	0.002	0.19	<.003	0.003
07-23-92	0.22	4.53	0.001	0.19	<.003	0.003
07-24-92	0.35	4.44	0.003	0.21	<.003	0.003
07-25-92	0.22	4.43	0.002	0.20	<.003	0.006
07-26-92	0.89	4.26	0.005	0.18	<.003	0.005

bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from Sadler.

As expected, concentrations of contaminants in sediment collected from Sadler Draw were higher than any other site in the Ashley Creek Drainage. Arsenic, selenium, boron, cobalt, copper, lithium, nickel, and zinc were all elevated (Table 8). However, concentrations of these elements in porewaters extracted from the sediment were not highest at this location. This is likely due to the high concentrations of salts at the Sadler location. Sediments at Sadler Drain had very little organic matter and were extremely high in calcium, sodium, magnesium and potassium. After collection, the sediments settled rapidly in the collection container and separated into a solid and liquid phase. The solid phase hardened and was very difficult to resuspend. Therefore, extraction of a porewater may have been affected by the physical and chemical characteristics of the sediment.

Table 8. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Sadler Draw.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	18.1	57.1
Boron	81	2.29
Barium	270	0.67
Calcium	52,600	152
Cobalt	25	0.038
Copper	18	0.15
Iron	12,800	18
Lithium	8	0.57
Magnesium	11,000	176
Potassium	5600	20
Sodium	3000	781
Nickel	28	0.02
Selenium	31.6	37.5
Silica	2700	2.30
Strontium	150	3.21
Titanium	27	0.30
Vanadium	20	0.10
Zinc	120	0.08

County Road 6550 Bridge

Water from this location induced mortality in all three species (Table 9), but at levels lower than those observed in water from Sadler Draw. Highest mortality occurred in daphnids. No appreciable mortality (>90%) occurred in treatments of any drainwater dilutions or the control.

Exposure of daphnids to water from 6550 also greatly reduced the reproductive success for these organisms. Time to first brood, total number of young produced, and mean number of young per adult were all affected by exposure to drainwater. Time to production of the first brood in the two highest treatments was delayed by 24 h as compared to first brood production in other treatments or the control. During the 10-d period, only 22 young were produced in the full-strength water from site 6550 compared to 364 young produced in the control. Production of young increased as concentration of drainwater decreased. In addition, the mean number of young produced per surviving adult increased from 1.7 young per adult in the full-strength drainwater to 19.2 in the control.

Specific conductivity of the water from site 6550 ranged from 1790 to 2090 μS/cm with a pH of 8.07 to 8.24 (Table 10). These measurements were very similar to the conductivity of 2350 to 2450 μS/cm and pH of 8.2 reported in 1988 water samples by Peltz and Waddell (1991). Sulfate concentrations were about 50% less than those measured in Sadler Draw. Similar to observations

Table 9. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from Ashley Creek at County Road 6550 Bridge (6550) beginning 17 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	90	100	100	100	100
Day 5	80	95	90	100	100
Day 6	80	95	90	100	100
Day 7	70	95	90	100	95
Day 8	70	90	90	100	95
Day 9	65	90	90	100	95
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	90	100	100	100	100
Day 5	80	95	90	100	100
Day 6	80	95	90	100	100
Day 7	80	95	90	100	95
Day 8	80	90	90	100	95
Day 9	80	90	90	100	95
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	90	100	100	100	100
Day 2	90	100	100	100	100
Day 3	80	100	100	100	100
Day 4	80	100	100	100	100
Day 5	80	100	100	100	100
Day 6	80	100	100	100	100
Day 7	80	100	100	100	100
Day 8	80	100	100	100	100
Day 9	80	100	100	100	100

Table 10. Water chemistry measurements on daily composite samples collected from Ashley Creek at County Road 6550.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	1068	290	7.2	8.26	1.0	1900
Day 2	1152	282	6.5	8.22	1.1	2100
Day 3	1180	290	6.1	8.12	1.0	2010
Day 4	1196	300	6.0	8.11	1.0	2010
Day 5	1252	276	6.8	8.24	1.0	2090
Day 6	1164	296	6.6	8.07	1.1	2090
Day 7	1316	282	7.5	8.08	1.0	1910
Day 8	1196	298	7.4	8.14	1.1	2050
Day 9	1052	272	7.2	8.10	0.9	1790

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	5.6	900	58	0.07	4.75
Day 2	10.0		30	0.05	4.75
Day 3	48.0	881			
Day 4	10.0		30	0.05	4.17
Day 5	7.3	744			
Day 6	6.6		44	0.18	11.4
Day 7	9.0	850			
Day 8	11.0		73	0.03	7.7
Day 9	7.4				

in tests with water from Sadler Draw, specific conductivity and major ion ratios were maintained constant across treatments. Lack of appreciable mortality in the low treatments suggests that these factors alone can not account for mortality in the highest treatment. Neither unionized ammonia nor nitrate exceeded acutely toxic concentrations during the test period. Oxygen always remained above 40% saturation.

Although basic water quality for this site was comparable to that measured by Peltz and Waddell 1991, their reported selenium concentrations (77 and 150 ug/L) were slightly higher than those measured during our 10-d study (Table 11). No additional information on inorganic constituents in water from this site was available for comparison in their report. This location had the second highest concentration of selenium recorded in our study. However, selenium at this site was 20 times less than that measured in Sadler Draw (Table 2). Similarly, levels of contaminants including boron, copper, cobalt, and lithium in water from 6550 were also lower than concentrations at Sadler. In contrast, levels of natural uranium were the same as those measured in Sadler Draw. Silver, arsenic, beryllium, bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from the 6550 Bridge.

Concentration of selenium in sediments from 6550 bridge (Table 12) was only 20% lower than that measured in Sadler sediments, but was 2-6 times higher than other sites in the

Table 11. Concentrations (mg/L) of dissolved inorganic constituents in water collected from Ashley Creek at County Road 6550 Bridge beginning 18 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.51	0.041	237.0	0.021	0.10	0.05
07-19-92	<.002	0.59	0.039	253.0	0.022	0.11	0.13
07-20-92	<.002	0.59	0.038	259.0	0.023	0.11	0.36
07-21-92	<.002	0.60	0.040	271.0	0.023	0.11	0.26
07-22-92	<.002	0.65	0.035	255.0	0.022	0.11	0.06
07-23-92	<.002	0.61	0.036	264.0	0.022	0.11	0.07
07-24-92	<.002	0.96	0.035	256.0	0.023	0.11	0.08
07-25-92	<.002	0.66	0.036	323.0	0.023	0.11	0.07
07-26-92	.002	0.54	0.035	231.0	0.018	0.10	0.06

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.18	116.0	4.3	118.0	<.01	0.043
07-19-92	0.20	129.0	4.3	132.0	<.01	0.051
07-20-92	0.20	130.0	4.0	132.0	<.01	0.054
07-21-92	0.21	134.0	3.9	138.0	<.01	0.054
07-22-92	0.20	133.0	4.3	133.0	<.01	0.059
07-23-92	0.21	135.0	4.3	143.0	<.01	0.063
07-24-92	0.20	133.0	4.5	130.0	<.01	0.048
07-25-92	0.20	130.0	5.1	120.0	<.01	0.045
07-26-92	0.17	112.0	4.0	109.0	<.01	0.041

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	8.55	3.41	0.002	0.021	<.003	0.003
07-19-92	8.04	3.68	0.003	0.020	<.003	0.003
07-20-92	7.98	3.77	0.002	0.017	<.003	0.003
07-21-92	9.25	3.93	0.004	0.024	<.003	0.004
07-22-92	8.12	3.85	0.002	0.020	<.003	0.003
07-23-92	8.03	3.90	0.001	0.021	<.003	<.002
07-24-92	8.11	3.83	0.001	0.020	<.003	0.003
07-25-92	9.00	3.69	0.002	0.020	<.003	<.002
07-26-92	8.04	3.42	0.002	0.022	<.003	0.003

Table 12. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Ashley Creek at County Road 6550 Bridge.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	2.4	477
Boron	< 20	2.37
Barium	62	0.41
Calcium	60,800	129
Cobalt	< 6	0.087
Copper	< 2	0.40
Iron	4200	0.78
Lithium	< 1	0.80
Magnesium	4280	511
Potassium	500	37
Sodium	960	963
Nickel	< 10	0.05
Selenium	25.3	177.6
Silica	1200	1.73
Strontium	313	3.96
Titanium	11	0.36
Vanadium	7	0.14
Zinc	14	0.02

Ashley drainage. Porewater concentrations of both arsenic and selenium were significantly higher at this location than at any other test site. In addition, sediment porewaters at this site were more toxic than at any other location (Parley Winger, NFCRC-Athens, GA, personal communication).

South Vernal Drain

Mortality did not exceed 20% in the full-strength drainwater for any species at this site and did not occur until day 8 of the exposure for either daphnids or razorback suckers (Table 13). No appreciable mortality occurred in any fathead minnow exposure or in any treatment or control for the other species.

Exposure of daphnids to water from South Vernal Drain had no significant effect on reproductive success. Time to first brood, total number of young produced, and mean number of young per surviving female did not differ among treatments.

Specific conductance at this site was lower than that recorded at Sadler Draw, 6550 Bridge, and Drain 31A1 (Tables 2 and 14). It was also similar to the level measured in 1988 (Peltz and Waddell 1991). Unionized ammonia and nitrate did not exceed levels known to be acutely toxic.

Concentrations of selenium, boron, cobalt, copper, and lithium during the 10-d exposure were the lowest measured in the Ashley Creek drainage and were among the lowest observed across all locations tested (Tables 2 and 15). Concentration of selenium in water at the site was similar to those reported by Peltz and Waddell (1991). Silver, arsenic, beryllium, bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from South Vernal Drain.

Concentration of selenium and other elements were also low in sediments and porewaters from this location (Table 16).

Table 13. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from South Vernal Drain (SVD) beginning 31 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	90	100	100	90	100
Day 3	90	100	100	90	100
Day 4	90	100	100	90	100
Day 5	90	100	100	90	100
Day 6	90	100	100	90	100
Day 7	90	100	100	90	100
Day 8	80	100	100	90	100
Day 9	80	100	100	90	100
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	95	100	100	100
Day 4	100	95	100	100	100
Day 5	100	95	95	100	100
Day 6	95	95	95	95	100
Day 7	95	95	90	90	100
Day 8	95	95	90	90	100
Day 9	95	95	90	90	100
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	100	100	100	100	100
Day 8	80	100	100	100	100
Day 9	80	100	100	100	100

Table 14. Water chemistry measurements on daily composite samples collected from South Vernal Drain.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	840	320	8.4	8.02	0.7	1200
Day 2	808	302	8.9	8.15	0.8	1250
Day 3	876	296	8.5	8.00	0.8	1225
Day 4	900	306	6.5	8.10	0.5	1000
Day 5	884	306	6.9	8.10	0.5	1100
Day 6	904	308	6.9	8.18	0.7	1150
Day 7	804	300	8.4	8.11	0.5	1090
Day 8	880	300	7.4	8.17	0.6	1050
Day 9	864	312	7.2	8.02	0.5	1050

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	4.0	150	11.2	0.04	1.4
Day 2	1.2	125	11.0	0.03	2.0
Day 3	2.4				
Day 4	0.5	160	5.8	0.02	1.0
Day 5	1.9				
Day 6	0.8		7.0	0.05	0.8
Day 7	1.2	140			
Day 8	3.1		2.7	0.01	0.9
Day 9	1.1				

Table 15. Concentrations (mg/L) of dissolved inorganic constituents in water collected from South Vernal Drain beginning 31 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.27	0.025	185.0	0.014	0.07	0.15
07-19-92	<.002	0.29	0.027	197.0	0.015	0.07	0.03
07-20-92	<.002	0.30	0.027	194.0	0.016	0.08	0.04
07-21-92	<.002	0.29	0.025	186.0	0.016	0.07	0.05
07-22-92	<.002	0.31	0.028	196.0	0.016	0.08	0.05
07-23-92	<.002	0.30	0.027	187.0	0.017	0.08	0.22
07-24-92	<.002	0.30	0.028	190.0	0.016	0.07	0.04
07-25-92	<.002	0.28	0.029	184.0	0.017	0.07	0.05
07-26-92	.002	0.29	0.030	191.0	0.017	0.07	0.04

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.09	83.0	3.3	25.3	<.01	0.0017
07-19-92	0.10	90.7	4.1	27.4	<.01	0.0015
07-20-92	0.10	92.1	8.8	29.2	<.01	0.0013
07-21-92	0.10	88.6	2.5	25.9	<.01	0.0011
07-22-92	0.10	93.3	3.9	27.0	<.01	0.0010
07-23-92	0.10	89.9	2.1	26.0	<.01	0.0011
07-24-92	0.10	89.9	2.1	26.0	<.01	0.0011
07-25-92	0.09	89.5	2.4	22.7	<.01	0.0010
07-26-92	0.09	87.1	2.2	23.9	<.01	0.0011

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	10.50	2.57	0.002	0.007	<.003	0.004
07-19-92	10.80	2.76	0.001	0.010	<.003	0.002
07-20-92	10.80	2.80	0.001	0.009	<.003	0.003
07-21-92	10.40	2.72	0.001	0.012	<.003	0.007
07-22-92	11.30	2.89	0.002	0.010	<.003	0.008
07-23-92	11.70	2.79	0.004	0.005	<.003	0.009
07-24-92	11.50	2.81	0.001	0.005	<.003	0.005
07-25-92	11.20	2.66	0.001	0.010	<.003	0.007
07-26-92	11.80	2.77	0.002	0.012	<.003	0.005

Table 16. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from South Vernal Drain.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	1.5	4.6
Boron	< 20	.52
Barium	90	0.38
Calcium	66,700	226
Cobalt	7	0.027
Copper	8.6	0.13
Iron	6320	0.79
Lithium	< 1	0.17
Magnesium	5470	161
Potassium	1200	15
Sodium	93	68
Nickel	< 10	< .01
Selenium	4.1	4.1
Silica	1400	1.20
Strontium	283	3.77
Titanium	19	0.30
Vanadium	12	0.006
Zinc	26	0.006

Drain 31A1

No appreciable mortality occurred for any species in any treatment or control at this site (Table 17). However, exposure of daphnids to water from Drain 31A1 affected some measures of reproductive success. Time to first brood was not affected, but total number of young produced (175) and mean number of young per surviving female (10.2) were lower in the full-strength drainwater than in other treatments. By comparison, total young production for other treatments ranged from 302-351 and mean number of young per surviving female ranged from 16.8-18.4.

Conductivity of Drain 31A1 ranged from 1790-2550 μS/cm (Table 18). Unionized ammonia and nitrate did not exceed acutely toxic concentrations.

Similar to South Vernal Drain, concentrations of selenium, boron, cobalt, copper, and lithium in water (Table 19) and in sediments (Table 20) were generally low. However, concentrations of each of those contaminants were consistently higher in water from Drain 31A1 than in South Vernal Drain. This difference in contaminant levels may account for the effects on reproductive success observed at this site, but not in observed in water from South Vernal Drain. Concentration of selenium and conductivity of water at the site were similar to those previously reported by Peltz and Waddell (1991). Silver, arsenic, beryllium, bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from South Vernal Drain.

