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State of Utah

Department of
Environmental Quality

Dianne R. Nielson, Ph.D.
Executive Director

DIVISION OF WATER QUALITY
Walter L. Baker, P.E.
Acting Director

OLENE S. WALKER
Governor

GAYLE F. McKEACHNIE
Lieutenant Governor

FILE COPY

Document Date 6/3/2004
DWQ-2004-002101

June 3, 2004

Ms. Sue Odekirk, P.E.
PacifiCorp
1407 West North Temple, Suite 330
Salt Lake City, UT 84116

Subject: Huntington Power Plant Ground Water Discharge Permit
Application Notice of Deficiency (Permit No. UGW150002)

Dear Ms. Odekirk:

We have reviewed the ground water discharge permit application for the Huntington Power Plant, which was hand-delivered at our meeting on May 4, 2004. The application does not contain enough information, as required under the Ground Water Protection Rules (UAC R317-6-6.3), for us to develop permit conditions to insure that the various discharges at the plant site are properly evaluated, monitored and controlled.

There are two possible ways to proceed with the permitting process at this point. The Division of Water Quality (DWQ) can delay issuance of the permit until adequate information has been obtained to allow development of all necessary permit conditions. Alternatively, a preliminary version of the permit may be issued which requires submission of the additional information before appropriate deadlines, in a compliance schedule. Under this scenario, as new information is received in the future, a revised version of the permit would be issued to incorporate new permit conditions developed from that information. Because PacifiCorp voluntarily requested this permit to be issued, DWQ does not have any deadline for permit issuance. Therefore, PacifiCorp may choose which option for permit issuance it prefers. If you choose to have the permit issued soon, based on the available information and with a compliance schedule, please review the additional information listed below, which will be needed eventually, and propose a timetable for submission of the various reports.

At the Huntington Research Farm, the land application has been ongoing since the late 1970s. Any effects that the land application has had on ground water quality were superimposed on the naturally complex patterns of ground water chemistry at the site, which reflect influence from both Huntington Creek and the Mancos Shale. The first set of monitor wells at this site were not constructed to modern standards and data from them are suspect, so it is not possible to accurately define the background water quality from before the

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start of the land application. Nevertheless, it appears that several wells have had significant increases in nitrate and boron since the 1980s. New wells were constructed in 1997, and data from them show that nitrate and boron concentrations have risen significantly since 2000. This seems to be adequate evidence that PacifiCorp's activities have affected ground water quality, and the situation needs to be addressed under the Corrective Action rules for ground water, UAC R317-6-6.15. According to the regulations, PacifiCorp must conduct a Contaminant Investigation into this rise in contaminant concentrations in the ground water. Unless it can be proven that the observed trends in ground water chemistry were not due to PacifiCorp's activities, a Corrective Action Plan must be proposed, based on the findings of the Contaminant Investigation, to prevent further contamination and restore ground water quality to the appropriate levels.

It seems probable that some of the rise in contaminant levels seen in monitor wells at the Research Farm was due to the flow of ground water influenced by the combustion products landfills. A new monitor well drilled downgradient of the old landfill, LF-7O, shows high levels of nitrogen. The old landfill, therefore, is a source of ground water pollution and the new landfill, because the same wastes are currently disposed there, is a potential source of pollution. Most likely, the source of ground water contamination is the scrubber slurry disposed in the landfills, which contains 80% moisture. PacifiCorp must propose discharge minimization technology for the old landfill to bring the discharge of contaminants to the lowest level practicable.

Since 2002, PacifiCorp has disposed of combustion wastes at a new landfill. Available information strongly suggests that these same wastes caused ground water pollution at the old landfill site. Under these conditions, it seems appropriate that the current, active combustion waste disposal should not cause any discharge of contaminants to the subsurface. The Ash Landfill Operations Manual that was submitted as part of the permit application does not specifically address prevention of discharge to the subsurface. If the Contaminant Investigation finds that ground water pollution was due to leakage of liquids from the old landfill, PacifiCorp must revise the design and operations of the new landfill to prevent such leakage. Landfill design should be justified by application of the HELP computer model or similar models for DWQ approval.

PacifiCorp has identified several other features, including water retention ponds and coal facilities, that could potentially cause a discharge of contaminants to ground water. We currently do not have enough information on these facilities to determine their actual threat to ground water, and whether they should be covered under the permit or whether they qualify for permit-by-rule status under UAC R317-6-6.2. PacifiCorp has installed monitor wells at these sites and is currently collecting ground water samples from them. The potential impact posed by each of these facilities must be evaluated before we can determine the appropriate regulatory actions for them.

The determination of permit conditions and permit-by-rule status for a particular facility depends on its potential threat to cause ground water pollution. This threat depends on several factors, which may include the nature and volume of the discharge, the quality of the receiving ground water, the hydrogeology of the site and factors specific to the facility such as engineered containment structures, best management practices and operational plans. PacifiCorp should present adequate information on each of these facilities so we can make this determination. Comparison of ground water chemistry at upgradient and downgradient wells may not provide an accurate assessment of the threat to ground water, particularly with deep wells, which have been drilled at several of these sites.

In summary, PacifiCorp should submit the following information before permit issuance, or propose dates for completion of the necessary activities that would become Compliance Schedule items in a permit which could be issued earlier:

1. A Contaminant Investigation and Corrective Action Plan for the Research Farm and the old Combustion Waste Landfill.

2. If, as seems likely, discharge of liquids from the new Combustion Waste Landfill must be prevented, a revised landfill design and operations plan with justification for the specific proposals.

3. Evaluations of any threats to ground water posed by the water retention ponds and coal facilities.

Please respond with your preferred options for the permitting process. Please contact me at (801) 538-6518 if you have any questions.

Sincerely,

MTN

Mark Novak
Ground Water Protection Section

cc: Lonnie Shull
Ed Hickey
Southeast Utah Health Dept.
Dave Ariotti, District Engineer

Pacc6-04NOD.ltr

Huntington Canyon Plant
P.O. Box 680
Huntington, Utah 84528
(801) 687-4000
(801) 636-4000

PACIFICORP
POWER SUPPLY

MTN

January 20, 2004

Mr. Mark Novak, E.H. Scientist
State of Utah
Department of Water Quality
288 North 1460 West
Salt Lake City, UT 84116

Dear Mr. Novak,

Enclosed is the Huntington Plant Water Quality Report for the year 2003. Annual graphs for each sampling site are included. As per our agreement, semi-annual sampling is done to monitor surface and ground water around the Huntington Research Farm.

Included are maps showing the locations of all surface and ground water sampling points, along with topography and the locations of any PacifiCorp facilities, such as ash disposal sites, which may affect ground water quality.

Data from the Huntington Research Farm is reported separately this year. Surface water and groundwater data are also reported separately. Monitoring well and surface data are listed according to area with up gradient and down gradient listed separately. Each graph and table is appropriately labeled and arranged in a logical order from top to bottom (elevation). Groundwater elevations in the wells and the flows in the Huntington River and Duck Pond Drain are also reported. A specific section graphed by constituent for each farm area or surface area is also included.

A question about the sampling site of the surface water sampling site H-11, Huntington Spring, came to light during the fall 2003 sampling event. Apparently during a change in sampling personnel in spring 1997, the sampling site of H-11 was moved to a different spot. This new site was in a totally different water source. A sample was taken from the site of the original H-11 during the fall 2003 sampling event, and the analysis matches the results from the pre-1997 samples. It has been determined by interviewing all the samplers from before 1997, that the original site, Huntington Spring, was sampled consistently and that the change occurred in 1997. The H-11 graphs and tables have been divided into the two separate sites as sampled. Site H-11 will continue to be Huntington Spring and H-10 will become Duck Pond Inflow.

If there are any questions or comments, please feel free to contact Brad Giles at 748-6576, or send correspondence to Hunter Research Farm, P.O. Box 826, Castle Dale, Utah 84513.

Sincerely,

Dave Sharp
Plant Manager

dg/BG

enclosures

RECEIVED
FEB 2 3 2004
DIVISION OF
WATER QUALITY

Mark N.

PACIFICORP ENERGY
A PACIFICORP COMPANY

Huntington Power Plant
6 miles west of Huntington, Utah on Hwy. 31
P.O. Box 680
Huntington, Utah 84528

RECEIVED
DEC 12 2011
Utah Division of Water Quality

December 9, 2011

Mr. Rob Herbert
Utah Department of Environmental Quality
Division of Water Quality
P.O. Box 144870
Salt Lake City, Utah 84114-4870
Attention: Ground Water Protection Program

Subject: Closure Report, Lacey's Lake Pond Area
Ground Water Discharge Permit No. UGW150002
PacifiCorp, Huntington Power Plant

Dear Mr. Herbert,

Enclosed is the Closure Report for Lacey's Lake Pond Area as required by the Huntington Power Plant Ground Water Discharge Permit No. UGW150002, Appendix G, "Closure Plan, Lacey's Lake Pond Area". The schedule for submission of the final report was updated and approved in a letter from the Utah Department of Environmental Quality dated September 27, 2011.

Should you have questions or need additional information, please feel free to contact Bradley Giles. His phone is (435) 748-6576. His e-mail address is Bradley.Giles@Pacificorp.com

I hereby certify that the information submitted herein is true, accurate, and complete, based on information and belief formed after reasonable inquiry.

Sincerely,

Darrell Cunningham

Darrell Cunningham
Huntington Plant Managing Director

cc: Mark Novak (DWQ)
Attachments

DWQ-2011-008903 Document Date 12/9/2011

Closure Report
Lacey's Lake Pond Area

PacifiCorp Huntington Power Plant

December 2011

Prepared by:
URS Corporation

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1.0 INTRODUCTION

The purpose of this report is to document closure of Lacey's Lake for Utah Division of Water Quality (DWQ) review and approval. Lacey's Lake is identified in PacifiCorp Huntington Power Plant (Huntington) Huntington's Ground Water Discharge Permit (Permit) number 150002 (UDEQ, 2009), issued by the DWQ, as an unlined pond with potential to impact groundwater. Huntington management determined that closure of Lacey's Lake would reduce the environmental footprint of the plant by eliminating an unlined surface water impoundment. Huntington's approach to closure of Lacey's Lake was described in the *Final Closure Plan Lacey's Lake Pond Area* dated May 2011 (URS, 2011).

This report includes a brief description of closure activities including deviations from the approved plan based on site conditions encountered during implementation of the Plan. Estimated quantities of material removed from Lacey's Lake and adjacent waste handling areas are reported and disposal location noted. Estimated quantities of backfill material are reported and a description of the final site grading is included. Field observations including site photographs of the extent of excavation and final site conditions are included in Attachment A – Photographic Log.

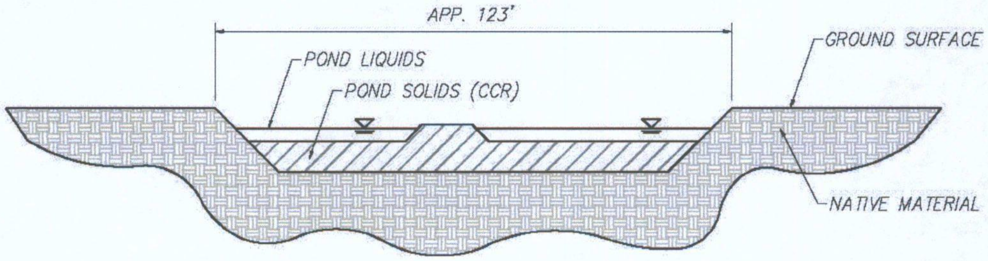
1.1 Operating History

Lacey's Lake was originally constructed in 1979 to serve as a settling and evaporation pond with a design volume of approximately four acre-feet (ac ft). Waste streams with high suspended and dissolved solids concentrations were routed to the pond prior to flowing to the on-site waste water collection pond for treatment and reuse.

Wastewater streams from the plant discharging to Lacey's Lake included RCC blowdown water, coal conveyor wash water, wash water associated with the fly ash loadout area (both Pug Mill wash water and water used to clean spills of ash in the loadout area), pump seal water, and truck wash water. In addition to the above plant process wastewater streams, Lacey's Lake received stormwater runoff from the south coal pile area and the south area of the plant upgradient from the pond.

These waste streams previously directed to Lacey's Lake contain high solids concentrations, both dissolved and suspended. Suspended solids are primarily ash or coal combustion residuals (CCR). This solid material would accumulate in Lacey's Lake requiring periodic removal. This was accomplished using a long arm reach excavator capable of dredging sludge from all but the center of the pond, as shown in Photographs 1 and 2 in Attachment A. This dredged material was then staged adjacent to the pond for drying prior to transport to the on-site Class III Industrial Waste Landfill for disposal. The schematic below depicts the cross section configuration of Lacey's Lake prior to closure.

Schematic 1. Cross Section View of Lacey's Lake Prior to Closure



2.0 CLOSURE ACTIVITIES

Huntington's approach to closure of Lacey's Lake included the following activities; identification and rerouting of all inputs, sampling, waste removal, and site restoration including backfill, compaction and final site grading. A brief description of each activity is included below.

