ASSESSMENT OF POTENTIAL ENVIRONMENTAL IMPACTS OF SALINE OIL-FIELD DISCHARGES INTO SALT CREEK AND THE POWDER RIVER, WYOMING

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ABSTRACT

Environmental and regulatory concerns are increasing over the possible effects of discharging co-produced waters from oil fields to natural receiving waters. These discharges, known as oil-field brines, are typically high in total dissolved solids and have a variety of organic and inorganic constituents. Relatively little is known about the toxicity and persistence of these discharges in the receiving waters. This study was undertaken to assess the effects of oil-field brines on water quality in Salt Creek and downstream in the Powder River of Wyoming. Methods included (1) laboratory toxicity tests of ambient stream waters with fathead minnows and Ceriodaphnia dubia, (2) chemical characterization of the salt load and organic compounds introduced along the stream gradient, (3) preliminary assessment of the contributions of salt, organic compounds and other constituents to toxicity, and (4) a qualitative stream fauna survey.

Oil-field brines discharged from the upper Salt Creek oil field have toxic effects on surface waters in Salt Creek and the Powder River, especially during low flow. Toxicity could not be attributed to organic compounds or trace elements, as measured in this study. Salinity, alkalinity and pH correlated well with observed toxicity, but could not be singled out individually because of a high degree of covariance. Suitable habitat for macroinvertebrates was scarce at most sample sites, and the qualitative survey of stream fauna was of minimal use in detecting effects from oil field discharge waters.

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INTRODUCTION

Environmental concerns over the discharge of oil-field production waters have been voiced since the first well was drilled at Titusville, Pennsylvania in 1859 (Pettyjohn 1971). These concerns are based on potential effects of toxic and saline releases from oil production on ground and surface waters. During production, a mix of petroleum and water (often saline) is pumped to the surface and then separated. The produced saline water, frequently called oil-field brine, is usually released untreated to surface waters. Produced waters are typically high in total dissolved solids (TDS), and have ionic compositions qualitatively similar to seawater (Drever 1982). In addition, these brines may also contain a variety of other organic and inorganic constituents, including those derived from drilling and pumping operations. Virtually all these constituents, including the salts themselves, may be toxic.

The problems associated with discharging brines into ground and surface waters were recognized years before federal regulatory agencies were established. Most oil producing states had enacted laws that regulated the drilling and disposal of brines (Pettyjohn 1971). Currently, any state that has surface discharges of water associated with the production of oil and gas are required to follow regulatory guidelines established by the U.S. Environmental Protection Agency (USEPA).

The impetus for adherence to these guidelines is provided by the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and the Clean Water Act of 1977, as amended in 1987 (PL 100-4), wherein it states that ". . .it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited." Under the new water-quality-based toxics control program being implemented by the USEPA and the states, most dischargers are required to successfully complete biomonitoring tests as part of the requirements for renewal of permits issued under the National Pollution Discharge Elimination System (NPDES).

In Wyoming and other western oil states the discharge of oil-field effluents is becoming a controversial issue. In the arid west, water supply is often sparse; hence, the conflicts of competing water uses for municipalities, agriculture, fish and wildlife are heightened. To render a portion of a water course unusable would be costly. In areas where the discharges are deemed non-threatening, the loss of discharge flow would be detrimental to downstream water uses. On the other hand, it is also costly to require reinjection of the production water as an alternative to discharge.

Such controversial concerns are prominent in the Salt Creek drainage of the Powder River basin located in northeastern Wyoming. Salt Creek and the Powder River are important sources of water in an arid area that is primarily sagebrush (*Artemisia sp.*), plains-grassland, and a ribbon of Cottonwoods (*Populus sp.*) that line the banks (Smith 1987). Because of the potential influence that oil production can have on the natural characteristics of these waters, there are concerns about oil-field discharges causing problems with beneficial water uses in these drainages. Recent studies by Gerhardt (1989) conclude that a viable catfish fishery is in the early stage of development. Prior to spawning, around mid-June, channel catfish (*Ictalurus punctatus*) move upstream in the Powder River to near the Salt Creek confluence. Currently, no information has been gathered on the potential effects that brine discharges may have on catfish. Also, the sturgeon chub (*Hybopsis gelida*), a species not found frequently in Wyoming, exists in the Powder River (Stewart 1981). Petroleum production operations in the Salt Creek drainage release large amounts of produced water to Salt Creek, constituting a significant proportion of the flow. Salt Creek, consequently, is an important contributor to downstream flows of the Powder River. Indeed, during the water year 1986, Salt Creek represented as much as 81% of the Powder River flow downstream of the confluence with Salt Creek (USGS 1986). Discharges into Salt Creek have the potential for heavily influencing downstream water quality. With the pending review and renewal of the NPDES permits for the Salt Creek oil fields in 1990, the Wyoming Department of Environmental Quality (WDEQ) will have to consider many factors to properly manage oil field discharges for maximum benefit and minimum environmental risk.

At present, relatively little is known about the potential environmental risks posed by these discharges. The complex chemical composition of the discharges makes assessment of their potential hazard difficult. To address difficult assessment problems such as this, the USEPA has established biomonitoring policies and procedures under the Complex Effluent Toxicity Testing Program. The methodology includes toxicity tests on effluent samples using aquatic invertebrates and vertebrates.

Acute effects on survival are measured using toxicity tests lasting two to four days (USEPA 1985a). Effects on survival and sub-lethal physiological dysfunctions, such as impairment of reproduction or growth, are measured in short-term chronic tests lasting seven days (USEPA 1985b, 1989). Results from these toxicity tests allow one to predict whether there will be adverse effects of effluent discharges on the aquatic biota in a receiving stream. These methods have been used successfully for tests of whole effluents before they enter receiving waters, and for testing instream (ambient) toxicity of effluents after they are discharged into receiving waters (e.g. Mount et al. 1984). In addition, the tests have been used effectively to detect contaminated groundwater entering surface waters in a recent study conducted in Wyoming (Meyer et al. 1988).

The purpose of this study was to use these new toxicity testing procedures to examine the effects of produced water discharges on surface water quality in Salt Creek and the Powder River. If these waters were found to be toxic, additional goals were to identify the nature of toxic materials within the Salt Creek and Powder River drainages, their temporal and spatial variability, their effects on downstream water quality, and their potential effects on the desired uses of Salt Creek and Powder River waters. Strategies derived from this study for assessing effects of saline discharges would also be applicable to assessing effects of other non-point sources of toxic chemicals.

OBJECTIVES

We expected, *a priori*, that any toxicity of the discharges would likely come from one or more of three sources: (1) the salt load itself, or trace ions present in the salt load; (2) hydrogen sulfide; or (3) organic compounds dissolved in the water.

To test these hypotheses the following objectives were set:

1. Estimate the ambient toxicity (if present) of Salt Creek waters and the persistence of this toxicity downstream.
2. Characterize the salt load and organic compounds introduced by oil-field effluents.
3. Determine the contribution of salts, organic compounds, and other materials to the toxicity of Salt Creek and Powder River waters.
4. Conduct a qualitative survey of stream fauna to identify any noticeable changes as discharges enter the drainages.

METHODS

Site Descriptions and Sample Locations

Powder River Basin. Annual precipitation in this semi-arid basin averages 40 cm at Sheridan, on the western edge, to 30 cm at Casper on the southern edge (Smith 1987). Potential evaporation exceeds annual precipitation (Hodson et al. 1971). Elevation in the basin ranges from 700 m at the confluence with the Yellowstone River near Terry, Montana to 3450 m at its headwaters in the Big Horn Mountains of Wyoming.

Salt Creek. Salt Creek originates approximately 40 km north of Casper, Wyoming, and flows north through an area geologically and historically described as Teapot Dome. The creek meanders through an alkali basin until it reaches the confluence with the Powder River, 56 km downstream.

In the late 1880's, the area encompassing Teapot Dome was of interest to oil prospectors because of oil seeps that could run from one gallon to ten barrels per day (Bille 1978). Today, oil producers along Salt Creek are located within the first 35 km of the drainage, including the Castle Creek tributary.

Three sample sites were selected to study the possible effects of oil-field brine discharges on Salt Creek. The site designated USC was located upstream from any oil treater facility (SE1/4 S26 T39N R78W); LIN was located 26 km downstream from USC (SE1/4 S8 T42N R79W) in the Linch, Wyoming area; and CSC was placed about 9.1 m above the confluence of the Powder River (SE1/4 S15 T43N R79W) (Figure 1). USC served as the upstream control. All the oil companies that release discharges that reach Salt Creek are located between USC and LIN.