Table 17. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from Drain 31A1 beginning 31 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	95	100	100	100
Day 2	100	95	100	100	100
Day 3	90	95	90	100	100
Day 4	90	95	90	100	100
Day 5	90	95	90	90	100
Day 6	90	95	90	90	100
Day 7	90	95	90	90	100
Day 8	90	95	90	90	100
Day 9	90	95	90	90	100
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	95	100	100
Day 5	95	100	95	100	100
Day 6	95	95	95	95	100
Day 7	90	95	95	90	100
Day 8	90	95	95	90	100
Day 9	90	95	95	90	100
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	100	100	100	100	100
Day 8	100	100	100	100	100
Day 9	100	100	100	100	100

Table 18. Water chemistry measurements on daily composite samples collected from Drain 31A1.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	1660	300	8.9	7.44	1.3	2550
Day 2	1580	284	6.2	7.41	1.3	2200
Day 3	1464	284	7.8	7.38	1.0	1790
Day 4	1572	288	5.1	7.31	1.1	1790
Day 5	1504	290	6.1	7.40	1.1	1800
Day 6	1540	292	6.8	7.35	1.0	1800
Day 7	1708	300	6.6	7.65	1.0	1900
Day 8	1656	292	7.2	7.76	1.5	1950
Day 9	1624	320	6.7	7.30	1.2	2250

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	3.5	240	21.2	0.04	2.8
Day 2	0.8	375	26.5	0.07	3.4
Day 3	2.7				
Day 4	0.5	190	23.4	0.06	3.4
Day 5	0.5				
Day 6	0.3	300	21.5	0.01	4.2
Day 7	1.0				
Day 8	2.7	220	25.8	0.07	3.9
Day 9	0.9				

Table 19. Concentrations (mg/L) of dissolved inorganic constituents in water collected from Drain 31A1 beginning 31 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.64	0.012	371.0	0.026	0.12	0.35
07-19-92	<.002	0.60	0.013	361.0	0.026	0.12	0.02
07-20-92	<.002	0.59	0.013	357.0	0.025	0.12	0.02
07-21-92	<.002	0.60	0.014	350.0	0.025	0.12	0.03
07-22-92	<.002	0.64	0.014	361.0	0.025	0.12	0.10
07-23-92	<.002	0.64	0.014	360.0	0.025	0.12	0.30
07-24-92	<.002	0.63	0.012	356.0	0.024	0.12	0.02
07-25-92	<.002	0.63	0.012	350.0	0.025	0.12	0.04
07-26-92	.002	0.68	0.012	379.0	0.026	0.13	0.02

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.18	153.0	4.6	88.6	<.01	0.007
07-19-92	0.17	148.0	4.2	82.2	<.01	0.006
07-20-92	0.17	146.0	4.1	82.6	<.01	0.006
07-21-92	0.18	143.0	4.1	85.7	<.01	0.006
07-22-92	0.18	149.0	4.6	88.1	<.01	0.006
07-23-92	0.18	148.0	4.1	86.9	<.01	0.006
07-24-92	0.18	148.0	4.7	86.4	<.01	0.007
07-25-92	0.17	146.0	4.4	81.9	<.01	0.007
07-26-92	0.21	156.0	5.0	99.3	<.01	0.007

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	11.00	5.10	0.003	0.008	<.003	0.004
07-19-92	11.20	5.03	0.002	0.010	<.003	0.002
07-20-92	11.20	4.97	0.002	0.010	<.003	0.007
07-21-92	11.80	4.86	0.003	0.008	<.003	0.006
07-22-92	11.80	5.08	0.004	0.009	<.003	0.007
07-23-92	11.30	5.07	0.002	0.005	<.003	0.010
07-24-92	11.10	5.03	0.002	0.012	<.003	0.006
07-25-92	11.10	5.03	0.003	0.010	<.003	0.006
07-26-92	11.50	5.32	0.002	0.009	<.003	0.009

Table 20. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Drain 31A1.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	1.9	80.1
Boron	< 20	0.90
Barium	120	0.41
Calcium	71,000	607
Cobalt	< 6	0.045
Copper	8.6	0.21
Iron	7930	1.36
Lithium	< 1	0.26
Magnesium	6420	255
Potassium	1300	22
Sodium	180	109
Nickel	< 10	< .01
Selenium	4.0	18.2
Silica	2100	1.09
Strontium	396	9.12
Titanium	24	0.05
Vanadium	9.6	0.005
Zinc	38	0.015

Ashley Creek Mouth at Green River

Mortality occurred in all species exposed to water from Ashley Creek, but was slightly higher for fathead minnows than for the other two species (Table 21). For daphnids and razorback suckers, mortality occurred within the first 48-96 hours and then subsided. For fathead minnows, mortality continued to decline during the exposure. However, the toxicity of the Ashley Creek water was not high enough to exhibit a dose response effect across treatments. No appreciable mortality occurred for any species in dilutions of Ashley Creek water.

Exposure to water from Ashley Creek had a negative effect on reproductive success of daphnids. Time to first brood, total number of young produced, and mean number of young per adult were all reduced by exposure to Ashley Creek water and to the 50% treatment. Initiation of reproduction was delayed by 24-48 h in the two highest treatments as compared to other treatments and controls. During the 10-d period, only 36 young were produced in the full-strength water and 91 young in the 50% dilution as compared to 364 young in the controls. Production of young increased as concentration of drainwater decreased. In addition, the mean number of young produced per surviving adult increased from 2.2 young per adult in the full-strength water to 19.2 in the control.

Table 21. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from the mouth of Ashley Creek at the Green River (ACGR) beginning 18 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	85	100	100	100	100
Day 3	85	100	100	100	100
Day 4	80	100	100	100	100
Day 5	80	95	95	100	100
Day 6	80	95	95	100	100
Day 7	80	90	95	100	100
Day 8	80	90	95	100	100
Day 9	80	90	95	100	100
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	90	100	100	100	100
Day 3	80	95	100	100	100
Day 4	70	90	100	100	100
Day 5	60	90	100	100	100
Day 6	55	90	100	100	100
Day 7	55	90	100	100	100
Day 8	55	90	100	100	100
Day 9	55	90	100	100	100
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	90	100	100	100	100
Day 2	70	100	100	100	100
Day 3	70	100	100	100	100
Day 4	70	100	100	100	100
Day 5	70	100	100	100	100
Day 6	70	100	100	100	100
Day 7	70	100	100	100	100
Day 8	70	100	100	100	100
Day 9	70	100	100	100	100

Specific conductance of water from the mouth of Ashley Creek ranged from 1970 to 2400 μS/cm; pH remained near 8.0 (Table 22). These values were similar to conductivity measurements of 2190-2550 μS/cm and pH of 8.1-8.2 reported by Peltz and Waddell (1991). However, because irrigation drainwater contributes substantially to flows in Ashley Creek during the summer months, water quality at the confluence of Ashley Creek with the Green River may vary with discharge from upstream locations.

Concentrations of selenium, boron, cobalt, copper, and lithium at this location were less than concentrations at Sadler Draw, but similar to levels measured at Site 6550 (Tables 2 and 23). Concentrations of natural uranium did not differ from those at Sadler Draw or Site 6550. Silver, arsenic, beryllium, bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from Ashley Creek.

Concentration of selenium in the Ashley Creek sediment and sediment porewaters and concentration of arsenic in the porewater was lower than at Site 6550 (Table 24). However, other contaminants associated with the sediments were similar at both locations.

Table 22. Water chemistry measurements on daily composite samples collected from the mouth of Ashley Creek at the Green River beginning 18 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	1022	260	8.1	8.17	1.0	1970
Day 2	1136	260	8.1	8.14	1.0	2200
Day 3	1092	242	6.9	8.13	1.2	2175
Day 4	1160	254	8.0	8.04	1.2	2075
Day 5	1180	250	8.3	8.23	2.2	2400
Day 6	1224	268	6.8	8.00	1.5	2310
Day 7	1260	264	7.5	8.11	1.5	2340
Day 8	1244	268	6.9	8.10	1.5	2300
Day 9	1280	280	8.1	8.20	1.5	2150

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	41.0	1439	33.6	0.01	2.5
Day 2	32.0	1095	41.3	0.01	2.7
Day 3	30.0				
Day 4	21.0	750	31.4	0.02	3.5
Day 5	29.0				
Day 6	24.0	840	38.8	0.04	1.5
Day 7	24.0				
Day 8	30.0	981	37.6	0.02	1.6
Day 9	37.0				

Table 23. Concentrations (mg/L) of dissolved inorganic constituents in water collected from the mouth of Ashley Creek at Green River beginning 18 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.49	0.043	229.0	0.020	0.07	0.09
07-19-92	<.002	0.55	0.042	252.0	0.021	0.10	0.12
07-20-92	<.002	0.53	0.046	243.0	0.022	0.10	0.09
07-21-92	<.002	0.56	0.041	250.0	0.021	0.10	0.05
07-22-92	<.002	0.55	0.040	254.0	0.020	0.01	0.04
07-23-92	<.002	0.62	0.036	273.0	0.024	0.12	0.14
07-24-92	<.002	0.64	0.036	266.0	0.025	0.12	0.17
07-25-92	<.002	0.63	0.059	271.0	0.023	0.11	0.08
07-26-92	.002	0.63	0.035	251.0	0.024	0.12	0.07

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.17	109.0	5.8	134.0	<.01	0.031
07-19-92	0.20	122.0	7.5	156.0	<.01	0.037
07-20-92	0.19	118.0	7.0	163.0	<.01	0.037
07-21-92	0.20	124.0	6.6	163.0	<.01	0.038
07-22-92	0.20	121.0	8.3	160.0	<.01	0.040
07-23-92	0.14	139.0	7.7	175.0	<.01	0.045
07-24-92	0.21	138.0	6.3	167.0	<.01	0.046
07-25-92	0.22	134.0	9.5	181.0	<.01	0.052
07-26-92	0.21	140.0	5.5	159.0	<.01	0.042

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	7.60	3.34	0.002	0.025	<.003	0.002
07-19-92	8.20	3.69	0.003	0.021	<.003	0.003
07-20-92	6.93	3.49	0.003	0.020	<.003	0.004
07-21-92	7.01	3.64	0.002	0.028	<.003	0.003
07-22-92	7.64	3.70	0.002	0.021	<.003	0.003
07-23-92	7.80	4.04	0.004	0.021	<.003	0.005
07-24-92	7.80	4.04	0.004	0.023	<.003	0.005
07-25-92	7.75	3.96	0.003	0.021	<.003	0.004
07-26-92	8.77	3.91	0.003	0.020	<.003	0.004

Table 24. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from the mouth of Ashley Creek at Green River.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	8.4	15.4
Boron	< 20	0.58
Barium	81	0.77
Calcium	31,200	224
Cobalt	< 6	0.029
Copper	5.0	0.13
Iron	5090	21.30
Lithium	< 1	0.21
Magnesium	5010	163
Potassium	980	15
Sodium	58	177
Nickel	< 10	< .01
Selenium	12.5	11.5
Silica	1300	1.35
Strontium	116	4.05
Titanium	12	0.04
Vanadium	10	0.019
Zinc	57	0.051

II. Stewart Lake Waterfowl Management Area (SLWMA)

Stewart Lake Waterfowl Management Area is adjacent to the Green River about 12 miles south of Jensen, Utah. The Management Area is dominated by Stewart Lake with a surface area of about 250 acres. Five groundwater drains discharge to the Lake. Outflow from the Lake enters the Green River.

Three locations were evaluated in the SLWMA. Tests were conducted with water entering SLWMA from Drains J1 and J1A combined (J1/J1A) and from Drains J2, J3, and J4 combined (J234). One test was conducted with the SLWMA outflow water. Permission to individually sample drains J2, J3, and J4 (located on private property) was denied, therefore, samples were collected from a location on SLWMA where all three drains merged. Thus, J234 represents a composite of all three drains with no information to delineate the independent contribution of each drain to the composite.

Toxicity was low to moderate at all three sites. Water from Stewart Lake Outflow was less toxic than J1/J1A and J234. However, reproductive success of daphnids was impaired at all sites. Water from all Stewart Lake sites was well buffered, moderate to high in hardness and generally high in sulfate and chloride. Conductivities ranged from 1400 to 2000 μS/cm and pH ranged from 7.5 to 8.1. Water temperatures ranged from 18 to 22 $^{\circ}$C during the study and no measurable rainfall was recorded.

Drain J1/J1A

Mortality was observed in all three species at this location (Table 25). Highest mortality occurred in razorback suckers (50%) and fathead minnows (30%) with only low mortality (15%) in daphnids. Mortality of fish species in the full-strength drainwater occurred throughout the 10-day exposure, however, no appreciable mortality was observed in other treatments. Therefore, no dose response pattern could be defined.

Exposure of daphnids to water from Drain J1/J1A reduced reproductive success in the two highest treatments. Time to first brood, total number of young produced, and mean number of young per surviving adult were all affected by exposure to drainwater. Time to production of first brood in the two highest treatments was delayed by 24 h as compared to other treatments. During the 10-day exposure, only 96 young were produced in the full-strength drainwater compared to 364 young produced in controls. Production of young increased as concentration of drainwater decreased. In addition, the mean number of young produced per surviving adult increased from 5.6 young per adult in the full-strength drainwater to 19.2 in the control.

Specific conductance of the water from Drain J1/J1A ranged from 1400 to 1610 μS/cm with a pH of 7.5 to 7.7 (Table 26). Conductivities were within ranges previously reported in both drains, but were generally more similar to conductivities in J1A than J1 (Peltz and Waddell 1991). Sulfate concentrations were

Table 25. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from Drain J1/J1A beginning 18 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	95	100	100	100	100
Day 5	90	100	90	95	100
Day 6	85	100	90	95	100
Day 7	85	100	90	95	95
Day 8	85	100	90	95	95
Day 9	85	100	90	95	95
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	95	100	100	100	100
Day 4	95	100	100	100	100
Day 5	95	100	100	100	100
Day 6	90	95	95	100	100
Day 7	80	95	90	95	95
Day 8	80	95	90	95	95
Day 9	70	90	90	90	95
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	90	100	100	100	100
Day 4	80	100	100	100	100
Day 5	80	100	100	100	100
Day 6	80	100	100	100	100
Day 7	70	100	100	100	100
Day 8	50	100	100	100	100
Day 9	50	100	100	100	100

Table 26. Water chemistry measurements on daily composite samples collected from Drain J1/J1A.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	915	290	8.5	7.53	0.9	1610
Day 2	956	282	7.6	7.66	0.8	1580
Day 3	844	290	8.3	7.68	0.9	1580
Day 4	900	300	8.2	7.57	0.9	1510
Day 5	960	276	8.3	7.49	0.7	1400
Day 6	916	296	9.6	7.56	0.8	1450
Day 7	1080	282	9.0	7.56	0.9	1500
Day 8	984	298	9.5	7.55	1.0	1600
Day 9	1004	272	8.5	7.60	1.0	1590

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	25.0	650	49	0.03	5.0
Day 2	3.5		20	0.03	7.7
Day 3	48.0	720			
Day 4	1.4		30	0.09	7.8
Day 5	4.0	254			
Day 6	1.2		44	0.06	7.8
Day 7	25.0	305			
Day 8	4.0		78	0.05	7.2
Day 9	2.4				

similar to those previously measured for this site. Neither unionized ammonia nor nitrate exceeded acutely toxic concentrations during the test period. Oxygen always remained above 40% saturation.