2.1 Rerouting Waste Streams

Beginning in April, 2011 advance construction actions were implemented to reroute all waste streams from Lacey's Lake to alternate waste handling areas. These actions effectively served to facilitate dewatering of the pond and subsequent waste removal activity. Huntington completed these advance construction activities in May, 2011. A detailed description of each action is described in the Final Construction Plans dated September 27, 2011. A brief summary of these advance construction actions is included below for reference.

- Water that previously discharged from the Lacey's Lake Pump Station (Pump Station) was rerouted to the existing sewer collection facility
- Water decanted from the existing fly ash loadout area was collected and pumped to the RCC trough which discharges to the Pump Station.
- Coal conveyor washwater is commingled with the fly ash loadout area water and pumped to the RCC trough/Pump Station.
- The water and solids from the truck wash area continued to discharge to the RCC trough/Pump Station.
- Stormwater was rerouted south of Lacey's Lake for management in the South Detention Basin, which will be enlarged as part of this project.

Following completion of the Lacey's Lake Decommissioning facilities all plant process water that entered Lacey's Lake will be mixed with fly ash for disposal. Only truck washdown water and low flow Coal Pile runoff will discharge to the existing sewer collection system. Other stormwater will be collected in the new Coal Pile Detention Basin and the enlarged South Area Retention Basin.

2.2 Sampling and Analysis

As described in the approved Closure Plan (URS, 2011) surface water grab samples were collected from Lacey's Lake prior to waste removal activity to determine the expected contaminant concentrations in Lacey's Lake prior to closure. A total of eight samples were collected during routine ground water monitoring activity through the period of June 2010 to July 2011. Surface water samples from Lacey's Lake were not accessible after July 2011 because the pond area was dry.

The samples were analyzed for the parameters listed in Section I,E,2,(b) of Huntington's Ground Water Discharge Permit Number 150002 (UDEQ, 2009) identified below reference:

- Field Measurements: water level, pH, specific conductance, temperature.
- Laboratory Analysis: TDS, Major Ions (Na, K, Mg, Ca, Cl, SO4, CO3, HCO3), nitrate + nitrite as N, boron.

A summary of the analytical results is presented in Table 1.

2.3 Waste Removal

Huntington selected Nielson Construction located at 825 North Loop Road in Huntington, Utah, as the excavation contractor responsible for conducting waste removal activity and site restoration and URS corporation provided general project oversight during waste removal activity.

Nielson Construction began waste removal activity in the pond area beginning in mid-October 2011. Heavy equipment including excavators, backhoes and front end loaders were used to enter Lacey's Lake and methodically remove waste material beginning with the southeast embankment. Material was then consolidated and moved to the north side of Lacey's Lake where additional excavators and front end loaders transferred the material to dump trucks for transport and disposal in Huntington's on-site Class III Industrial Waste Landfill. As waste removal activity progressed Nielson Construction began excavating in the material handling area south of Lacey's Lake. This material was moved to the north end of the project site and consolidated with material removed form Lacey's Lake. Finally, material adjacent to Lacey's Lake on the north side of the project area was excavated.

Upon reaching the underlying native material a clear difference in color and texture was observed. This can clearly be seen in the series of site photographs included in Attachment A and provided a visual indicator of completion. A total of approximately 26,600 tons of waste material was removed from the Lacey's Lake pond area. Attachment A shows the general construction sequence as it progressed through the month of October 2011.

During excavation a large diameter culvert was observed in the southeast corner of the excavation. The culvert was approximately three feet in diameter and appeared to be designed to convey stormwater under the access road to the south although the terminal end of the culvert was not located. Based on site observations the culvert appeared to be at approximately the same elevation as surrounding native material. However, the surrounding native material and culvert had been buried by ash material in the past and was not anticipated prior to closure activity. This culvert may have inadvertently served as a conduit for contaminant migration in the horizontal flow direction thereby accelerating contaminant migration to the south toward groundwater monitoring location HSW-1. The culvert was plugged with concrete prior to site restoration in the area to prevent potential future migration of groundwater and/or contaminants in the subsurface.

On October 31, 2011, Nielson Construction, URS and Huntington staff inspected the site and determined that removal of waste material from Lacey's Lake and adjacent waste handling areas was completed. The approximate elevation at the base of the excavated areas were measured using an automatic level. These approximate elevations are shown in Figure 1.

2.4 Site Restoration

Site restoration activity began on October 31, 2011 with preliminary grading and placement of backfill material in the former Lacey's Lake pond area. Nielson Construction provided the backfill material (known as "reject sand") which they generated as a result of material sorting operations. This material met the construction specification for backfill material described in the associated construction plans dated September 27, 2011. Large belly dump trucks were used to place the backfill material directly in the former pond area where it was then graded and compacted in a series of lifts to the required 90% compaction. Placement of backfill material was completed at the end of November 2011. Photographs 23 and 24 in Attachment A show the final site grade after completion of site restoration activity. The approximate final grade follows the surrounding topography and is depicted in Figure 1. This final grade provides positive drainage with a surface slope of approximately two percent.

Huntington is currently considering future land use options for the area. Therefore, placement of six inches of topsoil and reseeding of the area as described in the approved Closure Plan (URS, 2011) has been temporarily suspended.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Decommissioning of the Lacey's Lake Pond Area was completed in December 2011 according to the approved Closure Plan (URS, 2011). A total of approximately 26,600 tons of waste material was removed from the pond area. Waste material removed from the pond area was disposed of in Huntington's on-site Class III Industrial Waste Landfill. The final site grading in the pond area follows the surrounding topography and provides draining with a surface slope of approximately two percent. No significant issues were encountered during closure activity and all tasks are complete with the exception of placement of topsoil and reseeding (described in Section 2.4).

URS recommends formal acknowledgement of the Lacey's Lake Pond Area closure with revision to Huntington's Ground Water Discharge Permit Number 150002 (UDEQ, 2009).

4.0 REFERENCES

UDEQ, 2009. Utah Department of Environmental Quality. *PacifiCorp Huntington Power Plant Ground Water Discharge Permit* (Permit No. UGW150002). Division of Water Quality, Utah Water Quality Board. March 30, 2009.

URS, 2011. *Final Closure Plan Lacey's Lake Pond Area.* May, 2011.

TABLES AND FIGURES

Table 1 - Surface Water Sample Results - Lacey's Lake

Year	Quarter	Boron (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium (mg/L)	Carbonate (mg/L)	Bicarbonate (mg/L)	Chloride (mg/L)	Conductivity (µmhos/cm)	Nitrate (mg/L)	pH (pH)	Sulfate (mg/L)	TDS (mg/L)	Elevation	Temp °C (°C)	Spec Cond (µS/cm)
2010	Jun	26.0	830	330	26.0	250	100	<10.0	1400	6900	7.90	9.15	2000	5300	Surface	15.7	9.20
2010	Oct	14.1	884	20	23.6	204	30	<10.0	512	4630	1.63	10.65	1130	3960	Surface	15.7	4.99
2010	Nov	12.2	779	<1.0	29.1	243	39	<20.0	418	4490	1.91	8.65	1410	3540	Surface	6.3	4.93
2010	Dec	13.9	816	76	24.3	202	42	<20.0	498	4080	3.46	8.45	1630	3520	Surface	9.6	4.51
2011	Apr	32.8	941	562	39.0	460	112	<20.0	1670	7950	13.40	9.80	2310	6450	Surface	14.6	8.97
2011	May	12.9	908	21	24.9	266	168	<20.0	724	4740	6.78	11.42	1690	4360	Surface	14.8	5.26
2011	Jun	15.5	1070	<1.0	22.5	227	70	<40.0	376	5480	10.4	12.46	1670	4010	Surface	17.6	5.83
2011	Jul	6.7	650	3	12.0	164	43	<20.0	265	3320	5.2	11.67	1260	2670	Surface	23.1	3.71

Notes:

TDS = Total Dissolved Solids
pH = per Hydrogen
°C = degrees Celsius
mg/L = milligrams per liter
µS/cm = microsiemens per centimeter
µmhos/cm = micromhs per centimeter

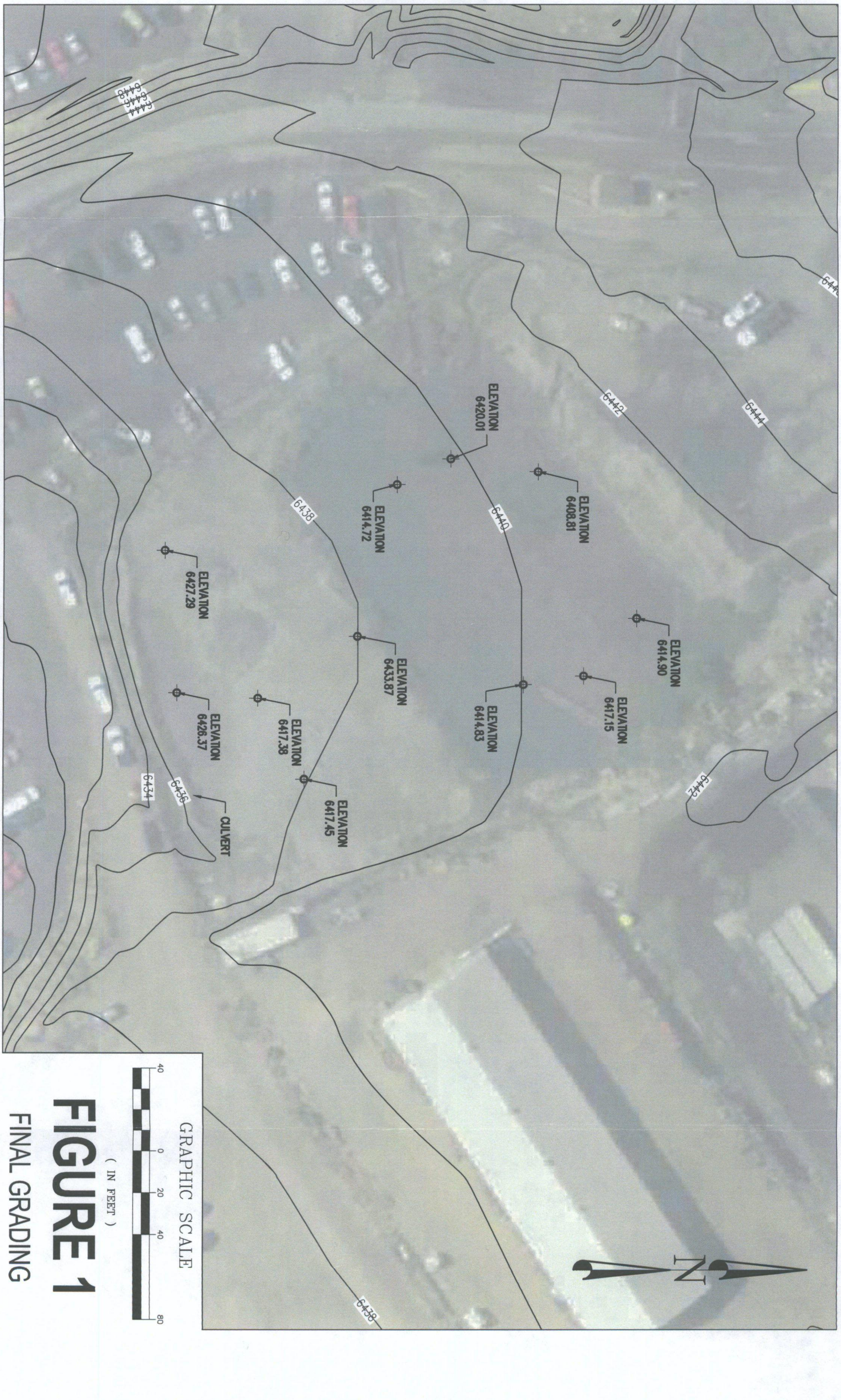


FIGURE 1

FINAL GRADING

ATTACHMENT A – PHOTOGRAPHIC LOG

URS

PHOTOGRAPHIC LOG

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No.	**Date:**
1	02/21/11

Direction Photo Taken:

South

Description:

View of Lacey's Lake looking South during sludge removal dredging prior to closure.

Photo No.	**Date:**
2	02/21/11

Direction Photo Taken:

South

Description:

View of Lacey's Lake looking South during sludge removal dredging prior to closure.

Client Name:	Site Location:	Project No.
PacifiCorp	Huntington Power Plant	24585242

Photo No. 3 **Date:** 10/19/11

Direction Photo Taken:

West

Description:

View of Lacey's Lake during initial waste removal activity during closure.

Photo No. 4 **Date:** 10/19/11

Direction Photo Taken:

Northwest

Description:

View of Lacey's Lake during initial waste removal activity during closure.

Client Name:	Site Location:	Project No.
PacifiCorp	Huntington Power Plant	24585242

Photo No. 5 **Date:** 10/20/11

Direction Photo Taken:

South

Description:

View of Lacey's Lake during waste removal activity.