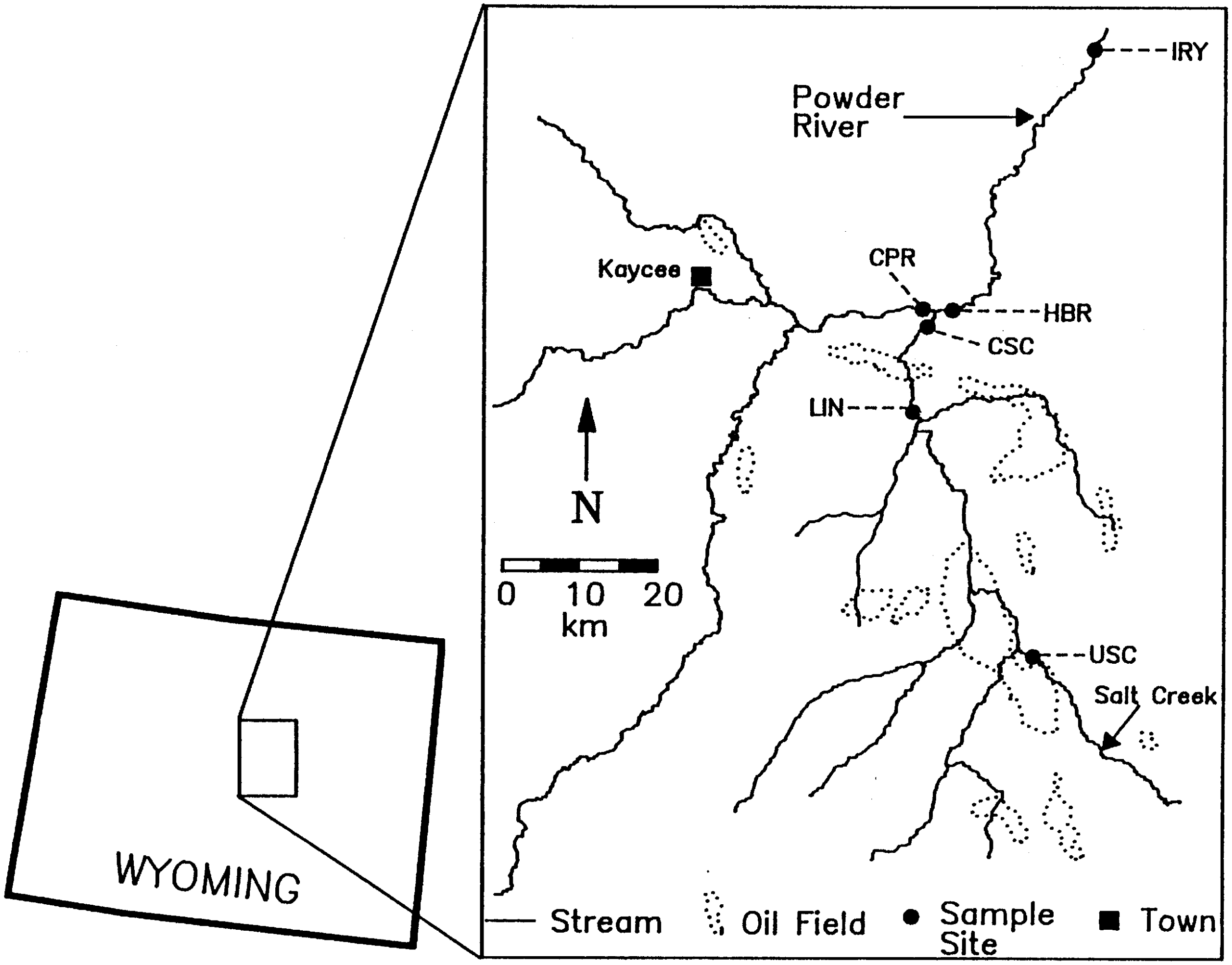

Figure 1. Location of Salt Creek and Powder River study area. Sample sites: USC = upstream Salt Creek, LIN = Linch, CSC = Salt Creek just upstream of confluence, CPR = Powder River just upstream of confluence, HBR = Powder River 6 km downstream of confluence at Highway 192 bridge, IRY = Powder River 68 km downstream of confluence at Irigary bridge.

Powder River. Originating near Kaycee, Wyoming, the Powder River drains 34,300 sq. kilometers in northeastern Wyoming and southeastern Montana before emptying into the Yellowstone River (Rehwinkel 1978). Flowing through erodible substrates as it meanders towards the Yellowstone River, the Powder River can exceed 500 Jackson Turbidity Units (JTU), and Total Dissolved Solids (TDS) can average greater than 1300 mg/l (Smith 1987). The flows fluctuate widely due to heavy spring rains in the headwaters, and the riparian zones are poorly developed (Gerhardt 1989). River depths are shallow with flows contained in a wide bed of fine sands and clays.

Three sample sites were chosen on the Powder River to evaluate the effects of Salt Creek discharges (Figure 1). The site designated CPR was approximately 0.6 km above the confluence of Salt Creek and the Powder River (SE1/4 S15 T43N R79W); HBR was located near Highway 192 bridge, 6 km downstream from the confluence (NW1/4 S13 T43N R79W); and IRY was 68 km downstream from the confluence at the Irigary Bridge (SW1/4 S19 T46N R77W). The Irigary Bridge site was chosen to observe any persistent effects from the oil field discharges into Salt Creek.

Sample Collection and Storage, and Field Observations

Samples were collected during three stream flow regimes, high, medium, and low. Stream flow data from 1986 (USGS) were used to estimate when these flow regimes occur. Sampling dates were May 11 for high flow, October 14 for medium flow, and August 1 for low flow.

At each sample location, a 19-L grab sample was collected in a polyethylene jug and then stored with ice in a large cooler. Samples from sites CSC, CPR and HBR were held in the cooler overnight during each sampling trip, and samples from site USC, LIN and IRY were held less than 5 hours in the cooler until all samples were returned to the Red Buttes Environmental Biology Laboratory at the University of Wyoming. There, samples were refrigerated at $4^{o}C$ for subsequent toxicity tests. After returning to the laboratory, a 500 ml aliquot was drawn from each sample and filtered with a 0.45 um cellulose acetate filter, acidified (500 ul/125 mls) with redistilled HNO_3 (1 ml/L) and stored at $4^{o}C$ for later analysis of cation, anion and trace elements.

Water quality parameters measured in the field included temperature (^{o}C), dissolved oxygen (mg/l) using a YSI Model 64A dissolved oxygen meter, and stream flow (feet^3/second), using a Teledyne Gurley Pygmy (No. 625) current meter.

Macroinvertebrates were qualitatively sampled using kick nets (#30 mesh), and preserved by the addition of 95% ethanol to the sample jars. Habitat was minimal along the stream for invertebrates, therefore collections were made at any suitable location.

Laboratory Chemical Analyses

Standard methods (APHA 1980) were used to analyze routine chemical parameters of temperature, pH, conductivity, alkalinity, hardness and total ammonia. Specifically, the instruments or methods for each parameter were a Corning Model 10 pH meter, an Extech Model 440 conductivity meter, alkalinity and hardness by titration, and an Orion Ionalyzer Model 407A provided with a selective-ion ammonia probe.

Major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}), were analyzed at the University of Wyoming Soils Laboratory using a Perkin-Elmer Model 5500 inductively coupled argon plasma spectrophotometer (ICP). Also, for verification, the same cations were analyzed at the Red Buttes Environmental Biology Laboratory using a Perkin-Elmer Model 2380 atomic absorption spectrophotometer (AA). Major anions (Cl^- and SO_4^{2-}) were analyzed by a Buchler-Cotlove Model 4-2000 Chloridometer (Cotlove et al. 1958) for chlorides and ICP methods for sulfates. For values of HCO_3^- and CO_3^{2-}, the titration values of total alkalinity (mg/l $CaCO_3$) and phenolphthalein alkalinity (mg/l $CaCO_3$) were converted to their respective milliequivalents and then expressed as mg/l HCO_3^- and CO_3^{2-}.

Because of potential addition of trace elements to Salt Creek from oil production operations, ten elements (Al, As, Fe, Hg, Li, Mn, Ni, Pb, Se, and Sr) were analyzed by ICP.

To detect the presence and persistence of organic compounds in Salt Creek and the Powder River, organic "fingerprints" of the waters were examined using a Walters Model 402 reverse-phase high-performance liquid chromatograph (HPLC). Sample analyses were accomplished by running 30 minute gradients. In a 30 minute run, 50 ul samples were eluted linearly along a gradient from 100% water to 100% CH_3CN at a flow rate of 2.0 ml/minute. Absorbance was read at 254 nm and 0.02 AUFS (Absorbance Units Full Scale). Baseline recordings were established prior to sample injections using sample gradients of a blank (no injection) and filtered water (reverse osmosis/de-ionized). The "fingerprint" illustrated types and relative concentrations of organic compounds present within the waters.

Toxicity Tests

To test instream toxicity, we used two short-term, chronic tests developed by the USEPA. Standard protocols (USEPA 1985b) were followed to conduct 7-day survival and growth tests with fathead minnows (*Pimephales promelas*) and 7-day survival and reproduction tests with *Ceriodaphnia dubia*, an aquatic invertebrate.

Stock cultures of fathead minnows and *Ceriodaphnia dubia* were originally obtained from the U.S. EPA Environmental Research Lab in Duluth, Minnesota, and have been cultured at the Red Buttes Environmental Biology Laboratory for several years. Neonates from these stock cultures were used for all toxicity tests conducted in this study.

Undiluted ambient water was tested for each sample location. And dilutions of 50%, 25%, and 10% ambient water were tested where toxicity was suspected (e.g., Linch site). The upstream sample location on Salt Creek (USC) served as the ambient control and a hard reconstituted laboratory water (Table 1) was used as the diluent and laboratory control. For statistical comparisons, the upstream Salt Creek (USC) sample was used as the control.

Temperature for all 7-day fathead minnow and *Ceriodaphnia* tests was maintained at 25 +/- 2°C using recirculating water baths, and tests were run under a 16-h light/8-h darkness photoperiod.

Fathead minnow tests were conducted in 1-L glass beakers that contained 250 ml of test water. Four replicate beakers were included for each test water and the laboratory control. Each beaker contained 10 larval fathead minnows, for a total of 40 minnows per test water. At the start of each test, the minnows were between 3 and 7 days old, and were hatched within 48 hours of each other.

The minnows were fed 0.1 ml newly hatched brine shrimp (*Artemia salina*) two times per day during the test. Test waters were renewed daily by siphoning out all but about 75 ml of the water, and replacing it

Table 1. Chemical characteristics of hard reconstituted water used for laboratory control and dilution water during toxicity tests conducted at the UW Red Buttes Environmental Biology Laboratory during May, August and October, 1988.

Date	pH units	Conductivity us/cm at 25°C	Alkalinity mg/L CaC03	Hardness mg/L $CaCO_3$	Dissolved oxygen mg/L	Ammonia mg/L total N
May	8.50	580	120	180	6.50	< 0.10
August	8.55	597	110	168	5.85	< 0.10
October	8.60	625	114	172	6.60	< 0.10

with fresh test water. Dead fish were counted and removed at this time. After 7 days, surviving minnows in each replicate beaker were dried and weighed as a group. Group weight for each replicate was then divided by the number of surviving fish in that replicate, to yield an average dry weight per fish for each replicate.