Concentrations of other inorganic constituents were basically similar to previous measurements. Selenium concentrations consistently exceeded acute and chronic national criteria for protection of aquatic life (EPA 1987) (Table 27). Range of concentrations of natural uranium overlapped with levels measured in the Ashley Creek Drainage. Silver, arsenic, beryllium, bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from the Drain J1/J1A.

Concentrations of inorganic contaminants in sediments and associated porewaters were relatively low in comparison with other locations (Table 28). Concentrations of arsenic and selenium were similar to those measured in South Vernal Drain and Stewart Lake Outflow.

similar to those previously measured for this site. Neither unionized ammonia nor nitrate exceeded acutely toxic concentrations during the test period. Oxygen always remained above 40% saturation.

Concentrations of other inorganic constituents were basically similar to previous measurements. Selenium concentrations consistently exceeded acute and chronic national criteria for protection of aquatic life (EPA 1987) (Table 27). Range of concentrations of natural uranium overlapped with levels measured in the Ashley Creek Drainage. Silver, arsenic, beryllium, bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from the Drain J1/J1A.

Concentrations of inorganic contaminants in sediments and associated porewaters were relatively low in comparison with other locations (Table 28). Concentrations of arsenic and selenium were similar to those measured in South Vernal Drain and Stewart Lake Outflow.

Table 27. Concentrations (mg/L) of dissolved inorganic constituents in water collected from Drain J1/J1A beginning 18 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.42	0.045	226.0	0.016	0.16	0.08
07-19-92	<.002	0.46	0.035	233.0	0.018	0.08	0.07
07-20-92	<.002	0.46	0.031	236.0	0.017	0.08	0.03
07-21-92	<.002	0.46	0.030	238.0	0.017	0.08	0.04
07-22-92	<.002	0.46	0.025	202.0	0.018	0.08	<.01
07-23-92	<.002	0.48	0.028	241.0	0.018	0.08	0.03
07-24-92	<.002	0.48	0.027	242.0	0.018	0.09	0.03
07-25-92	<.002	0.49	0.027	243.0	0.016	0.09	0.07
07-26-92	.002	0.47	0.026	228.0	0.017	0.08	0.03

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.09	92.1	5.8	131.0	<.01	0.022
07-19-92	0.09	97.6	5.2	133.0	<.01	0.027
07-20-92	0.09	96.4	4.9	135.0	<.01	0.027
07-21-92	0.09	97.5	4.9	137.0	<.01	0.026
07-22-92	0.09	98.0	4.2	132.0	<.01	0.027
07-23-92	0.09	99.1	4.6	138.0	<.01	0.028
07-24-92	0.09	101.0	4.4	132.0	<.01	0.028
07-25-92	0.09	99.0	4.4	140.0	<.01	0.029
07-26-92	0.08	94.9	4.0	126.0	<.01	0.028

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	8.03	2.43	0.001	0.018	<.003	0.002
07-19-92	7.99	2.54	0.002	0.012	<.003	0.002
07-20-92	7.68	2.55	0.002	0.011	<.003	0.003
07-21-92	7.71	2.58	0.001	0.015	<.003	0.002
07-22-92	7.52	2.53	0.002	0.012	<.003	<.002
07-23-92	7.63	2.63	0.001	0.013	<.003	0.004
07-24-92	7.57	2.66	0.001	0.015	<.003	0.002
07-25-92	7.67	2.65	0.002	0.012	<.003	0.004
07-26-92	7.21	2.51	0.001	0.012	<.003	0.002

Table 28. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Drain J1/J1A.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	1.7	8.2
Boron	< 20	0.61
Barium	86	0.37
Calcium	28,300	239
Cobalt	< 6	0.019
Copper	6.0	0.89
Iron	4190	3.22
Lithium	< 1	0.10
Magnesium	3200	107
Potassium	770	18
Sodium	190	149
Nickel	< 10	< .01
Selenium	6.4	7.5
Silica	810	2.34
Strontium	102	3.16
Titanium	24	0.04
Vanadium	8	0.007
Zinc	21	0.012

Drain J234

Mortality occurred in all three species exposed to water from this combination of drains (Table 29). Highest mortality occurred in fathead minnows (50%) and for this species, a dose response pattern was evident as survival increased with decreasing concentrations of drainwater.

Although mortality of daphnids was relatively low (25%), reproductive success was impaired in the two highest treatments. Time to first brood was reduced by 24 h and both total number of young produced and mean number of young per surviving adult were reduced in the two highest treatments. Effects on reproduction were more severe in water from J234 than in other SLWMA sites. During the 10-day exposure, only 56 young were produced in the full-strength drainwater and 112 young in the 50% dilution. Production of young increased with decreasing drainwater concentrations. In addition, the mean number of young produced per adult increased from 3.2 in the full-strength drainwater to 19.2 in the control.

Specific conductance of the water from Drain J234 ranged from 1900 to 2200 μS/cm with a pH of 7.9 to 8.1 (Table 30). Comparison with previous data is difficult based on the composited nature of the sample. Because access to individual drains was denied, the contribution of each drain to the water quality of the sample can not be determined. Historic information (Peltz and Waddell 1991) indicates that flows varied

Table 29. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in a composite water sample collected from Drains J2, J3, and J4 (J234) beginning 18 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	95	100	100	100	100
Day 3	95	100	100	100	100
Day 4	85	100	100	100	100
Day 5	80	95	95	95	100
Day 6	80	95	95	90	100
Day 7	80	95	95	90	95
Day 8	75	95	95	90	95
Day 9	75	90	95	90	95
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	95	100	100	100	100
Day 3	90	95	100	100	100
Day 4	75	90	95	100	100
Day 5	65	75	85	95	100
Day 6	65	75	80	90	100
Day 7	55	75	80	90	95
Day 8	50	70	80	90	95
Day 9	50	70	80	90	95
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	90	100	100	100	100
Day 4	90	100	100	100	100
Day 5	90	100	100	100	100
Day 6	80	100	100	100	100
Day 7	80	100	100	100	100
Day 8	80	100	100	100	100
Day 9	80	100	100	100	100

Table 30. Water chemistry measurements for daily composite samples collected from Drain J234 beginning 18 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	1162	382	8.3	7.99	1.2	2030
Day 2	1140	380	8.5	8.12	1.0	1990
Day 3	1176	376	8.4	7.92	1.0	2200
Day 4	1180	374	8.4	8.05	1.0	2090
Day 5	1180	380	9.1	8.12	1.3	2040
Day 6	1128	372	8.2	8.02	1.0	2000
Day 7	1272	368	7.5	8.04	1.2	1900
Day 8	1164	374	10.2	8.07	1.4	2150
Day 9	1220	358	9.8	8.04	1.3	2050

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	7.0	960	51	0.08	1.0
Day 2	16.0		30	0.06	1.3
Day 3	80.0	1025			
Day 4	3.6		38	0.09	1.8
Day 5	20.0	1919			
Day 6	11.0		73	0.09	1.8
Day 7	11.5	1326			
Day 8	8.0		38	0.07	1.5
Day 9	27.0	1215			

greatly among drains during 1988 and 1989 with no one drain consistently demonstrating the highest flow rate. Generally, conductivities were most similar to previous information on Drain J2 where specific conductance ranged from 1570 to 2750 μS/cm. Neither unionized ammonia nor nitrate exceeded acutely toxic concentrations during the test period. Oxygen always remained above 40% saturation.

Concentrations of other inorganic constituents were also basically similar to those measured previously in Drain J2. Selenium concentrations consistently exceeded acute and chronic water quality criteria (EPA 1987) (Table 31). Concentrations of natural uranium were similar to those measured in the Ashley Creek Drainage. Silver, arsenic, beryllium, bismuth, cadmium, chromium, tungsten, molybdenum, nickel, lead, tin, antimony, and vanadium were not detected or were measured at the detection limit in samples from the Drain J234.

Concentrations of inorganic contaminants in sediments and associated porewaters were higher than concentrations in J1/J1A or Stewart Lake Outflow (Table 32). Concentrations of arsenic and selenium in porewaters were respectively 2 times and 5 times higher than J1/J1A. Because historic flow rates of J2, J3, and J4 are basically similar to those of J1 and J1A, these data suggest that Drains J2, J3, and J4 provide a greater input of arsenic and selenium associated with sediments into Stewart Lake than do Drains J1 and J1A.

Table 31. Concentrations (mg/L) of dissolved inorganic constituents in water collected from Drain J234 beginning 18 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.90	0.029	298.0	0.019	0.09	0.04
07-19-92	<.002	0.71	0.026	285.0	0.020	0.09	0.03
07-20-92	<.002	0.66	0.024	288.0	0.018	0.09	0.04
07-21-92	<.002	0.67	0.025	293.0	0.020	0.09	0.05
07-22-92	<.002	0.67	0.024	284.0	0.019	0.10	0.06
07-23-92	<.002	0.65	0.025	296.0	0.021	0.10	0.04
07-24-92	<.002	0.65	0.025	291.0	0.020	0.09	0.18
07-25-92	<.002	0.65	0.024	290.0	0.019	0.09	0.03
07-26-92	.002	0.68	0.024	277.0	0.018	0.09	0.04

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.12	107.0	4.7	215.0	<.01	0.028
07-19-92	0.11	108.0	4.4	190.0	<.01	0.030
07-20-92	0.11	105.0	4.3	190.0	<.01	0.028
07-21-92	0.11	109.0	4.2	201.0	<.01	0.028
07-22-92	0.11	109.0	4.2	195.0	<.01	0.030
07-23-92	0.12	112.0	4.5	220.0	<.01	0.031
07-24-92	0.12	111.0	4.3	210.0	<.01	0.031
07-25-92	0.12	111.0	4.5	217.0	<.01	0.031
07-26-92	0.12	114.0	4.9	238.0	<.01	0.034

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	8.34	3.28	0.002	0.031	<.003	0.003
07-19-92	8.19	3.22	0.002	0.023	<.003	<.002
07-20-92	8.18	3.25	0.001	0.025	<.003	<.002
07-21-92	8.38	3.33	0.002	0.025	<.003	<.002
07-22-92	8.22	3.30	0.002	0.025	<.003	0.004
07-23-92	8.27	3.36	0.002	0.021	<.003	<.002
07-24-92	8.53	3.33	0.004	0.034	<.003	0.003
07-25-92	8.24	3.32	0.001	0.030	<.003	<.002
07-26-92	7.74	3.24	0.001	0.029	<.003	<.002

Table 32. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Drain J234.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	1.2	16.5
Boron	< 20	0.87
Barium	71	0.60
Calcium	94,800	260
Cobalt	< 6	0.025
Copper	5.0	0.11
Iron	4010	2.25
Lithium	< 1	0.14
Magnesium	5030	134
Potassium	1000	14
Sodium	440	252
Nickel	< 10	0.01
Selenium	44.1	37.5
Silica	1100	3.26
Strontium	528	3.79
Titanium	13	0.10
Vanadium	11	0.018
Zinc	22	0.017

Stewart Lake Outflow

No appreciable mortality of fathead minnows or razorback suckers occurred in water from Stewart Lake Outflow (Table 33). Thirty percent mortality occurred in daphnids. In addition, reproductive success was impaired in the two highest treatments. Time to first brood was reduced by 24 h and both total number of young produced and mean number of young per surviving adult were reduced in both treatments. Effects on reproduction were less severe than in water from J234 and J1/J1A. During the 10-day exposure, 157 young were produced in the full-strength drainwater and 235 young in the 50% dilution. The mean number of young produced per adult increased from 11.2 in the full-strength drainwater to 17.1 in the control.

Specific conductance of the water from Stewart Lake Outflow ranged from 1690 to 2090 μS/cm with a pH of 7.6 to 7.8 (Table 34). Oxygen levels in the Outflow water were very low at the time of collection, however, aeration of test chambers maintained oxygen above 40% saturation during toxicity tests. Both unionized ammonia and nitrate were below acutely toxic concentrations.

Concentrations of selenium were considerably lower than those measured in Drains J234 or J1/J1A (Table 35) and did not exceed the 5 μg/L national water quality criteria for selenium during our study. Levels of other major inorganic constituents were similar at all three sites. Concentrations of selenium in

Table 33. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from Stewart Lake Outflow (SLO) beginning 18 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	90	100	100	100	100
Day 5	80	100	100	100	100
Day 6	80	100	100	100	100
Day 7	70	95	100	100	95
Day 8	70	95	100	100	95
Day 9	70	95	95	90	95
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	100	100	100	100	95
Day 8	95	100	100	100	95
Day 9	90	100	100	100	95
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	90	100	100	100	100
Day 8	90	100	100	100	100
Day 9	90	100	100	100	100

Table 34. Water chemistry measurements on daily composite samples collected from Stewart Lake Outflow beginning 18 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	872	242	3.2	7.70	1.0	1850
Day 2	880	232	2.3	7.71	1.0	1900
Day 3	916	228	2.2	7.62	1.0	1920
Day 4	920	226	2.8	7.75	1.0	1850
Day 5	936	194	2.5	7.68	1.0	1800
Day 6	932	210	2.5	7.69	1.0	2090
Day 7	1008	198	1.2	7.81	1.0	1725
Day 8	992	206	1.2	7.74	1.1	1900
Day 9	988	202	3.0	7.80	1.0	1690

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	18.0	990	35	0.6	0.05
Day 2	18.4		30	0.5	0.05
Day 3	41.0	994			
Day 4	31.0		35	0.2	0.07
Day 5	59.0	590			
Day 6	120.0		67	0.3	0.05
Day 7	67.0	587			
Day 8	45.0		43	0.3	0.05
Day 9	126.0				

Table 35. Concentrations (mg/L) of dissolved inorganic constituents in water collected from Stewart Lake Outflow beginning 18 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.57	0.051	194.0	0.019	0.09	0.04
07-19-92	<.002	0.60	0.053	193.0	0.019	0.09	0.04
07-20-92	<.002	0.58	0.053	189.0	0.018	0.09	0.34
07-21-92	<.002	0.62	0.056	199.0	0.020	0.09	0.07
07-22-92	<.002	0.61	0.057	182.0	0.018	0.09	0.05
07-23-92	<.002	0.63	0.059	199.0	0.020	0.10	0.03
07-24-92	<.002	0.63	0.058	200.0	0.020	0.09	0.03
07-25-92	<.002	0.63	0.059	206.0	0.020	0.09	0.04
07-26-92	.002	0.63	0.060	205.0	0.020	0.09	0.06

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.10	104.0	7.4	175.0	<.01	0.003
07-19-92	0.11	105.0	7.6	184.0	<.01	0.003
07-20-92	0.11	104.0	7.2	180.0	<.01	0.003
07-21-92	0.12	104.0	7.5	189.0	<.01	0.003
07-22-92	0.11	106.0	7.5	182.0	<.01	0.003
07-23-92	0.12	109.0	7.6	198.0	<.01	0.003
07-24-92	0.12	109.0	7.6	200.0	<.01	0.005
07-25-92	0.12	110.0	7.4	205.0	<.01	0.003
07-26-92	0.12	110.0	7.3	204.0	<.01	0.003

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	6.31	2.48	0.002	0.005	<.003	0.003
07-19-92	6.37	2.50	0.001	0.006	<.003	0.003
07-20-92	6.86	2.47	0.003	0.009	<.003	0.005
07-21-92	6.47	2.62	0.002	0.008	<.003	0.002
07-22-92	5.77	2.50	0.002	0.005	<.003	0.004
07-23-92	5.79	2.69	0.001	0.005	<.003	0.003
07-24-92	5.94	2.69	0.001	0.009	<.003	0.003
07-25-92	5.69	2.75	0.001	0.008	<.003	0.002
07-26-92	5.53	2.74	0.002	0.009	<.003	0.003

sediments and associated porewaters were similar to levels in Drain J1/J1A, but 75% less than those in Drain J234 (Table 36). Our findings support those of Stephens et al. 1992 that, as one would expect, Stewart Lake serves as a depositional area for selenium. Levels of selenium associated with both water and sediment entering the Lake were higher than those leaving the Lake. Thus, the Lake provides a significant route for selenium to be incorporated into the ecosystem, through bioaccumulation in plants, invertebrates, waterfowl, fish and other organisms that use the area. In addition, Stewart Lake could provide a significant source of selenium to the Green River during times of high water when the SLWMA is flooded by the river.

