

U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

**Chemical results and variability assessment of selected water-extractable  
constituents from soils of the Uncompahgre Project area, west-central Colorado**

by

K.C. Stewart\*, J.G. Crock\*, and R.C. Severson\*

Open-File Report 93-507

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

\*U.S. Geological Survey, Box 25046, MS 973, Denver Federal Center, Denver, CO 80225

1993

## CONTENTS

	Page
Introduction . . . . .	1
Field Sampling . . . . .	1
Sample Preparation . . . . .	5
Analytical Techniques . . . . .	5
Quality Control . . . . .	5
Description of Results . . . . .	6
Summary . . . . .	8
Acknowledgements . . . . .	8
References Cited . . . . .	8

## ILLUSTRATIONS

Figure 1. Index map showing location of the Uncompahgre Project area. . . . .	2
Figure 2. Map of the Uncompahgre Project area showing geologic units from which soil samples were taken . . . . .	3
Figure 3. Locations of soil sampling sites within townships . . . . .	4

## TABLES

Table 1. Distribution of samples by geologic units within townships of the Uncompahgre Project area. . . . .	11
Table 2. Analytical techniques, reporting units and lower limits of determination (LLD) for water-extractable variables. . . . .	12
Table 3. Summary statistics for water-extractable variables from reference soil SJS-1 . . . . .	13
Table 4. Geometric means, ranges and detection ratios of water-extractable variables for all soils of the Uncompahgre Project area . . . . .	14
Table 5. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Cretaceous Dakota Sandstone—Kd . . . . .	15
Table 6. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Cretaceous Mancos Shale—Km . . . . .	16
Table 7. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Quaternary terrace gravels—Qt. . . . .	17
Table 8. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Quaternary alluvium of Mancos Shale—Qm . . . . .	18
Table 9. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Quaternary (Recent) alluvium—Qr. . . . .	19
Table 10. Comparison of geometric means of water-extractable variables for soils from various studies of the western United States. . . . .	20
Table 11. Geometric means by geologic unit of water-extractable variables, total selenium and percent total selenium extractable by water for soils of the Uncompahgre Project area . . . . .	21
Table 12. Site and analytical variance of water-extractable variables and total selenium for soils of the Uncompahgre Project area. . . . .	22
Table 13. Correlations of selenium in alfalfa with total soil selenium	

and water-extractable soil variables of the Uncompahgre Project area and percent of total variance of selenium in alfalfa accounted for by each soil variable. . . . .	23
--	----

APPENDIX TABLE

Table AI. Analytical data listing of water-extractable variables for soils of the Uncompahgre Project area in ppm dry weight . . . .	24
---	----

## INTRODUCTION

In 1986, the Department of the Interior (DOI) began field screening studies to identify the nature and extent of potential water-quality problems that might be attributed to drainage from federally-funded irrigation projects in the western United States. Twenty areas were selected in 13 western states for reconnaissance level sampling. Based on results of the original field screening study, the DOI selected the Uncompahgre Project area (UPA) in west-central Colorado for a detailed study of the effects of irrigation on element mobility (fig. 1). In this irrigation project area, selenium concentrations of 40 ppm in bottom sediments of a reservoir (Sweitzer Lake) constructed on the Cretaceous Mancos Shale exceeded those for all areas screened except for the Middle Green River in Utah (Severson and others, 1987, Harms and others, 1990, Butler and others, 1991). Median total selenium concentrations in Uncompahgre River water at Delta, Colorado of 15  $\mu\text{g/L}$  for samples collected from 1968-1988 also exceeded the U.S. Environmental Protection Agency's chronic 4-day criterion of 5  $\mu\text{g/L}$  for protection of aquatic life (Butler and others, 1991; U.S. Environmental Protection Agency, 1987).

The purposes of this part of the detailed study were to determine the sources of selenium and other trace elements associated with agricultural soils and to examine their mobilization by irrigation and uptake into alfalfa (a wide-spread commercial crop). This report presents results for the water-extractable elements of soils from the project area and discusses their significance with respect to irrigation drainage and movement of selenium from soils into alfalfa.

## FIELD SAMPLING

An unbalanced, four-level, stratified random sampling design was used to assess variation in soil element concentrations among and within geologic units in the project area. Five geologic units were identified and described based on a composite of geologic maps (Marshall, 1959; Williams, 1964; Tweto and others, 1976; Steven and Hail, 1989) and soil survey maps of the project area (Cline and others, 1967). Soils derived from these five units (fig. 2) were sampled. In order of decreasing age these were: Upper Cretaceous Dakota Sandstone (Kd); Upper Cretaceous Mancos Shale (Km); Quaternary gravels derived from ancient terraces and alluvial fans (Qt); Quaternary (Holocene) alluvium derived from Mancos Shale (Qm); and Quaternary (Recent) alluvium deposited by the Uncompahgre River and other streams on their floodplains (Qr). One sample was obtained from alluvium derived from Dakota Sandstone (Qd) but was not included in the variability assessment since it occurred in only one township.

The study area covered 15 townships. Random sections were selected in each township until all geologic units occurring within a township had been selected in triplicate for soil and plant sampling (fig. 3). Table 1 shows the sample distributions by geologic unit from the randomly-selected sections. Township four had four sites for the geologic unit Km; geologic unit Qd was sampled only in township 13. If a site proved unacceptable at the time of sampling, either because of current irrigation or absence of alfalfa, it was moved to an adjacent section as close as possible to the original site.

Soil cores measuring 100 cm x 9 cm were removed with a bucket auger and composited. A 1-kg portion of the composite was placed in a paper bag for

