On-site Toxicity of Irrigation Drainwater from Stillwater National Wildlife Refuge to Aquatic Organisms

1988 Progress Report

by

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EXECUTIVE SUMMARY

The toxicity of water from seven locations in the Stillwater Wildlife Management Area was evaluated in a series of on-site tests conducted over a 10 day period with bluegill, larval fathead minnows, and daphnids. Tests were also conducted with two saltwater species, mysids and larval sheephead minnows, at one location (Hunter Drain) where salinity exceeded 15%. In all assessments, organisms were exposed to full-strength drainwater and dilutions of 50, 25, and 12.5%. Dilution water was reconstituted to the appropriate ionic balance for each location so that salinity, hardness, alkalinity, pH, and sulfates remained constant across all treatments. This water was used as a control; well water transported from the National Fisheries Contaminant Research Center was used as an additional control to evaluate the condition of the test organisms. Another series of tests were conducted concurrently using the appropriate receiving water for dilution of drainwater.

TJ Drain and Hunter Drain were identified as locations with the greatest toxicity problems. Mortality was high for all species at these locations and no organisms survived exposure to full-strength or 50% drainwater from Hunter Drain. Groundwater collected from a well in the vicinity of TJ Drain was also acutely toxic and may have influenced the

water quality of TJ Drain. D-Line Canal and Paiute Drain were not toxic to any species tested. Water from Lead Lake was moderately toxic to all three species; cumulative mortality was 60% for bluegill and fathead minnows and 80% for daphnids. Lead Lake receives water from D-Line Canal, TJ Drain, and Paiute Drain, however, the water quality of Lead Lake was most similar to that of TJ Drain. Although concentration of salts in Lead Lake may be naturally increased by evaporation, our observations suggest that continued addition of water from TJ Drain will further degrade the water quality of Lead Lake.

Water quality of Hunter and TJ drains fluctuated dramatically during the 10-day study. These changes occurred rapidly and, in themselves, represent a significant stress to aquatic life. Changes in salinity and conductivity corresponded with changes in concentrations of contaminants. No individual contaminant was detected at acutely toxic concentrations, however, a strong relationship was defined between the combined presence of four metals--- arsenic, boron, lithium, and molybdenum --- and the mortality observed in our tests. TJ and Hunter drains had consistently higher levels of these four elements than did D-Line Canal and Paiute Drain where no appreciable mortality occurred. Low levels (<4.0 ug/L) of selenium were measured in filtered water from TJ Drain, Hunter Drain, Diagonal Drain, and Stillwater Point Reservoir; mercury was not detected in any sample.

Conductivity was also strongly related to the presence of arsenic, boron, lithium, and molybdenum and therefore, was related to mortality of organisms in the drainwater. It appears that conductivity may be valuable in assessing the acceptability of water for use by Stillwater Refuge, however, it is not known if this criterion may be extended for use in assessing groundwater toxicity or in evaluating problems in other areas where agricultural drainage is of concern.

Cumulative mortality (percent) of bluegill, fathead minnow larvae, and daphnids after 10 days of exposure to water collected from seven locations in the Stillwater National Wildlife Refuge. Dilution water was reconstituted to the same ionic balance as the drainwater maintaining a constant salinity across all treatments, including controls.

Location Species	% drainwater 100	50	25	12.5	recon control
D-Line Canal					
Bluegill	0	0	0	0	0
Fathead	0	0	0	0	0
Daphnid	0	0	0	0	0
Paiute Drain					
Bluegill	0	0	10	0	10
Fathead	0	0	0	0	0
Daphnid	0	0	10	0	5
TJ Drain					
Bluegill	90	70	30	20	0
Fathead	85	45	20	10	0
Daphnid	100	100	25	10	5
Lead Lake					
Bluegill	60	30	10	0	0
Fathead	60	30	10	0	0
Daphnid	80	50	20	0	0
Hunter Drain					
Bluegill	100	100	60	40	20
Fathead	100	100	60	40	0
Daphnid	100	100	75	50	10
Diagonal Drain					
Bluegill	80	40	20	10	10
Fathead	30	10	10	5	0
Daphnid	25	10	10	5	0
Stillwater Point					
Bluegill	20	0	10	0	0
Fathead	25	10	5	0	5
Daphnid	25	0	0	5	0

INTRODUCTION

During recent years, the presence of contaminants in agricultural irrigation drainwater has been recognized as a serious threat to fish and wildlife resources at several locations in the western United States. A Task Group established by the United States Department of Interior identified several locations for intensive biological assessment to determine drainwater-related contaminant problems. One area selected for study was the Stillwater National Wildlife Refuge, a part of the Stillwater Wildlife Management Area (SWMA), located in the lower Carson River Basin in western Nevada. This area was historically an extensive natural wetland estimated to have covered about 33,000 acres in 1905 (Hoffman et al. 1988). Recent assessments suggest that the SWMA has been reduced to about 9500 acres representing a 70% loss of wetland habitat. In addition to habitat loss, the quality of water reaching the Stillwater Refuge has declined due to increased irrigation demands. The major water supply to the refuge is obtained from irrigation canals, surface and subsurface irrigation return flows and occasional flood releases from Lahontan reservoir. Salinity of this water is often high and contains elevated levels of potentially toxic trace elements (Hoffman et al. 1988).

Because of antagonistic and/or synergistic interactions of complex mixtures of contaminants in the environment,

toxicological assessments of an aquatic system such as Stillwater can not be based on the hazards represented by the individual contaminants. Approaches that evaluate whole-effluent toxicity are more appropriate than contaminant-specific assessment.

The purpose to this study was to evaluate the toxicity of water from several drains that supply the Stillwater National Wildlife Refuge with water for management of its wetland. Toxicity assessments were conducted on-site for 10 consecutive days during August 1988 with water from seven locations.

METHODS OF STUDY

General Procedures

Locations for toxicity evaluations were selected on D-Line Canal, TJ Drain, Paiute Drain, Hunter Drain, Diagonal Drain, Lead Lake and Stillwater Point Reservoir (Figure 1). Composite samplers (ISCO Model 2710) were deployed on 9 August 1988 to collect water from each drain at 15-min intervals throughout the 10-d study. Water was pumped from the drain through 0.48-cm Teflon tubing into 19-L acid-washed glass collection containers held in ice baths during the water collection to keep the sample cool ($\sim 4^{\circ}C$) during the day. On-site toxicity assessments were conducted with a portion of this composite water sample collected daily from each drain location. Water samples from Lead Lake and

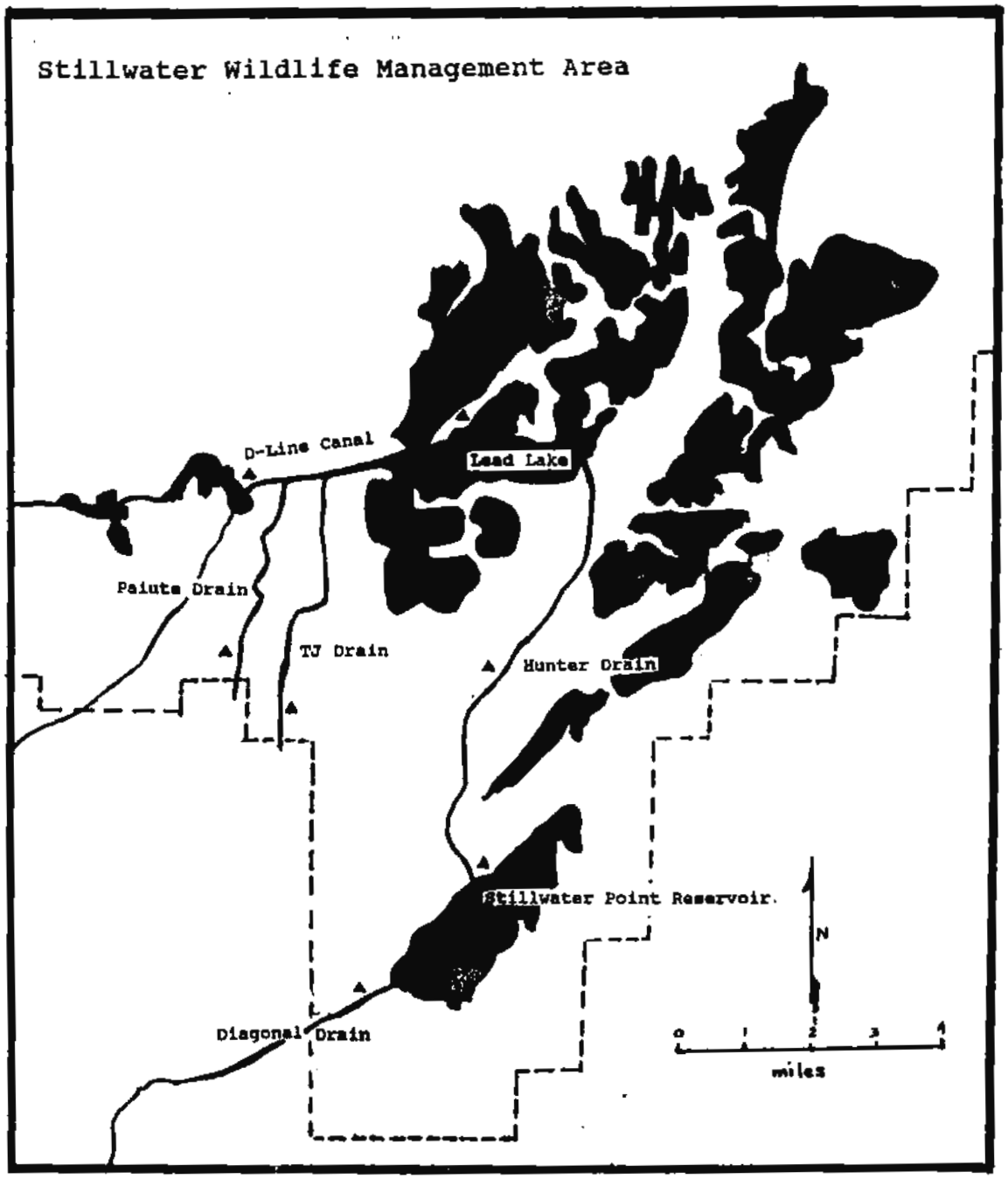

Figure 1. Map of the Stillwater Wildlife Management Area showing approximate locations of sample sites (▲).

Stillwater Point Reservoir were collected daily as grab samples. Temperature, pH, dissolved oxygen, hardness, alkalinity, turbidity, conductivity, salinity, calcium, sulfate, and chloride were measured daily on each water sample (APHA 1985). Ammonia, nitrate, and nitrite were measured on each sample three times during the study.