Table 36. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Stewart Lake Outflow.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	4.9	4.1
Boron	< 20	0.63
Barium	219	0.38
Calcium	57,400	165
Cobalt	10	0.026
Copper	20	0.11
Iron	21,000	.79
Lithium	10	0.11
Magnesium	9940	137
Potassium	5100	10
Sodium	910	242
Nickel	20	<.01
Selenium	6.5	10.0
Silica	3300	1.07
Strontium	323	2.77
Titanium	51	0.02
Vanadium	43	0.007
Zinc	84	0.011

III. Ouray National Wildlife Refuge (ONWR)

Ouray National Wildlife Refuge, established in 1960, is adjacent to the Green River about 30 miles southwest of Vernal, Utah. Although the area is used primarily for waterfowl habitat, it also provides habitat for Colorado squawfish, humpback chub, and bonytail. The refuge receives irrigation water through a system of canals and underground pipes, however, ponds in the Leota Bottoms area receive water exclusively from the Green River. During our study, the **North Roadside** and **South Roadside Ponds** were not receiving any visible input of water and were evaporating rapidly, however, **Leota Pond #6** was full. Because of the lack of toxicity at these three Ouray NWR locations, results from this portion of the study are described collectively in this section with all tables following the text.

No appreciable mortality of any species occurred in South Roadside Pond or Leota Pond #6 (Tables 37 and 38). No mortality occurred in razorback suckers or fathead minnows in North Roadside Pond, and the mortality of daphnids that was observed (25%) likely resulted from low oxygen stress on day 3 following a problem with aeration specific to those test chambers (Table 39). No effects on reproductive success of daphnids were detected for any Ouray NWR location.

Specific conductance ranged from a low of 550 μS/cm at Leota to a high of 1120 μS/cm at North Roadside Pond (Tables 40-42). The pH ranged from 7.5 to 9.4. Concentrations of contaminants

including selenium were generally lower in water from the Ouray NWR sites than in the Ashley Creek Drainage or in the Stewart Lake Wildlife Management Area (Table 2 and Tables 43-45). Exceptions were comparably low concentrations of selenium in Stewart Lake Outflow and South Vernal Drain.

In contrast, concentrations of selenium in sediments from the North and South Roadside Pond complex were as high as any measured during our study (Tables 46 and 47). Porewater associated with the sediments were also elevated. Potential for bioaccumulation from of selenium from this ponds is high. Selenium concentrations in sediments and associated porewaters at Leota Pond #6 were (along with sediment samples from the Green River) the lowest detected during our study (Table 48).

Table 37. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from South Roadside Pond (SRS) at Ouray NWR beginning 31 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	100	95	100	100	100
Day 8	100	95	100	100	100
Day 9	100	95	95	100	100
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	95	100	100
Day 4	95	100	90	100	100
Day 5	95	95	90	90	100
Day 6	95	95	90	90	100
Day 7	95	95	90	90	100
Day 8	95	95	90	90	100
Day 9	95	95	90	90	100
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	100	100	100	100	100
Day 8	100	100	100	100	100
Day 9	100	100	100	100	100

Table 38. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from Leota Bottoms #6 (L6) beginning 31 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	95	100	100	100
Day 6	100	95	100	100	100
Day 7	100	95	100	100	100
Day 8	100	95	100	100	100
Day 9	100	95	100	100	100
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	95	100	100	100
Day 6	100	95	90	90	100
Day 7	100	95	90	90	100
Day 8	100	95	90	90	100
Day 9	100	95	90	90	100
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	100	100	100	100	100
Day 8	100	100	100	100	100
Day 9	100	100	100	100	100

Table 39. Daily percent survival in four drainwater concentrations and a control treatment for Daphnia magna (n=20), fathead minnows (n=20), and razorback suckers (n=10) in water collected from North Roadside Pond (NRS) at Ouray NWR beginning 31 July 1992.

Species Day	% drainwater				
	100%	50%	25%	12.5%	control
Daphnia magna					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	90	85	100	100	100
Day 3	85	85	100	100	100
Day 4	80	80	90	100	100
Day 5	80	80	90	100	100
Day 6	75	80	90	100	100
Day 7	75	80	90	100	100
Day 8	75	80	85	100	100
Day 9	75	80	85	100	100
Fathead minnow					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	95	100	100	100	100
Day 4	95	90	100	100	100
Day 5	95	90	100	100	100
Day 6	90	90	100	100	100
Day 7	90	80	95	100	100
Day 8	90	80	95	100	100
Day 9	85	80	95	100	100
Razorback Sucker					
Day 0	100	100	100	100	100
Day 1	100	100	100	100	100
Day 2	100	100	100	100	100
Day 3	100	100	100	100	100
Day 4	100	100	100	100	100
Day 5	100	100	100	100	100
Day 6	100	100	100	100	100
Day 7	100	100	100	100	100
Day 8	100	100	100	100	100
Day 9	100	100	100	100	100

Table 40. Water chemistry measurements on daily composite samples collected from South Roadside Pond beginning 31 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	244	194	0.6	8.13	0.3	900
Day 2	236	164	0.7	8.48	0.5	920
Day 3	236	180	0.4	8.34	0.2	975
Day 4	236	156	1.6	8.82	0.2	850
Day 5	292	232	0.6	7.90	0.6	1000
Day 6	292	232	2.7	7.90	0.6	1050
Day 7	268	176	1.5	8.08	0.2	900
Day 8	240	176	1.3	8.44	0.5	900
Day 9	260	208	1.4	8.42	0.5	710

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	3.7	120	16.8	0.03	2.8
Day 2	2.7	135	11.0	0.06	1.0
Day 3	5.1				
Day 4	4.1	170	74.0	0.02	3.4
Day 5	3.7				
Day 6	2.7	144	55.0	0.02	1.6
Day 7	2.9				
Day 8	3.2	180	65.4	0.02	2.1
Day 9	2.0				

Table 41. Water chemistry measurements on daily composite samples collected from North Roadside Pond beginning 31 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	240	120	4.2	9.32	0.5	1010
Day 2	200	200	0.6	9.34	0.7	1120
Day 3	176	114	0.6	9.38	0.5	1110
Day 4	184	120	1.5	9.37	0.4	1000
Day 5	176	120	0.6	9.26	0.8	1110
Day 6	184	124	3.3	9.26	0.7	1150
Day 7	176	120	1.1	9.13	0.5	1100
Day 8	176	128	1.9	8.90	0.7	1000
Day 9	164	116	1.8	9.19	0.5	950

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	14.0	680	97.1	0.01	1.4
Day 2	7.3	520	72.6	0.06	1.3
Day 3	8.0				
Day 4	8.6	745	101.5	0.05	3.4
Day 5	8.0				
Day 6	3.5	624	74.7	0.02	2.1
Day 7	7.4				
Day 8	5.6	780	91.0	0.03	5.6
Day 9	6.3				

Table 42. Water chemistry measurements on daily composite samples collected from Leota Bottoms #6 beginning 31 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	252	230	0.4	7.49	0.2	610
Day 2	268	236	0.2	7.58	0.3	700
Day 3	288	236	0.4	7.62	0.1	675
Day 4	264	238	0.9	7.64	0.1	650
Day 5	260	246	0.4	7.67	0.3	700
Day 6	220	248	1.1	7.61	0.4	700
Day 7	252	244	0.9	7.65	0.1	650
Day 8	260	248	1.3	8.55	0.2	650
Day 9	264	256	0.6	8.30	0.1	550

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	11.0	110	39.7	0.04	0.55
Day 2	5.0	120	41.3	0.01	0.79
Day 3	9.8				
Day 4	9.6	200	20.4	0.04	0.50
Day 5	9.3				
Day 6	7.2	150	18.8	0.04	0.50
Day 7	7.2				
Day 8	3.3	200	22.8	0.06	0.62
Day 9	6.4				

Table 43. Concentrations (mg/L) of dissolved inorganic constituents in water collected from South Roadside Pond beginning 31 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.27	0.048	37.5	0.007	0.03	0.03
07-19-92	<.002	0.26	0.038	27.5	0.008	0.03	0.03
07-20-92	<.002	0.27	0.043	31.9	0.007	0.03	0.21
07-21-92	<.002	0.24	0.040	26.4	0.008	0.03	0.05
07-22-92	<.002	0.26	0.047	38.1	0.006	0.03	0.34
07-23-92	<.002	0.28	0.057	49.7	0.008	0.03	0.03
07-24-92	<.002	0.27	0.046	36.6	0.008	0.03	0.04
07-25-92	<.002	0.27	0.041	30.2	0.008	0.03	0.02
07-26-92	.002	0.27	0.049	35.5	0.008	0.03	0.03

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.06	36.3	1.6	150.0	<.01	0.002
07-19-92	0.06	33.5	1.5	147.0	<.01	0.002
07-20-92	0.06	35.8	1.7	155.0	<.01	0.003
07-21-92	0.06	35.4	1.7	152.0	<.01	0.003
07-22-92	0.06	36.3	1.3	149.0	<.01	0.001
07-23-92	0.06	37.5	1.4	146.0	<.01	0.001
07-24-92	0.06	36.7	1.7	149.0	<.01	0.001
07-25-92	0.06	36.4	1.5	150.0	<.01	0.001
07-26-92	0.06	36.4	1.5	144.0	<.01	0.001

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	8.83	0.90	<.0007	0.007	<.003	0.004
07-19-92	8.25	0.76	0.0009	0.006	<.003	<.002
07-20-92	8.90	0.84	0.002	0.006	<.003	0.004
07-21-92	8.24	0.76	0.001	0.006	<.003	0.005
07-22-92	7.82	0.91	<.0007	0.005	<.003	0.004
07-23-92	7.97	1.04	0.0009	0.007	<.003	0.007
07-24-92	8.22	0.90	0.0008	0.006	<.003	0.005
07-25-92	8.19	0.84	0.0008	0.006	<.003	0.005
07-26-92	8.34	0.90	0.0009	0.006	<.003	0.005

Table 44. Concentrations (mg/L) of dissolved inorganic constituents in water collected from North Roadside Pond beginning 31 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.27	0.031	25.7	0.005	0.02	0.04
07-19-92	<.002	0.26	0.032	22.6	0.006	0.02	0.03
07-20-92	<.002	0.27	0.036	23.9	0.007	0.02	0.04
07-21-92	<.002	0.28	0.036	24.6	0.005	0.02	0.03
07-22-92	<.002	0.29	0.032	23.5	0.004	0.02	0.06
07-23-92	<.002	0.29	0.034	24.4	0.006	0.02	0.02
07-24-92	<.002	0.31	0.038	23.9	0.007	0.02	0.15
07-25-92	<.002	0.28	0.033	23.4	0.006	0.02	0.07
07-26-92	.002	0.29	0.033	22.9	0.007	0.02	0.07

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.07	25.1	5.3	204.0	<.01	0.003
07-19-92	0.07	23.6	5.0	187.0	<.01	0.003
07-20-92	0.07	24.4	5.6	209.0	<.01	0.003
07-21-92	0.08	25.3	6.4	211.0	<.01	0.003
07-22-92	0.07	25.4	5.4	204.0	<.01	0.002
07-23-92	0.07	26.5	4.6	185.0	<.01	0.002
07-24-92	0.07	26.0	6.0	208.0	<.01	0.003
07-25-92	0.07	27.0	5.0	187.0	<.01	0.002
07-26-92	0.07	24.2	5.7	206.0	<.01	0.003

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	2.70	0.69	0.001	0.005	<.003	0.003
07-19-92	2.61	0.67	0.001	0.005	<.003	<.002
07-20-92	2.73	0.72	<.0007	<0.005	<.003	0.005
07-21-92	2.95	0.71	0.0009	0.006	<.003	0.004
07-22-92	2.91	0.70	0.001	0.006	<.003	0.004
07-23-92	3.33	0.67	0.001	0.005	<.003	0.008
07-24-92	3.67	0.71	0.002	<0.005	<.003	0.007
07-25-92	3.30	0.67	0.002	0.005	<.003	0.007
07-26-92	2.73	0.67	0.001	0.006	<.003	0.006

Table 45. Concentrations (mg/L) of dissolved inorganic constituents in water collected from Leota Bottoms #6 beginning 31 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.14	0.088	50.8	0.007	0.03	0.13
07-19-92	<.002	0.13	0.078	46.8	0.006	0.02	0.10
07-20-92	<.002	0.15	0.084	50.2	0.006	0.02	0.09
07-21-92	<.002	0.15	0.085	50.5	0.006	0.03	0.09
07-22-92	<.002	0.15	0.088	50.6	0.007	0.03	0.08
07-23-92	<.002	0.15	0.086	51.3	0.005	0.03	0.08
07-24-92	<.002	0.17	0.093	53.0	0.007	0.03	0.07
07-25-92	<.002	0.15	0.091	51.7	0.007	0.03	0.06
07-26-92	.002	0.15	0.099	53.2	0.006	0.03	0.07