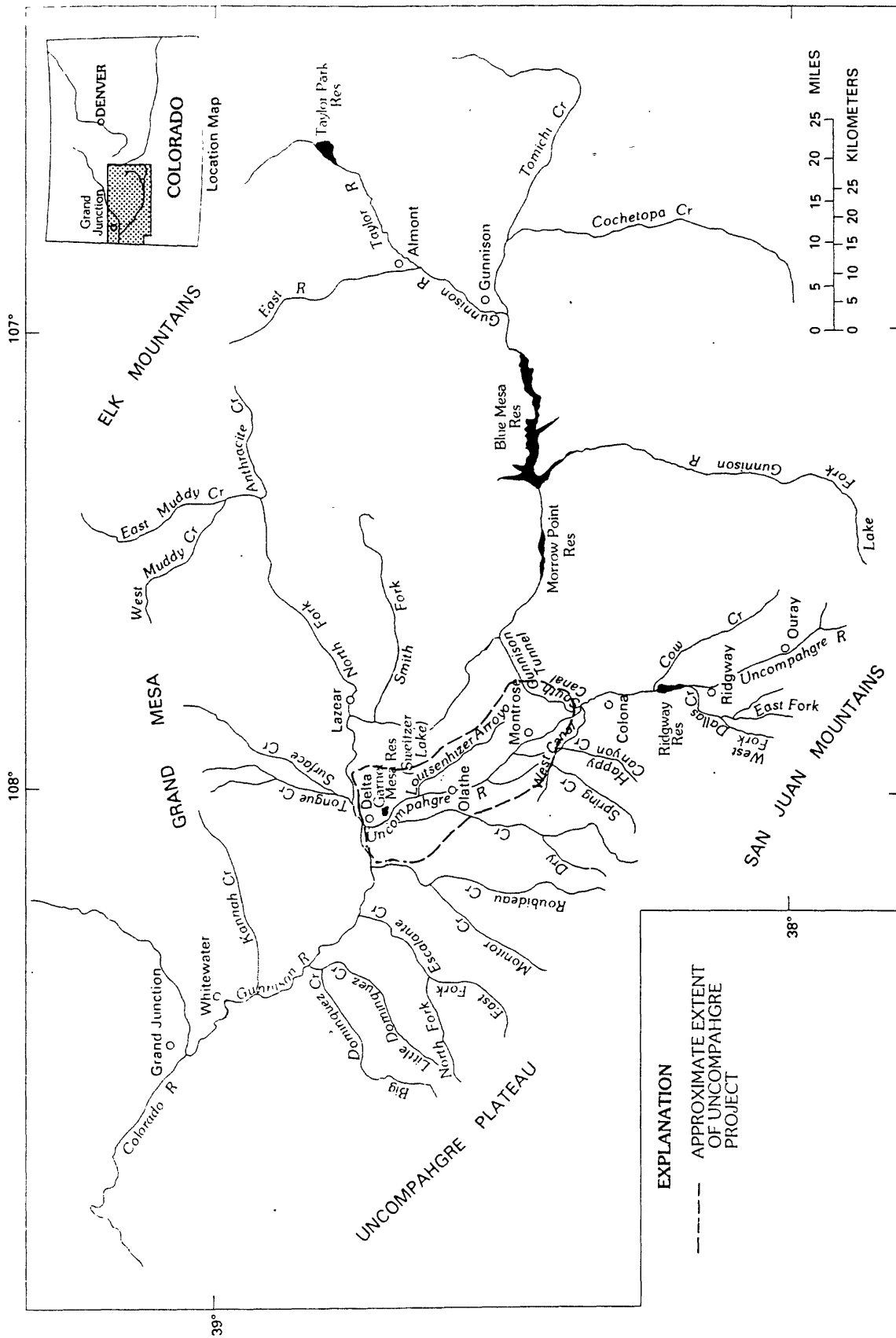


Figure 1. Index map showing location of the Uncompahgre Project area

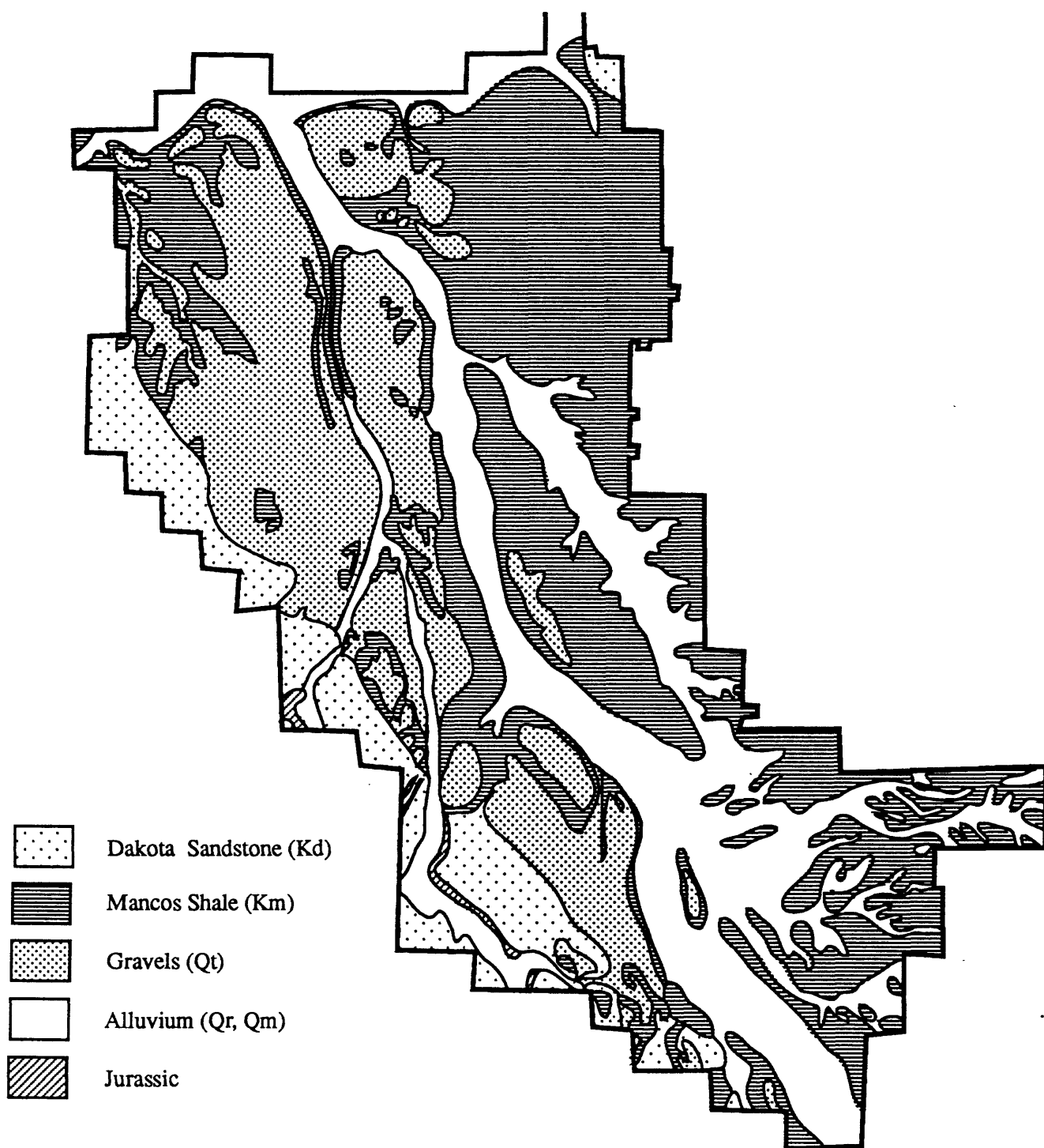


Figure 2. Map of the Uncompahgre Project area showing geologic units from which soil samples were taken