For the Ceriodaphnia tests, we started the test with neonates < 24 hours old and born within 4 hours of each other. One neonate was placed in each of 10 replicate beakers for each test water and the laboratory control. Test vessels were 30-ml plastic cups, each containing 15 ml of test water. Animals were transferred to fresh test water and fed 0.1 ml of an algae/trout chow mixture per cup each day.

The mean number of young per female was calculated at the end of the test by dividing the total number of offspring produced in each test water by the number of females that started the test in that water. If a female died before reproducing, her offspring total was recorded as zero.

Statistical Analyses

Toxicity tests. Data for all toxicity tests were analyzed using the computer program TOXSTAT Version 2.1 (Gulley et al. 1988). This program was developed specifically for analyzing data from 7-day chronic toxicity tests, and employs all the statistical procedures recommended in the standard U.S. EPA protocol (USEPA 1985b). TOXSTAT implements standard conventions for testing normality and homogeneity of variance and uses analysis of variance or non-parametric methods to compare organism survival, reproduction and growth.

If the data pass the Chi-square test for normality, then the Bartlett and Hartley tests for homogeneity of variance can be used. The

Bartlett test (described in USEPA 1985b) tests the hypothesis that the variances are equal. The Hartley test, described by Neter et al. (1985), evaluates the hypothesis that variances are homogeneous and is designed to show substantial differences between the smallest and largest group variances.

Data that fail the Chi-square test are transformed and then analyzed again. If all transformations fail, then non-parametric tests, Steel's (1959) and Kruskal-Wallis (Sokal and Rohlf 1981, Zar 1984), are employed.

Data for 7-day fathead minnow survival was examined using analysis of variance (ANOVA) on arcsine-square-root-transformed data. Using Dunnett's one-tailed critical values (Dunnett 1955, Dunnett 1964), survival of control organisms in Upstream Salt Creek (USC) water was compared to survival in each downstream water and dilutions of downstream waters ($p = 0.05$).

A Fisher's Exact Test (Sokal and Rohlf 1981) was used to analyze Ceriodaphnia survival data because only one animal is tested in each replicate. Critical Fisher's values ($p = 0.05$) were used to compare the upstream control (USC), downstream waters, and dilutions of downstream waters.

Using ANOVA and Dunnett's one-tailed test, critical values were calculated ($p = 0.05$) to compare fathead minnow weights in the upstream control (USC) to downstream waters and dilutions of downstream waters.

To compare total numbers of Ceriodaphnia offspring in the upstream control (USC) to downstream waters and dilutions of downstream waters, we used ANOVA and Dunnett's one-tailed test ($p = 0.05$). Waters in which no organisms survived were not included in the reproduction analyses.

Regression and Correlation Analyses. Stepwise logistic regression was performed for fathead minnow and *Ceriodaphnia* survival versus chemical and physical variables. Multiple linear regression for fathead minnow weights and *Ceriodaphnia* number of young versus chemical and physical variables was also performed. For these regressions, we used the BMDP statistical program (Dixon et al. 1985). Pearson product-moment correlation coefficients were computed using SPSS-X (SPSS 1988) to evaluate the covariance among physical and chemical variables, including Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, SO_4^{2-}, alkalinity, pH, conductivity, and flow (cfs). BMDP and SPSS statistical programs were run on the VAX mainframe computer at the University of Wyoming.

RESULTS

Flow

In the Powder River flows ranged from 3.5 cfs at the upstream site in August to 389 cfs at the last site downstream in May (Table 2 and Figure 2). Flows in Salt Creek were as low as 0.04 cfs at the upstream site in August and as high as 53 cfs just above the confluence with the Powder River in October. Salt Creek contributed 16% of the Powder River flow during high flow, 67% during medium flow, and 89% during low flow.

Chemical Analyses

Ammonia (as total N) and dissolved oxygen for all sampling locations were similar to the upstream control and remained consistent throughout sampling periods (Table 2). Conductivity, alkalinity and pH increased within the area of oil-field discharges (Linch site) and then decreased after Salt Creek entered the Powder River (HBR and IRY). In contrast, hardness decreased with the addition of production waters from the oil-field discharges.

Trends in concentrations of major inorganic ions (Table 3) followed a pattern that would be expected from conductivity, alkalinity and hardness measurements. Na^+, K^+, Cl^-, HCO_3^- and CO_3^{2-} increased at the Linch site, and then generally decreased downstream, while sulfates, Ca^{2+} and Mg^{2+} decreased at the Linch site and downstream.

Concentrations of major inorganic ions were converted to milliequivalents per liter for ion balance comparisons (Table 4). These data are illustrated in Figure 3 with the horizontal line in each bar representing the division between cations and anions. The K^+ does not appear in Figure 3 because it is masked by the magnitude of the

Table 2. Routine water chemistry paramters and flow in Salt Creek and Powder River during high, medium and low flow periods, 1988.[a]

Date	Site[b]	pH units	Conductivity us/cm	Alkalinity mg/L $CaCO_3$	Hardness mg/L $CaCO_3$	Ammonia mg/L Total N	Dissolved Oxygen mg/L	Temperature °C	Flow cfs
May, 1988 High flow	USC	8.30	4270	270	1056	< 0.10	6.90	23.5	0.70
	LIN	8.50	6090	588	396	0.18	7.10	19.0	48.00
	CSC	8.55	6740	728	410	0.13	7.10	24.0	48.00
	HBR	8.40	1815	224	310	< 0.10	7.00	20.0	357.00
	IRY	8.35	1688	202	308	< 0.10	7.00	16.0	389.00
	CPR	8.15	828	128	272	< 0.10	6.90	20.0	258.00
October, 1988 Medium flow	USC	8.20	4170	281	992	< 0.10	6.85	13.8	1.50
	LIN	8.52	6000	784	220	< 0.10	7.80	14.5	43.00
	CSC	8.72	6190	730	190	0.11	6.90	8.0	53.00
	HBR	8.38	5930	498	345	< 0.10	7.10	11.8	83.00
	IRY	8.50	3590	342	365	< 0.10	6.50	10.5	104.00
	CPR	8.30	2500	250	590	< 0.10	6.60	6.8	26.00
August, 1988 Low flow	USC	8.30	4840	252	1070	< 0.10	6.65	30.0	0.04
	LIN	8.82	6400	813	152	< 0.10	6.20	19.5	31.00
	CSC	8.93	6420	774	142	< 0.10	6.50	27.0	30.00
	HBR	8.72	4420	706	206	< 0.10	6.80	30.1	53.00
	IRY	8.86	5820	519	314	< 0.10	6.60	15.5	18.90
	CPR	8.19	2240	173	870	< 0.10	6.70	29.0	3.50

[a] Dissolved oxygen, temperature and flow were measured at sample site in the field; pH, conductivity, alkalinity hardness and ammonia were measured in the laboratory.

[b] Sample collection sites are shown in Figure 1.

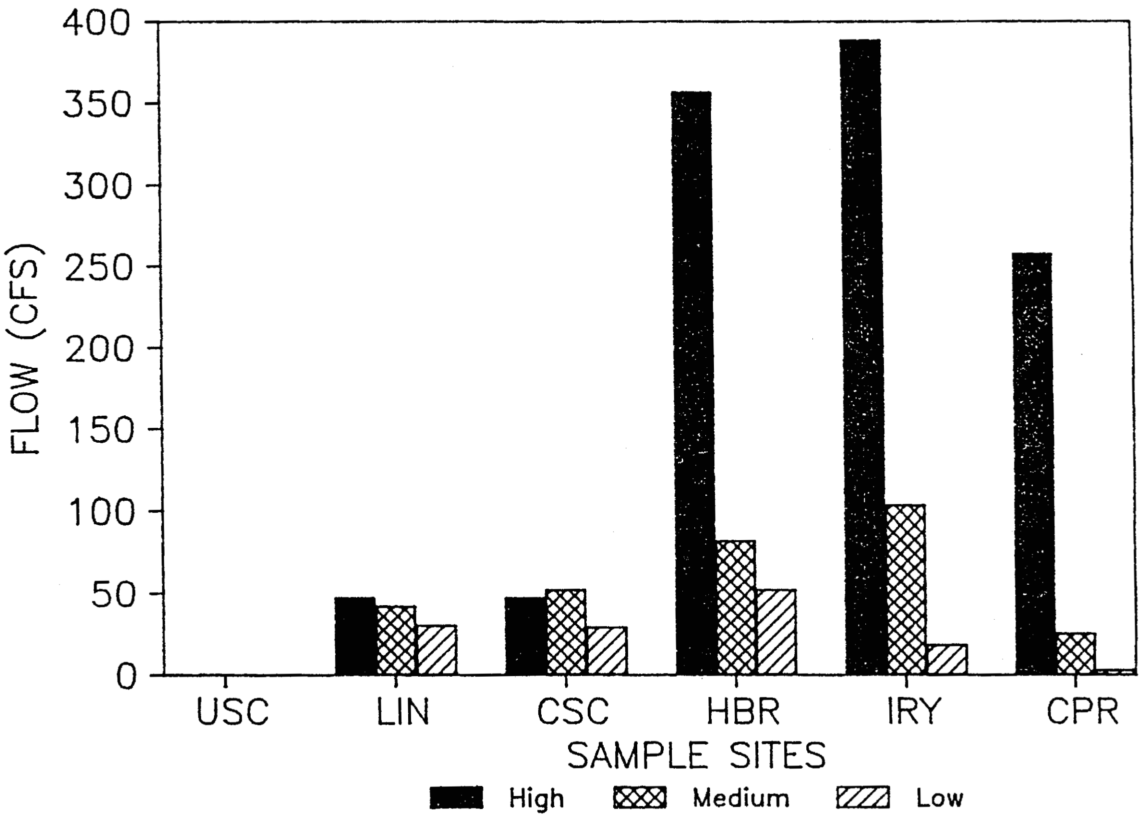

Figure 2. Stream flow at study sites during the three sampling periods: high flow in May, medium flow in October, and low flow in August, 1988. USC = upstream Salt Creek, LIN = Linch, CSC = Salt Creek just upstream of confluence, HBR = Powder River 6 km downstream of confluence at Highway 192 bridge, IRY = Powder River 68 km downstream of confluence at Irigary bridge, CPR = Powder River just upstream of confluence. Values for flow measurements at the USC site were too low to plot at the scale used but were measured as: high flow, 0.7 cfs; medium flow, 1.5 cfs; and low flow, 0.04 cfs.