Photo No. 6 **Date:** 10/20/11

Direction Photo Taken:

Northwest

Description:

View of Lacey's Lake during waste removal activity.

URS

PHOTOGRAPHIC LOG

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No. 7 **Date:** 10/24/11

Direction Photo Taken:

West

Description:

View of Lacey's Lake during waste removal activity.

Photo No. 8 **Date:** 10/24/11

Direction Photo Taken:

Northwest

Description:

View of Lacey's Lake during waste removal activity.

Client Name: PacifiCorp	**Site Location:** Huntington Power Plant	**Project No.** 24585242

Photo No. 9

Date: 10/25/11

Direction Photo Taken:

Northwest

Description:

View of Lacey's Lake during waste removal activity.

Photo No. 10

Date: 10/25/11

Direction Photo Taken:

Southwest

Description:

View of fly ash drying area south of Lacey's Lake during waste removal activity.

URS **PHOTOGRAPHIC LOG**

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No. 11

Date: 10/26/11

Direction Photo Taken:

East

Description:

View of Lacey's Lake during waste removal activity.

Photo No. 12

Date: 10/26/11

Direction Photo Taken:

East

Description:

View of fly ash drying area south of Lacey's Lake during waste removal activity.

URS

PHOTOGRAPHIC LOG

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No. 13 **Date:** 10/28/11

Direction Photo Taken:

East

Description:

View of Lacey's Lake during waste removal activity.

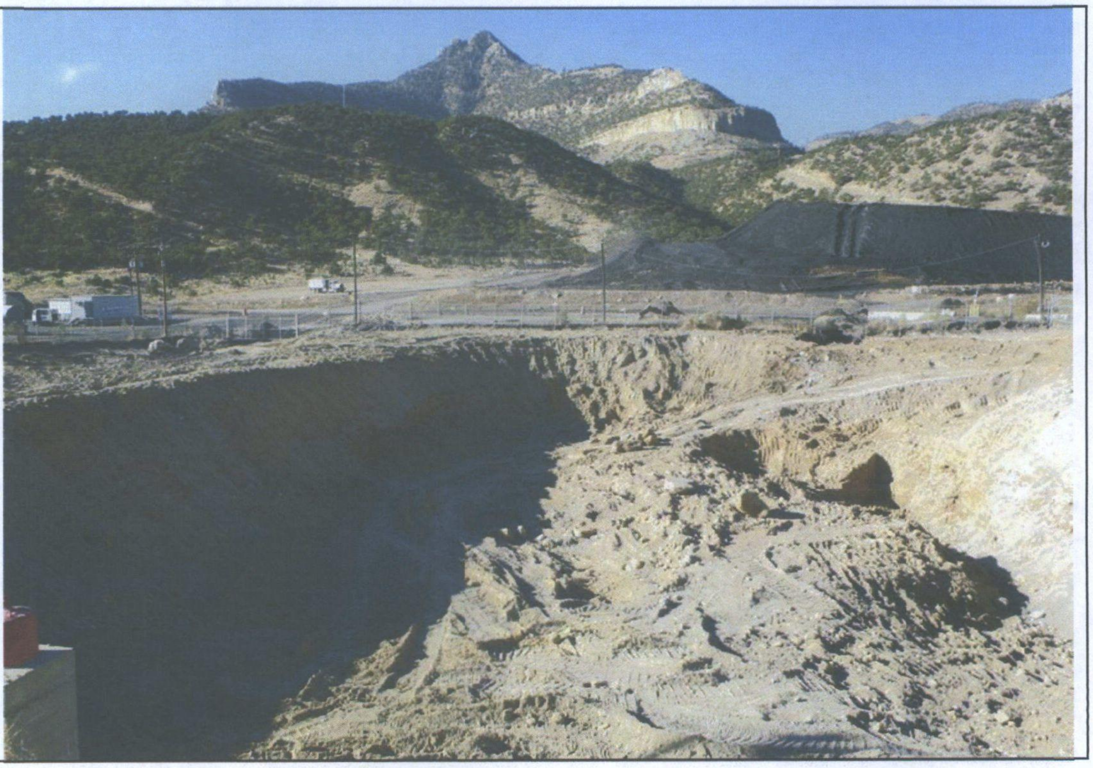
Photo No. 14 **Date:** 10/31/11

Direction Photo Taken:

West

Description:

View of Lacey's Lake during waste removal activity.



URS **PHOTOGRAPHIC LOG**

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No. 15 **Date:** 10/31/11

Direction Photo Taken:

East

Description:

View of fly ash drying area south of Lacey's Lake during waste removal activity.

Note the individual collecting elevation survey data at the approximate location of the three foot diameter culvert.

Photo No. 16 **Date:** 10/31/11

Direction Photo Taken:

East

Description:

View of the large diameter culvert located at the south end of the fly ash drying area south of Lacey's Lake.

URS

PHOTOGRAPHIC LOG

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No. 17

Date: 10/31/11

Direction Photo Taken:

Northwest

Description:

View of Lacey's Lake during site restoration activity.

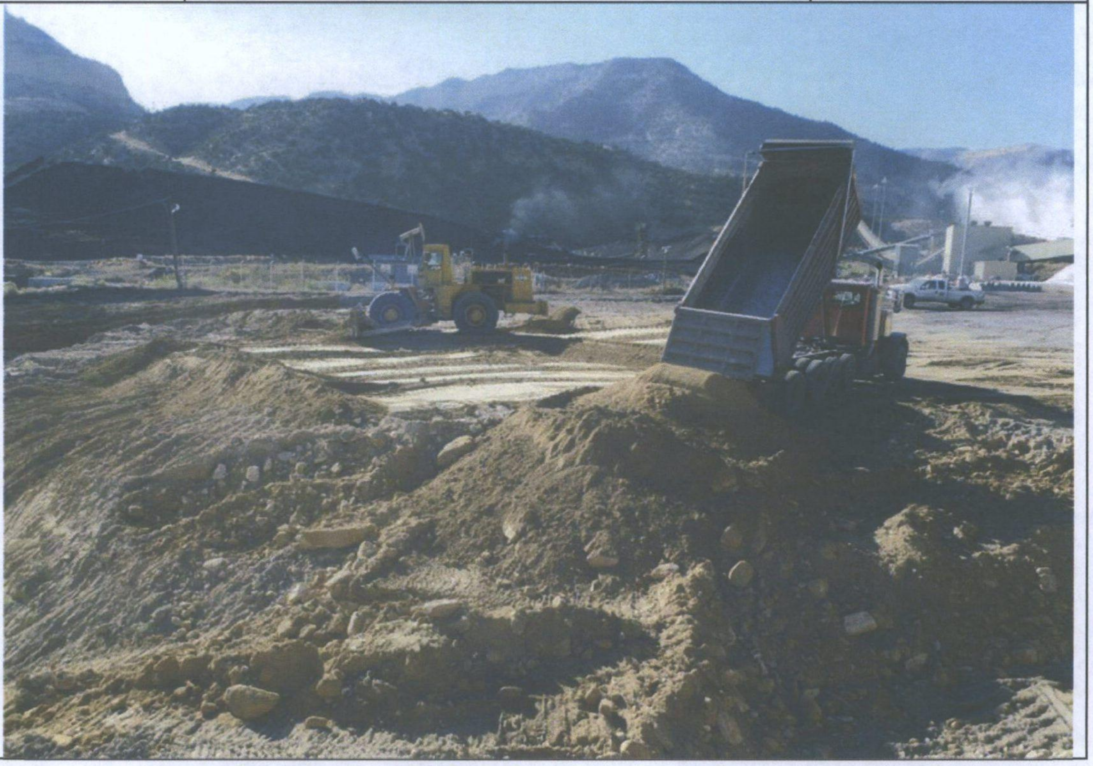


Photo No. 18

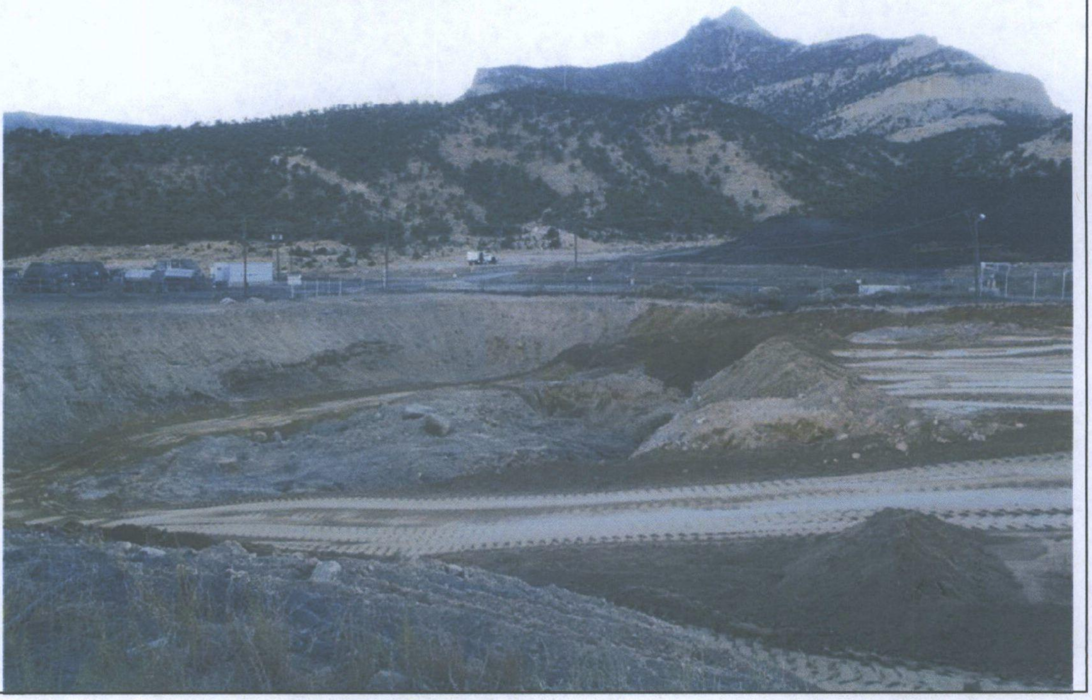
Date: 10/31/11

Direction Photo Taken:

Southwest

Description:

View of Lacey's Lake during site restoration activity.



PHOTOGRAPHIC LOG

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No. 19	**Date:** 11/01/11
Direction Photo Taken: West	
Description: View of Lacey's Lake during site restoration activity.	

Photo No. 20	**Date:** 11/01/11
Direction Photo Taken: West	
Description: View of Lacey's Lake during site restoration activity.	

URS		PHOTOGRAPHIC LOG
Client Name: PacifiCorp	**Site Location:** Huntington Power Plant	**Project No.** 24585242

Photo No. **21**	**Date:** 11/01/11

Direction Photo Taken:

Northwest

Description:

View of Lacey's Lake during site restoration activity.

Photo No. **22**	**Date:** 11/02/11

Direction Photo Taken:

West-Southwest

Description:

View of Lacey's Lake during site restoration activity.

Client Name:	**Site Location:**	**Project No.**
PacifiCorp	Huntington Power Plant	24585242

Photo No. 23	**Date:** 12/02/11
Direction Photo Taken: Northwest	
Description: View of Lacey's Lake post closure activity.	

Photo No. 24	**Date:** 12/02/11
Direction Photo Taken: South	
Description: View of Lacey's Lake post closure activity.	