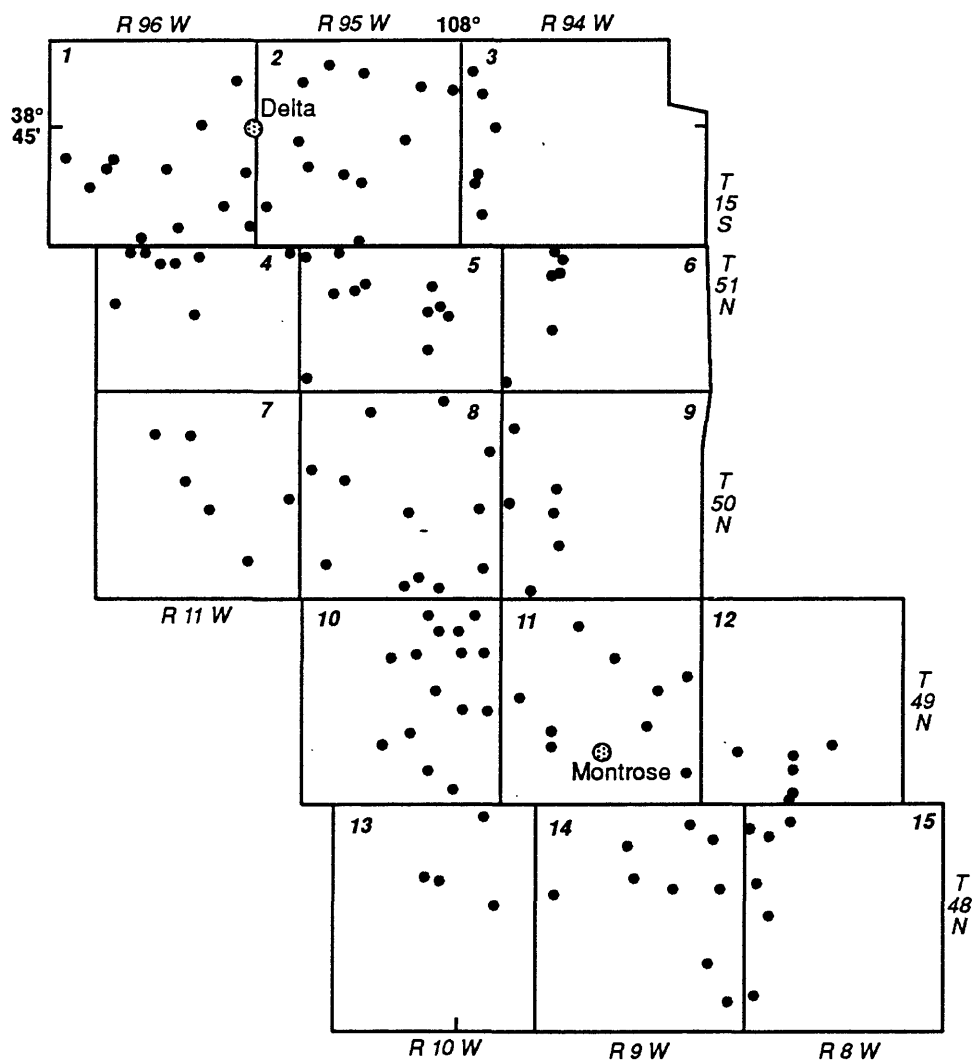


Figure 3. Locations of soil sampling sites within townships

transport to the laboratory. The top 20 cm of several alfalfa plants at 10 percent bloom stage (Medicago sativa L.) were cut within a few meters of the auger bore, composited, and placed in paper bags. Alfalfa samples were air-dried in the field before transport to the laboratory. When it was not possible to obtain alfalfa, only the soil core was taken. To assess variability within a section, two sites approximately 100 m apart were sampled in 14 randomly-selected sections.

#### SAMPLE PREPARATION

Soil samples were air dried in the laboratory at ambient room temperature (about 20° C), disaggregated with a mechanical mortar and pestle, and sieved to pass a 2-mm screen (10 mesh). Larger material was discarded. A split of this material was ground to less than 100 mesh with a ceramic-plate grinder for total analyses, but for the extractions, the unground, -2 mm fraction was used.

Soils were extracted with deionized water (1 part soil: 5 parts water, w:w) in 4-oz polypropylene bottles (Stewart and others, 1990). Soil material was kept in suspension by agitation on a horizontal reciprocating shaker for 16 hours at 58 oscillations per minute. Solutions were clarified by centrifugation at 15,000 rpm for 10 minutes, filtered through 0.45  $\mu$ m filters, and separated into two portions. One portion was stored untreated for anion analysis. The other portion was first used for conductivity and pH determinations, then acidified with nitric acid for arsenic and selenium determinations.

Soluble arsenic and selenium were predigested according to a modification of Presser and Barnes' method (1985). Organic matter was decomposed with potassium persulfate followed by digestion on a hotplate at 100° C and reduction with hydrochloric acid. The concentration of the final solution was 10 percent in hydrochloric acid.

#### ANALYTICAL TECHNIQUES

Specific conductivity of the extract was measured at room temperature by pouring the clarified solution directly into the pre-calibrated cell of a Myron L conductivity meter. A Fisher Accumant 925 pH meter equipped with a standard combination pH electrode was used for determination of solution pH. Anion determinations were made with a Dionex model 2010i chromatograph (Wilson and others, 1987). Selenium and arsenic hydrides were generated and detected by continuous-flow atomic absorption spectroscopy with a Perkin-Elmer 2380 spectrometer (Crock and Lichte, 1982). All values were reported on the basis of dry weight except pH and electrical conductivity (EC), which were reported in solution. Lower limits of determination (LLD) for variables are shown in table 2.

#### QUALITY CONTROL

In the laboratory, 14 soil samples were randomly chosen from all geologic units for analysis in duplicate to assess procedural error of the preparation and analytical techniques. Eight replicates of the in-house reference soil SJS-1 from the San Joaquin Valley, California were also



prepared and analyzed simultaneously with the UPA soil samples in order to monitor reproducibility of the extractions. The use of a quality-control soil with partial extractions enables comparisons to be made between studies, but no certified values exist for partial extractions of these materials. All soil samples, duplicates and reference soils were arranged in a randomized order and were processed in that order to convert any systematic laboratory error to random error.

## DESCRIPTION OF RESULTS

Table 3 presents the basic statistics for the in-house reference soil SJS-1 obtained from this study and from a previous study in California where this soil was used to monitor the extraction technique (Stewart and others, 1990). Arithmetic means from the UPA all compare favorably with the previous data. The means for extractable selenium, chloride and pH are all within one standard deviation of the previous data. The means for extractable sulfate and conductivity are higher than the previous means, but they are within the range of one standard deviation for the previous values. The precision for extractable element determination in this study was better than for the previous work. Because the method of preparation and analysis was the same and the data for the reference material are comparable between this study and the previous one, experimental data for soil samples from the two studies can be directly compared.

Table 4 presents the geometric means, ranges and detection ratios for extractable variables of all UPA soils. Analytical duplicates are not included in the calculations, and site duplicates are averaged to obtain one value for each site. Numbers in parentheses apply if site duplicates are considered as independent values as in the tabulation of total data (Crock and others, 1993). Of all the extractable variables, only arsenic concentrations were below the determination limit for some samples; the other variables could be measured in all samples. Tables 5-9 show the statistical summaries by geologic unit.

Table 10 presents water-extractable data from four areas in the western United States, which have been investigated by detailed studies connected with the National Irrigation Water Quality Program since its inception. Water-extractable data from the UPA can be rigorously compared only with data from the San Joaquin Valley because the other studies used different extraction times, soil fraction or digestion technique, but general tendencies can be ascertained. All extractions were done at a 1:5 soil:water ratio.

Soils from the Kendrick Project in Wyoming show the highest extractable selenium—39 ppb (table 10). Extractable selenium of 27 ppb from soils of the UPA is only about 2/3 of that from Kendrick. Extractable sulfate, however, is highest from UPA soils and is the major ion responsible for conductivity in the extracts. Soils from the Carson Sink show higher conductivity than soils from the UPA, but a higher proportion of the conductivity is due to chloride. This would be consistent with evaporative concentration of irrigation drainage in the Carson Sink (Hoffman and others, 1990) compared with relatively good drainage of soils in the UPA. Extractable arsenic is 50 times lower in soils from the UPA than in soils from the Carson Sink (table 10) and was detectable in only 52 percent of UPA soils (table 4). The mean pH of extracts from UPA soils is comparable to the other areas except the San Joaquin Valley where the

pH is one unit lower.