Table 3. Concentrations of major inorganic ions in Salt Creek and Powder River during high, medium and low flow periods, 1988.[a]

		Cations				Anions[c]			
Date	Site[b]	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SO_4^{2-}	HCO_3^-	CO_3^{2-}
May 1988 High flow	USC	845	219	109	8.7	8	809	323.34	0.0
	LIN	1255	55	52	18.2	1042	383	724.77	12.0
	CSC	1410	47	62	17.2	1066	466	893.15	14.4
	HBR	268	71	32	3.8	171	152	270.87	3.6
	IRY	239	70	31	3.9	139	149	247.69	4.8
	CPR	73	70	24	1.8	8	85	157.40	0.0
October 1988 Medium flow	USC	805	229	112	8.8	8	804	342.86	0.0
	LIN	1390	30	30	15.8	1294	242	956.60	21.6
	CSC	1395	25	33	15.9	1299	260	890.71	14.4
	HBR	845	51	42	8.9	777	282	607.64	3.6
	IRY	685	74	53	10.9	552	273	417.29	3.6
	CPR	200	161	64	4.7	144	320	305.04	0.0
August 1988 Low flow	USC	895	235	132	11.5	8	914	307.48	0.0
	LIN	1420	24	24	14.2	1123	204	991.98	63.6
	CSC	1430	20	26	14.8	1238	215	944.40	84.0
	HBR	1290	24	33	14.2	1118	249	861.43	30.0
	IRY	1205	37	53	14.6	1006	322	633.26	33.6
	CPR	254	208	93	8.0	82	419	211.09	0.0

[a] Values are expressed as mg/L.

[b] Sample collection sites are shown in Figure 1.

[c] Methods for calculating values for HCO_3^- and CO_3^{2-} are explained in Methods - Chemical Analyses

Table 4. Ion concentrations (mEq/L) for Salt Creek and Powder River during high, medium and low flow periods, 1988.[a]

Date	Site[b]	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SO_4^{2-}	Alkalinity[c]
May 1988 High flow	USC	36.76	10.93	8.97	0.22	0.23	16.84	5.30
	LIN	54.59	2.74	4.28	0.47	29.39	7.97	11.88
	CSC	61.33	2.35	5.10	0.44	30.07	9.70	14.64
	HBR	11.66	3.54	2.63	0.10	4.82	3.16	4.44
	IRY	10.40	3.49	2.55	0.10	3.92	3.10	4.06
	CPR	3.18	3.49	1.97	0.05	0.23	1.77	2.58
October 1988 Medium flow	USC	35.02	11.43	9.21	0.23	0.23	16.73	5.62
	LIN	60.46	1.50	2.47	0.40	36.50	5.04	15.68
	CSC	58.50	1.25	2.71	0.41	36.64	5.41	14.60
	HBR	36.76	2.54	3.46	0.23	21.92	5.87	9.96
	IRY	29.80	3.69	4.36	0.28	15.57	5.68	6.84
	CPR	8.70	8.03	5.27	0.12	4.06	6.66	5.00
August 1988 Low flow	USC	38.93	11.73	10.86	0.29	0.23	19.02	5.04
	LIN	61.77	1.20	1.97	0.36	31.68	4.25	16.26
	CSC	62.20	1.00	2.14	0.38	34.92	4.47	15.48
	HBR	56.11	1.20	2.71	0.36	31.54	5.18	14.12
	IRY	52.41	1.85	4.36	0.37	28.38	6.70	10.38
	CPR	11.05	10.38	7.65	0.20	2.31	8.72	3.46

[a] Values are expressed as mEq/L.

[b] Sample collection sites are shown in Figure 1.

[c] Alkalinity values are expressed as mEq/L HCO_3^-.

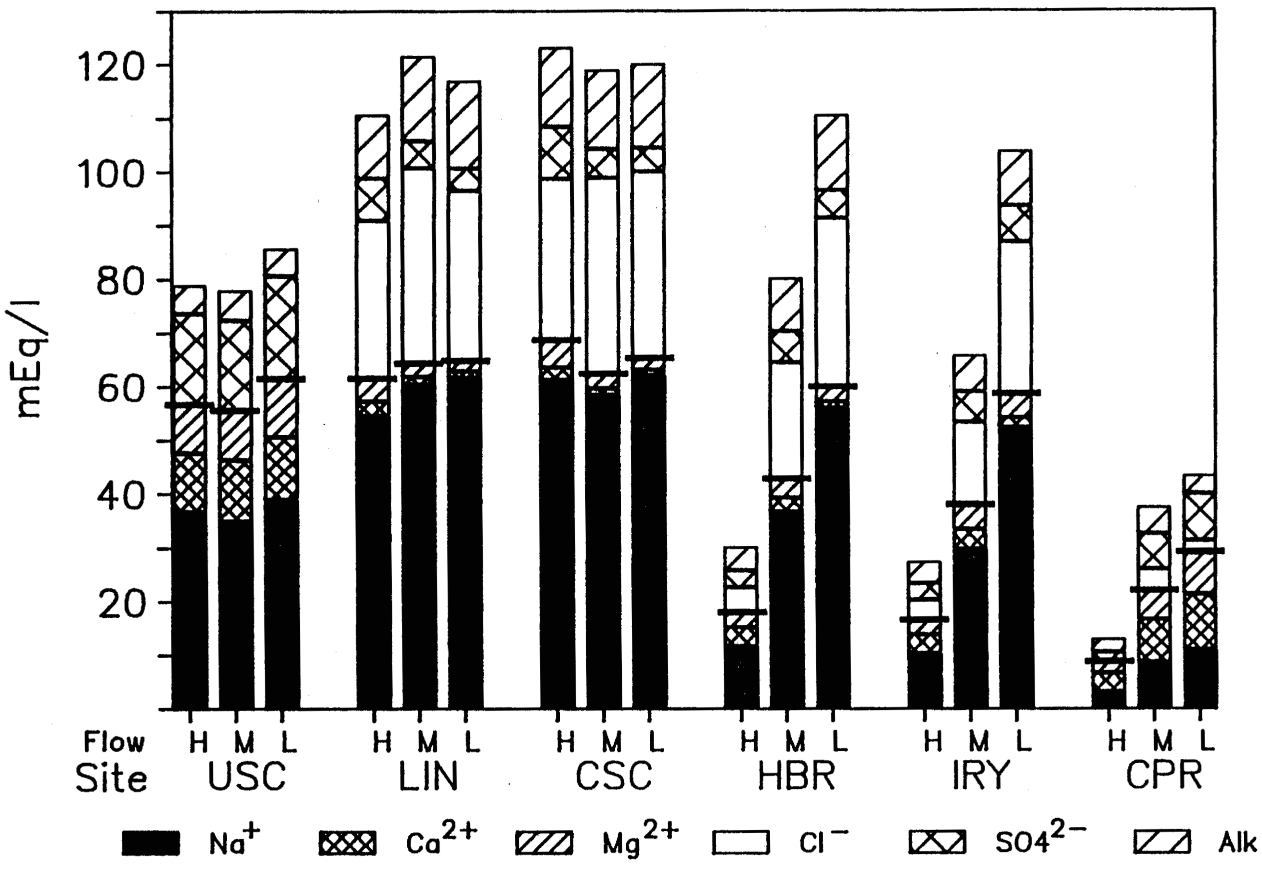

Figure 3. Cation and anion milliequivalent values for water collected during high (H) flow in May, medium (M) flow in October, and low (L) flow in August, 1988. USC = upstream Salt Creek, LIN = Linch, CSC = Salt Creek just upstream of confluence, HBR = Powder River 6 km downstream of confluence at Highway 192 bridge, IRY = Powder River 68 km downstream of confluence at Irigary bridge, CPR = Powder River just upstream of confluence. Horizontal line in each bar indicates division between cations and anions.

concentration of other ions. The comparison shows an imbalance, with total anion concentrations lower than total cation concentrations, especially at the upstream Salt Creek site (USC) and the upstream Powder River site (CPR). These same two sites also had much lower Cl^- concentrations compared to all other sites (Table 4).

Trace element concentrations were relatively low with few exceeding the upstream Salt Creek control values (Table 5). No major organic compounds were found in any water samples analyzed by HPLC methods using direct injection of the sample without prior concentration. Peaks that were detected at the beginning of each sample gradient, including the control, were considered to be the low molecular weight organic molecules naturally occurring in the samples.

Loading

Concentrations of several key ionic constituents were converted to loading in Kg/day (Table 6). Values increase substantially at the Linch site, but continue increasing at sites downstream in the Powder River. Ions depicting heaviest loading, Na^+, K^+ and Cl^-, were selected for graphical representation (Figure 4). Significant increases of these ions were found after oil field discharges entered Salt Creek.

Toxicity Tests

There were no significant effects on fathead minnow survival in any of the test waters (Figure 5 and Appendix Table 1). Fathead minnow weights were significantly lower than the upstream Salt Creek control (USC) at the upstream Powder River site (CPR) and in the 10% dilution of the Linch site (LIN) (but not the 100% or 50% dilution) during high flow,

Table 5. Concentrations of trace elements in Salt Creek and Powder River during high, medium and low flow periods, 1988.