PACIFICORP

Memorandum

Huntington Power Plant
8 miles west of Huntington, Utah on Hwy. 31
P.O. Box 680
Huntington, Utah 84528

Date: January 14, 2016

To: Bradly Giles

From: Russ Willson, PacifiCorp
Mark Rutherford, PacifiCorp

Subject: Confirmation of CCR Removal Efforts for the Huntington Power Plant Historic Scrubber Pond

Description of Historic Scrubber Pond

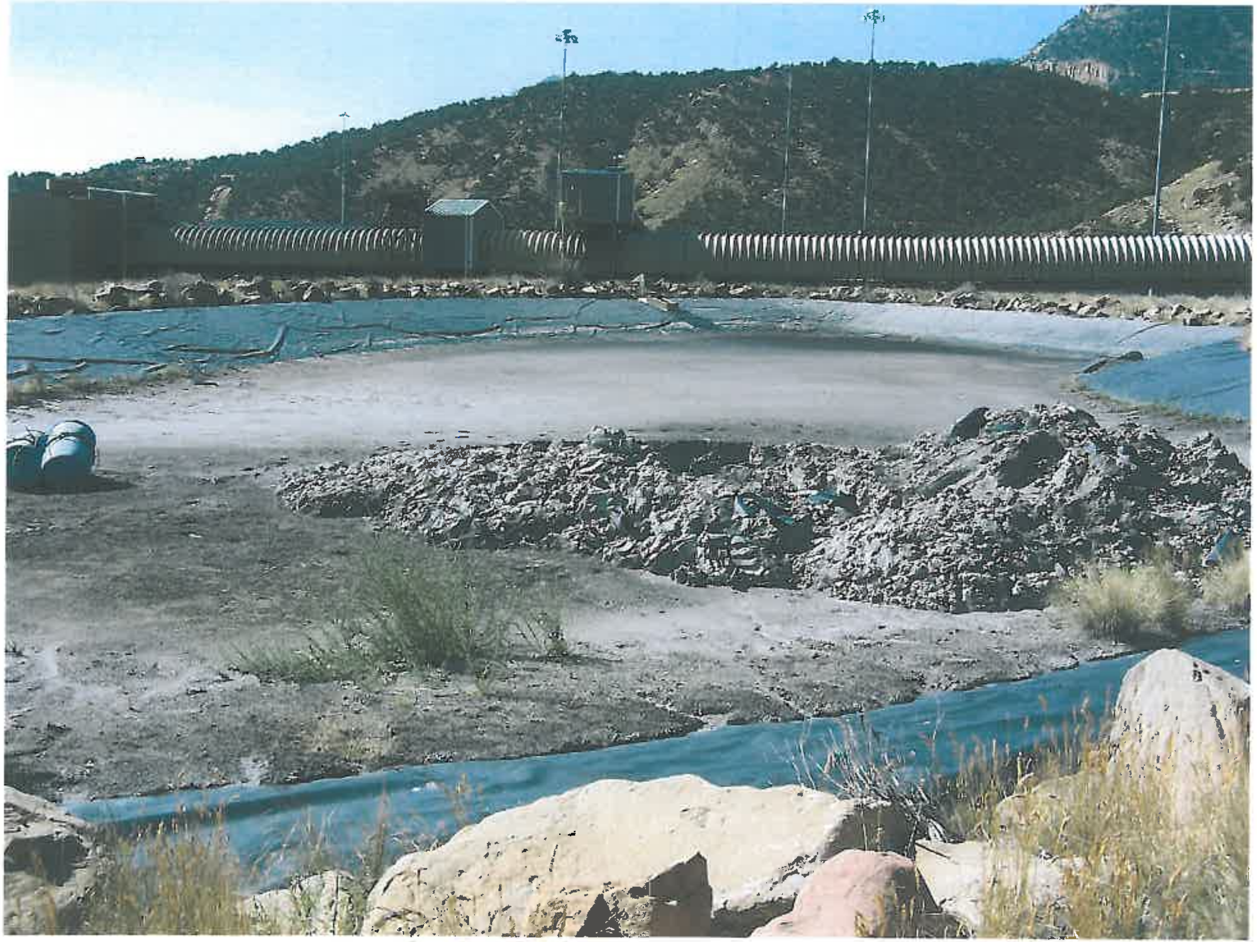
The scrubber pond (pond) at the Huntington Plant was a 7 acre foot storage pond historically used to store scrubber wastes. The pond covered 28,000 square feet in area and was located north of the coal blend pile and southeast of the Unit One and Unit Two cooling towers. The pond was approximately 6 feet deep at its deepest location. The pond was constructed with an asphaltic bottom and sides with the addition of a poly liner. The thickness of the asphalt was 6" – 8". Located at the fringe of the poly liner were large, 3' to 5' boulders. There were two concrete control structures located in the pond. The inlet structure was a 4' x 4' x 3' high concrete box structure with a 6" HDPE pipe used to historically deliver scrubber waste to the pond. The pond also had a 3.5' x 5' x 2' high concrete structure with an 18" PVC pipe used as an outlet for overflow conditions.

Prior to closure the pond had not been actively used to collect or store scrubber wastes for at least 6 years. At the time of closure, the pond contained approximately 2.5 acre feet of scrubber wastes consisting of FGD wastes, fly ash, bottom ash, coal dust and some soil from rainwater runoff events. The waste was moist from storm water capture and in the lower reaches of the pond was wet (see attached photo).

2015 Cleaning, CCR Removal and Analysis

Clean closing activities on the scrubber pond were conducted during the first week of October, 2015. The activities included the removal of all of the CCR materials with the use of an excavator and dump trucks. The CCR materials were placed in the CCR landfill for final disposal. Over-excavation to native and sandy soils was witnessed by Russ Willson during the CCR material removal portion of the project. Representative soil sampling was conducted on the native materials remaining in the bottom of the pond. The samples were tested for pH, TCLP metals and total petroleum hydro-carbons. The results of the analysis are attached to this document. The concrete structures were demolished and removed to the industrial waste landfill. The asphaltic and poly liners were also removed and disposed of in the industrial waste landfill. After the removal of the CCR materials, liners, structures and boulders was complete, the clean banks of the pond were pulled in and used to fill the void of the pond. Also, in December of 2015, the entire pond closure site was hydro-seeded with a reclamation seed mix to reduce the potential for erosion at the disturbed site (see attached photo)

In view of the historical use of the Scrubber Pond, the understanding that the pond was lined with a combination of asphalt and poly materials, visual and analytical evaluations of the native soil during decommissioning, filling in the pond void with clean materials and the final reclamation of the area, it is our belief that the Scrubber Pond has been properly clean closed.



Scrubber Pond Prior to Decommissioning

Photo Showing the Depth of CCR Materials to be Removed. Photo Also Reveals the Asphaltic Liner Below the Poly Liner.

Scrubber Pond Location after Closure and Reclamation

Attachment 1

Analytical Results from Soil Samples

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Jose Rocha
QA Officer

INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-001
Client Sample ID: Soil Sample #1
Collection Date: 9/24/2015 900h
Received Date: 9/29/2015 1025h

Analytical Results TCLP METALS Method 1311

TCLP Prep Date: 10/1/2015 2015h

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
Arsenic	mg/L	10/4/2015 1417h	10/6/2015 1245h	SW6020A	0.0100	< 0.0100	
Barium	mg/L	10/4/2015 1417h	10/6/2015 1245h	SW6020A	0.0500	**0.524**	
Cadmium	mg/L	10/4/2015 1417h	10/6/2015 1245h	SW6020A	0.00250	< 0.00250	
Chromium	mg/L	10/4/2015 1417h	10/6/2015 1245h	SW6020A	0.0100	< 0.0100	
Lead	mg/L	10/4/2015 1417h	10/6/2015 1245h	SW6020A	0.0500	< 0.0500	
Mercury	mg/L	10/3/2015 1515h	10/5/2015 830h	SW7470A	0.0100	< 0.0100	
Selenium	mg/L	10/4/2015 1417h	10/6/2015 1245h	SW6020A	0.0100	< 0.0100	
Silver	mg/L	10/4/2015 1417h	10/6/2015 1245h	SW6020A	0.0100	< 0.0100	

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INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-001
Client Sample ID: Soil Sample #1
Collection Date: 9/24/2015 900h
Received Date: 9/29/2015 1025h

Analytical Results

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
pH @ 25° C	pH Units		9/29/2015 1745h	SW9045D	1.00	**8.53**	H

H - Sample was received outside of the holding time.

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ORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-001A
Client Sample ID: Soil Sample #1
Collection Date: 9/24/2015 900h
Received Date: 9/29/2015 1025h

Test Code: 8015-S-TPH-3546

Analytical Results TPH-DRO (C10-C28) by Method 8015D Mod/3546

Analyzed: 9/30/2015 1323h **Extracted:** 9/29/2015 1355h
Units: mg/kg-dry **Dilution Factor:** 1 **Method:** SW8015D

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
Diesel Range Organics (DRO) (C10-C28)	68476-34-6	20.8	**140**	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 4-Bromofluorobenzene	460-00-4	17.4	34.72	50.0	10-122	

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ORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-001A
Client Sample ID: Soil Sample #1
Collection Date: 9/24/2015 900h
Received Date: 9/29/2015 1025h
Test Code: 8260-S-PPM

Analytical Results VOAs MBTEXN/GRO by GC/MS Method 8260C

Analyzed: 9/30/2015 1152h
Units: mg/kg-dry **Dilution Factor:** 2.48 **Method:** SW8260C

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
TPH C6-C10 (GRO)		0.0524	**0.469**	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 1,2-Dichloroethane-d4	17060-07-0	0.139	0.1309	106	51-170	
Surr: 4-Bromofluorobenzene	460-00-4	0.124	0.1309	95.1	60-144	
Surr: Dibromofluoromethane	1868-53-7	0.135	0.1309	103	60-145	
Surr: Toluene-d8	2037-26-5	0.131	0.1309	99.7	50-138	

Sampling and analytical preparation performed by method 5030C modified for analysis of soil samples collected in 2 or 4 oz jars.

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INORGANIC ANALYTICAL REPORT

Client:	PacifiCorp - Huntington Plant	**Contact:**	Russell Willson
Project:	Historic Scrubber Pond Closure - CCR / 3000107488		
Lab Sample ID:	1509566-002		
Client Sample ID:	Soil Sample #2		
Collection Date:	9/24/2015 905h		
Received Date:	9/29/2015 1025h		

Analytical Results TCLP METALS Method 1311

TCLP Prep Date: 10/1/2015 2015h

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
Arsenic	mg/L	10/4/2015 1417h	10/6/2015 1248h	SW6020A	0.0100	< 0.0100	
Barium	mg/L	10/4/2015 1417h	10/6/2015 1248h	SW6020A	0.0500	**0.659**	
Cadmium	mg/L	10/4/2015 1417h	10/6/2015 1248h	SW6020A	0.00250	< 0.00250	
Chromium	mg/L	10/4/2015 1417h	10/6/2015 1248h	SW6020A	0.0100	< 0.0100	
Lead	mg/L	10/4/2015 1417h	10/6/2015 1248h	SW6020A	0.0500	< 0.0500	
Mercury	mg/L	10/3/2015 1515h	10/5/2015 836h	SW7470A	0.0100	< 0.0100	
Selenium	mg/L	10/4/2015 1417h	10/6/2015 1248h	SW6020A	0.0100	< 0.0100	
Silver	mg/L	10/4/2015 1417h	10/6/2015 1248h	SW6020A	0.0100	< 0.0100	

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INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-002
Client Sample ID: Soil Sample #2
Collection Date: 9/24/2015 905h
Received Date: 9/29/2015 1025h

Analytical Results

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
pH @ 25° C	pH Units		9/29/2015 1745h	SW9045D	1.00	**8.70**	H

H - Sample was received outside of the holding time.

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ORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-002A
Client Sample ID: Soil Sample #2
Collection Date: 9/24/2015 905h
Received Date: 9/29/2015 1025h

Test Code: 8015-S-TPH-3546

Analytical Results TPH-DRO (C10-C28) by Method 8015D Mod/3546

Analyzed: 9/30/2015 1303h **Extracted:** 9/29/2015 1355h
Units: mg/kg-dry **Dilution Factor:** 1 **Method:** SW8015D

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
Diesel Range Organics (DRO) (C10-C28)	68476-34-6	20.7	**38.8**	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 4-Bromofluorobenzene	460-00-4	17.1	34.43	49.6	10-122	

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ORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-002A
Client Sample ID: Soil Sample #2
Collection Date: 9/24/2015 905h
Received Date: 9/29/2015 1025h

Test Code: 8260-S-PPM

Analytical Results VOAs MBTEXN/GRO by GC/MS Method 8260C

Analyzed: 9/30/2015 1253h
Units: mg/kg-dry **Dilution Factor:** 2.49 **Method:** SW8260C

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
TPH C6-C10 (GRO)		0.0519	**0.0527**	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 1,2-Dichloroethane-d4	17060-07-0	0.139	0.1298	107	51-170	
Surr: 4-Bromofluorobenzene	460-00-4	0.128	0.1298	98.6	60-144	
Surr: Dibromofluoromethane	1868-53-7	0.132	0.1298	102	60-145	
Surr: Toluene-d8	2037-26-5	0.129	0.1298	99.5	50-138	

Sampling and analytical preparation performed by method 5030C modified for analysis of soil samples collected in 2 or 4 oz jars.

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INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-003
Client Sample ID: Soil Sample #3
Collection Date: 9/25/2015 1530h
Received Date: 9/29/2015 1025h

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Analytical Results TCLP METALS Method 1311

TCLP Prep Date: 10/1/2015 2015h

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
Arsenic	mg/L	10/4/2015 1417h	10/6/2015 1251h	SW6020A	0.0100	< 0.0100	
Barium	mg/L	10/4/2015 1417h	10/6/2015 1251h	SW6020A	0.0500	**0.808**	
Cadmium	mg/L	10/4/2015 1417h	10/6/2015 1251h	SW6020A	0.00250	< 0.00250	
Chromium	mg/L	10/4/2015 1417h	10/6/2015 1251h	SW6020A	0.0100	< 0.0100	
Lead	mg/L	10/4/2015 1417h	10/6/2015 1251h	SW6020A	0.0500	< 0.0500	
Mercury	mg/L	10/3/2015 1515h	10/5/2015 842h	SW7470A	0.0100	< 0.0100	
Selenium	mg/L	10/4/2015 1417h	10/6/2015 1251h	SW6020A	0.0100	< 0.0100	
Silver	mg/L	10/4/2015 1417h	10/6/2015 1251h	SW6020A	0.0100	< 0.0100	

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INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-003
Client Sample ID: Soil Sample #3
Collection Date: 9/25/2015 1530h
Received Date: 9/29/2015 1025h

Analytical Results

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
pH @ 25° C	pH Units		9/29/2015 1745h	SW9045D	1.00	**8.51**	H

H - Sample was received outside of the holding time.