Table 11 compares geometric means for extractable variables, total selenium (Crock and others, 1993), and percent of total soil selenium extractable by water for all geologic units. Values for the single site in geologic unit Qd are also listed. The Mancos Shale units (Km and Qm) clearly have the highest total selenium, but all geologic units have total selenium concentrations above the geometric mean for western soils of 0.23 ppm (Shaklette and Boerngen, 1984). The Km and Qm units also have the highest water-extractable selenium. The percent of total selenium extractable by water is less than 3 percent for all the units. Mean extractable sulfate from Mancos-derived alluvium is one third that of the Mancos Shale, which may reflect long-term dissolution of gypsum by irrigation water. Mean conductivity, which closely parallels sulfate, is also lower for the alluvium than for the shale. Mean extractable chloride is higher in the two Mancos units than the others. For both shale-derived units extractable arsenic has a detection ratio of less than 60 percent. The pH of the extract is consistently alkaline for all geologic units.

Table 12 lists the site and analytical variance for the water-extractable variables and total selenium from soils of the UPA. The total variance for extractable selenium is twice that for total selenium. That is, the range of values was larger for extractable selenium than for total selenium relative to the amounts measured in the soils. Total selenium shows a larger percentage of the total variance among the geologic units and smaller percentage within geologic units than does the extractable selenium. This means that differences within units are relatively small. For extractable selenium, however, within-unit differences among townships, sections and within sections have a greater tendency to obscure subtle but still-significant differences between geologic units. This suggests that selenium is being mobilized and redistributed by irrigation water.

Chloride, on the other hand, shows 59 percent of its total variance within sections and probably reflects drainage and water evaporation patterns in individual fields. This was the only percentage that was significant at the 0.05 probability level.

Sulfate shows the largest variance of all the extractable constituents. Forty-four percent of its total variance could be attributed to geologic units and is probably accounted for by differences in gypsum content. The variability for sulfate was also significant among townships, sections and within sections. Conductivity follows the same trend as sulfate, which suggests that conductivity is mostly due to sulfate.

A large percentage of the total variance for pH measurements is found in the laboratory analyses, but statistically significant differences among geologic units can still be shown. The differences among sections are even greater than among geologic units.

Table 13 shows correlations among water-extractable soil variables, total soil selenium, and selenium in alfalfa. Water-extractable arsenic was not included because the detection ratio for all samples was less than 60 percent. All variables listed in the table show statistically significant correlations except pH with selenium in alfalfa and chloride, respectively. The highest correlation is shown for sulfate with conductivity (EC). Total soil selenium shows a relatively high correlation with water-extractable selenium. Selenium in alfalfa shows the highest correlation with water-extractable selenium and slightly less with total soil selenium. The last

column states the percent of the total variance for alfalfa selenium accounted for by these variables. Twenty-two percent of the total variance in alfalfa selenium is accounted for by water-extractable selenium; 18 percent by total soil selenium. This means that about 80 percent of the variance in alfalfa selenium is accounted for by factors other than total or water-extractable soil selenium. Other water-extractable variables each account for less than 8 percent of the variance in alfalfa selenium.

#### SUMMARY

Soils derived from five geologic units in the Uncompahgre Project area were examined for water-extractable selenium, arsenic, sulfate, chloride, pH and conductivity. Soils derived from the Cretaceous Mancos Shale (Km) and its alluvium (Qm) contained the highest concentrations of extractable selenium, sulfate and chloride, and also had the highest conductivities. Only 30 percent of the total variability in extractable selenium was accounted for by geologic units. In comparison, 57 percent of the total variance for total selenium was accounted for by geologic units. Mancos-derived alluvium contained even higher concentrations of total and extractable selenium than its parent unit. Of all variables analyzed, including total soil values (Crock and others, 1993), water-extractable soil selenium had the highest correlation with selenium in alfalfa from the same sites. Twenty-two percent of the total variation in alfalfa selenium was accounted for by extractable selenium. The data suggest that irrigation water is mobilizing and redistributing selenium in the project area and that selenium contents of alfalfa directly reflect this mobilization.

Extractable sulfate was highest in residual soils derived from Mancos Shale. Forty-four percent of the variability in extractable sulfate and 47 percent of the variability in conductivity was accounted for by geologic units. Fifty-nine percent of the variability in extractable chloride was accounted for by within-section differences reflecting greater variations within individual fields than among geologic units.

Extractable arsenic was detected in only 52 percent of the samples. Mean concentrations were higher in the terrace gravels (Qt) and Dakota-sandstone-derived (Kd) soils than in soils derived from other geologic units.

#### ACKNOWLEDGEMENTS

Gerald T. Gourdin and Eric P. Welsch prepared and predigested the soil extracts and quantitated the extractable variables.

#### REFERENCES CITED

- Butler, D.L., Krueger, R.P., Osmundson, B.C., Thompson, A.L., and McCall, S.K., 1991, Reconnaissance investigation of water quality, bottom sediment and biota associated with irrigation drainage in the Gunnison and Uncompahgre River Basins and at Sweitzer Lake, West-Central Colorado, 1988-89: U.S. Geological Survey Water-Resources Investigations Report 91-4103, 99 p.
- Cline, A.J., Spears, C. Mehaffey, F. Kubin, E., Franklin, R., Pachek, C., Knobel, E.W., Decker, R., and McMahan, D., 1967, Soil survey of Delta-

- Montrose area, Colorado: U.S. Department of Agriculture Series in cooperation with the Soil Conservation Service and Colorado Agricultural Experiment Station , 73 p.
- Crock, J.G., and Lichte, F.E., 1982, An improved method for the determination of trace levels of arsenic and antimony in geologic materials by automated hydride generation-atomic absorption spectroscopy: *Analytica Chemica Acta*, v. 144, p. 223-233.
- Crock, J.G., Severson, R.C., and Erdman, J.A., 1991, Water-extractable geochemical data for native and irrigated soils from the Kendrick Reclamation Project Area, Wyoming, 1988-89: U.S. Geological Survey Open-File Report 91-394, 16 p.
- Crock, J.G., Stewart, K.C., and Severson, R.C., 1993, Listing of geochemical data and assessment of variability for alfalfa and soils of the Uncompahgre Project area, Colorado: U.S. Geological Survey Open-File Report in review.
- Harms, T.F., Stewart, K.C., Briggs, P.H., Hageman, P.L., and Papp, C.S.E., 1990, Chemical results for bottom material for Department of the Interior irrigation drainage task group studies 1988-1989: U.S. Geological Survey Open-File Report 90-50, 47 p.
- Hoffman, R.J., Hallock, R.J., Rowe, T.G., Licao, M.S., Burge, H.L., and Thompson, S.P., 1990, Reconnaissance investigation of water quality, bottom sediment and biota associated with irrigation drainage in and near Stillwater Wildlife Management Area, Churchill County, Nevada, 1986-87: U.S. Geological Survey Water-Resources Investigations Report 99-4105, 150 p.
- Marshall, C.H., 1959, Photogeologic map of the delta Quadrangle Montrose and Delta Counties, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Series I-282, scale 1:62,500.
- Presser, T.S., and Barnes, I., 1985, Dissolved constituents including selenium concentrations in waters in the vicinity of Kesterson National Wildlife Refuge and West Grassland, Fresno and Merced counties, California: U.S. Geological Survey Water-Resources Investigations Report 85-4220, 73 p.
- Severson, R.C., Wilson, S.A., and McNeal, J.M., 1987, Analyses of bottom material collected at nine areas in the western United States for the DOI irrigation drainage task group: U.S. Geological Survey Open-File Report 87-490, 24 p.
- Shacklette, H.T., and Boerngen, J.G., 1984, Element concentrations in soils and other surficial materials of the conterminous United States: U.S. Geological Survey Professional Paper 1270, 105 p.
- Steven, T.A., and Hail W.J., Jr., 1989, Geologic map of the Montrose 30' x 60' quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-939, scale 1:100,000.
- Stewart, K.C., Fey, D.L., Dunlap, C.E., and Welsch, E.P., 1990, Water-extractable elements from the Panoche Fan area of the San Joaquin Valley, California: U.S. Geological Survey Open-File Report 90-292, 24 p.
- Tweto, O., Steven, T.A., Hail, W.J., Jr., and Moench, R.H., 1976, Preliminary geologic map of the Montrose 1' x 2' quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-761, scale 1:250,000.
- U.S. Environmental Protection Agency, 1987, Ambient water quality criteria for selenium-1987: Washington, D.C., U.S. Environmental Protection Agency,

39 p.