Date	Site[b]	Element[a]									
		Al	As	Fe	Hg	Li	Mn	Ni	Pb	Se	Sr
May, 1988 High flow	USC	1.20	< 0.20	0.09	< 0.20	0.02	0.17	0.04	< 0.20	< 0.20	3.91
	LIN	0.40	< 0.20	0.09	< 0.20	0.26	0.01	0.02	< 0.20	< 0.20	2.33
	CSC	0.50	< 0.20	0.07	< 0.20	0.24	0.01	0.04	< 0.20	< 0.20	2.11
	HBR	0.70	< 0.20	< 0.01	< 0.20	0.02	< 0.01	0.03	< 0.20	< 0.20	0.89
	IRY	0.70	< 0.20	< 0.01	< 0.20	0.02	0.01	0.01	< 0.20	< 0.20	0.95
	CPR	0.70	< 0.20	0.03	< 0.20	<0.01	0.01	0.04	< 0.20	< 0.20	0.65
October, 1988 Medium flow	USC	0.80	< 0.20	0.04	< 0.20	0.01	< 0.01	0.03	< 0.20	< 0.20	4.05
	LIN	1.90	< 0.20	< 0.01	< 0.20	0.26	0.01	0.02	< 0.20	< 0.20	1.87
	CSC	0.80	< 0.20	0.01	< 0.20	0.26	< 0.01	0.03	< 0.20	< 0.20	1.97
	HBR	1.50	< 0.20	< 0.01	< 0.20	0.13	< 0.01	< 0.01	< 0.20	< 0.20	1.73
	IRY	1.10	< 0.20	< 0.01	< 0.20	0.13	< 0.01	< 0.01	< 0.20	< 0.20	1.69
	CPR	0.80	< 0.20	< 0.01	< 0.20	0.05	< 0.01	0.03	< 0.20	< 0.20	1.97
August, 1988 Low flow	USC	1.60	< 0.20	0.09	< 0.20	0.02	0.01	0.05	< 0.20	< 0.20	4.97
	LIN	0.80	< 0.20	0.05	< 0.20	0.26	< 0.01	< 0.01	< 0.20	< 0.20	1.68
	CSC	0.60	< 0.20	0.05	< 0.20	0.27	< 0.01	0.02	< 0.20	< 0.20	1.30
	HBR	1.70	< 0.20	0.03	< 0.20	0.23	< 0.01	0.03	< 0.20	< 0.20	1.24
	IRY	0.70	< 0.20	0.02	< 0.20	0.21	< 0.01	0.04	< 0.20	< 0.20	1.63
	CPR	0.60	< 0.20	0.04	< 0.20	0.08	0.06	0.04	< 0.20	< 0.20	2.88

[a] Values expressed as mg/L.

[b] Sample collection sites are shown in Figure 1.

Table 6. Daily loading of major inorganic ions in Salt Creek and Powder River during high, medium and low flow periods, 1988.[a]

Date	Site[b]	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	SO_4^{2-}
May 1988	USC	1447.15	375.06	186.67	14.90	13.70	1385.49
High flow	LIN	147381.47	6458.95	6106.64	2137.32	122367.72	44977.77
	CSC	165583.96	5519.47	7281.00	2019.89	125186.17	54724.91
	HBR	234078.18	62013.25	27949.63	3319.02	149355.85	132760.76
	IRY	227460.20	66620.14	29503.21	3711.69	132288.57	141805.73
	CPR	46078.73	44185.08	15149.17	1136.19	5049.72	53653.31
October 1988	USC	2954.24	840.40	411.02	32.29	29.36	2950.57
Medium flow	LIN	146231.58	3156.08	3156.08	1662.20	136132.13	25459.02
	CSC	174403.85	3241.71	4279.05	2061.73	168439.11	33713.76
	HBR	171590.29	10356.34	8528.75	1807.28	157781.84	57264.45
	IRY	174293.76	18828.81	13485.50	2773.43	140452.78	69463.06
	CPR	12722.17	10241.35	4071.10	298.97	9159.96	20355.48
August 1988	USC	87.59	23.00	12.92	1.13	0.78	89.45
Low flow	LIN	107698.08	1820.25	1820.25	1061.81	85172.49	15472.12
	CSC	104957.92	1467.94	1908.33	1086.28	90865.67	15780.39
	HBR	167272.09	3112.04	4279.05	1841.29	144969.15	32287.40
	IRY	55719.44	1710.89	2450.73	675.11	46517.64	14889.34
	CPR	2175.00	1781.10	796.36	68.50	702.17	3587.90

[a] Values are expressed as Kg/day.

[b] Sample collection sites are shown in Figure 1.

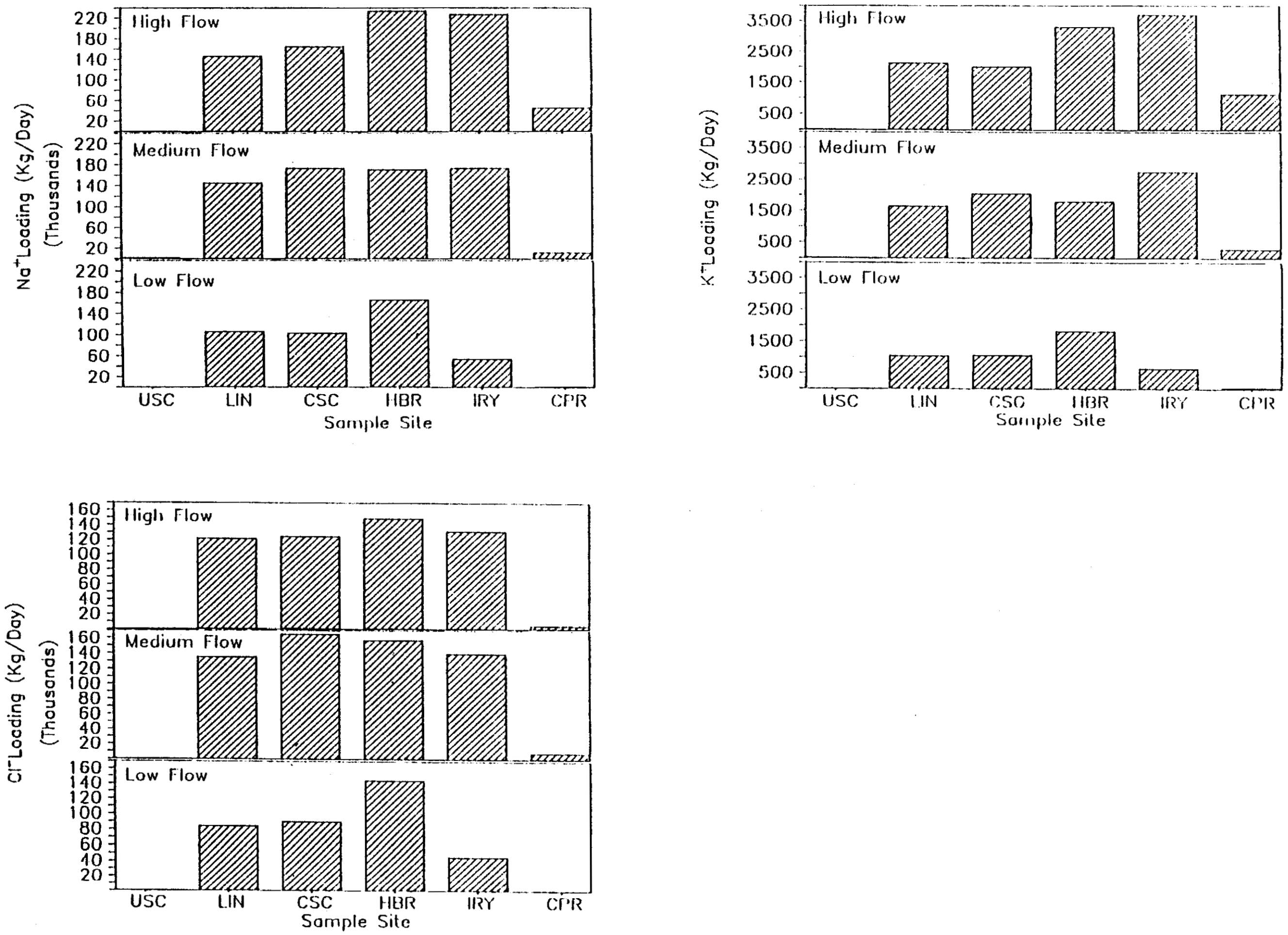

Figure 4. Daily loading of Na^{+}, K^{+}, and Cl^{-} during high flow in May, medium flow in October and low flow in August, 1988. USC = upstream Salt Creek, LIN = Linch, CSC = Salt Creek just upstream of confluence, HBR = Powder River 6 km downstream of confluence at Highway 192 bridge, IRY = Powder River 68 km downstream of confluence at Irigary bridge, CPR = Powder River just upstream of confluence.