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ORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-003A
Client Sample ID: Soil Sample #3
Collection Date: 9/25/2015 1530h
Received Date: 9/29/2015 1025h

Test Code: 8015-S-TPH-3546

Analytical Results TPH-DRO (C10-C28) by Method 8015D Mod/3546

Analyzed: 9/30/2015 1323h **Extracted:** 9/29/2015 1355h
Units: mg/kg-dry **Dilution Factor:** 1 **Method:** SW8015D

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
Diesel Range Organics (DRO) (C10-C28)	68476-34-6	21.1	**59.8**	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 4-Bromofluorobenzene	460-00-4	19.9	35.20	56.6	10-122	

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ORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-003A
Client Sample ID: Soil Sample #3
Collection Date: 9/25/2015 1530h
Received Date: 9/29/2015 1025h

Test Code: 8260-S-PPM

Analytical Results VOAs MBTEXN/GRO by GC/MS Method 8260C

Analyzed: 9/30/2015 1314h
Units: mg/kg-dry **Dilution Factor:** 2.51 **Method:** SW8260C

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
TPH C6-C10 (GRO)		0.0536	< 0.0536	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 1,2-Dichloroethane-d4	17060-07-0	0.144	0.1341	107	51-170	
Surr: 4-Bromofluorobenzene	460-00-4	0.132	0.1341	98.3	60-144	
Surr: Dibromofluoromethane	1868-53-7	0.137	0.1341	102	60-145	
Surr: Toluene-d8	2037-26-5	0.133	0.1341	99.0	50-138	

Sampling and analytical preparation performed by method 5030C modified for analysis of soil samples collected in 2 or 4 oz jars.

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INORGANIC ANALYTICAL REPORT

Client:	PacifiCorp - Huntington Plant	**Contact:**	Russell Willson
Project:	Historic Scrubber Pond Closure - CCR / 3000107488		
Lab Sample ID:	1509566-004		
Client Sample ID:	Soil Sample #4		
Collection Date:	9/25/2015 1540h		
Received Date:	9/29/2015 1025h		

Analytical Results TCLP METALS Method 1311

TCLP Prep Date: 10/1/2015 2015h

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
Arsenic	mg/L	10/4/2015 1417h	10/6/2015 1304h	SW6020A	0.0100	< 0.0100	
Barium	mg/L	10/4/2015 1417h	10/6/2015 1304h	SW6020A	0.0500	**0.495**	
Cadmium	mg/L	10/4/2015 1417h	10/6/2015 1304h	SW6020A	0.00250	< 0.00250	
Chromium	mg/L	10/4/2015 1417h	10/6/2015 1304h	SW6020A	0.0100	< 0.0100	
Lead	mg/L	10/4/2015 1417h	10/6/2015 1304h	SW6020A	0.0500	< 0.0500	
Mercury	mg/L	10/3/2015 1515h	10/5/2015 844h	SW7470A	0.0100	< 0.0100	
Selenium	mg/L	10/4/2015 1417h	10/6/2015 1304h	SW6020A	0.0100	< 0.0100	
Silver	mg/L	10/4/2015 1417h	10/6/2015 1304h	SW6020A	0.0100	< 0.0100	

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INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-004
Client Sample ID: Soil Sample #4
Collection Date: 9/25/2015 1540h
Received Date: 9/29/2015 1025h

Analytical Results

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
pH @ 25° C	pH Units		9/29/2015 1745h	SW9045D	1.00	**8.07**	H

H - Sample was received outside of the holding time.

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ORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-004A
Client Sample ID: Soil Sample #4
Collection Date: 9/25/2015 1540h
Received Date: 9/29/2015 1025h

Test Code: 8015-S-TPH-3546

Analytical Results TPH-DRO (C10-C28) by Method 8015D Mod/3546

Analyzed: 9/30/2015 1343h **Extracted:** 9/29/2015 1355h
Units: mg/kg-dry **Dilution Factor:** 1 **Method:** SW8015D

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
Diesel Range Organics (DRO) (C10-C28)	68476-34-6	21.2	**34.9**	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 4-Bromofluorobenzene	460-00-4	19.6	35.28	55.5	10-122	

ORGANIC ANALYTICAL REPORT

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Client: PacifiCorp - Huntington Plant **Contact:** Russell Willson
Project: Historic Scrubber Pond Closure - CCR / 3000107488
Lab Sample ID: 1509566-004A
Client Sample ID: Soil Sample #4
Collection Date: 9/25/2015 1540h
Received Date: 9/29/2015 1025h

Test Code: 8260-S-PPM

Analytical Results VOAs MBTEXN/GRO by GC/MS Method 8260C

Analyzed: 9/30/2015 1334h
Units: mg/kg-dry **Dilution Factor:** 2.51 **Method:** SW8260C

Compound	CAS Number	Reporting Limit	Analytical Result	Qual
TPH C6-C10 (GRO)		0.0540	**0.0586**	

Surrogate	CAS	Result	Amount Spiked	% REC	Limits	Qual
Surr: 1,2-Dichloroethane-d4	17060-07-0	0.144	0.1351	107	51-170	
Surr: 4-Bromofluorobenzene	460-00-4	0.131	0.1351	96.8	60-144	
Surr: Dibromofluoromethane	1868-53-7	0.137	0.1351	101	60-145	
Surr: Toluene-d8	2037-26-5	0.133	0.1351	98.3	50-138	

Sampling and analytical preparation performed by method 5030C modified for analysis of soil samples collected in 2 or 4 oz jars.

URS

Memorandum

Date: October 21, 2015

To: Glenn Pinterich, PacifiCorp
Steve Daley, PacifiCorp

From: Rick Cox, P.E.
Wil Pineda, P.E.

Subject: Confirmation of CCR Removal Efforts for the Huntington Power Plant Wastewater Pond (aka Holding Basin)

In August, September, and October, 2015, URS inspected coal combustion residual (CCR) and sediment removal activities at the PacifiCorp Huntington Power Plant Wastewater Pond, also known as the Holding Basin. Based on URS' inspections, visual characterization of the materials excavated from the pond, and observations of the pond invert after excavation, URS confirms that all but *de minimis* amounts of CCR material have been removed. The Wastewater Pond is characterized as clean.

Description of Wastewater Pond

The Wastewater Pond is located north of the Huntington Power Plant, adjacent to the existing concrete structures that include the Wastewater Sump (aka Wastewater Basin 1 [WWB1]), Neutralization Basin, and Holding Basin Sump. Historically, water that overflowed the Waste Disposal and Neutralization Basins was conveyed to the Wastewater Pond. When capacity became available in WWB1, the water was then pumped back to WWB1 which discharges to the Evaporation Pond. The Wastewater Pond was only a temporary holding basin (or regulating reservoir) which was never intended to store CCR. Consequently, the volume of CCR in the pond was minimal.

In October 2015, a new wastewater basin (WWB2) was constructed to settle out CCR from the wastewater stream and to minimize overflow to the Wastewater Pond. WWB2 and its associated drying pad were constructed in the southern portion of the original footprint of the Wastewater Pond. Sediment and CCR removal was conducted prior to construction of those facilities.

2015 Cleaning and CCR Removal

A major cleaning event was conducted between August and October 2015 to remove accumulated sediment and CCR from the Wastewater Pond. URS staff visited the Huntington Power Plant on August 7, 2015 to confirm that CCR had been removed from the proposed footprint of WWB2 prior to foundation preparation for the new structure. Refer to Photo 2 in the attached Photograph Log.

URS visited the site again on September 29 and October 6, 2015 to observe the cleaning activities and removal of CCR as the project progressed. The final site visit by URS to confirm pond cleaning was on October 13, 2015. Refer to the Photograph Log for photos taken during each site visit.

Native sandy and silty soil was encountered as the CCR was removed. The native material is a light brown coloring, similar to the surrounding mountains and is easily distinguishable from the grey CCR material. Approximately 3500 cubic yards of material were excavated from the pond and disposed of at the plant's ash landfill. This represents an average excavation depth of 1.5 feet below the encountered pre-excavation pond floor.

In view of the historical use of the Wastewater Pond, URS' inspections, visual characterization of the materials excavated from the pond, and the volume of excavated material, URS confirms that the CCR material in the Wastewater Pond has been removed and the pond is clean.

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End Memorandum

Photograph Log

General Information

Project Number: 60429408

Project Name: Wastewater Pond CCR Removal

Client: PacifiCorp Energy

Location: Huntington Power Plant, Huntington , Utah

Field Investigator: Wil Pineda and Rick J. Cox

Photographs

Photograph: 1

Description:

Wastewater pond prior to cleaning activities facing northeast.

Photograph: 2

Description:

Former wastewater pond area facing east. Area cleared of CCR in preparation for WWB 2 concrete structure.

8-7-2015

Recorded By: Rick J. Cox

Date: August 2015

Photograph Log

General Information

Project Number: 60429408

Project Name: Wastewater Pond CCR Removal

Client: PacifiCorp Energy

Location: Huntington Power Plant, Huntington , Utah

Field Investigator: Wil Pineda and Rick J. Cox

Photographs

Photograph: 3

Description:

Former wastewater pond area facing east. Area cleaned except for <1/8" thick layer of CCR in some areas.

9-29-2015

Photograph: 4

Description:

Former wastewater pond area facing east. Same condition as 9-29-15 with exception that fill has been stockpiled for the WWB2 structure and drying pad.

10-6-2015

Recorded By: Rick Cox

Date: September and October 2015

Photograph Log

General Information		
	Project Number: 60429408	**Project Name:** Wastewater Pond CCR Removal
	Client: PacifiCorp Energy	
	Location: Huntington Power Plant, Huntington , Utah	
	Field Investigator: Wil Pineda and Rick J. Cox	

Photographs

Photograph: 5

Description:

Former wastewater pond area facing west. Pond embankment and floor completely cleaned.

10-13-2015

Photograph: 6

Description:

Former wastewater pond area facing southwest. Pond embankment and floor completely cleaned.

10-13-2015

Recorded By: Wil Pineda

Date: October 2015

Photograph Log

General Information	
	Project Number: 60429408 | **Project Name:** Wastewater Pond CCR Removal
	Client: PacifiCorp Energy
	Location: Huntington Power Plant, Huntington , Utah
	Field Investigator: Wil Pineda and Rick J. Cox

Photographs

Photograph: 7

Description:

Former wastewater pond area facing south. Pond embankment and floor completely cleaned. Stockpile is the location for the new drying pad.

10-13-2015

Photograph: 8

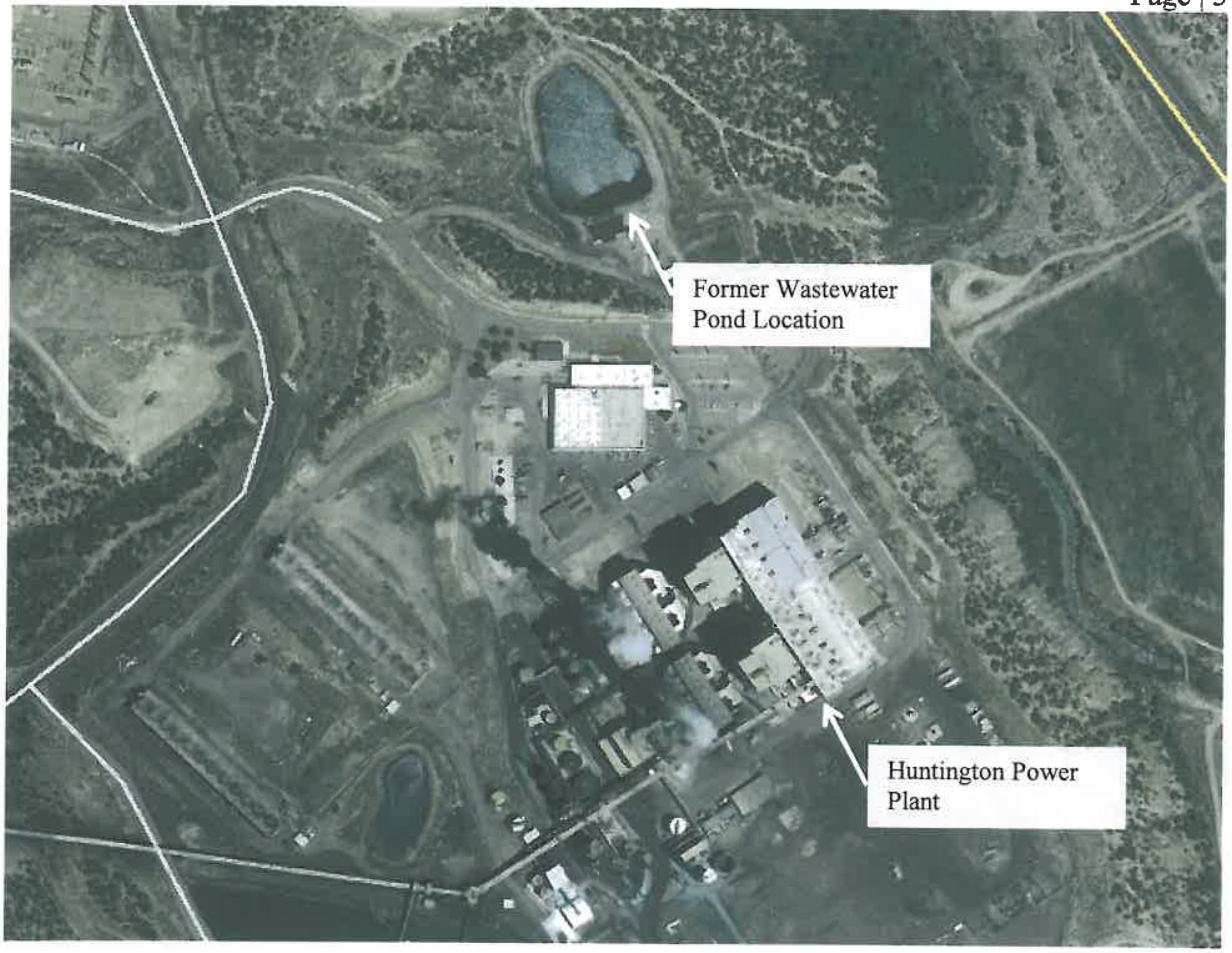
Description:

Former wastewater pond area facing southwest. Pond embankment and floor completely cleaned.

10-13-2015

Recorded By: Wil Pineda

Date: October 2015


Former Wastewater Pond Location
Huntington Power Plant

Huntington Research Farm
Isotope Analysis

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September 13, 2016

Project Reference: PERCM73

Executive Summary

Utah DEQ Division of Water Quality requested stable oxygen and hydrogen isotope sampling of the Research Farm monitoring network wells to evaluate possible water quality changes for the Groundwater Permit Renewal #UGW-150002 at the Huntington Power Plant (HPP or Plant). This report details that sampling effort, provides the analytical results and interprets the isotope analyses along with hydrogeologic and hydrologic data to identify the ground water characteristics in the valley aquifer beneath the Research Farm.

^{18}O and ^{2}H isotope samples were collected in Research Farm monitoring wells (NH-1W through 8W), Huntington Creek upstream and downstream (UPL-9) of the Farm, the Mancos Shale ground water upgradient of the landfills (HLF-1N) and the Irrigation Pond (UPL-13).

Installation of one additional Research Farm well was also requested by UDEQ; however, two wells were installed; one in the location UDEQ requested (NH-9W) and one on the north side of Huntington Creek (NH-10W). These wells were also sampled for the ^{18}O and ^{2}H isotopes and each well had static ground water elevation measured for this analysis.

The analysis concludes that the operation of the Research Farm at the Huntington Power Plant is having no discernable effect on water quality in monitoring well NH-8W. Both the isotopic and geochemical data indicate the water quality in NH-8W is very similar to the surface water quality in Huntington Creek. In addition, the upstream and downstream Huntington Creek isotope analysis is the same (i.e., analytical results are within the precision and accuracy of the analytical method). The ^{18}O and ^{2}H isotope sampling data results indicate evaporative losses in other Research Farm monitoring network wells (NH-1W through NH-7W). Several different processes are presented that explain the isotopic signature and although the isotope data indicate that ground water is influenced by evaporation, they do not indicate ground water degradation. As stated in the previous ground water reports, any deviations in ground water quality, if present, are within the precision and accuracy of the analytical method.

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1.0 INTRODUCTION

In response to the Utah DEQ Division of Water Quality's request for oxygen and hydrogen stable isotope sampling to delineate water quality changes, specifically in NH-8W and generally for the Research Farm monitoring wells, for Groundwater Permit Renewal #UGW-150002 for the Huntington Power Plant (HPP or Plant), Water and Environmental Technologies was contracted by PacifiCorp to complete sample collection, data analysis and reporting (Utah DEQ Completeness Review and request for additional information, May 3, 2016). In addition to stable isotope analyses, ground water and surface water monitoring data from the 37 years of monitoring at the site were considered to complete the multiple lines of evidence analysis. Stable ^{18}O and ^{2}H isotope samples were collected (Figure 1) in the Research Farm (Farm) Monitoring Wells (NH-1W through 8W), Huntington Creek upstream and below the Farm (UPL-9), the Mancos Shale ground water upgradient of the landfill (HLF-1N) and the Plant Wastewater Pond (UPL-13). Isotope samples were collected on June 6 through 9, 2016. These samples were submitted to the University of Waterloo in Ontario, Canada on June 10 for analysis. Oxygen and Hydrogen results were received on July 5, 2016 and are included as Attachment C.

One additional Research Farm well was also requested by UDEQ; however, two wells were installed; one in the location UDEQ requested and one on the north side of Huntington creek (NH-9W and NH-10W, respectively on Figure 1). These wells provide isotope and additional ground water elevation and chemistry data for the Farm.

The methodology and results of this data collection effort are detailed in this report. In order to provide meaningful isotopic results, all influent site waters were sampled, as well as, other Research Farm monitoring wells. The data from ? provide valuable information with which to provide context for the interpretation of the isotopic results. In addition, water levels were measured in the sampled wells and surface water elevation and flow measurements were collected during and after the sampling event. The report will provide a background site description including area climatic conditions, geology/hydrogeology, soil types and a description of site water sources. The data analysis incorporates information on ground water and surface water hydraulics, analytical and geochemical data analysis and the stable isotope analysis.

This report uses data from geologic, hydrologic and hydrogeologic studies conducted throughout the history of the HPP. Many of the conclusions stated in this report are based on data and analysis conducted as part of these referenced reports. Studies conducted as part of the referenced report include the installation of the first monitoring wells at the site in 2004, continued routine monitoring of ground water and surface water at the facility, landfill corrective measures to eliminate infiltration and liquids in and from the landfills, responses to requests from the State on specific topics, annual monitoring data, and routine site-wide monitoring report summaries. These reference are listed in the Section 5 of this report.

2.0 SITE DESCRIPTION

2.1 Location

The Huntington Power Plant facility (Figure 1) is located on Highway #31 in Emery County, Utah; approximately nine miles west of the town of Huntington. The community of Huntington is located at the junction of Highway #31 and Highway #10, approximately 20 miles south-southwest of Price, Utah. The Plant site is located in the Huntington Creek Valley at a mean elevation of 6,450 feet above sea level.

2.2 Climate

The average annual precipitation rate for this high desert climate is between 6 and 10 inches per year, mainly in late July through October. Ten to 20 inches of snow can be expected in the winter, representing between one and two inches of the annual precipitation. Skies are clear about 225 days per year. Winds are generally light to moderate in all seasons and predominantly blow from the northwest. The temperature ranges from a low of 10° (F) in January to the high 80's in July (Western Regional Climate Center, 2014).

2.3 Site History

The Huntington Power Plant (HPP), owned and operated by Rocky Mountain Power, is a two-unit coal-fired electrical generation plant. Unit 1 of the Plant began operation in 1977, while Unit 2 started in 1974. The coal-fired boilers produce steam used to power turbine generators producing electricity.

HPP utilizes wet scrubbers to meet State and Federal Regulations for sulfur dioxide emissions from both units. Flue gas from the boilers is routed through wet flue gas de-sulfurization (FGD) scrubbers to remove sulfur dioxide. The scrubbers use lime as an alkaline sorbent, which precipitates calcium sulfate/sulfite and converts it into synthetic gypsum by oxidizing it in the wet solution. The FGD solution has a blowdown stream of slurry which is then concentrated. In 2006, the waste handling procedure was updated to reduce free water in the Combustion Waste (CW) Landfill. New waste handling equipment was purchased to condition the FGD concentrate from the Unit 1 thickener and Unit 2 hydro cyclones with fly ash and lime in pug mills. In 2010, vacuum drum filters were installed to further dewater the FGD concentrate (gypsum). The FGD slurry is divided into two streams with the majority going to the vacuum drum filters for dewatering and the balance going to the pug mills for fly ash stabilization. Excess fluids from the dewatering process are sent to the waste water decanting basins, where it is either reused in the Plant or sent to the Irrigation Storage Pond. The dewatered waste material is trucked to the Combustion Waste Landfill for disposal.

Water handling procedures at HPP are complex. In general, water from multiple sources is used for Plant operations and multiple wastewater sources are collected for re-use in Plant processes or irrigation of the Research Farm. Wastewater includes normal blowdown water such as cooling tower circulation water, FGD wastewater, ash handling system water, boiler blowdown, etc. In addition to water treatment wastes and sewage treatment effluents, water from storm drains, building roofs and floor drains is also collected. These combine as mixed wastewater in the waste water decanting basins, where it is either reused in the Plant or sent to the Irrigation Storage Pond for use on the Research Farm.

2.4 Geology and Hydrogeology

The HPP is located in the northwestern portion of the Colorado Plateau physiographic province and within the Mancos Shale Lowlands (Stokes 1986). The Mancos Shale Lowlands are characterized by sloping, gravel-covered pediments, rugged badlands and narrow, flat-bottomed alluvial valleys. HPP is located in the Huntington Creek valley, which is incised into the Wasatch Plateau, draining east into the Castle Valley.

Because of its geochemical composition and erodibility, the Mancos Shale, a dark gray to black ridge forming marine shale deposit, provides a natural source of soluble salts. It was deposited in a transgressive/regressive coastal-marine environment and is a known source of halite (NaCl) and calcium and sodium-sulfate minerals, such as gypsum ($CaSO_4$*$10H_2O$), mirabilite (Na_2SO_4*$10H_2O$) and thenardite (Na_2SO_4) (Waddell et al.1979). These minerals are highly soluble and dissolve readily when in contact with ground water.

The Plant is principally built upon alluvial fan deposits at the confluence of Deer and Huntington Creeks. The uplands on both sides of Huntington Creek are composed of the Masuk Member of the Mancos Shale with scattered remnants of Quaternary pediments.

Based on previous site work and a review of monitoring well lithology logs, the site ground water monitoring wells can be broken into two broad classifications: alluvial/colluvial monitoring wells and Mancos Shale monitoring wells. A majority of the site monitoring wells are screened across the alluvial/shale contact. Exceptions include some wells along Deer Creek, which are completed in alluvium and some within the CW Landfill areas, which are completed in competent Mancos Shale.

Lithologic logs from the shale wells note a light gray to dark gray or gray-black shale in various stages of weathering from very weathered to consolidated and unweathered. Alluvial well descriptions describe a tan, orange-brown, and red mixture of fine to medium grained sand and sandstone boulders. Well drilling, development and monitoring procedures, in general, indicate higher permeability in the alluvial wells, as compared to the shale wells. While some shale wells recharge very slowly and take more than 24 hours to recover from sample purging, others completed in fractured shale recover very quickly. The wells completed in competent shale indicate low permeability, while the wells in the fractured Mancos recover more quickly and provide a greater volume of water. Gypsum is noted in both shale and alluvial well lithologic logs, indicating minerals and salts are abundant and readily available for dissolution. Ground water in the shale shows increased concentrations of minerals along flow paths because of the contact with soluble minerals in the aquifer matrix and the longer residence time of ground water due to the low permeability of the shale as compared to the higher permeability of the valley bottom alluvium. Ground water in the alluvium may show similar increased minerals, but with much lower concentrations due to lower mineral content in the aquifer matrix and shorter relative residence times in the more permeable alluvium.

Ground water at the site is present in three separate aquifers: the competent shale aquifer, colluvial/shale contact aquifer, and valley bottom alluvial aquifer. Infiltration of precipitation in the uplands moves down through the colluvium and accumulates in a water table aquifer at the colluvium/Mancos shale contact. Ground water flows along the contact following the topography of the shale and, in some areas, infiltrates into the fractured Mancos shale. Given the generally dry desert climate, infiltration is relatively minimal and ground water flow from the uplands to the Research Farm is a small component of the total flow into the alluvial valley aquifer.

In some areas, such as at the top of the upland ridges, ground water is not encountered along the Colluvium/Mancos contact and the wells are completed deeper in the competent Mancos Shale aquifer. These wells are typically deeper and have very limited production. Once the well is purged, it can take days to weeks to fully recharge.

The Huntington alluvial valley aquifer is typically composed of gravel to boulder sized material mixed with varying amounts of sand, silt and clay. It was deposited by Huntington Creek on an erosional contact with the Mancos Shale. In this environment, the alluvium is generally deposited during high energy storm events that wash eroded sediments from the uplands into the valley. These sediments are reworked by meandering stream channels and exhibit a fining upward depositional sequence.