- Williams, P.L., 1964, Geology, structure and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series I-360, scale 1:125,000.
- Wilson, S.A., Kane, J.A., Crock, J.G., and Hatfield, D.B., 1987, Chemical methods of separation for optical emission, atomic absorption spectrometry, and colorimetry, in *Methods for Geochemical Analysis*, Baedecker, P.A., ed.: U.S. Geological Survey Bulletin 1770, p. D1-D14.
- Wilson, S.A., Tidball, R., Kennedy, K., Briggs, P., Hageman, P., and Cappalucci, T., 1991, Assessment of geochemical variability and a listing of geochemical data for soils, drain sediments, alfalfa, greasewood, groundwater and water extractable soil constituents from the TJ-Drain Study Area, Nevada: U.S. Geological Survey Open-File Report 91-581, 122 p.

Table 1. Distribution of samples by geologic unit in townships of the Uncompahgre Project area. Numbers indicate sample sites in each geologic unit within each township. Geologic units are defined as follows: Kd--Cretaceous Dakota Sandstone; Km--Cretaceous Mancos Shale; Qt--Quaternary terrace gravels; Qm--Quaternary alluvium derived from Mancos Shale; Qr--Quaternary (recent) alluvium deposited by the Uncompahgre River and other streams on their floodplains; Qd--Quaternary alluvium derived from Dakota Sandstone

Number	Township	Range	Geologic				Unit	
		West	Kd	Km	Qt	Qm	Qr	Qd
01	15 South	96		3	3	3	3	
02	" "	95		3	3	3	3	
03	" "	94		3		3		
04	51 North	11		4*	3			
05	" "	10		3	3	3	3	
06	" "	9		3	3			
07	50 North	11	3		3			
08	" "	10		3	3	3	3	
09	" "	9		3		3		
10	49 North	10	3	3	3	3	3	
11	" "	9		3		3	3	
12	" "	8		3		3		
13	48 North	10	3					1**
14	" "	9		3		3	3	
15	" "	8		3		3		

\*Analytical data for all sites included for calculation of geometric means and ranges but only first 3 sites used for analysis of variance (ANOVA).

\*\*Analytical data included for calculation of geometric means and ranges, but not for ANOVA.

Table 2. Analytical techniques, reporting units, and lower limits of determination (LLD) for water-extractable variables

Method	Reporting Units	LLD	Variable
conductivity meter	$\mu\text{mho/cm}$ , in solution	2	electrical conductivity (EC)
pH meter	pH units, in solution	1.0	pH
anion chromatography	ppm, dry weight	0.5 5.0	$\text{Cl}^-$ $\text{SO}_4^{2-}$
hydride generation	ppb, dry weight	10 5	As Se

Table 3. Summary statistics for water-extractable variables from reference soil SJS-1. Values reported are based on dry weight except pH and conductivity (EC) which are reported in solution, n=8

Variable, units	Arithmetic	Range	Standard	ZSRSD	Mean
	Mean		Deviation		previous data*
Se, ppb	23	20-28	2.4	10	22
As, ppb	23	18-35	5.5	24	**
Cl <sup>-</sup> , ppm	360	330-390	21	5.8	350
SO <sub>4</sub> <sup>2-</sup> , ppm	1450	1400-1500	53	3.4	1300
pH, units	8.2	7.8-8.3	1.5	18	8.1
EC, $\mu$ mho/cm	970	960-990	10	1.0	930

\*Stewart and others, 1990; n=12.

\*\*Not determined.



Table 4. Geometric means, ranges and detection ratios of water-extractable variables for all soils of the Uncompahgre Project area. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution. Analytical duplicates are not included in the calculations; site duplicates are averaged to obtain one value for each site; numbers in parentheses apply if means are different when site duplicates are considered independent samples

Variable, Units	Geometric Mean	Geometric Deviation	Observed Range	Detection Ratio
Se, ppb	27	3.5	5-1400 (1800)	128:128 (142:142)
As, ppb	12*	2.2	<10-41 (45)	67:128 (76:142)
Cl <sup>-</sup> , ppm	21	2.3	(2) 3-350	128:128 (142:142)
SO <sub>4</sub> <sup>2-</sup> , ppm	2000 (1900)	5.9	45-24,000	128:128 (142:142)
pH, units	8.0**	0.29**	7.0-8.6	128:128 (142:142)
EC, $\mu$ mho/cm	1100	3.0	190-7300	128:128 (142:142)

\*Geometric mean estimated by Cohen's technique due to low detection ratio.

\*\*Arithmetic mean and standard deviation.

Table 5. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Cretaceous Dakota Sandstone--Kd. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution. Duplicate samples within a section are averaged to obtain one value for each site; numbers in parentheses apply if means are different when site duplicates are considered independent samples

Variable, Units	Geometric Mean	Geometric Deviation	Observed Range	Detection Ratio
Se, ppb	9 (8)	1.6	5-19	9:9 (11:11)
As, ppb	21	1.5	12-36	9:9 (11:11)
Cl <sup>-</sup> , ppm	18 (17)	2.5	4.9-110	9:9 (11:11)
SO <sub>4</sub> <sup>2-</sup> , ppm	620 (530)	7.4	45-9600	9:9 (11:11)
pH, units	8.1*	0.16*	7.9-8.4	9:9 (11:11)
EC, $\mu$ mho/cm	620 (560)	2.6	200-2800	9:9 (11:11)

\*Arithmetic mean and standard deviation.

Table 6. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Cretaceous Mancos Shale--Km. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution. Duplicate samples within a section are averaged to obtain one value for each site; numbers in parentheses apply if means are different when site duplicates are considered independent samples

Variable, Units	Geometric Mean	Geometric Deviation	Observed Range	Detection Ratio
Se, ppb	43 (46)	3.5	5-1400 (1800)	40:40 (43:43)
As, ppb	4* (3)	3.8	<10-41	8:40 (8:43)
Cl <sup>-</sup> , ppm	25 (24)	2.2	3-140	40:40 (43:43)
SO <sub>4</sub> <sup>2-</sup> , ppm	7600	3.0	82-24,000	40:40 (43:43)
pH, units	7.9**	0.26**	7.1-8.6	40:40 (43:43)
EC, $\mu$ mho/cm	2600	1.9	330-7300	40:40 (43:43)

\*Estimated by Cohen's technique due to low detection ratio.

\*\*Arithmetic mean and standard deviation.