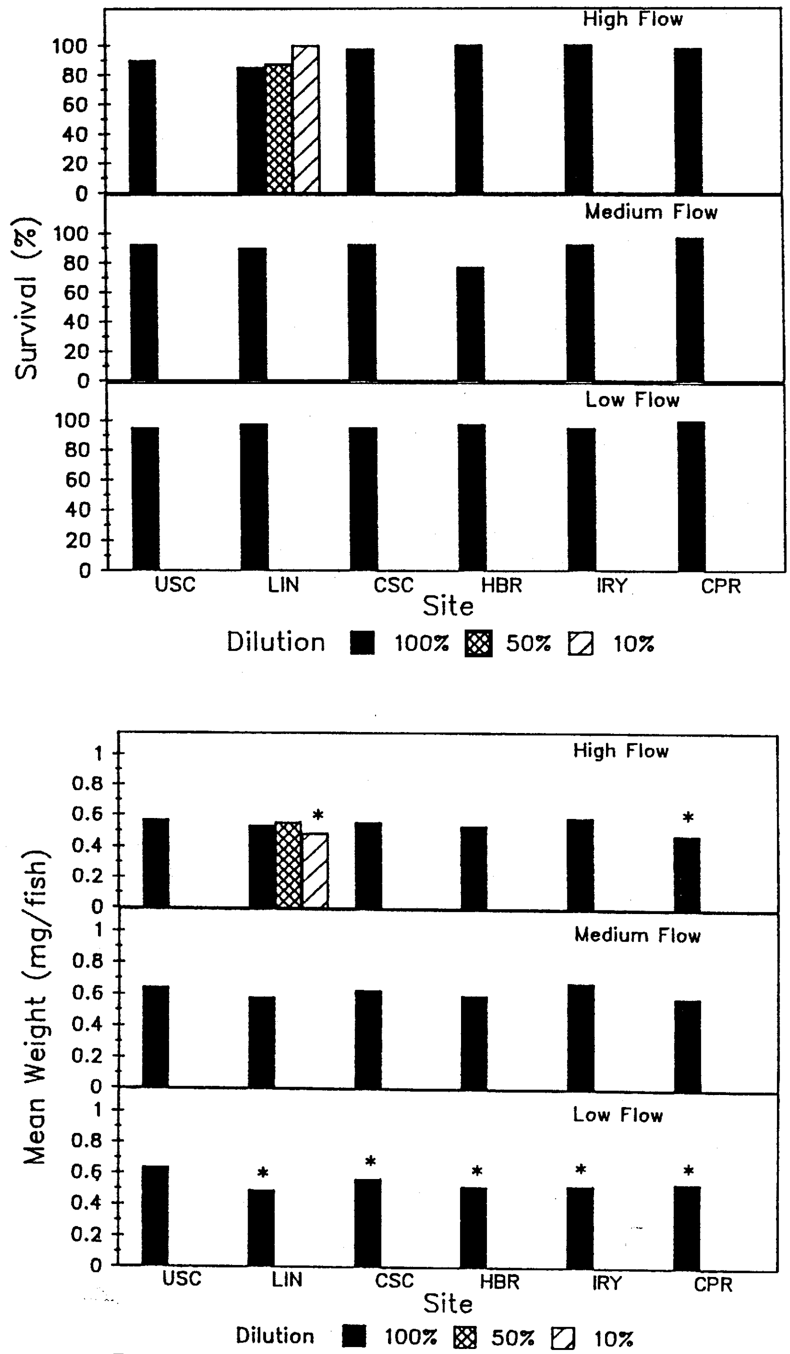

Figure 5. Fathead minnow (Pimephales promelas) survival and weight in toxicity tests conducted in waters collected during high flow in May, medium flow in October, and low flow in August, 1988. USC = upstream Salt Creek, LIN = Linch, CSC = Salt Creek just upstream of confluence, HBR = Powder River 6 km downstream of confluence at Highway 192 bridge, IRY = Powder River 68 km downstream of confluence at Irigary bridge, CPR = Powder River just upstream of confluence. * = significantly lower survival or weight than control (upstream Salt Creek) (P = 0.05).

and at all sites during low flow (Figure 5 and Appendix Table 1).

As shown in Figure 6 and Appendix Table 1, no Ceriodaphnia survived in ambient waters collected during all three flow regimes from the Linch site (LIN), or the Salt Creek site just upstream of the confluence (CSC). In Powder River waters, survival was significantly reduced at the Highway 192 bridge site (HBR) during medium flow, and no Ceriodaphnia survived at this site and the Irigary bridge site (IRY) during low flow.

For Ceriodaphnia survival, tests with diluted ambient waters (Figure 6 and Appendix Table 1) indicated reduced toxicity for all flow regimes in 50% dilutions of water from Linch (LIN), Salt Creek just upstream of the confluence (CSC), Highway 192 bridge (HBR), and at the Irigary bridge site (IRY). The exception to this was at the Linch site during medium flow, when water had to be diluted to 25% to eliminate significant mortality effects.

Sites where all organisms died were not included in statistical comparisons of Ceriodaphnia mean number of young. No significant effects on the number of young produced were seen in the Powder River sites during high flow (Figure 6 and Appendix Table 1). At the Linch site, diluting the water by 50% reduced the toxicity. No dilutions were tested for the Salt Creek site just upstream from the confluence (CSC). During medium flow, effects were seen at the Highway 192 bridge site (HBR) and the Irigary bridge site (IRY). Diluting the HBR sample by 50% reduced the toxicity, and 50% dilutions of water from the Linch site and the Salt Creek site just upstream from the confluence (CSC) also were not toxic. No dilutions were tested for the IRY site. During low flow, the mean number of young produced was not significantly different from the control in 50% dilutions of the CSC, HBR and IRY sites. At the Linch site (LIN),

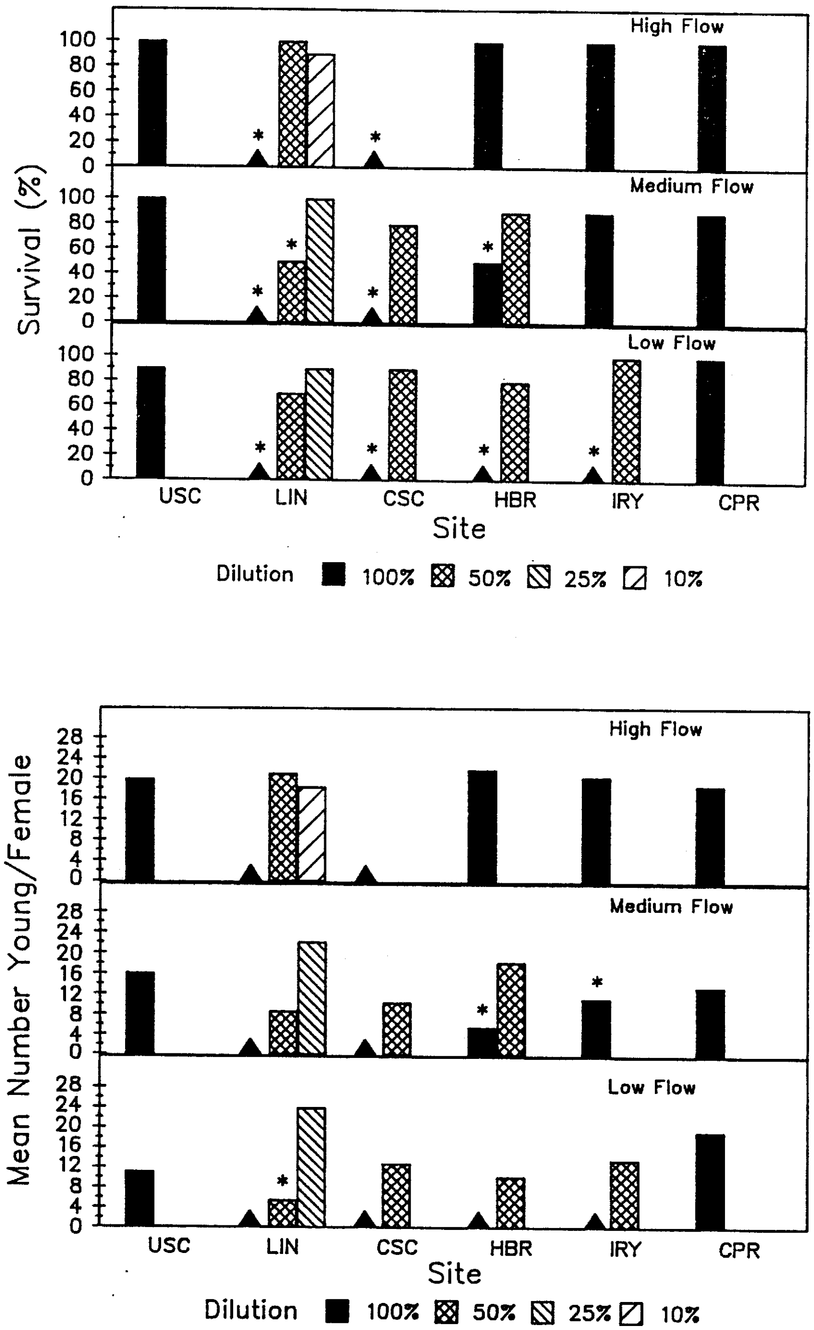

Figure 6. <u>Ceriodaphnia dubia</u> survival and reproduction in toxicity tests conducted in waters collected during high flow in May, medium flow in October, and low flow in August, 1988. USC = upstream Salt Creek, LIN = Linch, CSC = Salt Creek just upstream of confluence, HBR = Powder River 6 km downstream of confluence at Highway 192 bridge, IRY = Powder River 68 km downstream of confluence at Irigary bridge, CPR = Powder River just upstream of confluence. ▲ = all organisms died in the undiluted ambient water. * = significantly lower survival or mean number of young than control (upstream Salt Creek) (P = 0.05).

a 25% dilution was needed to reduce toxicity.

Statistical regressions that separately regress anions, cations, alkalinity, pH, conductivity and flow (cfs) against fathead minnow survival show significant ($P < 0.05$) correlations with Na^+, K^+ and flow (cfs), but they only accounted for 14%, 11% and 18% of the variance, respectively (Table 7). None of the parameters were significant in accounting for variance in fathead minnow weights.

Several parameters significantly accounted for the variance in Ceriodaphnia survival (Table 7). Alkalinity and pH, for example, accounted for 94% and 81% of the variance, respectively. The inorganic ions Na^+, K^+ and Cl^-, accounted for 90, 82 and 94% of the variance, respectively. Two of these ions, Na^+ and K^+, made significant contributions to the variance in the mean number of Ceriodaphnia young, but not as much as alkalinity which accounted for 70% (Table 7).