A subsample of the composite was collected daily for determination of inorganic contaminants present in the test water. These samples were collected in 1-L linear polyethlene bottles that had been previously washed with soap and water, rinsed with tap water, soaked in concentrated nitric acid and twice-rinsed with deionized water. Samples were filtered through a 0.4-µm polycarbonate filter with a positive pressure backflushing filtration system equipped with a peristaltic pump and preserved with 2-mL ultrapure nitric acid for later analysis. Environmental Trace Substances Research Center (Columbia, Missouri) conducted all inorganic chemical analyses. Spiked samples, blanks and replicates prepared on-site were included as quality assurance samples.

A grab sample was collected in 3.6-L amber glass bottles with Teflon-lined caps for analysis for organic contaminants. Samples were collected on August 17, 1988 from each location and immediately refrigerated. Analyses were conducted by the U.S. Geological Survey Laboratory in Arvada, Colorado.

Toxicity Assessments

Toxicity evaluations were conducted with a portion of the daily water sample from each location. Tests were conducted with bluegill (*Lepomis macrochirus*), larval fathead minnows (*Pimephales promelas*), and daphnids (*Daphnia magna*) at all locations. Daphnids and fathead minnow larvae were obtained from cultures at the National Fisheries Contaminant Research Center (NFCRC) and were maintained on-site in well water (hardness 283 mg/L as $CaCO_3$ alkalinity 255 mg/L as $CaCO_3$, pH 7.8) transported from NFCRC. Bluegill (~0.1 g) were obtained from the Missouri Department of Conservation, shipped to Stillwater Refuge, and then transferred into well water for 48h of observation prior to exposure. In Hunter Drain where salinities exceeded 15‰, additional tests were conducted with salt-tolerant species, sheephead minnow larvae (*Cyprinodon variegatus*) and mysids (*Mysidopsis bahia*). These organisms were obtained from the Environmental Protection Agency Laboratory in Gulf Breeze, Florida. Tests were conducted as static renewals under appropriate test conditions (EPA 1985, ASTM 1988) with test length extended to 10 days. Acceptability of a test required that control mortality not exceed 10%. All organisms were fed freshly hatched brine shrimp (*Artemia*) nauplii twice daily. Tests with daphnids and fathead minnows

included 2 replicates per treatment and 10 organisms per replicate. Tests with bluegill were initiated with 2 replicates per treatment and 5 organisms per replicate. Treatments included full-strength drainwater and serial dilutions of 50, 25, and 12.5 % drainwater. Dilution water for each test was reconstituted to the appropriate hardness, alkalinity, conductivity, and pH for that test location by the addition of major cations and anions to deionized water. Reconstitution of the dilution water to the same ion content as the drainwater maintained consistent concentrations of constituents such as calcium, magnesium, sodium, potassium, chloride, and sulfate across all treatments for each location. This reconstituted water was also used as a control. All locations were evaluated using the reconstituted dilution water and reconstituted control. In addition, locations such as Pauite Drain, TJ Drain, and Diagonal Drain where relevant receiving water existed were assessed by using this receiving water both as the dilution water and a control. Well water transported from NFCRC provided a second control (or reference water) to evaluate the condition of test organisms throughout the exposure. In addition, the toxicity of one sample of groundwater from the vicinity of TJ Drain (USGS well# DH-102B) was also evaluated in a set of 96 h static (non-renewal) acute toxicity tests conducted with the three freshwater species.

In summary, evaluation of potential toxicity problems in the Stillwater area included a total of 35 tests that were conducted concurrently:

1) Paiute Drain diluted with reconstituted water - 3 tests
2) Paiute Drain diluted with D-Line Canal - 3 tests

3) TJ Drain diluted with reconstituted water - 3 tests
4) TJ Drain diluted with D-Line Canal - 3 tests

5) Diagonal Drain diluted with reconstituted water - 3 tests
6) Diagonal Drain diluted with Stillwater Point - 3 tests

7) Stillwater Point diluted with reconstituted water - 3 tests

8) Lead Lake diluted with reconstituted water - 3 tests

9) Hunter Drain diluted with reconstituted water - 5 tests

10) D-Line Canal - 3 tests

11) TJ Drain Groundwater - 3 tests

During the study, mortality was recorded daily for each species. Bluegill were weighed and measured at the initiation and termination of the test for assessment of growth. A subsample of daphnids was preserved on the first day of the test and the surviving adults were also preserved on the final day of the test for later examination. Time to first brood production, total number of broods, and number of young per brood were recorded as measures of reproductive success for daphnids. The pH, dissolved oxygen, and temperature were measured daily in each beaker prior to renewal of test solutions.

Chemical Analyses

Filtered water 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). A separate digestate was analyzed for additional elements with a Jarrel-Ash 1100 inductively coupled plasma (ICP) spectrophotometer. Samples for mercury determinations were processed with a nitric reflux digestion and then analyzed by cold vapor AA.

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 1).

Water samples for organic contaminant analysis were extracted three times at both acidic and basic pHs with methylene chloride. The extracts were concentrated to about 1 mL, combined with an internal standard and analyzed on a Hewlett Packard 5996 gas chromatography-electron impact mass spectrometer. Surrogate compounds were added to each sample prior to extraction to verify method recoveries.

Table 1. Detection limits (mg/L) for inorganic contaminants.

Element	Concentration	Element	Concentration
Ag	0.02	Mg	0.002
Al	0.03	Mn	0.005
As	0.0005	Mo	0.02
B	0.02	Na	0.02
Ba	0.001	Ni	0.10
Be	0.001	P	0.10
Bi	0.06	Pb	0.04
Ca	0.002	Sb	0.04
Cd	0.002	Se	0.0003
Co	0.01	Si	0.01
Cr	0.01	Sn	0.01
Cu	0.002	Sr	0.004
Fe	0.005	Ti	0.004
Hg	0.0003	Tl	0.003
K	1.000	V	0.002
W	0.002	Zn	0.002
Li	0.0005		

RESULTS

Paiute Drain and D-Line Canal

Paiute Drain merges with D-Line Canal before entering Lead Lake. Toxicity tests for Paiute Drain were conducted with 1) drainwater diluted with reconstituted water and 2) drainwater diluted with receiving water from the D-Line Canal. Bluegill, fathead minnow larvae, and daphnids were tested.

Water from Paiute Drain exhibited no evidence of acute toxicity. No appreciable mortality occurred in any tests with water from this drain (Table 2). Conductivities were low compared to other sample locations and daily water quality measurements during the 10-d study did not document any dramatic fluctuations in the salinity, conductivity, hardness, or pH of the drainwater (Table 3). Turbidity was higher in Paiute Drain than in its receiving water (D-Line Canal), but other water chemistry variables measured in both locations were similar. No appreciable mortality occurred in tests where Paiute Drain was diluted with water from D-Line Canal and no mortality was recorded for any species exposed to 100% D-Line Canal water (Table 2).

No sublethal responses to drainwater exposure were identified in organisms exposed to water from Paiute Drain or D-Line Canal. Growth of bluegills did not significantly

Table 2. Cumulative mortality (percent) of bluegill (N=10), fathead minnow larvae (N=20), and daphnids (N=20) after 10 days of exposure to water from Paiute Drain diluted with reconstituted water (I) and water from D-Line Canal (II).

I. Reconstituted Water

Species	% Drainwater				Controls	
	100	50	25	12.5	Recon	Well
Bluegill	0	0	10	0	10	0
Fathead Minnows	0	0	0	0	0	0
Daphnids	0	0	10	0	5	0

II. D-Line Canal

Species	% Drainwater				Controls	
	100	50	25	12.5	D-Line	Well
Bluegill	0	10	10	0	0	0
Fathead Minnows	0	0	0	0	0	0
Daphnids	0	10	0	0	0	0

Table 3. Water chemistry measurements on daily composite samples collected from Paiute Drain and D-Line Canal from August 10 - 18, 1988.

	Hardness (mg/L)	Alkalinity (mg/L)	DO (mg/L)	Field pH	Sal (ppth)	Conductivity (umhos/cm)
Paiute						
Day 1	122	142	6.8	7.50	0.2	420
Day 2	111	111	8.9	8.41	0.2	370
Day 3	131	146	7.7	8.28	0.3	480
Day 4	123	133	7.3	8.03	0.2	390
Day 5	134	138	9.7	8.26	0.1	400
Day 6	142	145	8.9	8.45	0.1	400
Day 7	134	158	8.8	8.53	0.1	400
Day 8	129	135	9.0	8.58	0.1	383
Day 9	134	157	8.7	8.58	0.2	430
D-Line Canal						
Day 1	94	149	9.2	8.57	0.5	600
Day 2	102	156	10.0	9.32	0.4	490
Day 3	110	165	9.5	9.21	0.5	610
Day 4	100	155	9.2	9.17	0.0	400
Day 5	123	157	10.3	9.16	0.2	425
Day 6	110	135	9.8	9.02	0.1	380
Day 7	98	125	10.0	9.05	0.0	350
Day 8	126	174	9.0	8.68	0.0	445
Day 9	107	113	9.9	9.38	0.1	470

	Lab pH	Turbidity (NTUs)	Sulfate (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)
Paiute Drain						
Day 1	8.20	31	85	63		
Day 2	8.18	35	68	58		
Day 3	8.36	33	64	50	0.16	<0.01
Day 4	8.31	32	60	55		
Day 5	8.07	16	72	60	0.06	<0.01
Day 6	8.41	15	72	60		
Day 7	8.51	25	52	65		
Day 8	8.57	20	52	70	0.04	<0.01
Day 9	8.59	18	60	65		
D-Line Canal						
Day 1	8.68	4	110	50		
Day 2	8.97	5	106	12		
Day 3	9.02	4	60	50	0.10	<0.01
Day 4	8.98	3	56	43		
Day 5	8.89	4	130	47	0.04	0.01
Day 6	8.07	3	68	40		
Day 7	9.07	6	47	36		
Day 8	8.65	9	104	45	0.05	0.01
Day 9	9.32	9	48	45		

differ among treatments. In addition, daphnids produced equal numbers of young in all treatments with one brood produced in every treatment on day 8. For all treatments, mean number of young per brood ranged from 8.13 to 9.35 individuals. Microscopic examination of adults at the end of the study revealed production of eggs for a second brood and substantiated continued reproductive development that would be expected in healthy organisms.