Table 7. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Quaternary terrace gravels--Qt. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution. Duplicate samples within a section are averaged to obtain one value for each site; numbers in parentheses apply if means are different when site duplicates are considered independent samples

Variable, Units	Geometric Mean	Geometric Deviation	Observed Range	Detection Ratio
Se, ppb	13	1.8	5-62	24:24 (28:28)
As, ppb	23 (24)	1.6	<10-39 (45)	22:24 (25:28)
Cl <sup>-</sup> , ppm	17 (16)	1.8	(7) 8-130	24:24 (28:28)
SO <sub>4</sub> <sup>2-</sup> , ppm	410 (370)	4.4	75-9300	24:24 (28:28)
pH, units	8.1*	0.31*	7.3-8.4	24:24 (28:28)
EC, $\mu$ mho/cm	430 (410)	2.2	210-2600	24:24 (28:28)

\*Arithmetic mean and standard deviation.

Table 8. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Quaternary alluvium of Mancos Shale--Qm. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution. Duplicate samples within a section are averaged to obtain one value for each site; numbers in parentheses apply if means are different when site duplicates are considered independent samples

Variable, Units	Geometric Mean	Geometric Deviation	Observed Range	Detection Ratio
Se, ppb	48 (49)	3.2	8-480	33:33 (36:36)
As, ppb	9*	1.8	<10-31	14:33 (15:36)
Cl <sup>-</sup> , ppm	24 (25)	2.6	(2) 7-350	33:33 (36:36)
SO <sub>4</sub> <sup>2-</sup> , ppm	2500 (2700)	4.7	150-12,000 (19,000)	33:33 (36:36)
pH, units	8.0**	.26**	7.0-8.4	33:33 (36:36)
EC, $\mu$ mho/cm	1200	2.7	250-4100 (5600)	33:33 (36:36)

\*Estimated by Cohen's technique due to low detection ratio.

\*\*Arithmetic mean and standard deviation.

Table 9. Geometric means, ranges and detection ratios of water-extractable variables for soils of the Uncompahgre Project area derived from Quaternary (Recent) alluvium--Qr. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution. Duplicate samples within a section are averaged to obtain one value for each site; numbers in parentheses apply if means are different when site duplicates are considered independent samples

Variable, Units	Geometric Mean	Geometric Deviation	Observed Range	Detection Ratio
Se, ppb	18 (17)	3.1	5-1000	21:21 (23:23)
As, ppb	14	1.8	<10-33 (35)	13:21 (15:23)
Cl <sup>-</sup> , ppm	18	2.1	7-200	21:21 (23:23)
SO <sub>4</sub> <sup>2-</sup> , ppm	1400 (1300)	4.1	110-14,000	21:21 (23:23)
pH, units	8.1*	0.29*	7.0-8.4	21:21 (23:23)
EC, $\mu$ mho/cm	730 (720)	2.5	190-4100	21:21 (23:23)

\*Arithmetic mean and standard deviation.

Table 10. Comparison of geometric means of water-extractable variables for soils from various studies of the western United States. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution; extracted at 1:5 soil: water ratio

Variable,	This study	San Joaquin Valley, CA <sup>1</sup>	Carson Sink NV <sup>2</sup>	Kendrick Project, WY <sup>3</sup>
units	n=128	n=189	n=108	n=92
Se, ppb	27	15	14	39
As, ppb	12 <sup>4</sup>	--	570	--
Cl <sup>-</sup> , ppm	21	25	660	24
SO <sub>4</sub> <sup>2-</sup> , ppm	2000	500	810	330
pH, units <sup>5</sup>	8.0	7.1	8.1	8.1
EC, $\mu$ mho/cm	1100	550	1550	430

<sup>1</sup>Stewart and others, 1990.

<sup>2</sup>Wilson and others, 1991.

<sup>3</sup>Agricultural soils calculated from Crock and others, 1991.

<sup>4</sup>Detection ratio less than 60 percent.

<sup>5</sup>Arithmetic mean.

Table 11. Geometric means by geologic unit of water-extractable variables, total selenium and percent total selenium extractable by water for soils of the Uncompahgre Project area. Values reported are based on dry weight except pH and conductivity (EC), which are reported in solution. Duplicate samples within a section are averaged to obtain one value for each site

Variable,	Kd	Km	Qm	Qr	Qt	Qd
Units	n=9	n=40	n=33	n=21	n=24	n=1
Se, total, ppb <sup>1</sup>	460	2100	2900	660	870	300
Se, extr., ppb	9	43	48	18	13	8
% Se extractable	1.9	2.0	1.7	2.7	1.5	2.7
As, ppb	21	4 <sup>2</sup>	9 <sup>2</sup>	14	23	20
Cl <sup>-</sup> , ppm	18	25	24	18	17	5
SO <sub>4</sub> <sup>2-</sup> , ppm	620	7600	2500	1400	410	110
pH, units <sup>3</sup>	8.1	7.9	8.0	8.1	8.1	8.3
EC, $\mu$ mho/cm	620	2600	1200	730	430	210

<sup>1</sup>Crock and others, 1993

<sup>2</sup>Estimated by Cohen's technique due to low detection ratio.

<sup>3</sup>Arithmetic mean.



Table 12. Site and analytical variance of water-extractable variables and total selenium for soils of the Uncompahgre Project area. Extractable arsenic had a detection ratio of less than 60 percent and is therefore excluded from this table

Variable, units	Percentage of variance					
	Log <sub>10</sub>	Among				Between
	total variance	geologic units	Among townships	Among sections	Within sections	laboratory analyses
Se, total ppm <sup>1</sup>	0.1780	57*	13*	25*	4*	<1
Se, extr. ppb	0.3615	29.5*	21.9*	39.0*	6.9*	2.8
Cl <sup>-</sup> , ppm	0.1463	4.0	5.0	28.5	58.8*	3.8
SO <sub>4</sub> <sup>2-</sup> , ppm	0.6752	43.8*	13.0*	27.0*	15.7*	<1
pH, units	0.0836	19.7*	9.2	49.5*	<1	20.9
EC, $\mu$ mho/cm	0.2530	46.6*	10.9*	28.4*	14.0*	<1

<sup>1</sup>Crock and others, 1993.

\* statistically significant at the 0.05 probability level

Table 13. Correlations of selenium in alfalfa with total soil selenium and water-extractable soil variables of the Uncompahgre Project area and percent of total variance of selenium in alfalfa (% Se<sub>alf</sub>) accounted for by each soil variable. Correlations based on log distributions of values reported on dry-weight basis; pH and conductivity (EC) reported in solution; Se<sub>alf</sub>--alfalfa selenium (Crock and others, 1993), Se<sub>tot</sub>--total soil selenium, Se<sub>ex</sub>--extractable soil selenium, SO<sub>4 ex</sub>--extractable soil sulfate, Cl<sub>ex</sub>--extractable soil chloride; n=128

	Se <sub>alf</sub>	Se <sub>ex</sub>	Se <sub>tot</sub>	SO <sub>4 ex</sub>	Cl <sub>ex</sub>	EC	pH	% Se <sub>alf</sub> variance
Se <sub>alf</sub>	1.0							
Se <sub>ex</sub>	.47*	1.0						22
Se <sub>tot</sub>	.43*	.71*	1.0					18
SO <sub>4 ex</sub>	.27*	.62*	.62*	1.0				7
Cl <sub>ex</sub>	.25*	.42*	.21*	.39*	1.0			6
EC	.24*	.64*	.62*	.98*	.44*	1.0		6
pH	-.13	-.35*	-.40*	-.63*	-.19	-.64*	1.0	5

\*statistically significant at the 0.05 probability level

Table AI. Analytical data listing of water-extractable variables for soils of the Uncompahgre Project area in ppm dry weight. Conductivity (EC) and pH reported in solution.