2.5 Site Soils

The surface soils in the valley bottom in vicinity of the Huntington Power Plant are generally alluvial fans of well drained calcareous soils that are loamy textured mixed clay, silt, sand, and cobbles; mostly derived locally from the upgradient Mancos Shale. The Smithpond, Shupert-Dancehall and Kitipes soils generally occur along alluvial fan remnants or structural benches or mesas. At HPP, these soils occur along Huntington Creek and generally are coarser grained with a lower clay content than the upgradient Gerst-Strych-Badland Complex and Porser series soils that occur along the valley slopes.

2.6 Water Sources

Water sources to the HPP facility can be categorized as water used in the Plant (imported water), water pumped from the Plant to the Irrigation Pond (wastewater) and natural sources of water flowing through the site (stream and groundwater). Each of these sources is discussed below.

2.6.1 Stream Inflow

The USGS topographic map indicates Huntington Creek and Deer Creek are perennial streams, although Deer Creek has been dry through the Plant since mine dewatering discharge to the creek ceased in the Spring of 2015. Surface water in Huntington Creek has been monitored for many decades. Monitoring locations include: upgradient to HPP at H-1, cross gradient at H-2 and downgradient from HPP at UPL-9 (Huntington Power Plant Water Quality Analysis, January 11, 2016). Trends indicate similar water quality and typical seasonal fluctuations between 1979 and present. Geochemically, the Huntington Creek monitoring points plot near each other in the calcium bicarbonate water type area of the trilinear diagram.

Monitoring data shows slightly lower concentrations in H-1 and H-2 as compared to UPL-9, as is expected with natural increases in soluble minerals as stream water has additional contact time with sediments.. Historic monitoring data indicate that this trend was evident even in 1979, thus suggesting naturally increasing concentrations in the creek in the downgradient direction. Springs seeping into the creek along the stream reach from H-1 to UPL-9 show evident salt mobilization from the uplands ground water entering the valley. Ground water quality data from monitoring wells (NH-1W, NH-2W and NH-4W) along the ridge bottom adjacent to the creek indicate ground water saline seeps from the Mancos Shale into the alluvial valley aquifer and are, most likely, the reason for the water quality concentration increases both in the alluvial aquifer and in the downgradient stream water.

2.6.2 Imported Water

Water is imported to HPP from Huntington Creek. The imported water is used in Plant operations and stored onsite in the raw water storage pond (Settling Basin). The raw water quality has significantly lower mineral concentrations as compared to other site waters (with the exception of Huntington Creek stream inflow). Previous geochemical work indicates that the raw water type is predominantly calcium/bicarbonate, while other site waters, ground water and spring water, are calcium to sodium-sulfate type waters.

2.6.3 Wastewater

Wastewater is generated by normal blowdown from Plant processes such as cooling tower circulation water, liquid ash handling systems and boiler blowdown. Water treatment wastes and sewage treatment effluent also contribute to wastewater flow, as do storm drains, building roof and floor drains. These combine as mixed wastewater and are collected in the Irrigation Storage Pond (UPL-13 on Figure 1). This wastewater is used beneficially to irrigate the Research Farm.

Because waste material from this facility is derived from coal combustion, the liquid and slurry wastes are composed of naturally occurring elements (sodium, calcium, potassium, magnesium, carbonate, sulfate, chloride, boron, nitrate, and selenium). The water bearing formation beneath the facility (Mancos Shale) has background concentrations of these same elements, thus discerning impacts from facility operations can be challenging. Due to contact with the Mancos Shale, ground water also shows natural degradation of water quality along ground water flow paths.

Prior to 2006, FGD concentrate was disposed of in evaporation basins within the Coal ash waste landfills. In 2006, the waste handling procedure at HPP was updated. New waste handling equipment was purchased to condition the FGD concentrate from the Unit 1 thickener and Unit 2 hydro cyclones with fly ash and lime in pug mills, significantly reducing the moisture entering the landfill. In 2010, new vacuum drum filters were installed to further dewater the FGD concentrate (gypsum). Excess fluids from the dewatering process are sent to the waste water decanting basins for reuse at the Plant or sent to the Irrigation Storage Pond. The dewatered waste material is trucked to the Combustion Waste Landfill for disposal. This updated process eliminated free liquid in waste material deposited in the new Landfill and subsequently reduced water levels and constituent concentrations in the shallow Landfill monitoring network wells (Huntington Power Plant Water Quality Analysis, January 11, 2016). In addition to reducing water in the FGD waste handling process, infiltration of precipitation has been reduced at the old CW Landfill by designing and covering the Landfill with an evapotranspiration cap (Huntington Old Ash Landfill Modification and Maintenance Plans, May 29, 2015). The corrective measures described above were completed to reduce liquids in the landfill and eliminate seepage into the subsurface.

The Duck Pond drainage between the two Landfills, as shown in Figure 1 is fed primarily by upgradient ground water underflow, infiltration of precipitation and Landfill seepage. Seepage from the landfills was detected by the monitoring system and corrective measures were implemented at both landfill locations to resolve this issue. Infiltration of precipitation on the Old Landfill has been reduced significantly by the construction of an evapotranspiration cap and landfill seepage has been reduced by updating FGD handling procedures. Decreased ground water elevations in the landfill monitoring wells are indicative of increased efforts to minimize water content in waste material and infiltration of precipitation. In addition, a capture drain system was installed in this drainage in 2008/2009 to intercept shallow ground water with high constituent concentrations from impacting site ground water/surface water resources (Huntington Power Plant, Corrective Action Plan, October 2007). The captured water was re-routed for beneficial use within the Plant processes. Once the interception system was installed and optimized and the landfill disposal issues were addressed, seepage immediately reduced decreasing asymptotically to present conditions, where no seepage is evident. The seepage was discovered in 2004, and while the seepage has been eliminated, residual contamination is still moving through the flow system. As is common in ground water systems, especially ones with fine grained aquifer matrix, introduced total dissolved solids (TDS) reduce asymptotically with the majority of concentration decrease early and concentrations decreases slower over time, eventually approaching natural background conditions.

2.6.4 Ground Water

Ground water at the Research Farm originates from three sources, listed in order of highest contribution:

- Seepage from surface water (both streams and ponds),
- Inflow of ground water along upgradient facility boundaries, and
- Infiltration (precipitation, dust and combustion suppression, liquid disposal and irrigation).

Based on the available monitoring data for the facility, infiltration in the uplands results in a water table aquifer at the colluvial/shale contact. This is typically a thin zone of saturation in the colluvium perched on top of the less permeable shale. Flow in this aquifer generally follows the topography of the weathered surface of the shale bedrock. During monitoring well drilling activities, several locations were drilled where ground water was not encountered at the Colluvial/Mancos contact. In these situations, the perched aquifer is not present and the first ground water encountered may be deeper in the competent shale.

Regardless of where ground water is encountered in the uplands, it is a minor flow volume, with low permeability as compared to the alluvium, unless secondary permeability, such as fractures in the shale are present.

The Huntington Creek valley bottom alluvium, under the Research Farm is much more permeable than the surrounding shale aquifer. During drilling, development and purging of the wells, the alluvium produces sufficient water for sampling and drawdown during sampling is much less than in the shale or colluvial wells.

In general, ground water in the valley alluvium, flows in the same direction as surface water, exiting along the southeastern boundary of the Plant site. Ground water from the uplands enter along the valley margins, contributing ground water to the valley aquifer. From boring log descriptions and well development procedures, aquifer permeability is lower in the shale and colluvium and moderate in the alluvium. Coarse-grained material at the alluvium-shale contact accounts for a majority of the subsurface flow both in the uplands and in the Research Farm area. However, data from drilling indicates the shale/colluvial contact is composed of sandstones boulders to gravel sized material in a weathered shale matrix, whereas the valley alluvium has the same coarse grained component but much less clay in the aquifer matrix.

For this study, ^{18}O and ^{2}H isotopic results from each water source were collected and used to interpret the flow system in conjunction with previously collected data on ground water elevation, geochemical trends and streamflow elevation and flow data (Huntington Power Plant Site Wide Monitoring Program, 2004 Annual Monitoring Report, 9/20/05).

3.0 DATA ANALYSIS

Although isotope data can be very valuable in characterizing ground water flow paths and identifying source waters and contaminants, it should be used carefully and in conjunction with other hydrologic, geologic, and geochemical information (Clark, 2015). Because those data are available for this site, ^{18}O and ^{2}H isotope results will be presented as one part of multi-level analysis that also includes hydraulic flow measurements, analytical data, and geochemical analyses.

3.1 Hydraulic Flow Measurements

In general, ground water flows from the uplands into the incised creek valleys and then along the valley bottoms (arrows on Figure 2). Thus, higher elevation areas along Deer Creek, the Rock Garden (near RG-1) and the Duck Pond Drainage (between the landfills) flow to the alluvium in the Duck Pond drainage valley bottom which then discharge into the Huntington Creek Valley alluvium under the Research Farm.. Huntington Creek and the valley alluvium drain the site from the northwest to the southeast.

Figure 2 shows ground water elevation data that were collected June 7-8, 2016. The data includes two additional monitoring points from the newly drilled wells, NH-9W and NH-10W (elevation data from these wells as measured on June 9, 2016). The dataset also includes surface water elevations for Huntington Creek measured on June 7, 2016. Surface water elevations in the creek in June were higher than ground water elevations in the near stream ground water monitoring wells (NH-8W, NH-6W, NH-3W and NH-1W). This indicates that this reach of the stream may be losing water (recharging ground water). This would be expected in the spring.

Surface water elevations are much higher than ground water near NH-8W (approximately 14 ft. higher), while the differential is much smaller downstream at NH-1W and UPL-9 (stream is 0.46 ft. higher). The latter half of this stream reach (below the NH-6W) may reverse and become a gaining reach (i.e. ground water recharging the stream) in the latter part of the year as surface water flows decrease. It is likely, because of the large differential between stream water elevation and ground water elevation, that the upper portion of the reach is losing year-round.

In order to further define Huntington Creek characteristics, such as total flow, gaining or losing conditions and elevation of the stream water, additional data was collected at several locations. WET completed flow gauging at two locations, upgradient and downgradient of the Farm. PacifiCorp collected survey information on water levels in the creek, as compared to ground water at several locations along the Creek.

Stream gauging was completed upgradient (H-2) and downgradient of the Research Farm (UPL-9). These data indicate that the flow upgradient of the Farm was 114.36 cubic feet per second (cfs) and 122.49 cfs below the Farm. While these data indicate the stream is gaining, the accompanying surface water elevation data indicate the stream is losing above the Farm House and gaining below the House, with a transitional zone near the Farm House, that, most likely, varies throughout the year depending on the creek flow, elevation and precipitation. Most alluvial systems in the intermountain west have high spring flows that recharge the aquifer while low fall stream water flows are sustained by discharge from the aquifer. The ground water elevation fluctuations shown on the near creek hydrographs in Appendix A indicate that this is occurring in Huntington Creek in this area.

The majority of the increase in volume of 8 cfs or 6.5% of flow in Huntington Creek is most likely from inflow from springs and seeps from the uplands along the valley margin and discharge from Huntington Creek in the losing reach. Additional, although minor imputs are expected from irrigation and precipitation infiltration on the Research Farm. While additional studies would be needed to determine the exact contributions from these sources, the additional water represents a small portion (6.5%) of the total streamflow.

Ground water flow direction in the Huntington valley alluvium is predominantly from northwest to southeast at an average gradient of 0.014. The gradient is steeper at the northwest end of the valley (0.196) and shallower to the southeast (0.008).

Evidence of ground water under the influence of surface water is illustrated by the seasonal elevation and temperature fluctuations shown in Figures A-1 through A-4, Appendix A.

Notice that monitoring wells near the creek (NH-1W, NH-2W, NH-3W, NH-6W and NH-8W) show much more seasonal variation, as compared to wells further from the creek (NH-4W and NH-5W) which show a damped response to seasonal fluctuations of ground water temperature and elevation. The exception to this analysis is NH-2W which is completed along the base of the ridge, but the narrowing of the alluvial valley in this area forces the surface water influence throughout the valley alluvium also affecting NH-2W in this area.

As shown in Figures A-1 through A-6, most Farm wells exhibit a decreasing ground water elevation beginning in the fall of 2011 (NH-1W, NH-2W, NH-4W, NH-5W, NH-7W). Monitoring wells NH-3W, NH-6W and NH-8W are closer to the creek and although they show decreased water levels over the same period, they do not exhibit the prolonged decreased trend that other Farm wells do. Because of the widespread nature of the decrease and the larger magnitude of decrease in wells farther from the creek, it can be deduced that the decrease was in recharge to the valley alluvium from the uplands and not related to creek water. In 2009, a capture drain system was installed in the drainage between the landfills (Duck Pond Drainage) to prevent shallow ground water with high constituent concentrations from impacting site ground water/surface water resources. The system was optimized over the next year to collect baseflow but allow storm events to discharge down the drainages. The captured water is re-routed for beneficial use within the Plant processes. This effectively reduces the recharge to the valley alluvium. The largest magnitude effect on ground water from this capture system would be expected in monitoring wells nearest the system. In fact, the largest magnitude effect is in NH-7W, which is located near the mouth of the drainage in which the capture system is located.