Concentrations of contaminants in water from Paiute Drain (Table 4) and D-Line Canal (Table 5) were similar and did not approach acutely toxic levels. Daily fluctuations in levels of contaminants was minimal. Neither mercury nor selenium were detected in any sample. Elements including silver, aluminum, beryllium, bismuth, cobalt, chromium, copper, iron, tungsten, nickel, antimony, tin, titanium, and thallium did not exceed detection limits during our study.

Table 4. Concentration (mg/L) of inorganic contaminants detected in composite water samples collected from Paiute Drain.

Date	Arsenic	Boron	Barium	Calcium	Potassium
08/10/88	0.01	0.58	0.08	33.20	3.80
08/11/88	0.02	0.52	0.08	31.20	2.80
08/12/88	0.02	0.76	0.08	35.30	3.90
08/13/88	0.02	0.58	0.08	33.30	4.90
08/14/88	0.02	0.60	0.09	34.60	5.40
08/15/88	0.02	0.63	0.08	36.10	5.30
08/16/88	0.02	0.60	0.07	34.60	4.40
08/17/88	0.02	0.55	0.07	34.50	4.70
08/18/88	0.02	0.61	0.08	36.00	3.90

Date	Lithium	Silica	Magnesium	Molybdenum	Sodium
08/10/88	0.06	5.82	10.90	0.02	72.3
08/11/88	0.05	6.29	10.20	0.01	61.9
08/12/88	0.06	7.01	11.70	0.02	83.8
08/13/88	0.06	6.72	10.50	0.01	67.7
08/14/88	0.06	6.59	11.60	0.02	74.9
08/15/88	0.06	6.93	12.20	0.02	78.5
08/16/88	0.06	6.79	11.00	0.01	72.0
08/17/88	0.06	7.20	13.20	0.01	82.0
08/18/88	0.06	6.64	11.30	0.02	73.1

Date	Phosphorus	Strontium	Vanadium	Zinc
08/10/88	0.10	0.37	0.01	0.07
08/11/88	0.09	0.35	0.01	0.03
08/12/88	0.10	0.40	0.01	0.03
08/13/88	0.10	0.37	0.01	0.05
08/14/88	0.10	0.40	0.01	0.04
08/15/88	0.10	0.41	0.01	0.05
08/16/88	0.10	0.38	0.01	0.03
08/17/88	0.20	0.41	0.01	0.02
08/18/88	0.09	0.40	0.01	0.03

Table 5. Concentrations (mg/L) of inorganic contaminants detected in composite water samples from D-Line Canal.

Date	Arsenic	Boron	Barium	Calcium	Potassium
08/10/88	0.05	0.76	0.06	30.40	9.40
08/11/88	0.05	0.78	0.05	25.60	8.60
08/12/88	0.05	0.74	0.05	28.30	8.30
08/13/88	0.05	0.79	0.04	26.10	8.20
08/14/88	0.04	0.81	0.04	28.90	8.40
08/15/88	0.04	0.70	0.05	28.00	6.30
08/16/88	0.04	0.77	0.05	27.40	6.20
08/17/88	0.05	0.75	0.05	32.00	5.40
08/18/88	0.04	0.62	0.05	29.70	6.50

Date	Lithium	Silica	Magnesium	Molybdenum	Sodium
08/10/88	0.06	6.92	11.20	0.02	107.0
08/11/88	0.06	6.95	10.70	0.02	106.0
08/12/88	0.06	6.59	10.90	0.02	101.0
08/13/88	0.06	5.94	10.50	0.02	96.6
08/14/88	0.06	5.90	11.10	0.02	114.0
08/15/88	0.05	6.00	10.40	0.02	84.4
08/16/88	0.05	7.24	10.20	0.02	87.2
08/17/88	0.05	7.30	10.20	0.02	95.5
08/18/88	0.05	7.59	9.38	0.01	83.4

Date	Phosphorus	Strontium	Vanadium	Zinc
08/10/88	<0.10	0.37	0.02	0.03
08/11/88	<0.10	0.34	0.02	0.01
08/12/88	<0.10	0.36	0.02	0.01
08/13/88	<0.10	0.34	0.02	0.01
08/14/88	<0.10	0.37	0.02	0.01
08/15/88	<0.10	0.34	0.01	0.01
08/16/88	<0.10	0.34	0.01	0.01
08/17/88	<0.10	0.36	0.01	0.04
08/18/88	<0.10	0.34	0.02	0.02

TJ Drain

TJ Drain flows into D-Line Canal and is then discharged into Lead Lake. Salinities were not high enough to conduct toxicity tests with saltwater species, but were generally within the accepted range of tolerance for bluegill, fathead minnow larvae, and daphnids. Toxicity tests for TJ Drain were conducted with 1) drainwater diluted with reconstituted water and 2) drainwater diluted with receiving water from the D-Line Canal.

Water from TJ Drain was acutely toxic to bluegill, fathead minnow larvae, and daphnids (Tables 6 and 7). Appreciable mortality of bluegill occurred in all dilutions of water from TJ Drain with 90% mortality occurring in full-strength drainwater after 7 days of exposure. No mortality was observed in any well water controls, reconstituted water controls or exposures with 100% D-Line Canal water. Although salinities remained constant across all treatments (including controls) in tests where TJ Drain water was diluted with reconstituted water, a dose response pattern was evident for all species (Table 6). A similar pattern occurred in tests where TJ Drain was diluted with water from D-Line Canal (Table 7). Although salinity was undoubtedly stressful to test organisms, cumulative mortality in treatments where salinities were constant was similar to mortality in treatments in which salinity was diluted with water from D-Line Canal for all species. This

Table 6. Cumulative mortality (percent) of bluegill (N=10), fathead minnow larvae (N=20), and Daphnia magna (N=20) exposed to ater from TJ Drain. The dilution water, reconstituted to a balance of salts found in the drainwater, was used as the "recon" control. Well water from the National Fisheries Contaminant Research Center was also used as a control. All treatments had similar hardness, alkalinity, pH, sulfate, chloride, conductivity and salinity. Oxygen levels exceeded 40% saturation.

	% Drainwater				Control	
	100%	50%	25%	12.5%	recon	well
Bluegill						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	20	20	0	0	0	0
Day 4	40	30	10	0	0	0
Day 5	50	30	10	0	0	0
Day 6	70	30	10	10	0	0
Day 7	90	50	30	10	0	0
Day 8	90	50	30	10	0	0
Day 9	90	70	30	20	0	0
Fathead minnow						
Day 1	20	0	0	0	0	0
Day 2	20	0	0	0	0	0
Day 3	20	10	0	0	0	0
Day 4	20	20	10	0	0	0
Day 5	45	20	10	0	0	0
Day 6	45	30	20	10	0	0
Day 7	60	30	20	10	0	0
Day 8	60	40	20	10	0	0
Day 9	85	45	20	10	0	0
Daphnia magna						
Day 1	10	0	0	0	0	0
Day 2	25	0	0	0	0	0
Day 3	25	20	0	0	0	0
Day 4	60	30	10	0	0	0
Day 5	95	30	15	0	0	0
Day 6	100	40	20	10	0	0
Day 7		75	25	10	0	0
Day 8		80	25	10	0	0
Day 9		100	25	10	0	0

Table 7. Cumulative mortality (percent) of bluegill (N=10), fathead minnow larvae (N=20), and *Daphnia magna* (N=20) exposed to water from TJ Drain diluted with receiving water from D-Line Canal. Well water from the National Fisheries Contaminant Research Center was also used as a control. Oxygen levels exceeded 40% saturation.

	% Drainwater				D-Line	Well
	100%	50%	25%	12.5%	Canal	Water
Bluegill						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	20	20	0	0	0	0
Day 4	40	30	10	0	0	0
Day 5	50	30	10	0	0	0
Day 6	70	30	10	10	0	0
Day 7	90	50	30	10	0	0
Day 8	90	50	30	10	0	0
Day 9	90	60	30	20	0	0
Fathead minnow						
Day 1	0	0	0	0	0	0
Day 2	10	0	0	0	0	0
Day 3	25	10	0	0	0	0
Day 4	40	15	0	0	0	0
Day 5	60	20	5	0	0	0
Day 6	75	40	10	10	0	0
Day 7	80	40	10	10	0	0
Day 8	80	40	10	10	0	0
Day 9	85	40	10	10	0	0
Daphnia magna						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	35	20	0	0	0	0
Day 4	60	45	10	0	0	0
Day 5	100	50	15	0	0	0
Day 6		70	30	10	0	0
Day 7		70	30	10	0	0
Day 8		100	30	10	0	0
Day 9			30	10	0	0

strongly suggests that mortalities did not result from exposure to salinity alone.

Levels of mortality similar to those observed in bluegill were also recorded for fathead minnow (Table 6 and 7). Significant mortality occurred in treatments of 100% and 50% drainwater diluted with reconstituted water and diluted with D-Line Canal. No appreciable mortality occurred in dilutions of 12.5% or controls for either test.

Daphnids were more sensitive than were fish species to the two highest drainwater exposures (Table 6 and 7). Complete mortality occurred in treatments of 100% and 50% drainwater regardless of dilution water. No effects on mortality were observed in the 12.5% dilution, however, no reproduction occurred in this exposure regardless of dilution water. Control organisms in reconstituted water reproduced on day 8 with a mean brood size of 9.55 individuals; a first brood (9.28 young) was also produced in 100% D-Line Canal water on day 8.

Water quality of samples from TJ Drain was more variable than was water from D-Line Canal or Paiute Drain (Table 8). Salinities ranged from 4.1 to 13.0‰ during the 10-day exposure. The maximum level of conductivity measured during our study was 14,900 umhos/cm, however, levels up to 41,000 uS/cm have been reported by US Geological Survey (Hoffman et al. 1988).

Levels of contaminants also fluctuated throughout the 10-d exposure (Table 9), however, concentrations of arsenic,

Table 8. Water chemistry measurements on daily composite samples collected from TJ Drain and D-Line Canal from August 10 - 18, 1988.