Sample	Latitude	Longitude	Se, ppb	As, ppb	Cl, ppm	SO <sub>4</sub> , ppm	pH	EC, $\mu$ mho/cm
Cretaceous Dakota Sandstone								
KD07111	38 36 09	107 58 49	8	15	26	490	8.2	440
KD07211	38 35 06	107 57 51	10	18	17	4,300	8.1	1,500
KD07212	38 35 06	107 57 51	<5	13	15	4,500	8.1	1,500
KD07311	38 37 10	107 59 35	5	33	15	290	8.1	360
KD07321	38 37 05	107 59 36	6	17	14	4,800	8.0	1,600
KD07322	38 37 05	107 59 36	6	<10	13	5,000	7.9	1,600
KD10111	38 29 12	107 59 36	12	27	5	86	8.4	310
KD10211	38 28 00	107 57 11	19	12	110	3,800	8.1	1,500
KD10311	38 28 32	107 58 05	13	15	48	9,600	7.9	2,800
KD13111	38 25 53	107 58 25	5	33	11	150	7.9	330
KD13211	38 27 17	107 56 16	10	22	13	150	8.3	250
KD13221	38 27 24	107 56 16	5	20	10	94	8.2	210
KD13311	38 25 28	107 55 00	5	36	10	45	8.1	200
Cretaceous Mancos Shale								
KM01111	38 43 53	108 06 32	60	<10	51	11,000	7.6	3,400
KM01211	38 41 56	108 07 24	20	<10	18	9,200	7.6	2,700
KM01311	38 43 46	108 08 28	25	<10	140	9,900	7.9	3,000
KM02111	38 41 56	108 00 20	26	<10	31	9,800	7.6	2,800
KM02112	38 41 56	108 00 20	23	<10	20	9,700	7.8	2,800
KM02211	38 43 26	108 00 21	30	<10	25	9,000	7.9	2,600
KM02311	38 44 36	107 58 54	18	<10	14	6,400	7.7	2,700
KM03111	38 42 39	107 56 23	60	<10	56	9,400	8.2	2,800
KM03112	38 42 39	107 56 23	95	<10	51	7,000	7.8	2,800
KM03211	38 43 28	107 56 30	100	<10	14	5,800	8.0	1,900
KM03311	38 43 38	107 56 20	110	<10	40	9,000	7.7	2,600
KM03321	38 43 37	107 56 29	40	<10	7	2,400	8.1	990
KM04111	38 41 38	108 06 49	29	<10	41	9,800	7.9	2,900
KM04211	38 41 38	108 07 00	110	<10	22	14,000	7.8	4,100
KM04311	38 41 48	108 07 39	10	<10	20	13,000	7.9	3,800
KM04411	38 41 49	108 07 17	20	<10	13	8,900	7.1	2,600
KM05111	38 40 09	107 57 31	23	<10	3	8,800	8.1	2,700
KM05211	38 40 10	107 58 17	56	<10	23	9,600	7.8	2,800
KM05221	38 40 10	107 58 17	16	<10	13	10,000	7.8	3,100
KM05311	38 40 49	107 58 05	25	<10	16	9,200	7.7	2,600
KM06111	38 41 12	107 53 52	260	<10	140	24,000	7.4	7,300
KM06211	38 41 48	107 54 03	34	<10	29	13,000	7.9	4,700
KM06311	38 38 22	107 55 41	33	<10	58	9,200	7.7	2,600
KM08111	38 33 09	107 58 55	17	41	9	271	8.2	420
KM08211	38 34 12	107 56 22	12	21	17	8,500	8.0	2,600
KM08311	38 35 56	107 53 43	61	<10	27	8,600	7.9	2,500
KM08312	38 35 56	107 53 43	66	<10	37	6,200	7.9	2,600
KM09111	38 37 15	107 55 28	53	19	16	8,700	8.0	2,700
KM09211	38 35 43	107 53 50	900	<10	82	12,000	7.9	3,800
KM09212	38 35 43	107 53 50	890	<10	81	11,000	7.5	3,700
KM09311	38 33 07	107 54 44	30	28	11	8,900	7.6	2,600
KM10111	38 31 39	107 58 19	31	<10	130	18,000	7.7	5,300
KM10211	38 30 04	107 57 06	20	<10	31	9,500	7.9	2,700
KM10311	38 31 20	107 59 18	12	<10	33	15,000	8.0	4,500
KM11111	38 31 27	107 51 56	51	<10	46	9,200	7.9	2,700
KM11211	38 30 55	107 49 37	300	<10	33	12,000	7.7	3,700
KM11311	38 28 25	107 49 13	36	<10	11	8,500	8.1	2,600
KM12111	38 27 47	107 46 24	190	<10	22	11,000	7.9	3,300
KM12211	38 28 36	107 46 03	12	<10	25	11,000	8.0	3,600
KM12311	38 29 05	107 48 06	27	13	23	10,000	7.9	2,800

Table AI cont.

Sample	Latitude	Longitude	Se, ppb	As, ppb	Cl, ppm	SO <sub>4</sub> , ppm	pH	EC, $\mu$ mho/cm
Cretaceous Mancos Shale (cont.)								
KM14111	38 25 21	107 54 04	5	33	33	82	8.6	330
KM14211	38 22 44	107 47 46	16	22	24	380	8.4	380
KM14311	38 26 32	107 51 36	15	26	19	9,600	7.8	2,800
KM15111	38 27 14	107 46 19	740	<10	8	14,000	7.7	4,500
KM15211	38 25 34	107 48 02	920	<10	29	14,000	7.6	4,300
KM15212	38 25 34	107 48 02	990	<10	22	11,000	7.8	4,200
KM15221	38 25 32	107 48 07	1,800	<10	27	14,000	7.5	4,400
KM15311	38 24 49	107 47 09	46	<10	11	8,400	7.9	2,500
Quaternary Alluvium derived from Dakota Sandstone								
QD13111	38 25 47	107 57 48	8	20	5	110	8.3	210
Quaternary Alluvium derived from Mancos Shale								
QM01111	38 46 07	108 04 21	63	<10	30	8,800	7.8	2,700
QM01211	38 43 42	108 04 09	64	13	24	4,400	8.0	1,600
QM01311	38 44 03	108 08 22	50	<10	19	11,000	7.7	3,100
QM02111	38 42 45	108 03 07	36	15	10	560	8.3	410
QM02211	38 45 40	107 59 18	47	13	340	8,600	7.9	2,700
QM02311	38 45 53	107 57 30	9	16	30	150	8.2	280
QM03111	38 46 21	107 56 32	10	23	31	370	8.4	320
QM03211	38 45 40	107 56 05	28	<10	47	8,900	7.9	2,600
QM03221	38 45 40	107 56 05	53	<10	2	8,600	7.9	2,500
QM03311	38 44 50	107 55 55	32	<10	18	8,800	7.9	2,500
QM05111	38 39 13	107 58 05	38	<10	47	11,000	7.9	3,300
QM05211	38 40 55	108 00 03	19	13	15	510	7.9	380
QM05311	38 41 34	108 01 01	190	<10	30	12,000	7.9	3,400
QM08111	38 37 48	107 57 00	86	20	19	8,600	7.8	2,600
QM08211	38 36 46	107 55 52	75	<10	11	8,700	7.7	2,500
QM08311	38 35 16	107 56 24	320	10	48	11,000	7.8	2,800
QM09111	38 35 12	107 54 04	20	<10	13	720	7.0	470
QM09211	38 35 22	107 55 28	340	31	350	12,000	7.8	4,100
QM09212	38 35 22	107 55 28	310	13	380	12,000	8.0	4,100
QM09311	38 34 11	107 54 05	22	<10	25	430	8.1	350
QM10111	38 31 35	107 56 15	88	<10	11	2,300	8.1	1,000
QM10211	38 32 35	107 57 07	8	15	13	200	8.2	250
QM10311	38 31 56	107 57 13	16	<10	10	6,200	8.0	1,800
QM11111	38 32 06	107 53 07	38	<10	19	9,100	7.9	2,700
QM11211	38 30 27	107 50 32	15	<10	18	2,100	8.1	870
QM11311	38 29 40	107 50 52	40	<10	12	8,300	8.0	2,500
QM12111	38 28 57	107 46 02	14	15	19	370	8.2	360
QM12121	38 28 57	107 45 57	8	13	16	220	8.2	280
QM12211	38 27 40	107 46 33	14	<10	7	240	8.2	260
QM12212	38 27 40	107 46 33	12	<10	10	240	8.2	260
QM12311	38 29 10	107 44 58	33	11	22	510	8.4	410
QM14111	38 25 36	107 50 12	15	24	9	290	8.3	360
QM14211	38 26 52	107 48 54	370	13	10	870	8.2	480
QM14311	38 27 05	107 49 38	410	<10	210	17,000	7.7	5,400
QM14321	38 27 05	107 49 26	860	<10	280	19,000	8.1	5,600