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.03	29.9	7.2	77.0	<.01	0.0001
07-19-92	0.03	27.3	6.8	72.3	<.01	0.0008
07-20-92	0.03	29.6	7.4	76.4	<.01	0.0002
07-21-92	0.03	29.8	7.6	75.4	<.01	0.0001
07-22-92	0.03	29.5	7.2	74.1	<.01	0.0006
07-23-92	0.03	29.9	7.5	76.7	<.01	0.0006
07-24-92	0.03	30.5	7.8	78.1	<.01	0.0002
07-25-92	0.03	30.3	7.5	74.8	<.01	0.0001
07-26-92	0.03	30.4	7.5	77.6	<.01	0.0006

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	1.54	0.58	0.002	0.011	<.003	0.006
07-19-92	1.48	0.54	0.0009	0.012	<.003	0.002
07-20-92	1.60	0.58	<.0007	0.009	<.003	0.003
07-21-92	1.71	0.58	<.0007	0.009	<.003	0.004
07-22-92	1.74	0.58	0.001	0.010	<.003	0.006
07-23-92	1.91	0.59	0.002	0.005	<.003	0.009
07-24-92	2.08	0.60	0.0009	0.009	<.003	0.006
07-25-92	2.13	0.59	0.0009	0.011	<.003	0.007
07-26-92	2.34	0.60	<.0007	0.009	<.003	0.005

Table 46. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from South Roadside Pond.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	2.3	6.0
Boron	< 20	0.51
Barium	189	0.59
Calcium	58,100	114
Cobalt	8	0.012
Copper	14	0.05
Iron	12,700	.45
Lithium	4.8	0.08
Magnesium	7970	63.2
Potassium	4100	7.5
Sodium	580	175
Nickel	< 10	<.01
Selenium	35.2	8.5
Silica	4200	2.40
Strontium	403	2.38
Titanium	70	0.12
Vanadium	22	< .003
Zinc	42	0.022

Table 47. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from North Roadside Pond.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	1.2	6.9
Boron	< 20	0.63
Barium	222	0.67
Calcium	95,500	120
Cobalt	8	0.014
Copper	15	0.05
Iron	13,200	.81
Lithium	3	0.10
Magnesium	9390	63.6
Potassium	3800	8.7
Sodium	930	216
Nickel	< 10	<.01
Selenium	34.2	13.5
Silica	3800	0.60
Strontium	822	2.50
Titanium	55	0.05
Vanadium	24	0.003
Zinc	42	0.003

Table 48. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Leota Bottoms # 6.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	6.2	15.7
Boron	< 20	0.32
Barium	262	0.53
Calcium	43,000	180
Cobalt	10	0.018
Copper	19	0.07
Iron	22,700	11.9
Lithium	9.2	0.06
Magnesium	11,600	91.8
Potassium	6000	14.0
Sodium	560	117
Nickel	30	<.01
Selenium	0.82	0.9
Silica	3500	0.65
Strontium	179	1.87
Titanium	68	0.22
Vanadium	35	< .003
Zinc	89	0.009

IV. Green River at Highway 40

No appreciable mortality of any species occurred in samples from the Green River. Survival was 100% for razorback suckers and Daphnia magna and 90% for fathead minnows. Specific conductance ranged from 500 to 580 μS/cm and pH ranged from 8.25 to 8.51 (Table 49). Selenium concentrations in daily water samples from the Green River collected as grab samples near Highway 40 were measurable (Table 50), but below the analytical limit of detection (.001 mg/L) for selenium. Concentrations of boron were lower than at any other site and levels of other contaminants were similar to those measured in Leota Pond #6 at Ouray NWR. Correspondingly, concentrations of contaminants in sediments and associated porewaters (Table 51) were as low as those measured in Leota Pond #6. Ammonia and nitrate were also extremely low.

No samples from the Green River below the Stewart Lake and Ashley Creek inflows were analyzed during this 1992 study. Information collected on concentrations of inorganic constituents during 1993 at sites extending from Green River near the Highway 40 bridge to the Green River near Ouray NWR is pending.

Table 49. Water chemistry measurements on daily composite samples collected from Green River (HWY 40) on 18 July 1992.

	Hardness (mg/L as $CaCO_3$)	Alkalinity (mg/L as $CaCO_3$)	Oxygen dissolved (mg/L) (field measure)	pH	Salinity (ppth)	Conductivity (µS/cm)
Day 1	202	140	0.4	8.45	ND	510
Day 2	196	164	0.2	8.44	ND	510
Day 3	204	138	0.4	8.48	ND	500
Day 4	204	138	0.9	8.34	ND	510
Day 5	180	136	0.4	8.25	ND	500
Day 6	196	142	1.1	8.30	ND	520
Day 7	212	144	0.9	8.51	ND	510
Day 8	220	143	1.3	8.47	ND	550
Day 9	224	150	0.6	8.49	ND	580

	Turbidity (NTUs)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Ammonia (NH_3) (mg/L)	Nitrate (mg/L)
Day 1	71.0	160	19.7	0.05	ND
Day 2	192.0	120	21.3	0.02	ND
Day 3	86.0				
Day 4	43.0	180	18.6	0.02	ND
Day 5	74.0				
Day 6	79.0	150	19.0	0.02	ND
Day 7	77.0				
Day 8	39.0	170	21.5	0.02	ND
Day 9	152.0				

Table 50. Concentrations (mg/L) of dissolved inorganic constituents in water collected from Green River at Highway 40 beginning 18 July 1992. Samples were filtered with 0.45 μm polycarbonate filter and acidifed to pH < 2.

Date	Arsenic	Boron	Barium	Calcium	Cobalt	Copper	Iron
07-18-92	<.002	0.08	0.052	50.3	0.006	0.02	0.05
07-19-92	0.004	0.08	0.052	52.0	0.005	0.02	0.03
07-20-92	0.002	0.08	0.055	51.2	0.004	0.02	0.02
07-21-92	<.002	0.09	0.054	52.6	0.006	0.02	0.03
07-22-92	0.002	0.08	0.055	53.1	0.006	0.02	0.03
07-23-92	<.002	0.08	0.056	53.3	0.004	0.02	0.02
07-24-92	<.002	0.08	0.055	54.0	0.004	0.02	0.04
07-25-92	<.002	0.09	0.057	54.5	0.006	0.02	0.04
07-26-92	<.002	0.09	0.058	57.2	0.003	0.02	0.05

Date	Lithium	Magnesium	Potassium	Sodium	Nickel	Selenium
07-18-92	0.02	19.4	2.3	50.3	<.01	0.0004
07-19-92	0.02	19.8	2.7	52.1	<.01	0.0010
07-20-92	0.02	19.3	2.5	49.9	<.01	0.0005
07-21-92	0.02	19.5	2.6	50.5	<.01	0.0007
07-22-92	0.02	20.4	2.4	50.4	<.01	0.0006
07-23-92	0.02	21.0	2.4	53.5	<.01	0.0007
07-24-92	0.02	21.1	2.3	54.8	<.01	0.0009
07-25-92	0.02	21.3	2.4	52.8	<.01	0.0008
07-26-92	0.02	22.3	2.5	55.3	<.01	0.0005

Date	Silica	Strontium	Titanium	Uranium	Vanadium	Zinc
07-18-92	1.51	0.46	0.0009	0.005	<.003	<.002
07-19-92	1.98	0.46	0.0010	0.007	<.003	<.002
07-20-92	2.00	0.45	0.0010	0.009	<.003	0.002
07-21-92	2.09	0.47	0.0010	0.009	<.003	<.002
07-22-92	1.87	0.48	0.0010	0.005	<.003	<.002
07-23-92	1.66	0.49	<.0007	0.005	<.003	<.002
07-24-92	1.49	0.50	<.0007	0.009	<.003	<.002
07-25-92	1.54	0.51	0.0010	0.008	<.003	<.002
07-26-92	1.67	0.54	0.0009	0.005	<.003	<.002

Table 51. Concentrations of inorganic constituents in sediments (μg/g, dry weight) and in sediment porewaters (μg/L) collected from Green River at Highway 40.

ELEMENT	SEDIMENT (μg/g, dry weight)	POREWATER (μg/L)
Arsenic	6.5	42.0
Boron	< 20	0.14
Barium	158	0.43
Calcium	23,200	169
Cobalt	< 6	0.015
Copper	6.8	0.06
Iron	9320	14.2
Lithium	2.0	0.04
Magnesium	5340	72.4
Potassium	2400	7.5
Sodium	390	82.8
Nickel	<10	<.01
Selenium	0.30	0.5
Silica	2700	0.95
Strontium	78	1.62
Titanium	38	0.69
Vanadium	13	< .009
Zinc	33	0.026

DISCUSSION

During the past decade, waters in many irrigated areas of the western United States have been the focus of national attention. Irrigation practices have resulted in the concentration of contaminants and salts in areas that are critical to survival and reproduction of fish and wildlife resources. These irrigation waters are commonly dominated by sulfate instead of bicarbonate and are also high in sodium. Thus, these waters are characterized by an atypical balance of ions that can result in toxicity to aquatic organisms (Saiki et al. 1992). Although the exact constituents of drainwaters vary among locations, individual sites can often be characterized by specific combinations of elements. For example, studies on the Stillwater National Wildlife Refuge identified arsenic, boron, lithium, and molybdenum as major constituents of drainwater associated with that area (Finger et al 1993). Similarly, elevated concentrations of selenium, boron, and molybdenum were prevalent in waters from the Kesterson National Wildlife Refuge. Elements common to sites evaluated in the Middle Green River Basin during this study were boron, copper, cobalt, lithium, selenium and strontium.

Uniformity and correlation of measurements

Concentrations of inorganic constituents measured at different locations in the Basin during this study did not differ

appreciably from previous information on those same sites collected in different months and different years between 1982 and 1989 (Stephens et al. 1988, Peltz and Waddell 1991, Stephens et al. 1992). In addition, the absence of daily fluctuations in water quality at the test sites suggests that dramatic changes in water quality that are stressful to aquatic organisms do not occur as commonly in the Middle Green River Basin as in other irrigated areas of the western United States (Finger et al. 1993). This low temporal variability in drainwater quality across years provides credibility to estimates of mass transport derived from existing data on selenium and other contaminants in the Middle Green River system .

Many inorganic elements in drainwaters from the Middle Green River Basin were highly correlated with eachother (Table 52). Copper and cobalt were most highly correlated (r^2=0.99), however correlations among selenium, boron, copper, cobalt, and lithium were also high (r^2>0.80). Other elements such as barium, strontium, uranium, titanium, or zinc, although consistently measured in water samples, were not significantly correlated with the presence of other major constituents. Because concentrations of contaminants in Sadler Draw were considerably higher than other locations, the relationship among drainwater constituents was also examined in the absence of data from Sadler. Correlation between copper and cobalt remained high (r^2=0.99) and their relationship with most other elements remained highly correlated. However, correlations of selenium with both of these

Table 52. Correlation matrix for major components of waters from the Middle Green River Basin with (A) and without (B) Sadler Draw.

A.

	Se	B	Co	Cu	Li	Sr
Se	1.00	0.92	0.81	0.81	0.95	0.40
B	0.92	1.00	0.95	0.94	0.97	0.67
Co	0.82	0.95	1.00	0.99	0.94	0.64
Cu	0.81	0.94	0.99	1.00	0.93	0.86
Li	0.95	0.97	0.94	0.93	1.00	0.64
Sr	0.41	0.67	0.64	0.86	0.64	1.00

B.

	Se	B	Co	Cu	Li	Sr
Se	1.00	0.64	0.61	0.63	0.71	0.42
B	0.64	1.00	0.89	0.89	0.82	0.65
Co	0.61	0.89	1.00	0.99	0.89	0.72
Cu	0.63	0.89	0.99	1.00	0.90	0.81
Li	0.71	0.82	0.89	0.90	1.00	0.70
Sr	0.42	0.65	0.72	0.81	0.70	1.00

elements as well as other constituents was decreased markedly by elimination of data from Sadler Draw (Table 52). This is not surprising given that selenium concentrations were 20 times higher at Sadler Draw than at any other location; locational differences in concentrations were not as extreme for other elements. Based on information derived from the correlation matrix (Table 52), prediction of selenium concentrations using concentrations of other major elemental constituents is not recommended for this river basin.

Identification of toxic components

No single element was present in water from any site at concentrations known to be acutely toxic to aquatic organisms. Based on laboratory information, no toxicity would have been predicted in this study. However, mortality exceeded 10% for one or more species at 10 of the 12 locations tested, and exceeded 20% at 7 of those sites. Toxicity for all species was highest in the Ashley Creek Drainage at Sadler Draw, however, appreciable mortality also occurred at Site 6550 and in water from the mouth of Ashley Creek in that drainage. Mortality in SLWMA was moderate at all three sites; the lowest mortality occurred in Stewart Lake Outflow. Of the three sites evaluated at Ouray NWR, the only mortality that occurred was in daphnids at North Roadside Pond and this may have resulted from low oxygen stress on day 3 of the study.

In several sites where mortality was low or insignificant, effects on reproductive success of daphnids were evident. Once again, based on values in the literature derived from laboratory tests, no effects on reproductive success would have been expected for daphnids in the test waters. However, only the three locations in Ouray NWR, South Vernal Drain, and the one site in the Green River at Highway 40 showed no reduction in reproductive success. The difference between affected and unaffected sites was irrefutable. For example, the total number of young produced in the five unaffected sites ranged from 295 to 357 as compared to 3 young produced in full-strength water from Sadler Draw. Furthermore, production of young increased as concentration of drainwater decreased for affected locations.

An exploratory statistical analysis was conducted to determine if the level of mortality or reproductive success occurring in toxicity tests with water from various locations was related to the concentration of any individual trace element in the water. Regression models were fit by maximum likelihood methodology assuming a binomial error distribution (McCullagh and Nelder 1989) to determine the relation between individual elements and mortality for each species. The fit of the model to the data was assessed with a goodness of fit likelihood ratio test (deviance). With this procedure, a low deviance and a level of significance where $p>0.1$ (indicating that the predicted relationship does not significantly differ from the observed data) is desired.