	Hardness (mg/L)	Alkalinity (mg/L)	DO (mg/L)	Field pH	Sal (ppth)	Conductivity (umhos/cm)
TJ Drain						
Day 1	1261	232	7.4	8.52	6.5	8100
Day 2	1860	289	8.4	8.54	10.0	12000
Day 3	1950	263	8.7	8.58	10.1	11800
Day 4	2512	319	8.7	8.53	13.0	14900
Day 5	1800	276	9.2	8.60	9.2	11000
Day 6	1091	224	8.3	8.40	5.0	6100
Day 7	1267	217	8.9	8.40	4.1	7200
Day 8	1947	292	8.7	8.46	8.9	13700
Day 9	1738	244	10.9	8.60	9.2	14300
D-Line Canal						
Day 1	94	149	9.2	8.57	0.5	600
Day 2	102	156	10.0	9.32	0.4	490
Day 3	110	165	9.5	9.21	0.5	610
Day 4	100	155	9.2	9.17	0.0	400
Day 5	123	157	10.3	9.16	0.2	425
Day 6	110	135	9.8	9.02	0.1	380
Day 7	98	125	10.0	9.05	0.0	350
Day 8	126	174	9.0	8.68	0.0	445
Day 9	107	113	9.9	9.38	0.1	470

	Lab pH	Turbidity (NTUs)	Sulfate (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)
TJ Drain						
Day 1	8.46	2	1384	2700		
Day 2	8.99	3	2944	4800		
Day 3	8.46	2	2881	4875	0.11	<0.01
Day 4	8.32	3	3600	6250		
Day 5	8.43	2	1602	4700	0.02	<0.01
Day 6	8.09	4	884	3750		
Day 7	8.31	4	1480	5775		
Day 8	8.41	3	1599	4938	0.16	<0.01
Day 9	8.36	8	1599	4800		
D-Line Canal						
Day 1	8.68	4	110	50		
Day 2	8.97	5	106	12		
Day 3	9.02	4	60	50	0.10	<0.01
Day 4	8.98	3	56	43		
Day 5	8.89	4	130	47	0.04	0.01
Day 6	8.07	3	68	40		
Day 7	9.07	6	47	36		
Day 8	8.65	9	104	45		
Day 9	9.32	9	48	45	0.05	0.01

Table 9. Concentration (mg/L) of inorganic contaminants detected in composite water samples collected from TJ Drain.

Date	Arsenic	Boron	Barium	Calcium	Potassium
08/10/88	0.11	7.80	0.08	175.00	29.00
08/11/88	0.13	12.70	0.11	257.00	42.00
08/12/88	0.12	11.90	0.11	236.00	40.00
08/13/88	0.17	16.70	0.10	309.00	57.00
08/14/88	0.15	11.90	0.07	227.00	43.00
08/15/88	0.13	6.80	0.05	139.00	29.00
08/16/88	0.11	6.75	0.05	162.00	29.00
08/17/88	0.14	14.10	0.11	286.00	50.00
08/18/88	0.12	10.40	0.08	208.00	39.00

Date	Lithium	Silica	Magnesium	Molybdenum	Sodium
08/10/88	0.40	2.10	201.00	0.32	2050.0
08/11/88	0.62	0.91	315.00	0.54	3490.0
08/12/88	0.57	2.00	297.00	0.45	3280.0
08/13/88	0.76	0.55	412.00	0.67	4700.0
08/14/88	0.55	0.06	290.00	0.45	3420.0
08/15/88	0.34	3.70	161.00	0.27	1860.0
08/16/88	0.38	2.91	176.00	0.38	1860.0
08/17/88	0.67	0.81	361.00	0.67	4050.0
08/18/88	0.46	3.81	251.00	0.46	2870.0

Date	Phosphorus	Strontium	Vanadium	Zinc
08/10/88	0.70	4.03	0.02	0.05
08/11/88	1.00	6.23	0.02	0.07
08/12/88	0.80	5.81	0.02	0.09
08/13/88	1.00	7.87	0.02	0.01
08/14/88	0.80	5.67	0.02	0.03
08/15/88	0.36	3.24	0.02	0.02
08/16/88	0.38	3.54	0.01	0.02
08/17/88	1.00	7.02	0.02	0.02
08/18/88	0.80	4.89	0.02	0.02

boron, lithium, and molybdenum were consistently higher in TJ Drain than levels measured in Paiute Drain (Table 4) or D-Line Canal (Table 5) where no mortality was observed. Levels of arsenic consistently exceeded 100 µg/L and boron concentrations reached a maximum level of 16,700 µg/L during our study. Concentrations of dissolved selenium ranged from 0.9 to 1.6 µg/L with the highest concentration occurring on day 4 when salinity was highest and the lowest concentration corresponding to the day of lowest measured salinity. No mercury was detected in any sample. Elements including silver, aluminum, beryllium, bismuth, cobalt, chromium, copper, iron, tungsten, nickel, antimony, tin, titanium, and thallium did not exceed detection limits during our 10 d study.

TJ Groundwater

Groundwater from USGS well # DH-102B was the most toxic water sample tested during our study. The test was conducted as a static non-renewal with one grab sample collected by USGS personnel. Salinity of the groundwater was 7.9‰ with a conductivity of 12,000 µmhos/cm and was tested with bluegill, larval fathead minnows, and daphnids. All organisms exposed to 100%, 50%, 25%, and 12.5% groundwater died within 24 h of exposure. No mortality occurred in any controls. The ionic composition and water quality of TJ groundwater was different from that of water from the drain (Table 10). The groundwater was harder, with

Table 10. Concentrations (mg/L) of inorganic elements in groundwater collected from USGS well #DH-102B in the vicinity of TJ Drain on August 17, 1988.

Element	Concentration	Element	Concentration
Ag	<0.02	Mg	268.00
Al	<0.03	Mn	1.44
As	0.56	Mo	1.15
B	24.40	Na	2390.00
Ba	0.048	Ni	<0.10
Be	<0.001	P	0.80
Bi	<0.06	Pb	<0.04
Ca	544.00	Sb	<0.04
Cd	<0.002	Se	<0.0003
Co	<0.01	Si	36.10
Cr	<0.01	Sn	<0.01
Cu	<0.002	Sr	13.30
Fe	<0.005	Ti	<0.02
Hg	<0.0003	Tl	<0.003
K	87.00	V	<0.002
W	<0.002	Zn	0.057
Li	1.64		

calcium levels about two-fold higher than concentrations in the drainwater and better buffered (higher alkalinity) than was the drainwater. In addition, groundwater pH (6.97) was a unit lower than that of the drainwater (8.03 - 8.77).

Concentrations of arsenic in the groundwater (Table 10) were higher than in any drainwater sample tested. Levels of boron, lithium, and molybdenum were higher than those measured in TJ Drain, but similar to levels measured in water from Hunter Drain. No selenium or mercury were detected in the groundwater sample. Survival of freshwater control organisms in reconstituted water of 7.9‰ indicates that the observed mortality was likely induced by the presence of contaminants in the groundwater.

Lead Lake

Lead Lake receives water from D-Line Canal, TJ Drain, and Paiute Drain. Water samples were collected as grab samples from the vicinity of the South Lead Lake Landing. The water quality of Lead Lake remained relatively constant during the study with no appreciable daily fluctuations in hardness, pH, or conductivity (Table 11) and levels of oxygen were adequate for survival of aquatic life. Salinities (3.1 - 4.2‰) were within the range tolerated by bluegill, fathead minnow larvae, and daphnids. Tests were conducted with water from Lead Lake diluted with reconstituted water.

Water from Lead Lake was moderately toxic to all species tested with most mortality occurring after 96 h of exposure (Table 12). Survival of bluegill was reduced in treatments with 50% Lead Lake water, however no effects on growth were observed in any treatment. Mortality of fathead minnow larvae was similar to that of bluegills with the lowest level of effect occurring in the 50% dilution. Daphnids were more sensitive to the toxic components of the water than were the fish with mortality occurring in the 25% dilution of Lead Lake water. No mortality occurred in the 12.5% dilution or the controls for any species. Survival of organisms in the reconstituted control water where salinity was similar to that found in other treatments suggests that salinity alone did not account for the observed mortality.

Table 11. Water chemistry measurements on daily grab samples collected from Lead Lake from August 10 - 18, 1988.

Date	Hardness (mg/L)	Alkalinity (mg/L)	DO (mg/L)	Field pH	Sal (ppth)	Conductivity (umhos/cm)
Day 1	585	227	9.2	8.86	3.5	6100
Day 2	566	272	7.2	8.84	3.5	6000
Day 3	629	257	6.8	8.85	3.8	5900
Day 4	585	266	5.6	8.77	3.2	5300
Day 5	600	256	7.1	8.57	3.5	5600
Day 6	597	249	5.7	8.86	4.2	5100
Day 7	606	258	6.9	8.88	3.1	5300
Day 8	635	258	8.5	8.93	3.5	5900
Day 9	676	227	8.6	8.85	3.3	5300

Day	Lab pH	Turbidity (NTUs)	Sulfate (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)
Day 1	8.86	62	428	1300		
Day 2	9.23	96	596	1400		
Day 3	8.87	59	680	1187	0.14	<0.01
Day 4	8.84	63	401	1700		
Day 5	8.83	53	520	1425	0.14	0.01
Day 6	8.81	37	472	1275		
Day 7	8.89	53	364	1775		
Day 8	8.97	50	408	1787	0.24	0.05
Day 9	8.93	43	560	1775		

Table 12. Cumulative mortality (percent) of bluegill (N=10), fathead minnow larvae (N=20), and *Daphnia magna* (N=20) exposed to water from Lead Lake. The dilution water, reconstituted to a balance of salts found in the lake water, was used as the "recon" control. Well water from the National Fisheries Contaminant Research Center was also used as a control. All treatments had similar hardness, alkalinity, pH, sulfate, chloride, conductivity and salinity. Oxygen levels exceeded 40% saturation.

	% Lead Lake				Control	
	100%	50%	25%	12.5%	recon	well
Bluegill						
Day 1	0	0	0	0	0	0
Day 2	20	0	0	0	0	0
Day 3	20	0	0	0	0	0
Day 4	30	0	0	0	0	0
Day 5	30	20	0	0	0	0
Day 6	30	20	10	0	0	0
Day 7	40	20	10	0	0	0
Day 8	40	30	10	0	0	0
Day 9	60	30	10	0	0	0
Fathead minnow						
Day 1	0	0	0	0	0	0
Day 2	20	0	0	0	0	0
Day 3	20	5	5	0	0	0
Day 4	25	5	5	0	0	0
Day 5	25	5	10	0	0	0
Day 6	30	15	10	0	0	0
Day 7	40	20	10	0	0	0
Day 8	60	25	15	0	0	0
Day 9	60	30	15	0	0	0
Daphnia magna						
Day 1	0	0	0	0	0	0
Day 2	20	0	0	0	0	0
Day 3	20	5	5	0	0	0
Day 4	25	5	5	0	0	0
Day 5	30	15	10	0	0	0
Day 6	30	15	10	0	0	0
Day 7	45	30	15	0	0	0
Day 8	60	35	20	0	0	0
Day 9	80	45	20	0	0	0

Reproduction of D. magna was significantly delayed in all treatments. No young were produced by daphnids in any Lead Lake treatment and there was no evidence of production of a first brood in any individuals examined at the termination of the exposure. Production of young occurred in both the reconstituted control and well water control on day 9. Mean number of young per brood for these controls was 8.88 and 9.23, respectively.