Table AI cont.

Sample	Latitude	Longitude	Se, ppb	As, ppb	Cl, ppm	SO <sub>4</sub> , ppm	pH	EC, $\mu$ mho/cm
Quaternary Alluvium (cont.)								
QM15111	38 27 03	107 47 49	190	<10	61	12,000	7.8	3,600
QM15211	38 26 58	107 46 51	480	<10	87	10,000	8.0	3,200
QM15311	38 25 38	107 47 40	45	<10	11	2,600	8.0	1,000
Recent Alluvium								
QR01111	38 42 20	108 03 54	15	<10	12	4,000	7.9	1,400
QR01112	38 42 20	108 03 54	13	<10	13	5,800	7.9	1,800
QR01211	38 44 57	108 05 29	22	31	18	8,600	7.9	2,700
QR01311	38 44 05	108 09 47	20	<10	24	1,600	7.0	710
QR02111	38 46 30	108 01 33	18	26	31	960	8.2	710
QR02121	38 46 30	108 01 24	12	35	17	220	8.3	290
QR02211	38 46 14	108 00 26	26	22	8	340	8.4	310
QR02311	38 46 04	108 02 10	16	22	17	4,000	8.1	1,400
QR05111	38 41 49	108 02 29	15	<10	45	880	8.3	590
QR05211	38 40 44	108 00 27	1,000	<10	200	14,000	8.1	4,100
QR05311	38 38 28	107 59 59	20	<10	27	6,000	8.3	1,900
QR08111	38 37 37	108 00 05	110	14	18	6,900	8.0	2,300
QR08211	38 35 06	107 58 46	12	12	39	3,100	8.0	1,200
QR08311	38 33 23	107 58 25	11	32	10	1,500	8.0	680
QR08321	38 33 29	107 58 26	9	14	16	6,800	8.0	1,800
QR10111	38 31 34	107 56 57	5	<10	18	270	8.3	260
QR10211	38 32 06	107 57 56	9	22	10	110	8.2	240
QR10311	38 32 29	107 58 06	18	15	15	730	8.2	470
QR11111	38 30 17	107 55 06	5	29	11	210	8.3	260
QR11211	38 29 06	107 54 11	12	19	7	1,600	8.4	280
QR11311	38 29 32	107 54 09	24	<10	21	750	8.2	500
QR14111	38 23 37	107 49 06	23	<10	16	4,000	8.1	1,400
QR14211	38 22 37	107 48 26	5	33	8	160	8.1	190
QR14311	38 25 49	107 51 17	12	12	8	1,000	8.1	560
Quaternary Terrace Deposits								
QT01111	38 42 14	108 06 17	11	34	10	230	8.3	290
QT01112	38 42 14	108 06 17	12	36	6	230	8.4	280
QT01211	38 43 25	108 09 03	25	29	10	180	8.3	340
QT01311	38 42 56	108 53 00	13	38	20	250	8.2	310
QT02111	38 43 44	108 02 07	8	13	13	3,200	8.0	1,200
QT02211	38 43 38	108 00 57	30	24	16	8,900	7.4	2,600
QT02311	38 44 34	108 02 20	27	21	9	400	8.3	360
QT02312	38 44 34	108 02 20	25	20	10	460	8.2	370
QT02321	38 44 31	108 02 21	25	24	16	490	8.3	430
QT04111	38 40 10	108 05 52	20	<10	19	9,300	7.9	2,600
QT04211	38 40 20	108 08 17	9	29	10	360	8.3	320
QT04311	38 41 39	108 05 41	15	45	17	210	8.1	300
QT04321	38 41 38	108 05 35	8	32	10	240	8.3	290
QT05111	38 38 35	108 02 13	10	28	28	390	8.1	330
QT05211	38 40 41	108 01 16	19	35	8	520	8.2	390
QT05311	38 41 33	108 02 17	15	34	29	210	8.1	430
QT06111	38 39 54	107 54 10	62	<10	130	4,800	7.9	1,800
QT06211	38 41 01	107 53 59	24	15	26	190	8.4	290
QT06212	38 41 01	107 53 59	30	<10	21	200	8.3	290
QT06311	38 41 41	107 53 58	12	25	11	130	7.5	240
QT07111	38 33 50	107 56 15	11	25	38	5,300	7.3	1,800

Table AI, cont.

Sample	Latitude	Longitude	Se, ppb	As, ppb	Cl, ppm	SO <sub>4</sub> , ppm	pH	EC, $\mu$ mho/cm
Quaternary Terrace deposits (cont.)								
QT07211	38 35 28	107 55 16	5	30	21	280	8.4	280
QT07311	38 37 11	107 58 28	8	17	25	96	8.3	300
QT08111	38 32 54	107 57 05	9	16	7	150	8.3	230
QT08121	38 33 00	107 57 04	10	27	10	140	8.4	250
QT08211	38 33 47	107 53 59	6	17	12	75	8.2	230
QT08311	38 36 19	107 54 28	17	38	17	220	8.3	300
QT10111	38 30 30	107 57 43	9	32	15	140	8.2	250
QT10211	38 29 56	107 56 17	5	34	16	160	8.4	230
QT10212	38 29 56	107 56 17	5	34	20	150	8.3	230
QT10221	38 29 57	107 56 09	5	42	19	100	8.2	250
QT10311	38 29 24	107 58 37	14	17	12	150	8.4	210
San Joaquin reference soil								
SJS1	--	--	23	21	390	1,500	8.2	990
SJS1	--	--	22	22	370	1,500	8.2	970
SJS1	--	--	25	35	340	1,500	8.2	980
SJS1	--	--	20	28	340	1,400	7.8	960
SJS1	--	--	22	21	380	1,500	8.2	980
SJS1	--	--	28	20	350	1,400	8.2	970
SJS1	--	--	24	22	350	1,400	8.2	960
SJS1	--	--	23	18	330	1,400	8.3	970