Selenium was the only single element to have a statistically significant relationship with mortality. A significant relationship existed between selenium and mortality of razorback suckers (Figure 2) and selenium and mortality of fathead minnows (Figure 3). Although a general trend was apparent, a similar significant relationship did not occur between selenium and daphnid mortality (Figure 4). However, further analysis did indicate a significant relationship between selenium and reproductive success of daphnids (number of young per surviving adult) (Figure 5). This specific relationship is particularly important because of the documented effects of selenium on reproduction (Lemly et al. 1993). Reproductive success is the most sensitive biological endpoint for assessing selenium poisoning in fish (Lemly 1985 a,b, 1992; Gillespie and Baumann 1986, Coyle et al. 1992). The significant impairment of reproduction in daphnids and its relationship to aqueous selenium concentrations provides evidence that selenium is a toxic component of irrigation drainwater in this region. It is important to note that under environmental conditions in the presence of a mixture of contaminants, effects on daphnid reproduction determined in this study occurred at selenium concentrations 10 to 20 times lower than levels known to impair reproduction in laboratory exposures (Ingersoll et al. 1990). It is plausible to expect that effects on reproductive success in fish exposed to irrigation drainwater will also occur at levels below those predicted under laboratory conditions or under field

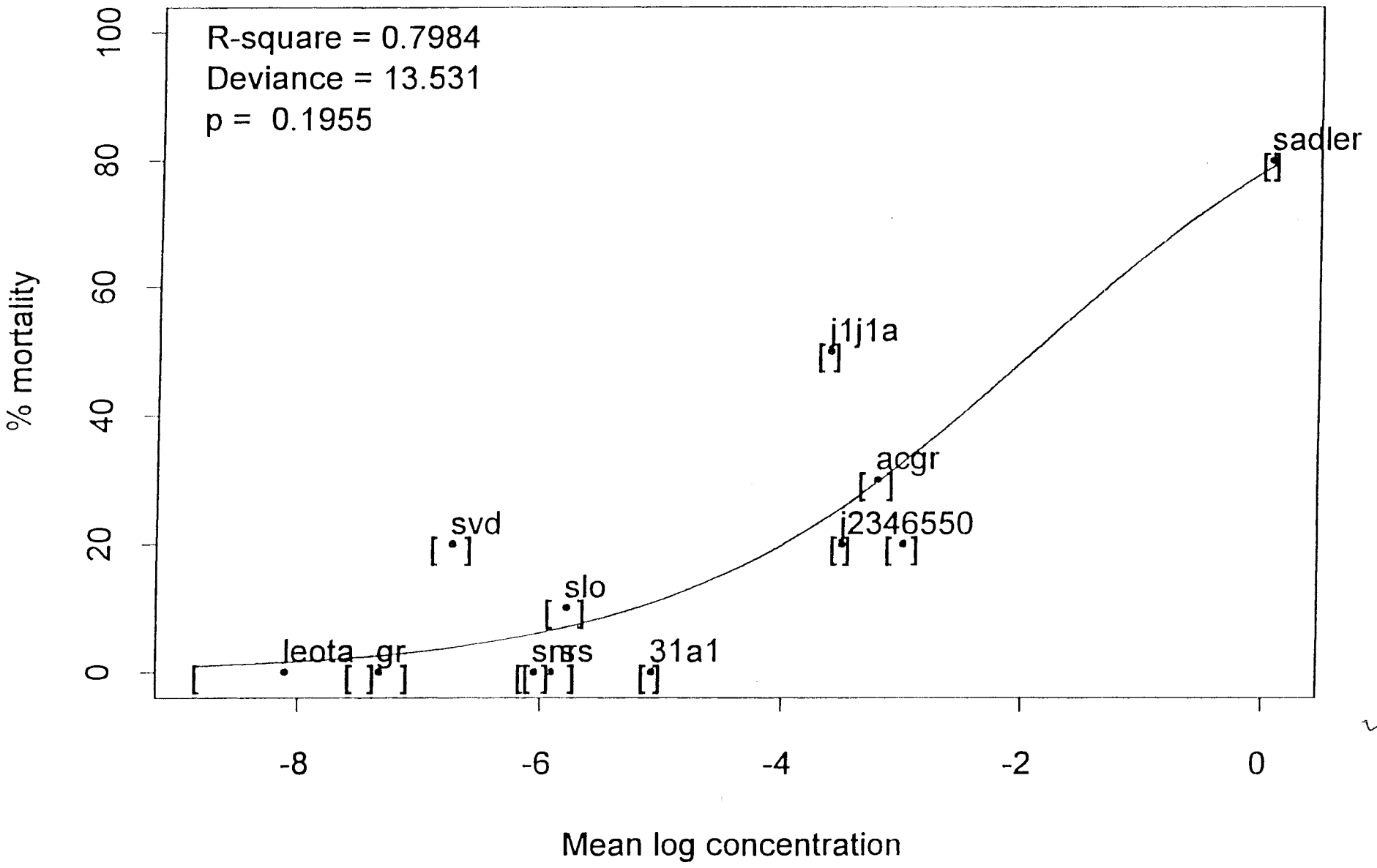


Figure 2. Significant relationship between log concentration of selenium and mortality of razorback suckers in water from 12 locations in the Middle Green River Basin.

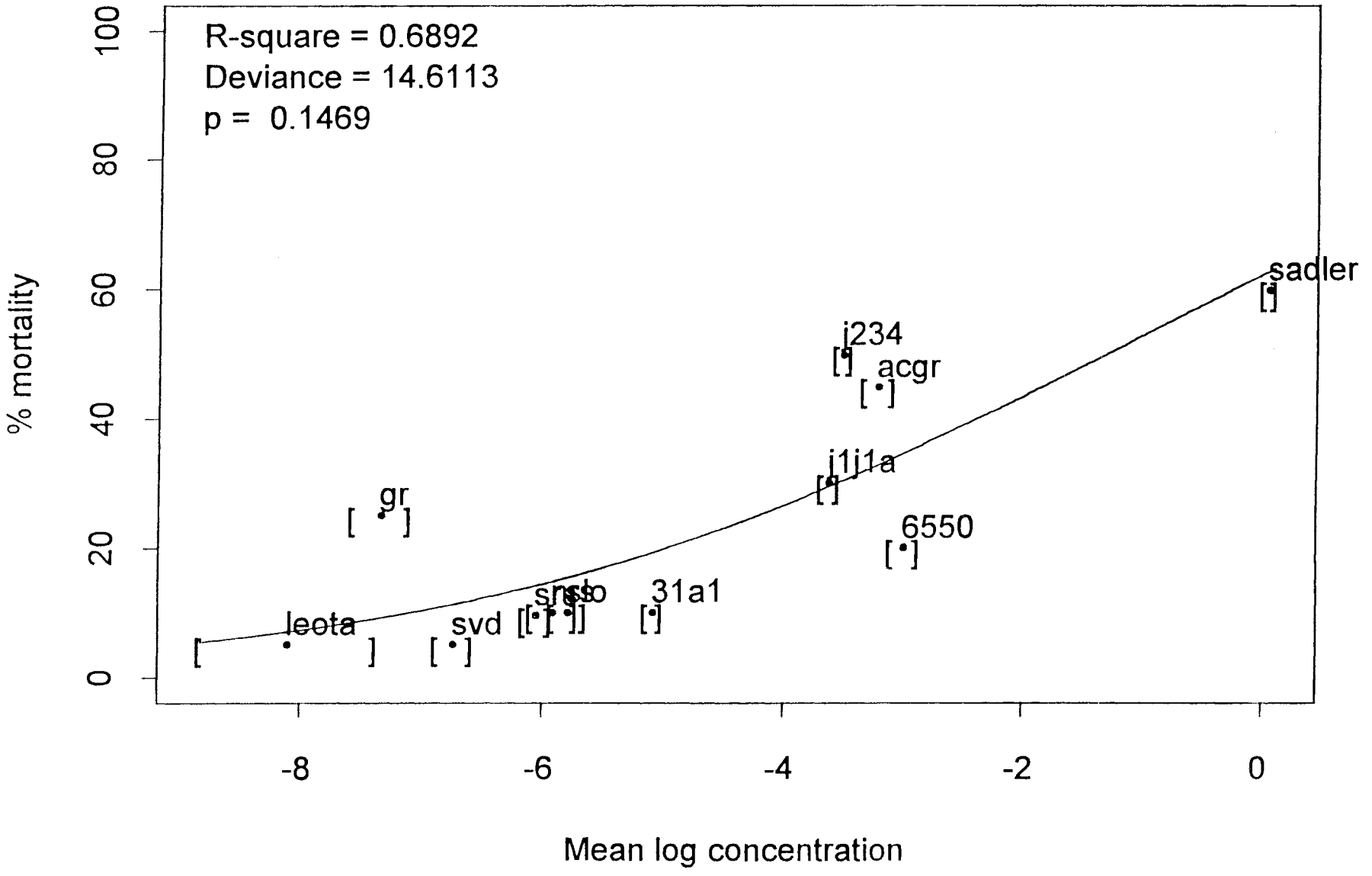


Figure 3. Significant relationship between log concentration of selenium and mortality of fathead minnows in water from 12 locations in the Middle Green River Basin.

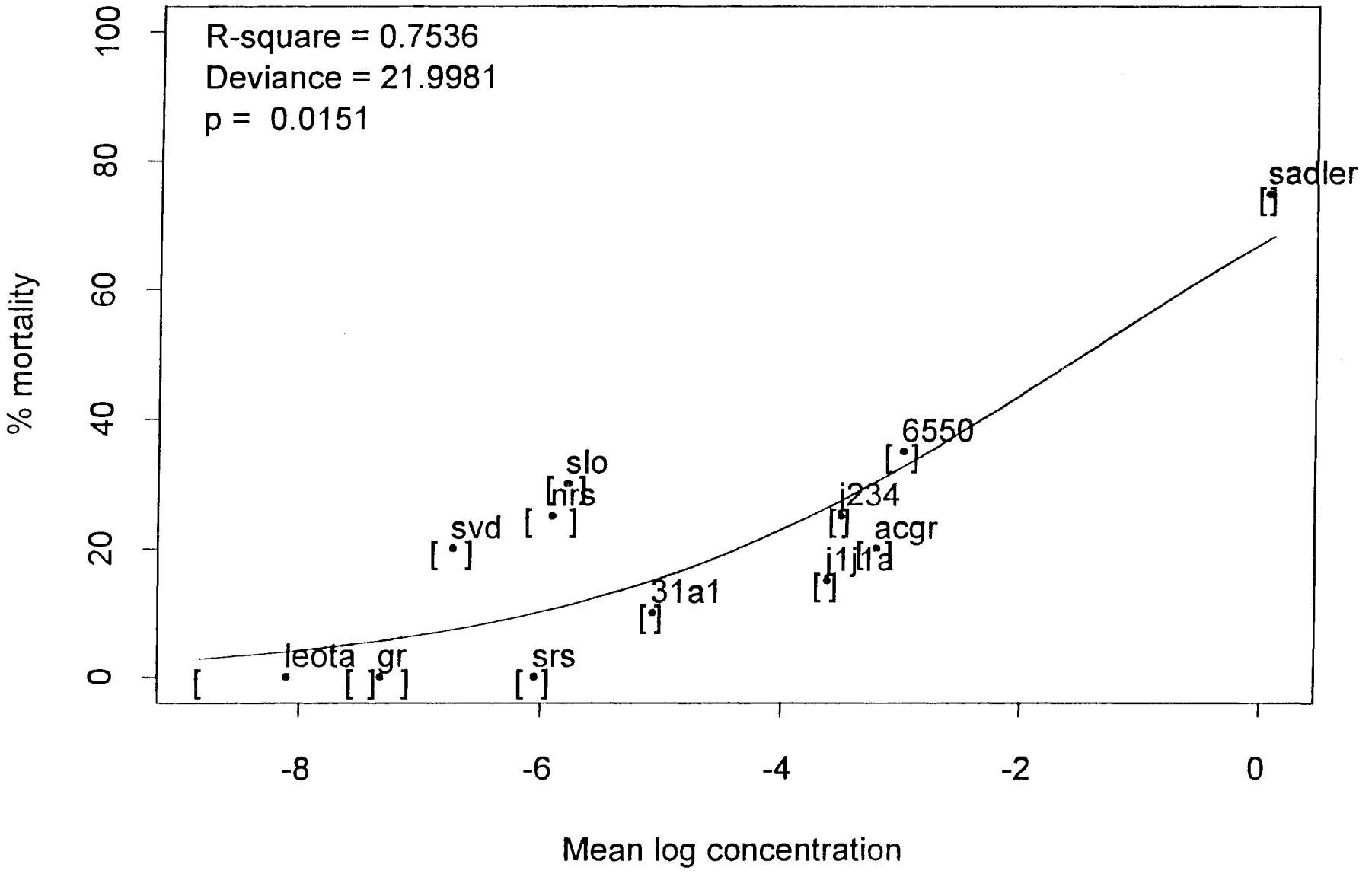


Figure 4. Relationship between log concentration of selenium and mortality of Daphnia magna. A general trend was apparent but the relationship was not significant.

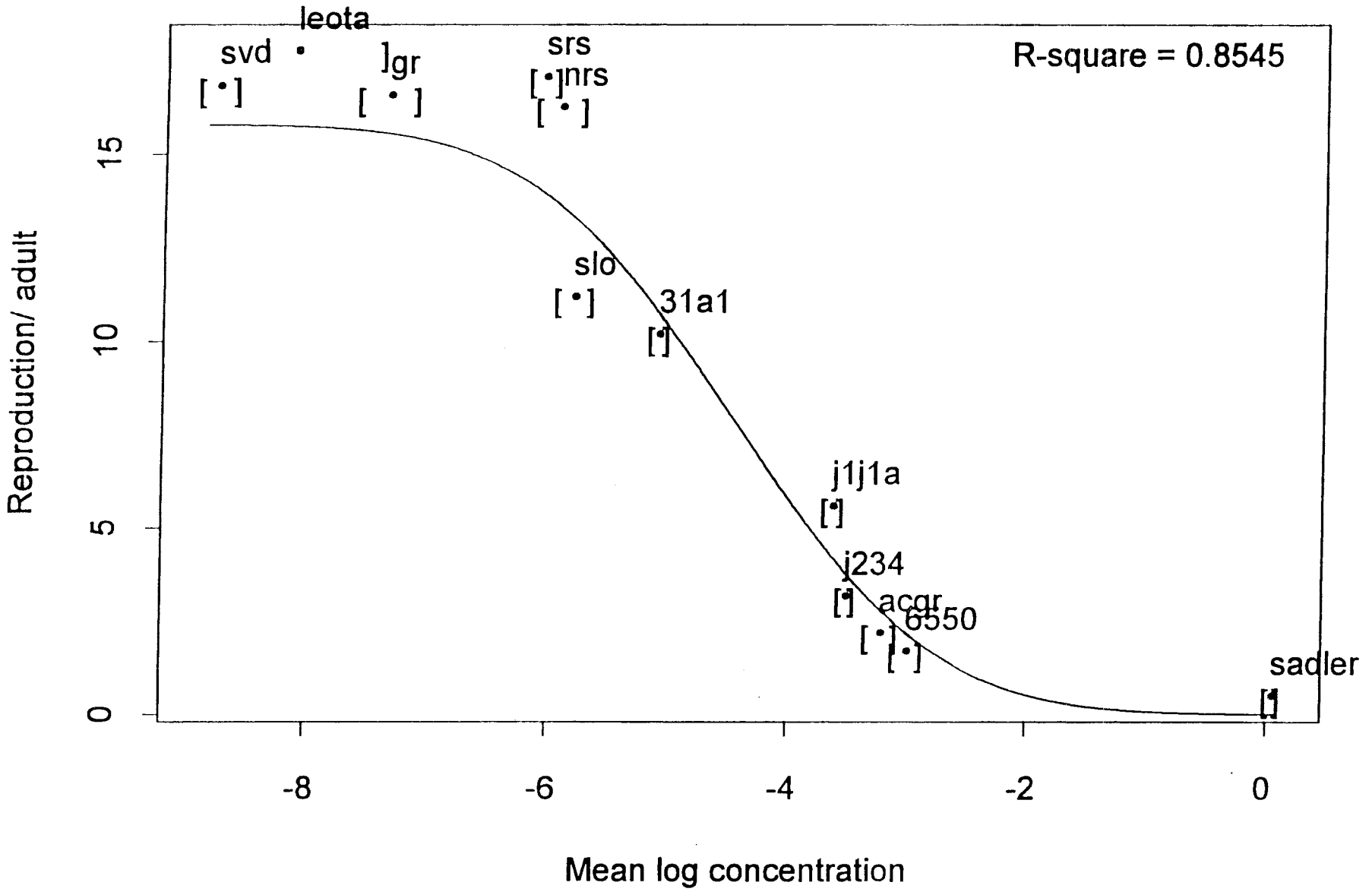


Figure 5. Significant relationship between log concentration of selenium and reproductive success (number of young/adult) of Daphnia magna.

conditions where selenium is the primary or sole contaminant of concern.