Levels of contaminants did not fluctuate markedly throughout the 10-d exposure (Table 13). Concentrations of arsenic, boron, lithium, and molybdenum were consistently higher in Lead Lake than levels measured in Paiute Drain (Table 4) or D-Line Canal (Table 5) where no mortality was observed. The presence of these four contaminants as well as the level of conductivity (and elements associated with water hardness) in Lead Lake appear to be strongly influenced by input from TJ Drain. Although concentrations of salts in the waters of Lead Lake may be naturally increased by evaporative loss, the addition of water from TJ Drain does not enhance the water quality of Lead Lake.

Table 13. Concentrations (mg/L) of inorganic contaminants detected in grab water samples collected from Lead Lake.

Date	Arsenic	Boron	Barium	Calcium	Potassium
08/10/88	0.12	5.97	0.14	67.10	32.00
08/11/88	0.12	5.35	0.13	68.80	32.00
08/12/88	0.13	5.60	0.13	70.70	33.00
08/13/88	0.11	5.17	0.12	65.20	31.00
08/14/88	0.11	5.47	0.13	68.00	33.00
08/15/88	0.10	4.99	0.12	63.50	30.00
08/16/88	0.11	5.33	0.13	66.90	31.00
08/17/88	0.11	5.73	0.13	67.50	33.00
08/18/88	0.10	5.43	0.11	74.30	29.00

Date	Lithium	Silica	Magnesium	Molybdenum	Sodium
08/10/88	0.36	6.89	96.30	0.11	1040.0
08/11/88	0.36	7.51	96.60	0.11	1040.0
08/12/88	0.37	6.87	100.00	0.12	1080.0
08/13/88	0.34	6.85	91.90	0.11	995.0
08/14/88	0.37	6.82	98.50	0.12	1060.0
08/15/88	0.34	6.28	90.30	0.11	976.0
08/16/88	0.36	6.36	95.70	0.11	1030.0
08/17/88	0.39	7.30	103.00	0.12	1120.0
08/18/88	0.34	5.06	103.00	0.13	1140.0

Date	Phosphorus	Strontium	Vanadium	Zinc
08/10/88	0.20	1.86	0.02	0.02
08/11/88	0.20	1.86	0.02	0.04
08/12/88	0.20	1.94	0.02	0.01
08/13/88	0.20	1.78	0.02	0.02
08/14/88	0.20	1.89	0.02	0.02
08/15/88	0.20	1.75	0.02	0.02
08/16/88	0.20	1.85	0.02	0.02
08/17/88	0.37	1.96	0.02	0.04
08/18/88	0.20	2.01	0.02	0.02

Hunter Drain

Hunter Drain was the only drain in which salinities were high enough to allow testing with saltwater species. Therefore, tests with sheephead minnows and mysids were initiated on day 3 when salinities first exceeded 15‰. Tests were conducted with bluegill, fathead minnow larvae, and daphnids for 10 days.

Hunter Drain contained water that was highly toxic to all species tested (Table 14 and 15). Appreciable mortality of all species occurred in all dilutions of water from Hunter Drain. Neither freshwater nor saltwater organisms survived in treatments of 100% and 50% drainwater. In tests with fathead and sheephead minnow larvae, mysids and daphnids, mortality occurred rapidly with 90% mortality of mysids and daphnids occurring within 48 hours of exposure.

Water quality was highly variable in Hunter Drain (Table 16). Salinities ranged from 0‰ to 28‰ during the study. The extremely high salinities (days 3, 4, and 5) were measured under conditions of low flow when there was no visible contribution of irrigation water to the drain. During this three day period, the seepage of groundwater into Hunter Drain was evident along the banks of the drain. The return of irrigation water to the drain on day 6 was apparently responsible for the reduction in salinity and conductivity. Observations during our study suggest that

Table 14. Cumulative mortality (percent) of bluegill (N=10), fathead minnow larvae (N=20), and Daphnia magna (N=20) exposed to water from Hunter Drain. The dilution water, reconstituted to a balance of salts found in the drainwater, was used as the "recon" control. Well water from the National Fisheries Contaminant Research Center was also used as a control. All treatments had similar hardness, alkalinity, pH, sulfate, chloride, conductivity and salinity. Oxygen levels exceeded 40% saturation.

	% Drainwater				Control	
	100%	50%	25%	12.5%	recon	well
Bluegill						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	0	0	0	0	0	0
Day 4	100	10	10	10	10	0
Day 5		60	10	10	20	0
Day 6		80	30	20	20	0
Day 7		80	30	20	20	0
Day 8		100	50	30	20	0
Day 9			60	40	20	0
Fathead minnow						
Day 1	25	10	0	0	0	0
Day 2	40	50	0	0	0	0
Day 3	65	85	0	0	0	0
Day 4	70	90	20	10	0	0
Day 5	100	90	30	10	0	0
Day 6		100	45	25	0	0
Day 7			60	25	0	0
Day 8			60	25	0	0
Day 9			60	40	0	0
Daphnia magna						
Day 1	25	20	0	0	0	0
Day 2	90	50	0	0	0	0
Day 3	100	85	0	0	0	0
Day 4		90	15	10	0	0
Day 5		90	30	10	10	0
Day 6		100	50	25	10	0
Day 7			50	25	10	0
Day 8			60	25	10	0
Day 9			75	50	10	0

Table 15. Cumulative mortality (percent) of mysids (N=20) and sheephead minnow larvae (N=20) exposed to water from Hunter Drain. The dilution water, reconstituted to a balance of salts found in the drainwater, was used as the "recon" control. Well water from the National Fisheries Contaminant Research Center was also used as a control. All treatments had similar hardness, alkalinity, pH, sulfate, chloride, conductivity and salinity. Oxygen levels exceeded 40% saturation.

	% Drainwater				Control	
	100%	50%	25%	12.5%	recon	well
Mysids						
Day 4	70	50	20	20	0	0
Day 5	90	65	35	15	0	0
Day 6	100	90	50	30	0	0
Day 7		100	70	55	5	0
Day 8			100	60	5	0
Day 9				60	10	0
Sheephead minnow						
Day 4	60	45	25	20	0	0
Day 5	90	65	40	35	0	0
Day 6	100	75	55	40	0	0
Day 7		100	80	50	0	0
Day 8			100	55	0	0
Day 9				55	0	0

Table 16. Water chemistry measurements on daily composite samples collected from Hunter Drain from August 10 - 18, 1988.

Date	Hardness (mg/L)	Alkalinity (mg/L)	DO (mg/L)	Field pH	Sal (ppth)	Conductivity (umhos/cm)
Day 1	863	223	7.0	8.32	9.5	12000
Day 2	1082	250	6.2	8.44	12.0	13900
Day 3	2330	242	7.4	8.52	28.0	27500
Day 4	1842	255	6.3	8.77	18.0	22000
Day 5	196	276	5.6	8.74	23.0	25000
Day 6	664	179	7.5	8.68	7.0	8000
Day 7	106	255	8.2	8.03	0.0	410
Day 8	144	124	8.4	8.28	1.0	600
Day 9	166	102	8.8	8.16	1.0	1200

Day	Lab pH	Turbidity (NTUs)	Sulfate (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)
Day 1	8.23	14	1216	4150		
Day 2	8.87	7	1272	6950		
Day 3	8.44	37	2001	11125	0.30	<0.01
Day 4	8.67	13	2923	10000		
Day 5	8.51	8	2885	12550	0.10	0.04
Day 6	8.60	14	1207	3700		
Day 7	8.00	19	52	84		
Day 8	8.15	14	130	194	0.15	0.05
Day 9	8.29	10	196	305		

groundwater in the area of Hunter Drain merits further toxicological investigation.

Complete mortality of bluegill occurred on day 4 (Table 14) after 24 h of exposure to Hunter Drain water when salinity was 28‰; this salinity was over twice as high as the measured salinity on the previous day (Table 16). Only 10% mortality occurred on day 4 in other treatments exposed to this same level of salinity, however, the cumulative mortality of 20% in controls observed on day 5 is likely related to the elevated salinity of the water during this 3 day period. Survival, even for one day, of any bluegill at salinities of 28‰ was unexpected based on accepted salt tolerances for that species. The ionic content of water in Hunter Drain as well as other Stillwater locations was not representative of the ion balance found in seawater which is typically used to estimate saltwater tolerances of freshwater organisms. It appears that freshwater organisms such as bluegill, fathead minnows, and daphnids were more tolerant of these salt balances (as illustrated by their survival in our reconstituted control water) than of similar salinities of seawater. However, it is likely that continued exposure to these elevated salinities would have significantly reduced control survival.

Significant mortality of fathead minnow larvae and daphnids in the two highest treatments occurred prior to the dramatic change in salinity (Tables 14). Mortality of these two species in the 25 and 12.5% dilutions did not begin

until day 4, and indicates that elevated salinity in the presence of contaminants may have contributed to the observed mortality. Although control organisms exposed to these dramatic fluctuations in salinity survived during the 10 days of our study, such severe changes in water quality would likely not be tolerated by any species over a more extended period of exposure.

Tests conducted with saltwater species were intiated with the composite water sample collected on August 12, 1988 (Day 3) when salinity first exceeded 15‰. Complete mortality of both species occurred in the two highest treatments within 96 h of exposure (Table 15). The saltwater organisms were exposed under conditions of static renewal during the first 72 h, however, because salinity of the drainwater decreased to 7‰ (below the tolerance of both species) on August 15, testing was continued without renewal for the remainder of the 7 day exposure. Oxygen concentrations exceeded 6.4 mg/L during the non-renewal phase of this study and pH stabilized between 8.40 - 8.45. Appreciable mortality occurred in all treatments; no mortality occurred in the controls.

Higher levels of contaminants corresponded with the higher levels of salinity (Table 17). During days with elevated salinity, concentrations of arsenic were similar to those measured in TJ Drain; levels of boron, lithium, and molybdenum in Hunter Drain were higher than at any other location. Concentrations of selenium ranged from below detection limits to 3.6 ug/L and were highest during periods

Table 17. Concentrations (mg/L) of inorganic contaminants detected in composite water samples from Hunter Drain.