Chemical variables which significantly accounted for toxicity (Na^+, K^+, Cl^-, alkalinity and pH) were highly correlated with each other, and with other chemical and physical parameters (Table 8). Na^+, K^+ and Cl^-, for example, showed a high degree of covariance with each other and with alkalinity and pH.

Macroinvertebrate and Vertebrate Survey

Sample sites along Salt Creek and the Powder River had a poor faunal structure, as shown in Table 9. The number of species collected at each site was low, especially where the flow was medium to high (50 - 300 cfs) and aquatic vegetation or submerged habitat scarce. Both the upstream sites on the Salt Creek and Powder River had the highest number of species collected. The Orders of Coleoptera, Diptera and Odonata had the

Table 7. Regression analyses for fathead minnow (*Pimephales promelas*) survival and *Ceriodaphnia* survival and reproduction during 7-day toxicity tests versus chemical and physical variables.

Toxicity Test	Parameter	Coefficient	Intercept	R^2
Fathead Minnows				
% Survival	Na^+	-0.0008	3.59	0.14
	K^+	-0.0727	3.64	0.11
	Cl^-	ns[a]	--	--
	Mg^{2+}	ns	--	--
	Ca^{2+}	ns	--	--
	SO_4^{2-}	ns	--	--
	Alkalinity	ns	--	--
	pH	ns	--	--
	Conductivity	ns	--	--
	cfs	+0.0049	2.49	0.18
Ceriodaphnia				
% Survival	Na^+	-0.0108	10.41	0.90
	K^+	-0.9056	10.44	0.82
	Cl^-	-0.0083	5.63	0.94
	Mg^{2+}	+0.0358	-1.84	0.25
	Ca^{2+}	+0.0811	-4.89	0.63
	SO_4^{2-}	+0.0026	-0.86	0.06
	Alkalinity	-0.0200	8.81	0.94
	pH	-14.2850	120.70	0.81
	Conductivity	-0.0009	4.05	0.34
	cfs	+0.0083	-5.69	0.12
Mean No./Young	Na^+	-0.0114	20.90	0.55
	K^+	-1.0310	22.38	0.45
	Cl^-	ns	--	--
	Mg^{2+}	ns	--	--
	Ca^{2+}	ns	--	--
	SO_4^{2-}	ns	--	--
	Alkalinity	-0.0416	25.95	0.70
	pH	ns	--	--
	Conductivity	-0.0025	20.70	0.30
	cfs	ns	--	--

[a] ns = not significant ($P < 0.05$).

Table 8. Correlations among chemical and physical variables measured in Salt Creek and Powder River waters.

Bivariate correlation coefficient (r) between Variable 1 and Variable 2[a]

	Variable 2				
Variable 1	Na^+	K^+	Cl^-	Alk	pH
Na^+	1.00	0.94*[b]	0.86*	0.92*	0.68*
Ca^{2+}	-0.46	-0.41	-0.80*	-0.69*	-0.70*
Mg^{2+}	-0.15	-0.07	-0.58*	-0.46	-0.54*
K^+	0.94*	1.00	0.84*	0.85*	0.62*
Cl^-	0.86*	0.84*	1.00	0.96*	0.77*
SO_4^{2-}	0.09	0.11	-0.40	-0.25	-0.40
Alkalinity	0.92*	0.85*	0.96*	1.00	0.73*
Conductivity	0.69*	0.70*	0.57*	0.70*	0.30
pH	0.68*	0.62*	0.77*	0.73*	1.00
Flow (cfs)	-0.57*	-0.61*	-0.31	-0.40	-0.15

[a] $n = 18$

[b] * Significant correlation ($P < 0.05$).

Table 9. Macroinvertebrate and vertebrate organisms collected at sampling locations along Salt Creek and Powder River, Wyoming during high flow (H) in May, medium flow (M) in October, and low flow (L) in August, 1988[a].

	USC Upstream Salt Creek			LIN Linch			CSC Confluence up Salt Creek			CPR Confluence up Powder River			HBR Highway 192 Bridge			IRY Irigary Bridge		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
MACROINVERTEBRATES																		
OLIGOCHAETA	-	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-
GASTROPODA																		
Physa sp.	X	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
HEMIPTERA																		
Corixidae[b]	-	-	X	-	-	X	-	-	-	X	-	X	-	-	-	-	-	-
Gerris sp.	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
COLEOPTERA																		
Dytiscidae[b]	-	-	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-
Curculionidae[b]	-	-	-	-	-	-	-	-	-	X[c]	-	-	-	-	-	-	-	-
Hydrophilidae[b]	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
DIPTERA																		
Chironomidae[b]	-	-	X	X	-	X	-	-	-	X	-	X	X	-	-	-	-	-
Simuliidae[b]	-	-	-	-	-	X	-	-	-	X	-	X	-	-	-	-	-	-
Tabanidae[b]	-	-	-	-	-	-	-	-	-	X[c]	-	-	-	-	-	-	-	-
ODONATA																		
Coenagrionidae[b]	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Gomphaeschna sp.	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Lestis sp.	X	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
Argia sp.	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stylurus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X
EPHEMEROPTERA																		
Baetidae[b]	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
Heptagenia sp.	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-
Baetis sp.	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-
Callibatis sp.	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Ephemerella sp.	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
TRICHOPTERA																		
Psychomyiidae[b]	X[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VERTEBRATES																		
Cyprinidae																		
Pimephales promelas	X	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	X
Campostoma anomalum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X
Hybopsis gracilis	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Semotilus atromaculatus	-	-	X	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-
Cyprinodontidae																		
Fundulus kansae	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-

[a] qualitative survey; X = organism present, - = organism not present

[b] keyed to family only

[c] adult

[d] pupa

greatest representation. Sites with the least number of species collected were Salt Creek just upstream of the confluence with the Powder River (CSC), Highway 192 bridge (HBR), and Irigary bridge (IRY) on the Powder River.

At three sites, upstream Salt Creek, the Powder River upstream from the confluence, and Irigary bridge, fish were collected in the kick nets.

DISCUSSION

Production waters released from the upper Salt Creek oil field have toxic effects on surface waters in the Salt Creek and Powder River drainages. In this oil field, all produced water discharges that reach Salt Creek enter the creek between the upstream Salt Creek sample site and the sample site at Linch. Our toxicity tests show adverse effects on aquatic organisms at the Linch site and at sites far downstream in the Powder River. Indeed, in August 1988, when Salt Creek comprised about 89% of the Powder River flow, toxicity was measured 68 km downstream from the confluence of Salt Creek and the Powder River.

Ceriodaphnia were the more sensitive of the two test organisms we used. Survival and reproduction were significantly reduced at the Linch site and at one or more downstream sites during all flow regimes studied. Toxicity increased as stream flow decreased; at low flow, no *Ceriodaphnia* survived in ambient stream waters from Linch and all downstream sites.

Fathead minnows were more tolerant of the waters. Their survival was not affected, but there were effects on fish weight. During high flow, mean weight was significantly higher in water samples from upstream Salt Creek (USC) than in waters from the upstream Powder River site and in the Linch 10% dilution, but not in the 50% dilution or the 100% Linch sample. These differences may be due to the possibly lower nutrient content of the upstream Powder River water and the diluted Linch water. Alternatively, for the 100% and 50% Linch dilutions, chemical complexations in the highly saline water may have masked toxicants that were detected in the 10% dilution. During low flow, significant reductions in fathead minnow weights were seen at Linch and all downstream sample sites, again indicating that toxicity increased as stream flow decreased.

We did not detect acute or short-term chronic toxic effects attributable to non-polar, high molecular weight organic compounds, based on HPLC analyses of these samples. However, the analyses did not include extraction and concentration methods, and some organics may have been present but were not detected because we used a relatively insensitive method. Furthermore, the duration of these short-term toxicity tests may not be long enough to detect effects of chemicals that act through different modes of action, requiring longer exposure. Steadman (1986) examined enzyme activity in fish exposed to Number 2 Fuel Oil and to petroleum refinery effluents. He found these exposures did not result in typical exposure-response profiles but rather involved complex responses, including exposure and time interactions. Chronic sublethal exposure to petroleum and petroleum-derived compounds has been shown to disrupt circulatory, osmoregulatory, central nervous system, and possibly immunological functions in fish (Whitman et al. 1982). These effects can lead to disruption of social and reproductive behavior, feeding activity and predator avoidance.

A volatile compound associated with oil production, H_2S, is suspected as a major toxicant in oil field discharges. However, the characteristic odor of H_2S was not present in the ambient water samples we collected. If H_2S was present in discharges to Salt Creek, it had been dissipated by dilution with the Salt Creek receiving water or was purged by the time toxicity tests were conducted. No manipulations, such as pH adjustment and aeration, were conducted on the sample waters.

None of the ten trace elements analyzed in this study appeared to contribute to the toxicity of the water samples. However, bioavailability of many elements is difficult to predict since their toxicities have not been determined in saline waters. And other trace elements, such as Cd, Cr and Zn, could be present but were not examined in this study.

Toxicity tests and comparative chemical analyses show that an increase in salinity is detrimental to Ceriodaphnia survival and reproduction and to fathead minnow growth. Significant correlations can be shown between toxicity and individual ions, and between toxicity and other parameters such as alkalinity and pH. However, singling out any one ion or parameter as a major toxicant would be misleading due to the covariance among all these variables.

Evaluation of loading values for major inorganic ions shows a considerable increase in salts at the Linch site. But since ion concentrations continue increasing at downstream sites, it appears there are inputs of salts to the Powder River from sources other than oil field discharge waters. Contributions from other sources would have to be examined before definitive statements about salt loading from oil field discharges could be made.

The qualitative survey of stream fauna showed no obvious trends of species change due to produced water discharges, although effects due to such discharges cannot be ruled out completely. The lack of suitable habitat in both the Salt Creek and Powder River influenced low community development. Also, the sampling schedule (May, August and October) was not frequent enough to observe many aquatic invertebrate life stages.