Although concentrations of selenium consistently exceeded national water quality criteria for the protection of aquatic life (the 4-day average concentration not to exceed 5 μg/L or the 1-hour average not to exceed 20 μg/L more than once every 3 years (USEPA 1987)) at 4 of the 5 sites in the Ashley Creek drainage and 2 of the 3 sites in SLWMA, concentrations at all sites were lower than those associated with acute toxicity. Criteria for ammonia, nitrate, copper and zinc were never exceeded. National criteria are not available for boron, cobalt, lithium or strontium.

The 96-h acute toxicity of waterborne exposure to selenium reported in the literature routinely occurs in the mg/L range for aquatic species (Lemly et al. 1993). Therefore, based on laboratory studies, acute toxicity would not have been expected in water from any of the locations tested. The toxicity of selenium is dependent on whether it is present as selenate (+6), selenite (+4), or selenomethionine. Selenite is more toxic than selenate, but the selenomethionine form is much more toxic than either inorganic form (USDI 1990, Ingersoll et al. 1990, Lemly et al. 1993). Hamilton (in review) reported that the toxicity of selenite determined in water reconstituted to the ionic balance of the Green River was about 3 times more toxic to razorback suckers than was selenate.

Water from the Green River Basin was predominately selenate,

but the ratio of selenate:selenite in samples from the Green River Basin (3:2) was different from that reported in Kesterson NWR (6:1). In our study, speciation of inorganic selenium was attempted on two randomly selected samples per location. Unfortunately, selenium concentrations in the Ouray locations, Green River at Highway 40, South Vernal Drain, Drain 31A1, and Stewart Lake Outflow yielded concentrations at or below detection limits. Analysis of water from Sadler Draw indicated a 1:1 ratio of selenate:selenite. However, analysis of water from the remaining four sites (n=8) resulted in a consistent selenate:selenite ratio of 3:2. Analysis of organic selenium was not conducted.

The high percentage of selenite at the Sadler location may have contributed to the acute toxicity, but alone was not high enough to have independently induced the observed mortality. Because no other element was present at concentrations sufficient to have induced the observed mortality, toxicity attributable to additive or synergistic effects was explored. Additive toxicity has been demonstrated in the laboratory for a mixture of six inorganics commonly occurring in drainwater from the Stillwater NWR tested with striped bass (Dwyer et al. 1992), a mixture of 13 inorganic elements tested with chinook salmon (Hamilton and Buhl 1990b), and a mixture of four inorganics tested with chinook and coho salmon (Hamilton and Buhl 1990a). Additive toxicity of drainwater constituents has also been suggested by results of field toxicity tests at Stillwater NWR (Finger et al. 1993) and

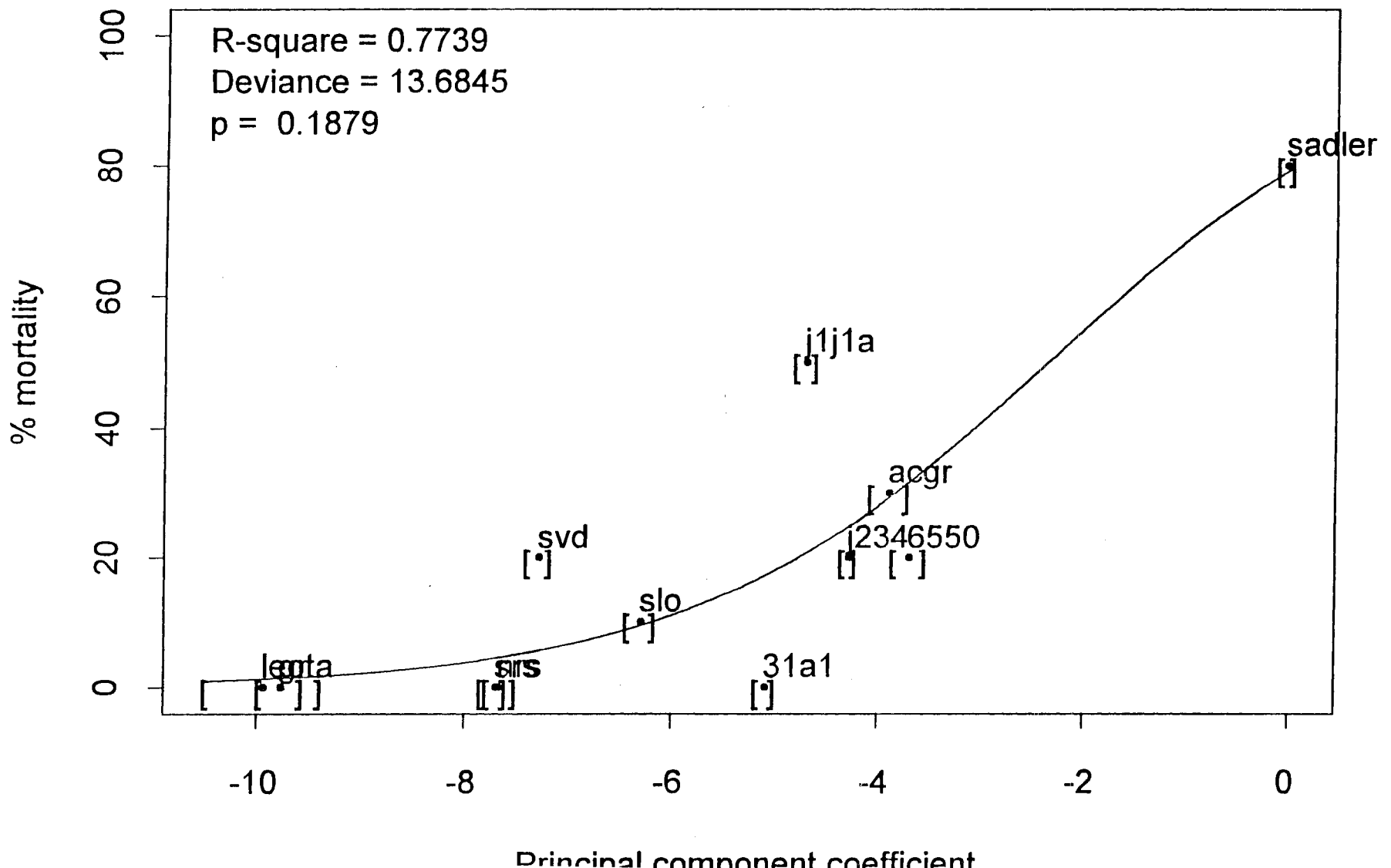
at Kesterson NWR (Lemly et al. 1993).

A variable representing an index of contamination or contaminant load was constructed as a function of a number of the individual elements measured. Principal components analysis was used to determine if overall contaminant loads in the various sites could be summarized as linear combinations of the concentrations of individual elements. Daily values of contaminant concentrations were used resulting in 108 observations (9 days for 12 locations). The major interest centered on elements known to be potentially toxic and that could be considered important in producing the total variability of elemental concentrations. Elements that consistently produced high loadings on the first principal component were chosen to form a meaningful subset of the entire suite of measured elements. This subset comprised boron, cobalt, copper, lithium, selenium and strontium.

A principal components analysis run using daily measurements of only those elements indicated that the first component accounted for about 88% (88.83%) of the total variability in these variables. Because it accounted for such a high percent of the variability, this first component alone was retained to construct a variable indicative of the overall level of contamination present in the various locations. Component scores were computed for each day at each location for the time during which toxicity tests were active. The mean value of these component scores computed over days at each location was then

used as an indicator of the overall level of contamination at a location during a given toxicity test. The data set produced in this manner contained 12 values for total mortality and 12 values of the constructed indicator of contamination. Results from this principal components analysis indicated that the overall level of metals contamination could be summarized using linear combinations of individual element concentrations and 2) the overall level of contamination due to elements that occurred in elevated concentrations could be summarized using a single linear combination of those elements.

Statistical analysis was conducted to determine if a relationship existed between toxicity and the above described index of contamination derived through principal components analysis. Daily component scores were computed for each location by retaining the first principal component. Locational means of these values were significantly related to mortality of razorback suckers (Figure 6). General trends of increased mortality with increased contaminant load were apparent for other species, but relationships were not significant for mortality of fathead minnows or daphnids. However, the component was significantly related to reproductive success of daphnids (r^2=0.89) (Figure 7). In summary, this single component representing the mixture of boron, cobalt, copper, lithium, selenium, and zinc was significantly related to mortality of razorback suckers and reproductive impairment of daphnids.


R-square = 0.7739
Deviance = 13.6845
p = 0.1879
% mortality
Principal component coefficient
sadler
j1j1a
acgr
j2346550
svd
slo
31a1
0
20
40
60
80
100
-10
-8
-6
-4
-2
0

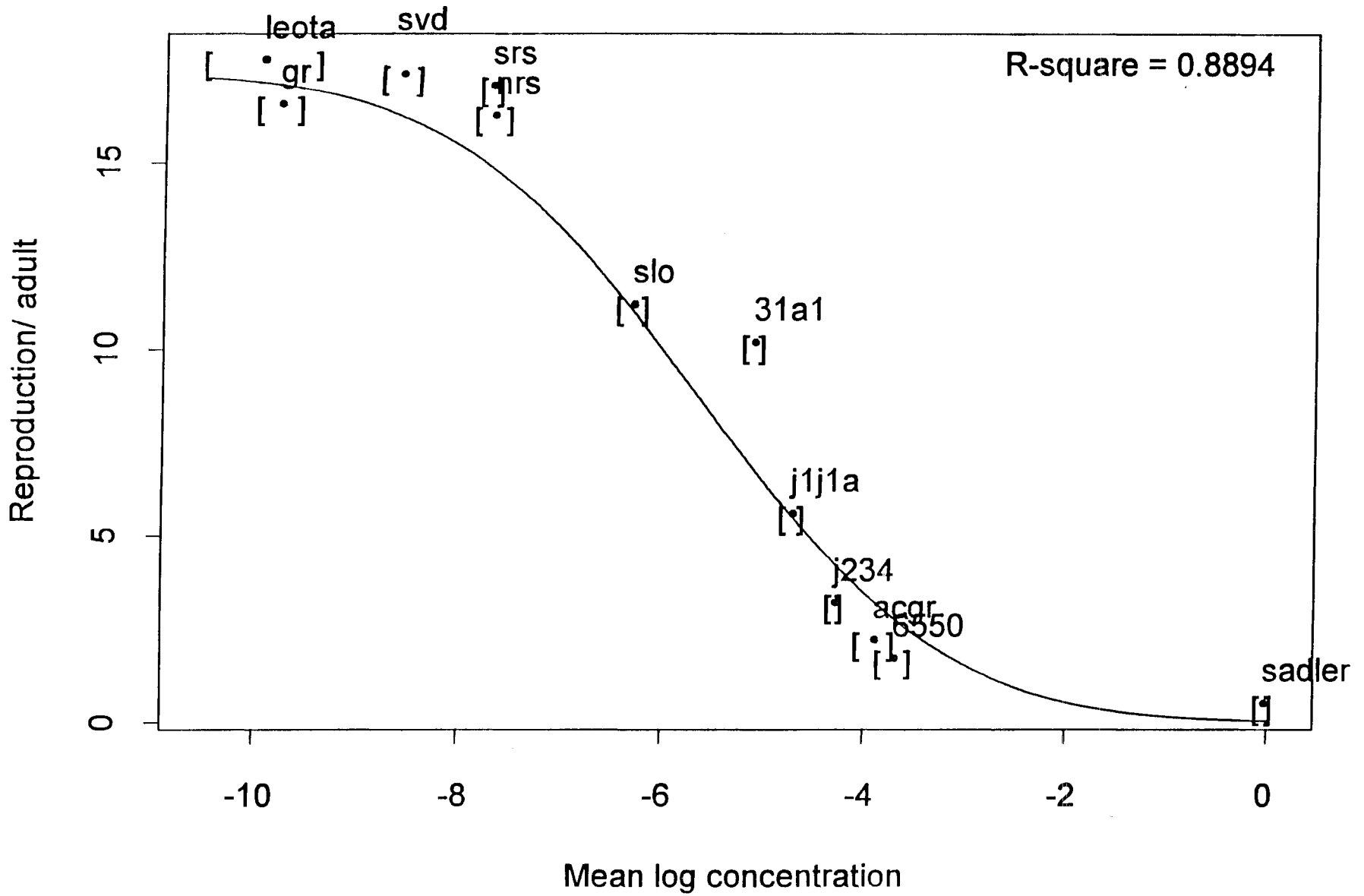


Figure 7. Significant relationship between the index of contamination (derived using principal component analysis) and reproductive success (number of young per adult) of Daphnia magna.

This analysis demonstrates that a measure of toxic response (mortality or reproduction) is related to a measure of total contamination in water from the Green River Basin. Although it does not demonstrate a causative relationship between the presence of boron, cobalt, copper, lithium, selenium and strontium and toxicity, the variable constructed to represent overall contaminant load serves as an index of contamination. Similarly, the significant relationship between selenium alone and mortality does not directly implicate selenium as the cause. However, in both instances, the appropriate inference is that whatever the cause of mortality, it is related to constituents of irrigation drainwater in a direct manner. That is, as the concentration of selenium or the component representing overall contaminant load increases, the agents responsible for causing mortality also increase.

Specific conductance was also strongly related to the occurrence of selenium (r=0.90)(Figure 8) and to the component representing overall contaminant load (r=0.96)(Figure 9). Measurement of conductivity offers a means to estimate concentrations of contaminants associated with drainwaters and to evaluate overall water quality at a location. The relationship between selenium and conductivity defined in this study is much improved over the one offered by Stephens et al. (1992). At this point, the cause of this improvement is unclear.