Date	Arsenic	Boron	Barium	Calcium	Potassium
08/10/88	0.06	20.30	0.10	190.00	89.00
08/11/88	0.07	24.90	0.09	221.00	110.00
08/12/88	0.11	43.10	0.10	352.00	180.00
08/13/88	0.17	46.20	0.09	378.00	200.00
08/14/88	0.19	48.90	0.09	390.00	210.00
08/15/88	0.06	18.20	0.07	164.00	76.00
08/16/88	0.02	0.81	0.08	32.00	4.80
08/17/88	0.02	1.30	0.05	34.90	4.90
08/18/88	0.03	1.21	0.05	38.00	4.00

Date	Lithium	Silica	Magnesium	Molybdenum	Sodium
08/10/88	1.01	4.96	103.00	0.46	3640.0
08/11/88	1.21	13.30	128.00	0.59	4470.0
08/12/88	2.04	13.80	227.00	1.10	7620.0
08/13/88	2.22	13.15	244.00	1.20	8210.0
08/14/88	2.32	13.70	254.00	1.30	8640.0
08/15/88	0.86	9.03	101.00	0.47	3240.0
08/16/88	0.06	7.58	10.20	0.02	98.4
08/17/88	0.08	6.85	12.80	0.04	182.0
08/18/88	0.08	6.81	15.00	0.06	196.0

Date	Phosphorus	Strontium	Vanadium	Zinc
08/10/88	0.60	4.96	0.02	0.09
08/11/88	0.60	5.97	0.02	0.06
08/12/88	0.60	9.57	0.02	0.01
08/13/88	0.80	10.17	0.03	0.06
08/14/88	0.90	10.40	0.02	0.01
08/15/88	0.60	4.11	0.02	0.08
08/16/88	<0.10	0.39	0.01	0.02
08/17/88	<0.10	0.51	0.01	0.02
08/18/88	<0.10	0.89	0.02	0.02

of highest salinity. No mercury was detected in samples from Hunter Drain. Elements including silver, aluminum, beryllium, bismuth, cobalt, chromium, copper, iron, tungsten, nickel, antimony, tin, titanium, and thallium did not exceed detection limits during our study.

Diagonal Drain
and
Stillwater Point Reservoir

Diagonal Drain enters the southwest portion of the refuge and discharges into Stillwater Point Reservoir. Salinities were within the range of tolerance for bluegill, fathead minnows, and daphnids. Toxicity tests were conducted with 1) drainwater diluted with reconstituted water and 2) drainwater diluted with receiving water from Stillwater Point. Tests to evaluate the toxicity of water from Stillwater Point Reservoir were diluted with reconstituted water.

Water from Diagonal Drain was moderately toxic to bluegill and marginally toxic to fathead minnow larvae and daphnids (Tables 18 and 19). Mortality occurred after an extended exposure to drainwater; no mortality of any species occurred during the first 72 h of exposure. Tests organisms were differentially sensitive to water from Diagonal Drain. In all tests with bluegill, survival was reduced in treatments of 100, 50, and 25% drainwater. In the tests where drainwater was diluted with reconstituted water, there was no appreciable mortality in 12.5% drainwater, or in the reconstituted or well water controls. However, in tests diluted with water from Stillwater Point, 20% mortality occurred in the 12.5% dilution as well as in treatments of 100% Stillwater Point water. Cumulative mortality of

Table 18. Cumulative mortality (percent) of bluegill (N=10), fathead minnow larvae (N=20), and *Daphnia magna* (N=20) exposed to water from Diagonal Drain diluted with receiving water from Stillwater Point Reservoir. Well water from the National Fisheries Contaminant Research Center was also used as a control. Oxygen levels exceeded 40% saturation.

	% Drainwater					
	100%	50%	25%	12.5%	Stillwater Point	Well Water
Bluegill						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	0	0	0	0	0	0
Day 4	30	20	10	0	0	0
Day 5	60	20	10	0	0	0
Day 6	60	20	10	0	0	0
Day 7	60	20	10	0	0	0
Day 8	70	30	20	0	10	0
Day 9	80	40	20	0	20	0
Fathead minnow						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	5	0
Day 3	0	0	0	0	10	0
Day 4	10	15	10	0	10	0
Day 5	10	15	15	10	10	0
Day 6	15	20	15	10	15	0
Day 7	20	20	15	10	20	0
Day 8	25	20	15	15	20	0
Day 9	30	25	20	25	25	0
Daphnia magna						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	5	0
Day 3	0	0	0	0	5	0
Day 4	10	20	10	0	10	0
Day 5	10	20	10	0	10	0
Day 6	15	20	10	0	20	0
Day 7	25	20	10	0	20	0
Day 8	25	20	10	0	25	0
Day 9	25	25	20	20	25	0

Table 19. Cumulative mortality (percent) of bluegill (N=10), fathead minnow larvae (N=20), and Daphnia magna (N=20) exposed to water from Diagonal Drain. The dilution water, reconstituted to a balance of salts found in the drainwater, was used as the "recon" control. Well water from the National Fisheries Contaminant Research Center was also used as a control. All treatments had similar hardness, alkalinity, pH, sulfate, chloride, conductivity and salinity. Oxygen levels exceeded 40% saturation.

	% Drainwater				Control	
	100%	50%	25%	12.5%	recon	well
Bluegill						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	0	0	0	0	0	0
Day 4	20	20	10	0	0	0
Day 5	40	30	20	0	0	0
Day 6	40	30	20	10	0	0
Day 7	40	30	20	10	10	0
Day 8	60	30	20	10	10	0
Day 9	80	40	20	10	10	0
Fathead minnow						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	0	0	0	0	0	0
Day 4	5	0	10	0	0	0
Day 5	5	5	10	0	0	0
Day 6	10	10	10	0	0	0
Day 7	10	10	10	0	0	0
Day 8	15	10	10	5	0	0
Day 9	30	10	10	5	0	0
Daphnia magna						
Day 1	0	0	0	0	0	0
Day 2	0	0	0	0	0	0
Day 3	0	0	0	0	0	0
Day 4	0	0	10	0	0	0
Day 5	10	10	10	0	0	0
Day 6	10	10	10	0	0	0
Day 7	15	10	10	0	0	0
Day 8	15	10	10	5	0	0
Day 9	25	10	10	5	0	0

fathead minnow larvae and daphnids exposed to water from Diagonal Drain diluted with water from Stillwater Point was lower than that of bluegill; mortality ranged from 20 to 30% across all treatments with no clear pattern of dose response. Mortality of both species in 100% Stillwater Point water was 25%. In contrast, effects on survival of fathead minnows and daphnids only occurred in 100% drainwater in tests using reconstituted dilution water.

The water quality variables measured in Diagonal Drain and Stillwater Point Reservoir remained consistent during the study. The water was well oxygenated and of relatively low salinity and conductivity (Table 20). Turbidity of Diagonal Drain was similar to that measured in Paiute Drain. Levels of inorganic contaminants were also similar to those measured in D-Line Canal and Paiute Drain with no single contaminant exceeding acutely toxic concentrations (Table 21). Because of the relatively high mortality of bluegill in Diagonal Drain as compared to daphnids and fathead minnows, samples were collected on 17 August from all drain locations for chemical analysis of organic contaminants. No biologically significant concentration of any contaminant was measured in any sample. Consistent levels of phenols (2.58 - 5.41 µg/L) were detected in every sample suggesting incidental contaminantion during sample collection or chemical analysis. Results from these analyses did not suggest an explanation for the mortality observed in Diagonal Drain.

Table 20. Water chemistry measurements on daily composite samples collected from Diagonal Drain and on daily grab samples from Stillwater Point Reservoir from August 10 - 18, 1988.

	Hardness (mg/L)	Alkalinity (mg/L)	DO (mg/L)	Field pH	Sal (ppth)	Conductivity (umhos/cm)
Diagonal Drain						
Day 1	138	234	9.0	8.43	0.5	700
Day 2	202	227	8.5	8.49	0.5	550
Day 3	146	114	8.4	8.33	0.5	620
Day 4	153	312	8.3	8.39	0.8	710
Day 5	152	211	8.9	8.15	0.5	468
Day 6	151	210	8.7	8.32	0.2	520
Day 7	142	210	8.9	8.43	0.2	510
Day 8	155	221	9.6	8.57	0.2	580
Day 9	162	245	8.4	8.54	0.4	720
Stillwater Point						
Day 1	155	261	8.8	9.10	1.7	2510
Day 2	157	263	8.9	8.97	1.2	1950
Day 3	162	289	8.2	9.06	1.3	1710
Day 4	146	298	8.3	9.06	1.5	2270
Day 5	168	300	9.3	9.07	1.2	2000
Day 6	136	292	8.2	9.19	1.9	2210
Day 7	167	291	8.8	9.06	0.9	1590
Day 8	158	292	8.4	9.02	1.1	1720
Day 9	134	235	10.2	9.15	1.2	2020

	Lab pH	Turbidity (NTUs)	Sulfate (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)
Diagonal Drain						
Day 1	8.43	39	130	60		
Day 2	8.26	36	140	63		
Day 3	8.44	35	116	63	0.21	<0.01
Day 4	8.41	32	112	58		
Day 5	8.40	54	112	50	0.50	0.05
Day 6	8.34	25	124	55		
Day 7	8.42	37	140	55		
Day 8	8.36	23	150	43	0.44	0.04
Day 9	8.54	21	142	48		
Stillwater Point						
Day 1	8.91	410	121	300		
Day 2	8.98	580	244	310		
Day 3	9.10	390	153	313	0.15	<0.01
Day 4	9.14	280	177	550		
Day 5	8.97	195	137	375	0.18	0.01
Day 6	9.14	256	188	475		
Day 7	9.11	186	104	475		
Day 8	9.06	237	188	413	0.18	<0.01
Day 9	9.19	168	188	450		

Table 21. Concentrations (mg/L) of inorganic contaminants detected in composite water samples from Diagonal Drain.