SUMMARY AND CONCLUSIONS

In this study, we (1) evaluated the ambient toxicity of Salt Creek waters above and below the area where oil field production waters are discharged into the creek, (2) evaluated the persistence of toxicity downstream in Powder River waters, (3) began characterization of the salt load, organic compounds and trace elements introduced by oil field discharge waters, (4) examined the contribution of chemical and physical parameters to toxicity, and (5) conducted a qualitative survey of stream fauna. Results are as follows:

- Production water discharges from the upper Salt Creek oil field have toxic effects on surface waters in Salt Creek and the Powder River.
- Toxicity increased as stream flow decreased. During low flow, when the Powder River consisted mostly of water contributed by Salt Creek, toxicity was measured as far as 68 km downstream from the confluence of Salt Creek and the Powder River.
- Toxicity could not be attributed to organic compounds or trace elements, as measured in this study.
- Salinity, alkalinity and pH correlated well with observed toxicity, but could not be singled out individually because of a high degree of covariance.
- Suitable habitat for macroinvertebrates was scarce at most sample sites. Therefore, the qualitative survey of stream fauna was of minimal use in detecting detrimental effects from oil field discharge waters.

During Year 2 of this study, we will collect stream water samples for toxicity tests, and for further characterization through Toxicity Identification Evaluation (TIE) procedures (USEPA 1988). This will include measurement of trace elements not included in Year 1 analyses, and extraction/concentration analyses for organic compounds. Because organic contaminants may be bound to sediments, we will also collect sediment samples for extraction and toxicity tests.

REFERENCES

American Public Health Association (APHA). 1980. Standard methods for the examination of water and wastewater. 15th Edition. American Public Health Association, Washington, D.C.

Bille, E. 1978. Early days at Salt Creek and Teapot Dome. Mountain States Lithographing Company, Casper, WY. 170 pp.

Cotlove, E., H.V. Trantham and R.L. Bowman. 1958. An instrument for and method for automatic, rapid, accurate, and sensitive titration of chloride in biological samples. J. Lab. Clin. Med. 50(3):358-371.

Dixon, W.J., M.B. Brown, L. Engleman, J.W. Frane, M.A. Hill, R.I.Jennrich and J.D. Toporek. 1985. BMDP Statistical Software. University of California Press, Berkeley, CA. 734 pp.

Drever, J.I. 1982. The Geochemistry of Natural Waters. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Dunnett, C.W. 1955. A multiple comparison procedure for comparing several treatments with a control. J. Amer. Stat. Assoc. 50:1096-1121.

Dunnett, C.W. 1964. New tables for multiple comparisons with a control. Biometrics 20:482-491.

Gerhardt, D.R. 1989. Population dynamics, movement and spawning habitat of channel catfish in the Powder River system, Wyoming-Montana. M.S. Thesis. University of Wyoming, Laramie, WY.

Gulley, D.D., A.M. Boelter and H.L. Bergman. 1988. TOXSTAT Version 2.1. Department of Zoology and Physiology, University of Wyoming, Laramie, WY.

Hodson, W.G., R.H. Pearl and S.A. Druse. 1971. Water resources of the Powder River Basin and adjacent areas, Northeastern Wyoming. Department of the Interior, USGS, Wyoming State Engineer, Hydrologic Investigations Atlas HA - Open file report, Utah International, Inc.

Meyer, J.S., A. Boelter and M.J. Crossey. 1988. Evaluation of Ambient Toxicity Tests for Detecting Groundwater Pollution Entering Streams and Rivers: Final Report. USGS G-1262, U.S. Geological Survey, Department of Interior.

Mount, D.I., N.A. Thomas, T.J. Norberg, M.T. Barbour, T.H. Roush and W.F. Brandes. 1984. Effluent and Ambient Toxicity Testing and Instream Community Response on the Ottawa River, Lima Ohio. U.S. Environmental Protection Agency, EPA 600/3-84-080.

Neter, J., W. Wasserman and M.H. Kutner. 1985. Applied Linear Statistical Models. Richard D. Irwin, Inc., IL.

Pettyjohn, W.A. 1971. Water pollution by oil-field brines and related industrial wastes in Ohio. Ohio J. Sci. 71(5):257-269.

Rehwinkel, B.J., M. Gorges and J. Wells. 1978. Powder River Aquatic Ecology Project. Final Report, Utah International, Inc.

Smith, J.B. 1987. Movement and spawning of fishes in Crazy Woman Creek, a tributary to the Powder River, Wyoming. M.S. Thesis. University of Wyoming, Laramie, WY.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Co., San Francisco, CA.

SPSS, Inc. 1988. SPSS-X User's Guide, 3rd edition. Chicago, IL.

Steadman, B.L. 1986. Xenobiotic Metabolism in Rainbow Trout: Toxicology, Biochemistry and Biomonitoring. Ph.D. Dissertation, University of Wyoming, Laramie, WY.

Steel, R.G. 1959. A multiple comparison rank sum test: Treatments versus control. Biometrics 15:560-572.

Stewart, D.D. 1981. The Biology of the Sturgeon Chub (Hyobopsis gelida Girard) in Wyoming. M.S. Thesis, University of Wyoming, Laramie, WY.

U.S. Department of the Interior, U.S. Geological Survey. 1986. Water resource data for Wyoming. USGS Water-Data Report, WY-86-1.

U.S. Environmental Protection Agency (USEPA). 1985a. Methods for measuring the acute toxicity of effluents to freshwater and marine organisms. Environmental Monitoring Systems Laboratory, Cincinnati, OH. EPA/600/4-85/013.

U.S. Environmental Protection Agency (USEPA). 1985b. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA/600/4-85/014.

U.S. Environmental Protection Agency (USEPA). 1988. Methods for Aquatic Toxicity Identification Evaluations. Phase I Toxicity Characterization Procedures. Environmental Research Laboratory, Duluth, MN. EPA/600/3-88/034.

U.S. Environmental Protection Agency (USEPA). 1989. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA/600/4-89/001. 248 pp.

Whitman, R.P., E.L. Brannon and R.E. Nakatani. 1982. Literature Review on the Effects of Oil on Fishes and an Overview of Fish Chemoreception. Final Report to American Petroleum Institute, Washington, D.C.

Zar, J.H. 1984. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, NJ.

APPENDIX

Chronic Toxicity Test Results

Appendix Table 1. Seven-day survival and growth of fathead minnows (<u>Pimephales promelas</u>) and seven-day survival and reproduction of <u>Ceriodaphnia dubia</u> in toxicity tests conducted in Salt Creek and Powder River waters collected during high, medium and low flow periods, 1988.

		Fathead Minnows		<u>Ceriodaphnia</u>	
Date	Site[a]	Percent survival	Mean weight mg/fish[b]	Percent survival	Mean number young/female[b]
May 1988 High flow	USC	90.0	0.571 ± 0.017	100.0	19.9 ± 1.424
	LIN	85.0	0.534 ± 0.024	0.0*[c]	0.0
	LIN 50%	87.5	0.556 ± 0.023	100.0	21.0 ± 0.601
	LIN 10%	100.0	0.488 ± 0.011*	90.0	18.4 ± 2.414
	CSC	97.5	0.556 ± 0.035	0.0*	0.0
	HBR	100.0	0.534 ± 0.024	100.0	21.8 ± 1.705
	IRY	100.0	0.586 ± 0.023	100.0	20.3 ± 1.342
	CPR	97.5	0.479 ± 0.010*	100.0	18.7 ± 0.882
	Lab Control	100.0	0.489 ± 0.030	100.0	19.9 ± 0.407
October 1988 Medium flow	USC	92.5	0.646 ± 0.021	100.0	16.2 ± 0.554
	LIN	90.0	0.585 ± 0.022	0.0*	0.0
	LIN 50%	----[d]	----	50.0*	8.7 ± 2.925
	LIN 25%	----	----	100.0	22.2 ± 0.611
	CSC	92.5	0.632 ± 0.019	0.0*	0.0
	CSC 50%	----	----	80.0	10.5 ± 2.344
	HBR	77.5	0.601 ± 0.021	50.0*	5.7 ± 1.915*
	HBR 50%	----	----	90.0	18.4 ± 0.600
	IRY	92.5	0.682 ± 0.021	90.0	11.3 ± 0.943*
	CPR	97.5	0.589 ± 0.033	90.0	13.6 ± 1.600
	Lab Control	97.5	0.536 ± 0.017	90.0	17.6 ± 3.142
August 1988 Low flow	USC	95.0	0.641 ± 0.013	90.0	11.2 ± 1.569
	LIN	97.5	0.493 ± 0.010*	0.0*	0.0
	LIN 50%	----	----	70.0	5.6 ± 1.701*
	LIN 25%	----	----	90.0	24.0 ± 1.528
	CSC	95.0	0.567 ± 0.026*	0.0*	0.0
	CSC 50%	----	----	90.0	12.9 ± 1.716
	HBR	97.5	0.523 ± 0.016*	0.0*	0.0
	HBR 50%	----	----	80.0	10.3 ± 1.832
	IRY	95.0	0.529 ± 0.018*	0.0*	0.0
	IRY 50%	----	----	100.0	13.7 ± 1.955
	CPR	100.0	0.545 ± 0.019*	100.0	19.4 ± 1.166
	Lab Control	100.0	0.500 ± 0.023	100.0	19.1 ± 1.636

[a] Sample collection sites are shown in Figure 1. Tests were run with 100% sample water unless otherwise specified (e.g. Linch 10% = 10% Linch sample water and 90% hard reconsituted water).

[b] Values are expressed as mean ± one standard error of the mean.

[c] * indicates significantly different from the control (USC) (P = 0.05); laboratory control not included in statistical analyses. Data analyses for <u>Ceriodaphnia</u> mean number young/female include only those sites or dilutions with surviving adult organisms.

[d] ---- indicates test was not run.