Although small differences in cumulative mortality occurred for the three species across locations, overall the response to

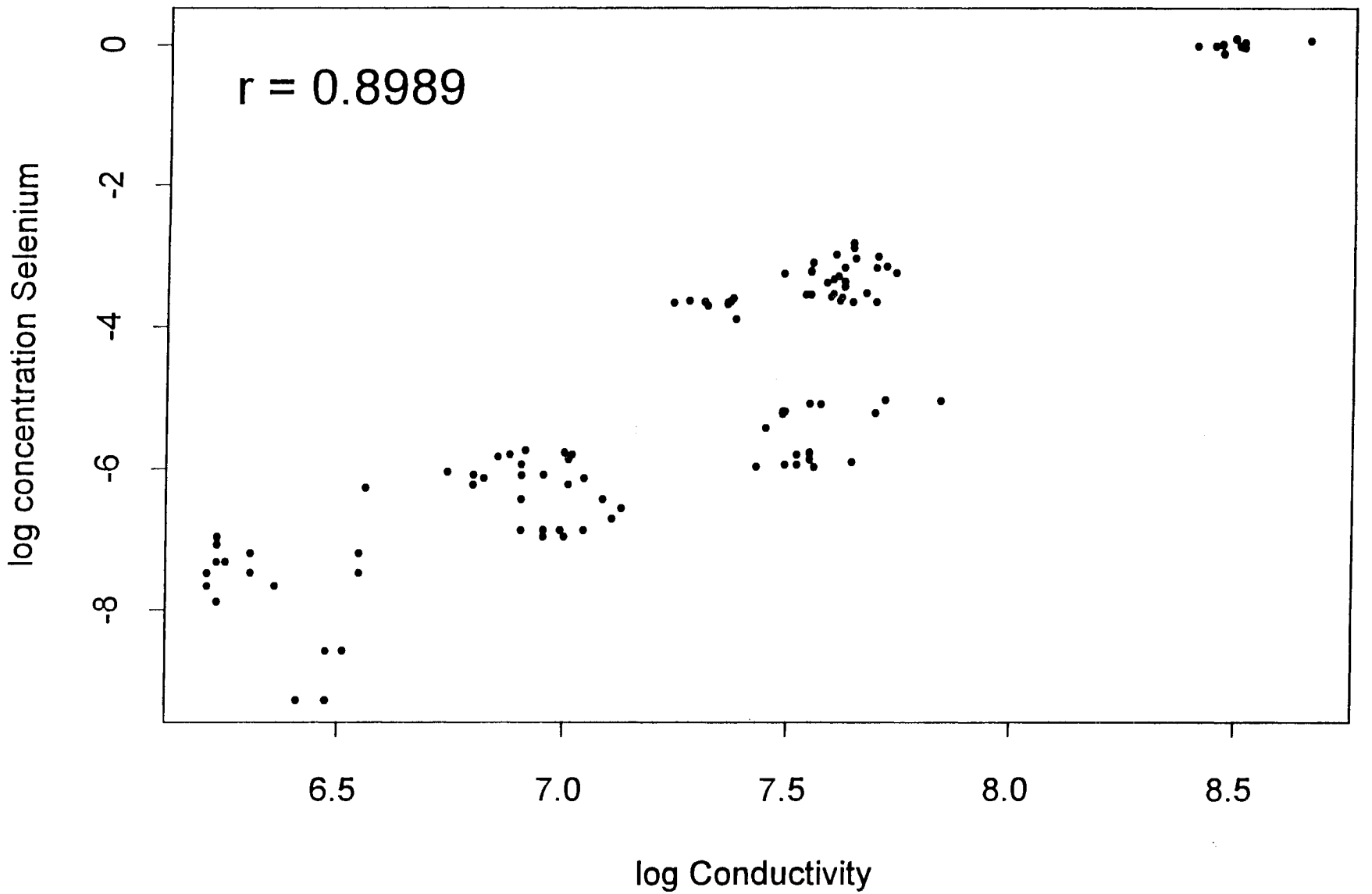


Figure 8. Relationship of specific conductance (log) and selenium (log concentration) for 12 locations in the Middle Green River Basin.

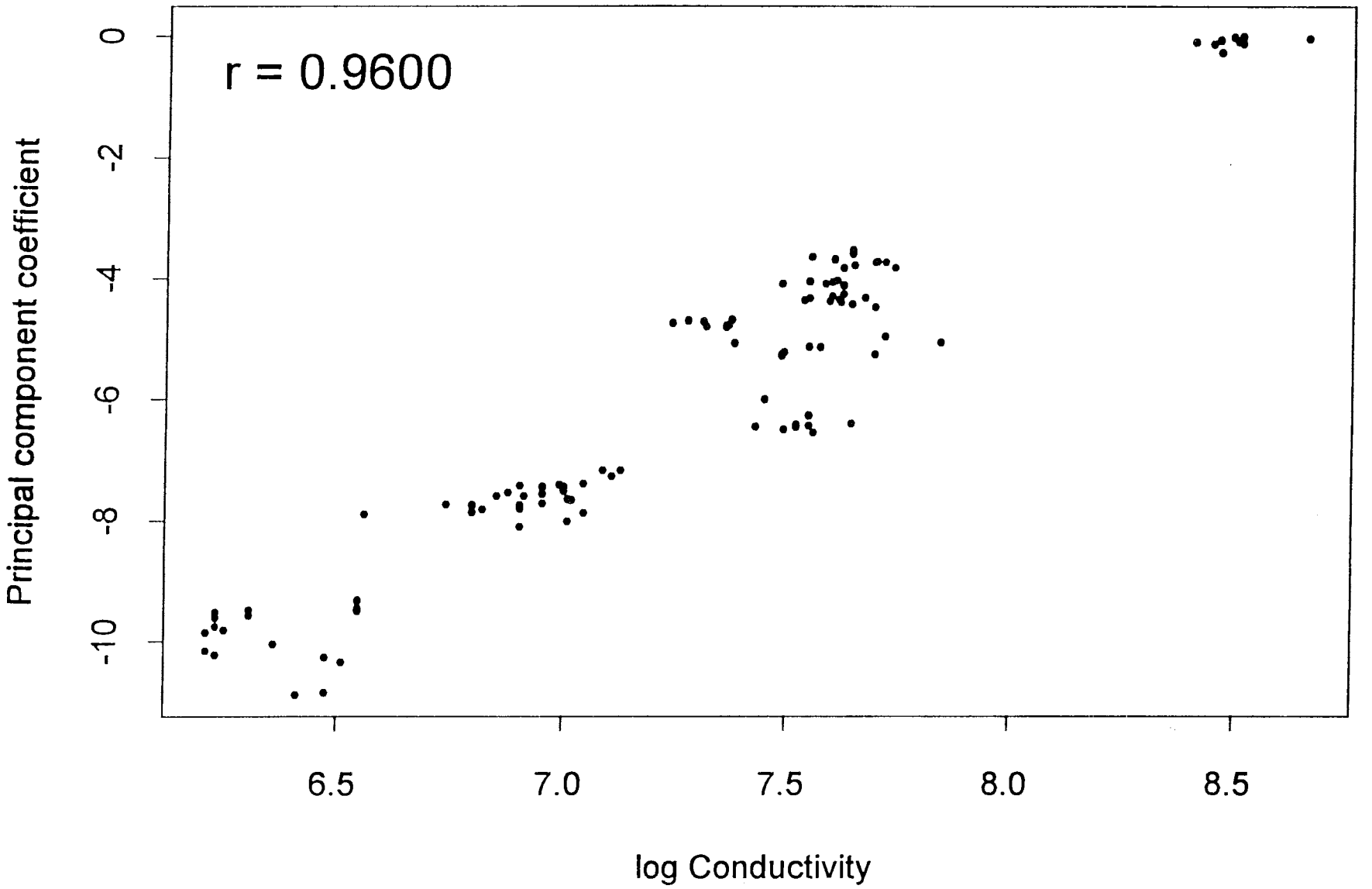


Figure 9. Relationship of specific conductance (log) and the index of contamination (derived using principal component analysis) for 12 locations in the Middle Green River Basin.

drainwater exposure was similar among species. This similarity is best illustrated by the pattern of mortality for all three species in water from Sadler Draw (Figure 10). There was no appreciable difference in the rate or degree of mortality after 10 days. This suggests that either fathead minnows or Daphnia magna, which are readily available for testing throughout the year, could be used as surrogates for razorback suckers to monitor changes in water quality in areas where mortality is expected. In addition, tests with daphnids can provide a sub-lethal measure of reproductive success that can be used to evaluate water quality in areas where mortality does not occur. Furthermore, Hamilton (in review) reported similar sensitivities of razorback suckers, bonytail, and Colorado squawfish to a number of inorganic contaminants. It is likely that the sensitivities of fathead minnows and daphnids to contaminants in the Green River system may be representative of responses exhibited by those three endangered fish species.

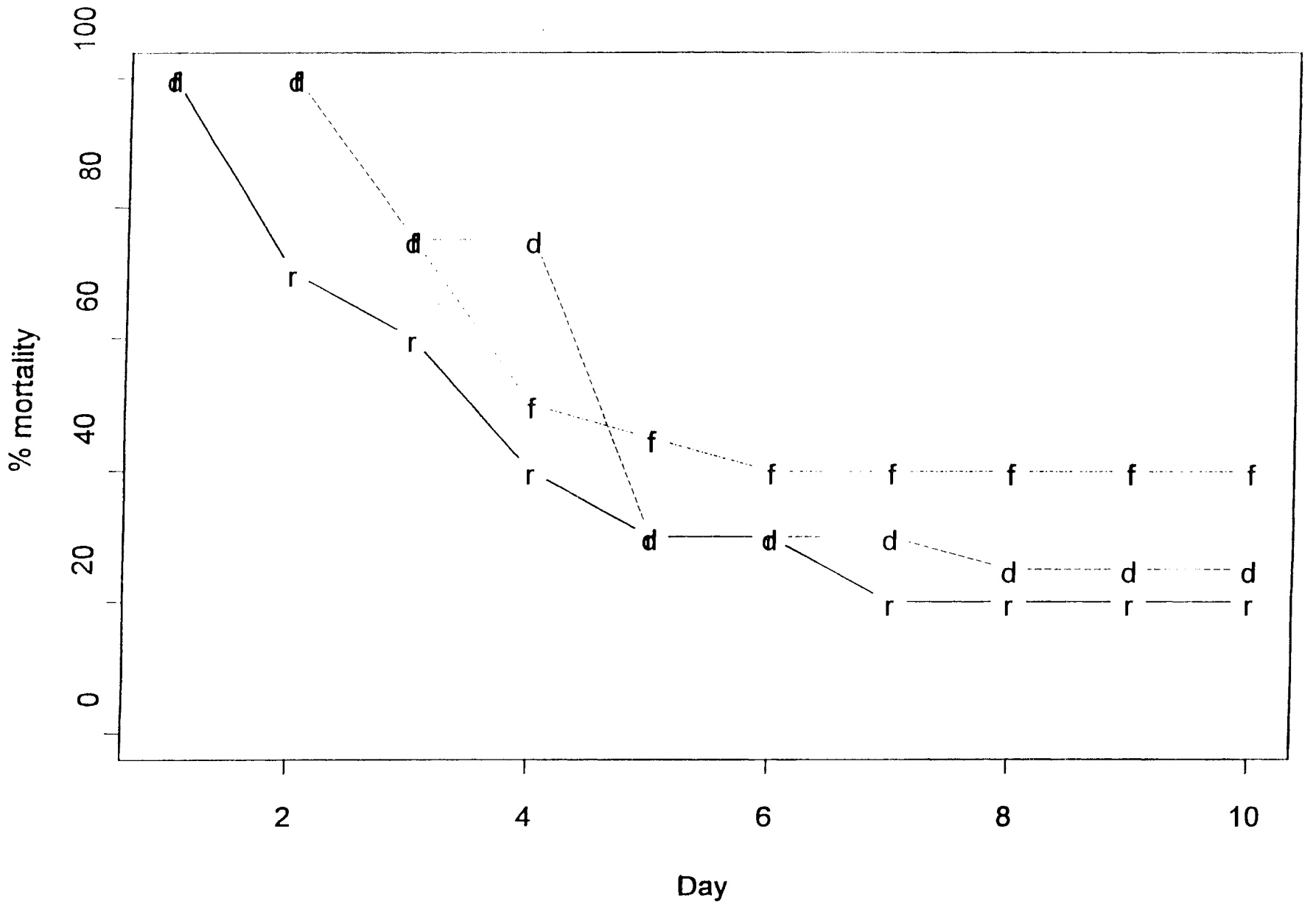


Figure 10. Distribution of mortality for Daphnia magna (d), fathead minnows (f) and razorback suckers (r) during the 10-day exposure to water from Sadler Draw. Patterns were similar among species.

CONCLUSIONS

Although water quality criteria for selenium were exceeded at numerous sites, the mortality and reproductive impairment observed during our studies could not have been predicted based on laboratory toxicity tests with individual elements. It is apparent from this study, that the toxic responses observed were influenced by, but did not result exclusively from selenium; other constituents of the drainwater interacted either additively or synergistically to cause toxic responses in the test organisms. This study clearly indicates that exposure to agricultural irrigation drainwater in the Middle Green River Basin can result in adverse effects to aquatic organisms including the endangered razorback sucker. Specific conclusions from this study follow.

- Concentrations of contaminants were highest in the Ashley Creek Drainage where mortality was highest. Reproductive success of daphnids was reduced at every location in this drainage except South Vernal Drain. Moderate toxicity occurred in SLWMA; reproductive success was affected at all locations. Mortality of all species was lowest in Ouray NWR where waterborne contaminants were lowest. No effects on reproductive success were observed at Ouray NWR.

- Although no element was present at concentrations known to be acutely toxic, mortality exceeded 10% at 10 of the 12 sites evaluated and exceeded 20% at 7 of those sites.

- Selenium consistently exceeded national water quality criteria at 6 of the 12 study sites. Selenium was the only individual element to have a statistically significant

relationship with mortality of razorback suckers and fathead minnows; mortality occurred at selenium levels not expected to be acutely toxic. Reproductive impairment of daphnids was also significantly related to selenium and occurred at selenium concentrations 10 to 20 times lower than levels known to impair daphnid reproduction under laboratory conditions.

- Principal components analysis was used to construct an index of contamination that included boron, cobalt, copper, lithium, selenium, and strontium. This component representing the combined presence of these elements was significantly related to mortality of razorback suckers and reproductive impairment of daphnids.

- Conductivity was strongly related to the concentration of selenium in the test water as well as to the index of contamination (combined presence of boron, cobalt, copper, lithium, selenium and strontium).

- The significant relationship between the index of overall contamination and toxic responses of the test species and the relationship between selenium and toxic responses suggests that the observed toxicity is directly related to constituents of irrigation drainwater in the Green River Basin.

- Sensitivity of razorback suckers was similar to that of fathead minnows and Daphnia magna. Both species may provide appropriate surrogates for monitoring areas where toxicity is expected. The sub-lethal measure of reproductive success of daphnids may offer an endpoint with which to evaluate the success of remedial measures after acute toxicity has been eliminated.

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