Date	Arsenic	Boron	Barium	Calcium	Potassium
08/10/88	0.05	0.99	0.07	48.40	8.80
08/11/88	0.05	1.20	0.07	47.30	8.80
08/12/88	0.04	1.10	0.07	45.10	8.60
08/13/88	0.04	1.80	0.06	51.20	13.00
08/14/88	0.04	0.86	0.07	42.80	8.60
08/15/88	0.04	0.99	0.07	42.50	7.90
08/16/88	0.04	0.88	0.07	43.00	7.70
08/17/88	0.04	0.91	0.07	43.70	7.30
08/18/88	0.05	1.10	0.07	47.30	8.60

Date	Lithium	Silica	Magnesium	Molybdenum	Sodium
08/10/88	0.06	12.80	13.90	0.03	140.0
08/11/88	0.07	13.90	14.00	0.03	147.0
08/12/88	0.06	12.00	13.20	0.03	133.0
08/13/88	0.10	12.15	18.10	0.05	274.0
08/14/88	0.06	11.60	12.50	0.03	119.0
08/15/88	0.06	11.20	12.80	0.03	138.0
08/16/88	0.06	11.80	12.30	0.03	122.0
08/17/88	0.06	12.10	12.60	0.03	125.0
08/18/88	0.07	12.90	14.00	0.04	159.0

Date	Phosphorus	Strontium	Vanadium	Zinc
08/10/88	0.20	0.52	0.02	0.04
08/11/88	0.20	0.51	0.02	0.06
08/12/88	0.30	0.48	0.02	0.05
08/13/88	0.30	0.67	0.02	0.10
08/14/88	0.20	0.46	0.02	0.04
08/15/88	0.20	0.47	0.02	0.06
08/16/88	0.20	0.45	0.02	0.07
08/17/88	0.20	0.46	0.02	0.04
08/18/88	0.20	0.52	0.02	0.04

Mortality that occurred in water from Stillwater Point Reservoir was low, but consistent (20 - 25%). No appreciable mortality of any species occurred in dilutions of Stillwater Point water. Daphnids reproduced equally across all treatments on day 9 with mean number of young per brood ranging from 8.02 to 9.54. The reservoir water was turbid ranging from 186 - 580 NTUs, and may have stressed the test organisms in the 100% treatment. Levels of boron, lithium and molybdenum in the reservoir (Table 22) were similar to those in Diagonal Drain, however, concentrations of arsenic were only slightly lower than those measured in Lead Lake and TJ Drain and may have contributed to the observed mortality. Because arsenic was measured at low concentrations in Diagonal Drain, it may be entering the reservoir through groundwater seepage.

Table 22. Concentrations (mg/L) of inorganic contaminants detected in a grab sample from Stillwater Point Reservoir

Date	Arsenic	Boron	Barium	Calcium	Potassium
08/10/88	0.09	2.25	0.10	35.30	17.00
08/11/88	0.11	3.03	0.11	24.20	21.00
08/12/88	0.08	2.32	0.11	35.10	15.00
08/13/88	0.11	2.87	0.10	25.70	19.00
08/14/88	0.10	2.61	0.10	29.60	18.00
08/15/88	0.11	2.93	0.09	22.50	20.00
08/16/88	0.08	2.00	0.09	36.30	15.00
08/17/88	0.09	2.24	0.09	30.90	15.00
08/18/88	0.10	2.70	0.12	27.60	18.00

Date	Lithium	Silica	Magnesium	Molybdenum	Sodium
08/10/88	0.11	10.80	17.80	0.05	361.0
08/11/88	0.12	11.35	20.20	0.07	484.0
08/12/88	0.10	11.69	16.40	0.05	312.0
08/13/88	0.13	10.34	18.20	0.06	445.0
08/14/88	0.12	10.20	18.10	0.06	407.0
08/15/88	0.13	9.70	18.40	0.07	460.0
08/16/88	0.10	10.44	16.30	0.05	309.0
08/17/88	0.11	11.20	16.80	0.05	345.0
08/18/88	0.13	10.99	21.40	0.06	421.0

Date	Phosphorus	Strontium	Vanadium	Zinc
08/10/88	<0.10	0.57	0.03	0.01
08/11/88	<0.10	0.55	0.03	0.01
08/12/88	<0.10	0.54	0.03	0.05
08/13/88	<0.10	0.54	0.03	0.02
08/14/88	<0.10	0.55	0.03	0.01
08/15/88	<0.10	0.52	0.03	0.01
08/16/88	<0.10	0.54	0.02	0.01
08/17/88	<0.10	0.53	0.02	0.02
08/18/88	<0.10	0.57	0.03	0.02

CONCLUSIONS

Water from Hunter Drain, TJ Drain, and groundwater from a well near TJ Drain were acutely toxic to all species tested, thus these areas were identified as locations where major toxicity problems existed on the Stillwater National Wildlife Refuge. Based on effects of the drainwater on cumulative mortality and daphnid reproduction, the No Observed Effect Concentration (NOEC) for both Hunter and TJ drains was less than 12.5% drainwater. Lead Lake was moderately toxic to all species tested with a NOEC of 25% drainwater for both fish species and a NOEC of less than 12.5% for daphnids. In tests with Diagonal Drain diluted with Stillwater Point where mortality occurred in every treatment, a NOEC was not established, however, in tests with Diagonal Drain diluted with reconstituted water the NOEC was 25% for daphnids and fathead minnows and 12.5% for bluegill. No effects were observed in any treatment of Paiute Drain or D-Line Canal.

In both Hunter and TJ drains, dramatic daily fluctuations in water quality were measured with conductivity ranging from 410 to 27,500 µmhos/cm in Hunter Drain and from 6100 to 14,900 µmhos/cm in TJ Drain. Control organisms in reconstituted water where conductivities were similar to those of the drainwater survived exposure to daily fluctuations of similar magnitudes survived . In Hunter Drain, bluegill mortality occurred immediately after

exposure to a dramatic increase in drainwater salinity, however, mortality of daphnids and fathead minnow larvae occurred prior to this increase. Sheephead minnow larvae and mysids (saltwater organisms) did not survive in Hunter Drain although salinities were within their range of tolerance. A dose-response relationship was evident in tests with TJ drainwater diluted with reconstituted water of a similar salinity as well as in tests where water from D-Line Canal diluted the effects of salinity across treatments. Although the elevated salinities in tests with drainwater from both locations undoubtedly stressed the organisms, results from these tests suggest that salinity alone does not account for the mortality observed. Similarly, tests with water from Lead Lake showed no reduction in control survival under water quality conditions similar to those in 100% Lead Lake water where mortality was significant.

Higher concentrations of contaminants generally corresponded to higher levels of conductivity. In addition, visual comparison of cumulative mortalities and concentrations of contaminants at each location suggested that four contaminants--arsenic, boron, lithium, and molybdenum were higher at locations where appreciable mortality occurred. No single contaminant was measured at concentrations that were acutely toxic to the species tested (USEPA 1986), therefore toxicity attributable to additive effects of contaminants present in drainwater was explored. Principal components analysis was used to determine if overall contaminant concentrations in various drains could

be summarized as linear combinations of the concentrations of individual elements. While a number of subsets of the total elemental analysis might have been used, our major interest was in summarizing potentially toxic elements, therefore, arsenic, boron, lithium, and molybdenum were used in the principal component analysis. When these four elements were included, the first principal component accounted for 86% of the total variability present in daily measurements. If two principal components were retained, additional elements such as barium, strontium, vanadium, and zinc could be included with the total variability accounted for remaining high. (>85%). These results indicate that 1) the overall level of metals contamination of these drains could be summarized using several linear combination (components) of the individual element concentrations, and 2) the overall level of contamination due to elements that apparently occurred in elevated concentrations could be summarized using a single linear combination of those elements.

Daily component scores were computed for each location by retaining the first principal component. Locational means of these daily values were significantly related to total mortality of bluegill (r=0.88), fathead minnows (r=0.93) and Daphnia magna (r=0.97) (Figure 2); all coefficients reported are from rank correlation analysis.

A linear regression variable selection procedure was used to identify water chemistry variables which were

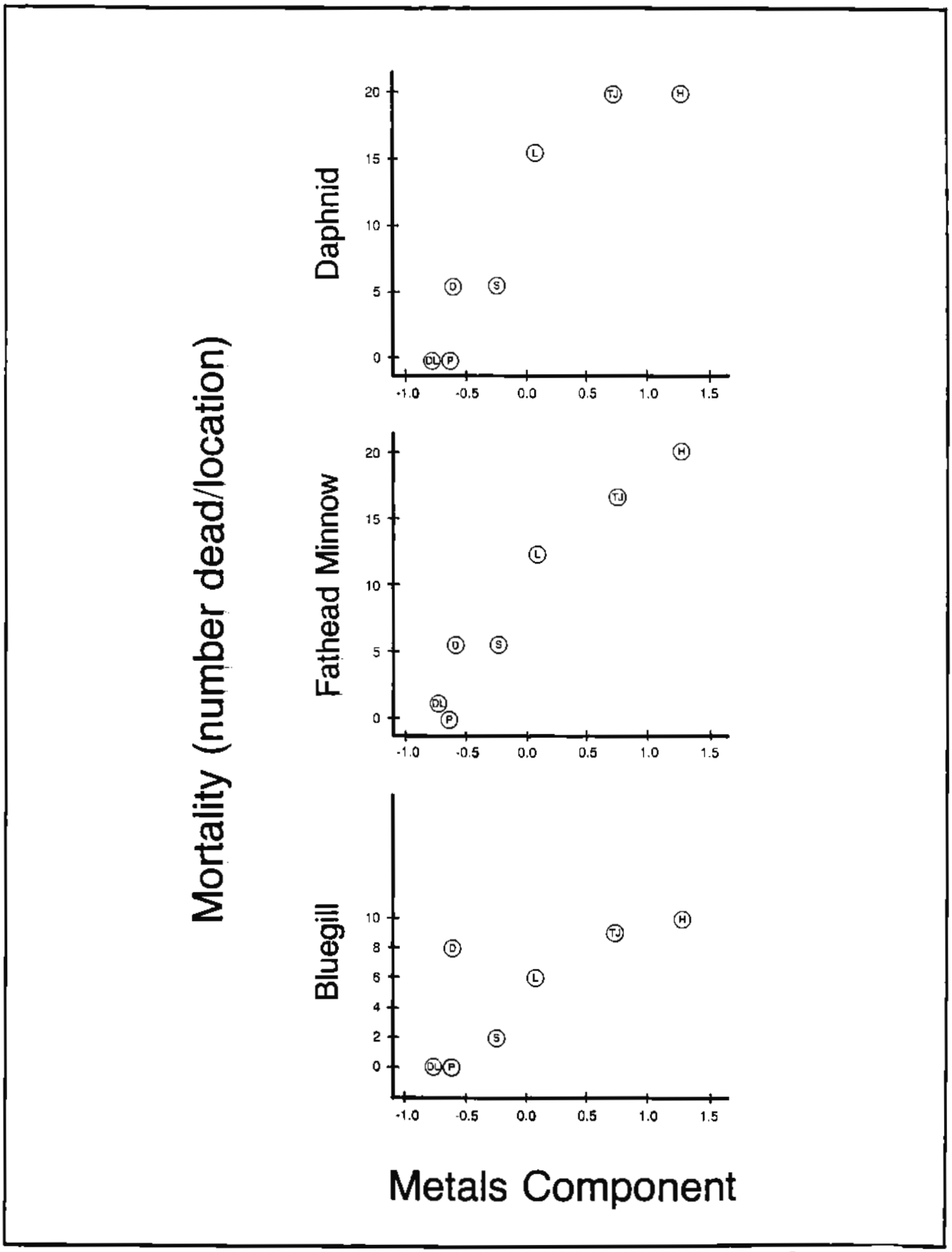

Figure 2. Relationship between metals component and mortality of bluegill (r=0.88), fathead minnow larvae (r=0.93), and daphnids (r=0.97) for Paiute Drain (P), D-Line Canal (DL), Diagonal Drain (D), Stillwater Point Reservoir (S), TJ Drain (TJ), and Hunter Drain (H).

related to the daily metals components scores. This analysis indicated that the single measurement of conductivity was strongly related to the component scores, and thus the overall level of contamination by the four metals included in calculation of those scores. Simple linear regression of daily principal component scores (calculated from the concentrations of arsenic, boron, lithium, and molybdenum) against daily conductivity yielded a coefficient of determination of 0.95 (r =0.95) (Figure 3). The mean conductivity at various locations was also related to the total mortality at those locations for all three test species using rank correlation; bluegill (r=0.88), fathead minnow (r=0.93), and Daphnia magna (r=0.97) (Figure 4).

The strength of this relationship between conductivity and mortality identifies conductivity as a useful method to estimate toxicity of the drainwater, and thus, to determine its acceptability for use in the refuge. Although the locations that we tested cover a broad spectrum of conductivities and mortalities, the total number of location tested (N=6) is insufficient to estimate a specific upper limit of acceptability. In addition, the daily fluctuations in water quality that occurred during our tests make it impossible to relate a specific level of conductivity to an effect. Such a limit might be established by evaluating water from a toxic drain such as TJ across a range of dilutions with increments smaller than those used in our study. One can not assume that the relationship between the concentrations of metals, conductivity, and mortality

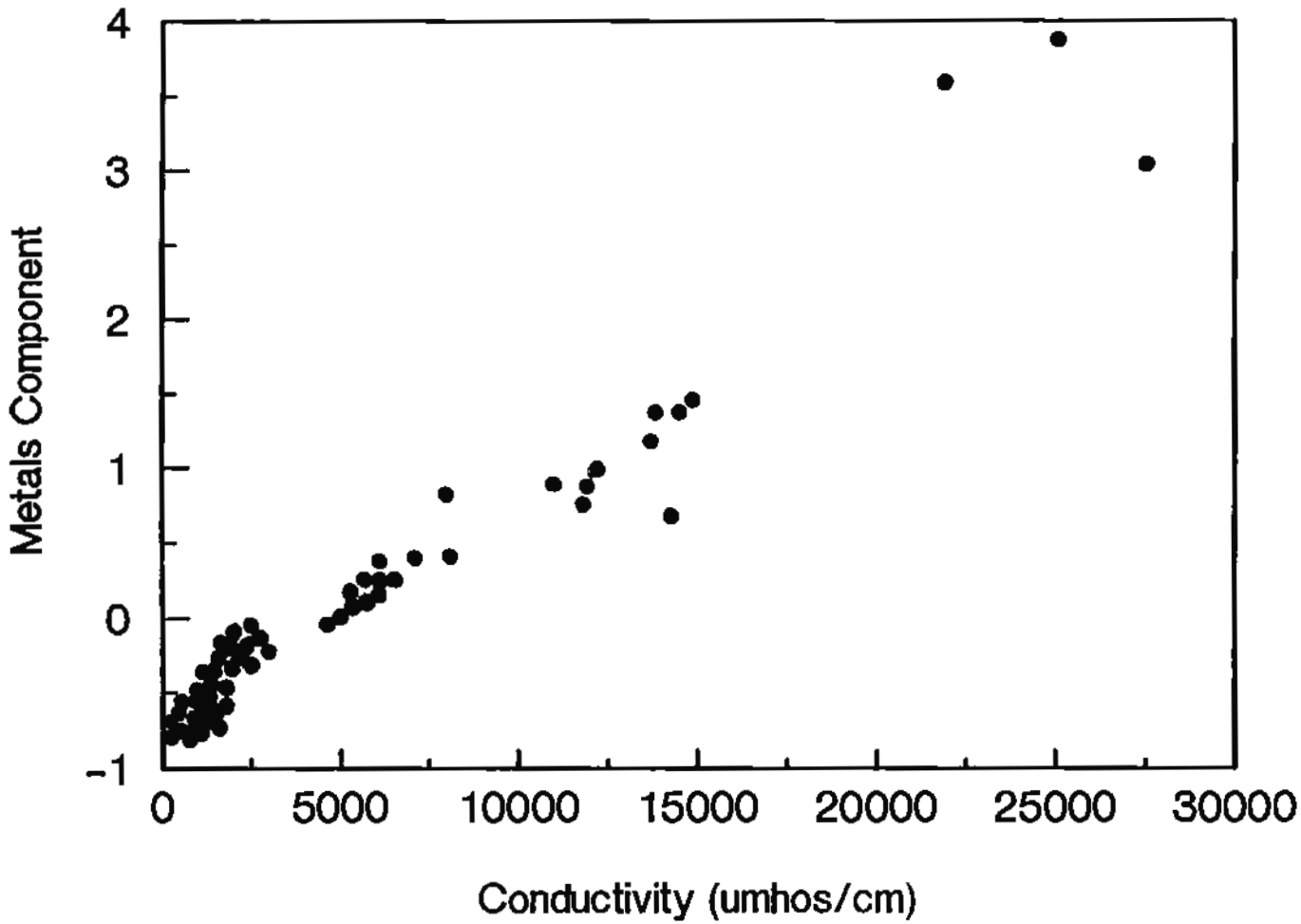

Figure 3. Relationship between the Metals Component (daily scores from a principal component analysis which includes arsenic, boron, lithium, and molybdenum) and conductivity (umhos/cm). (r=0.95)

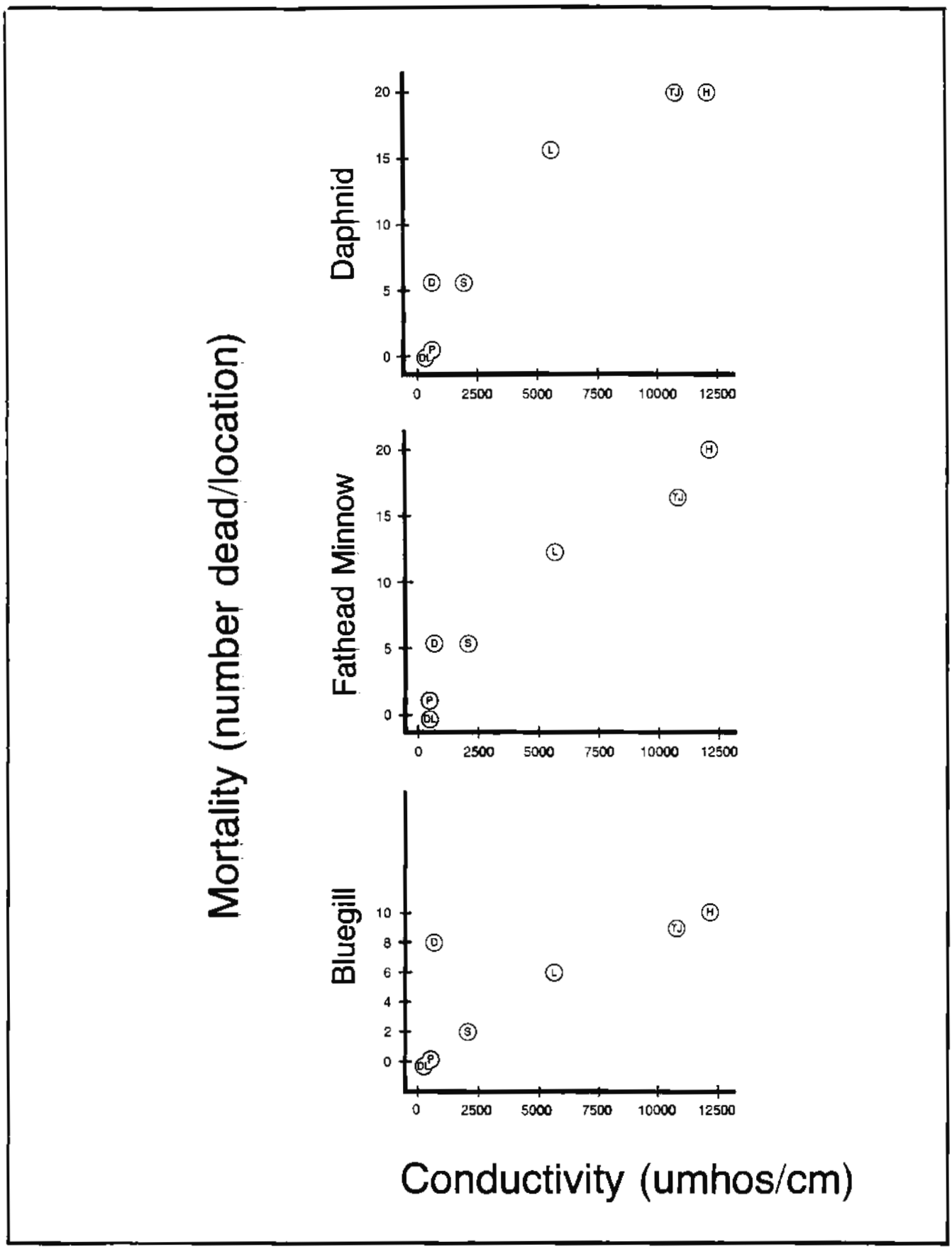

Figure 4. Relationship between conductivity and mortality of bluegill (r=0.88), fathead minnow larvae (r=0.93), and daphnids (r=0.97) for Paiute Drain (P), D-Line Canal (DL), Diagonal Drain (D), Stillwater Point Reservoir (S), TJ Drain (TJ), and Hunter Drain (H).

will exist for groundwater or for other areas where agricultural drainage is of concern.

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