3.2 Analytical Data

Trend Analysis

Intra-well (comparison of data constituent trends within the same well) and inter-well (comparison to other wells) trend analyses were performed on the analytical data results for the Research Farm wells. Significant trends identified in the Farm monitoring well sub-group are described below.

Research Farm water chemistry for key constituents is plotted on Figures A-4 through A-6. These graphs generally indicate seasonality in the TDS trends especially in NH-1W, NH-2W, and NH-3W with the highest TDS values in the fall. This correlates with the wells that are highly influenced by surface water and indicates that the lower reach of the stream may seasonally gain water from ground water inflow. Thus these monitoring wells are receiving proportionally more recharge from Mancos derived ground water in the fall as compared to the spring. Since the Creek only gains approximately 6.5% in flow volume across this reach and a majority of that gain is probably infiltration from the creek in the upper reach, the inflow from the Mancos is most likely a small increase in volume, but the water quality constituents are concentrated enough to show a discernable influence on the water chemistry in the valley alluvium, hence the higher TDS values.

TDS trends are relatively stable in most Farm monitoring wells; with the exception of NH-4W, NH-6W, NH-7W and NH-8W. NH-4W and NH-7W, which are located near the outlet of the Duck Pond drainage and were likely impacted by leachate from the upgradient landfill, as indicated by their elevated water quality concentrations and geochemical signature. The leachate issue has been addressed through changes in disposal practices and interception of seepage using infiltration trenches and a collection system. Both wells have sharply decreasing water levels and contaminant concentrations (TDS, sulfate, nitrate) from 2009 to present. The timing of the trends correlates with corrective actions at the landfall. The corrective actions included dewatering of waste before deposition in the landfill, an ET cap on the old landfill to prevent infiltration of precipitation and installation of a ground water capture system in the Duck Pond Drainage and at the toe of the New Landfill to intercept higher concentration landfill leakage and to reduce impacts to downgradient surface and ground water. These corrective actions are described in more detail in Section 2.6.3. The geochemical, analytic and ground water trends, in conjunction with the timing, indicate that the corrective actions are the most likely cause for the trend changes in these wells, indicating that the interception system has been effective in removing the seepage from the ground water system. (Huntington Power Plant Water Quality Analysis, January 11, 2016)

NH-6W, however, has increased TDS values, but only for the fall measurements. As with NH-1W, NH-2W and NH-3W, this may indicate that the stream is gaining water from ground water in this reach in the fall, thus there is more influence from Mancos ground water in this well in the fall. (The elevated values in this well were most likely exacerbated by a leak that was discovered in the valve to the lateral line that fed the field area around NH-6W. The monitoring well network detected the leak, as designed, and the leak was reported to the State of Utah and remedied by PacifiCorp personnel. It was repaired before the 2014 irrigation season and the 2015 constituent levels are much lower with fall levels lower than spring.)

NH-8W is the outlier. It does not show the clear seasonality of NH-6W or the sharply decreasing trend as in NH-4W and NH-7W. It has an increasing trend for TDS, sulfate and chloride and a decreasing water level trend, but its overall constituent concentrations are the lowest of the Farm monitoring well network. Decreasing water level trends, combined with increasing TDS, sulfate and chloride indicate a reduction in recharge water with lower constituent concentrations to the area surrounding this well. Capture of springs, along the base of the ridgeline which formerly flowed in a ditch along the northern edge of the Farm (shown on Figure 1) that discharged into Huntington Creek near NH-8W, most likely resulted in the water level and geochemical trends seen in NH-8W.

3.3 Geochemical Analysis

Geochemical analyses consisted of using trilinear diagrams to evaluate water types and changes in water chemistry over the monitoring period. As ground water moves through an aquifer matrix, it acquires a diagnostic chemical composition, as a result of the interaction between the ground water and the lithologic aquifer framework. At the HPP, water quality analyses have delineated a range of water quality types in monitoring wells across the site, as described in section 2.6.1 and 2.6.2. This suggests that aquifer water quality at the site is highly dependent upon the aquifer composition and water levels. It also suggests that the aquifer matrix is reactive with ground water, because of the low permeability of the shale aquifer material and the resulting relatively longer ground water residence times in the uplands aquifers as compared to the Valley alluvial aquifer. Details on ground water geochemistry for the Research Farm monitoring wells are provided using Trilinear diagrams.

Figure B-1 (Appendix B) is a Trilinear diagram which exhibits the overall geochemical signature of the Research Farm monitoring points, along with Huntington Creek and spring sample points, for the Spring 2015 monitoring event. Notice that monitoring wells NH-6W and NH-8W plot near the three monitoring points from Huntington Creek (UPL-9, H-2 and H-1), indicating the similarity in water chemistry.

Generally, the trilinear diagram indicates that the Huntington Creek sample points have much lower percent chloride and sulfate relative to the calcium and bicarbonate than the other monitoring points. The Research Farm wells, NH-4W and NH-2W, plot closer to Landfill wells when considering the sulfate component, which may indicate the effect of seepage from the Mancos Shale ground water at the toe of this slope. NH-6W and NH-8W plot very near the Huntington Creek points indicating less mixing with the ground water on the northern portion of the Farm and significant direct interaction between surface water and ground water in these wells.

A Trilinear Diagram (Figure B-2) showing NH-8W monitoring data over time indicates the difference in water quality in this well between seasons. The regularity of the seasonal differences in not, however, as consistent as that found in NH-6W (Figure B-3).

3.4 Stable Isotope Analysis

The stable ^{18}O and ^{2}H isotope sampling results are included as Appendix C and shown graphically in Figure 3. Several trends are apparent in the isotopic results. The depletion evident in the ^{18}O and ^{2}H isotope results indicates that the continental, elevation and latitude effect on precipitation is significant in the area of HPP. Meteoric water becomes more depleted as it moves farther from the ocean. As the air mass moves inland, it fractionates, whereby the heavier isotopes are rained out and the resulting air mass becomes more depleted in comparison. A similar effect occurs with increasing elevation, where cooling of the air mass causes increased precipitation at higher elevations, again depleting the resulting air mass. The depletion of the air mass at higher elevations is also effected by the increased fractionation between the liquid and vapor phases that occurs at lower temperatures. The degree of depletion of the air mass due to the continental effect versus the elevation effect cannot be accurately differentiated. In addition, higher latitudes also tend to have depleted air masses again due to the fact that temperatures are generally lower at higher latitudes.

Although Local Meteoric Water Lines (LMWL) can be developed for specific sites and can be different than the Global Meteoric Water Line (GMWL), the data results for this analysis are compared to the GMWL because the LMWL calculated for North America by the IAEA (International Atomic Energy Agency) varies only slightly from the GMWL for the ^{18}O and ^{2}H isotope results from our study. The lines actually intersect very near the data values for our site.

Also obvious from the graphical representation of the data results, is that the majority of the data fall along a trend line which insects with the GMWL at a shallower slope. The equation for the GMWL is $y=8X+10$ while the equation for the intersecting trend line is $y= 3.9X-57$ with an R^2 value close to 0.95. The trend line is indicative of an "evaporation line" (EL). Any slope less than 8, the slope of the GMWL, indicates that the waters have been influenced by kinetic fractionation. The change in slope is significant, because practically the only process which modifies the isotopic signatures of waters in this manner is evaporation. The EL slope of approximately 4 is also interesting in that it indicates evaporation that has taken place at very low humidity levels, which is characteristic of this site. The intersection of the evaporation line and the GMWL indicates the isotopic composition of the precipitation from which the waters originated. This intersection is very near the location of the upstream sample on the GMWL. The NH-8W DUP sample is a duplicate sample collected from the NH-8W monitoring well shortly after the NH-8W sample for QA/QC purposes and plots almost on top of the NH-8W sample.

Several outliers to the best fit line are evident in the data set. These include HLF-1N, UPL-13 and NH-4W. UPL-13 is the sample collected from the Irrigation Storage Pond and HLF-1N is an upgradient landfill well and that water represents deeper Mancos Shale ground water with a relatively longer residence time. The proximity of HLF-1N to the rest of the Research Farm samples indicates the influence of Mancos water in ground water samples for this site. HLF-1N is also offset from the GMWL indicating this water has been influenced by a kinetic process(es) that make it isotopically distinct. It is not surprising that UPL-13 would be distinct, as it is partially composed of Plant water which has undergone mechanical evaporation processes within the Facility. Both HLF-1N (Mancos water) and NH-4W also plot below the

EL, indicating that NH-4W has a similar isotopic signature to HLF-1N (Mancos water) with an additional evaporative influence.

NH-8W plots isotopically very near both the upstream and downstream (UPL-9) sample points, indicating strong similarity to surface water. NH-8W and the stream samples also plot very near the Global Meteoric Water Line (GMWL), indicating that these samples are isotopically very similar to local precipitation and the average isotopic signature from meteoric water worldwide with little of the evaporative signature evident in some of the other Research Farm monitoring wells.

Several other interesting trends can be noted in the trend line shown on Figure 3. NH-8W, the most upgradient Research Farm monitoring well, plots nearest the GMWL, while NH-1W and NH-2W, the furthest downgradient Farm monitoring wells, plot at the furthest end of the best fit evaporation line. NH-5W and NH-6W, mid-Farm flow regime wells, plot closer to NH-8W than NH-7W or NH-10W. Both NH-7W and NH-10W are completed along the valley margin, although on different sides of the valley. Monitoring well NH-9W is physically located near NH-10W, but plots near NH-3W on Figure 3. Both of these wells are completed near Huntington Creek but plot farther down the evaporation line than NH-5W or NH-6W which are upgradient in the flow regime. In summary, the wells further down the ground water flow path show greater influence from evaporative effects.

The best fit line represents an evaporation line with the majority of the Research Farm wells falling near that line with a correlation coefficient of 95%, thus these wells have been affected by evaporative processes. Several different interpretations can be made about exactly what evaporative processes resulted in the isotopic signature of the site waters. It can be any or a combination of the those listed below.

1. The irrigation system at the Research Farm has been managed to maximize evapotranspiration. As a result there is more evaporated water flowing through the aquifer at the lower end of the Farm, which results in greater evaporative effects than those at the upper end of the Farm.
2. The Research Farm is being irrigated with water that has been effected by evaporative processes at HPP, thus infiltration of this water would also result in ground water with an evaporative signature that increases in a downgradient direction.
3. In 2004, site investigation data documented process water from the landfill causing impacts to several wells downgradient of the landfill, down the Duck Pond Drainage and discharging into the Alluvial Aquifer beneath the Farm. These impacts were evident beneath the farm, but especially along the northern edge of the pond downgradient from the Duck Pond. The HPP monitoring network worked as designed, impacts were detected, reported to the appropriate State Agency and addressed through

corrective measures. The Landfill water was also Plant process water, with significant evaporative effects similar to the current Irrigation pond. Corrective actions have been taken to eliminate these impacts, but this contaminated water did move into the valley alluvium affecting downgradient Farm monitoring wells. With the Landfill seepage addressed, ground water monitoring shows the residual effects of the landfill seepage in the wells downgradient of the landfill.

Irrigation of the Research Farm with another water source would most likely also show an evaporative isotopic signature. Because of the arid nature of this site, evaporation would take place regardless of the source of water for irrigation, although the magnitude of the evaporative signature may not be as large because the current irrigation system is operated to maximize evapotranspiration losses and minimize infiltration.

4.0 CONCLUSIONS

The purpose of this isotope study was to determine if the Research Farm at the HPP was having an adverse effect on water quality in NH-8W or the other Research Farm monitoring network wells. Analyzing previous site data in conjunction with the new ^{18}O and ^{2}H isotope results, the conclusion can be made that HPP is having very little to no effect on water quality in well NH-8W. Both the isotopic and geochemical data indicate the water quality in this well is very similar to the surface water quality in Huntington Creek. The analytical data and hydrologic data indicate increases in TDS, sulfate and chloride in this well that correlate with a decrease in water level. These data, when evaluated in conjunction with the geochemical and new isotopic analyses, indicate that the changes in NH-8W are most likely a result of changes in the sources of recharge to this well. The changes are coincident to the construction of the capture system in the Duck Pond Drainage and subsequent capture of springs that previously flowed along the base of the ridge and into a ditch which discharged to Huntington Creek near NH-8W. The loss of this recharge component most likely resulted in the reduction in water level and the increase in water quality concentrations, as the springs generally had lower major mineral concentrations.

The ^{18}O and ^{2}H isotope sampling data results indicate evaporative losses in the other Research Farm monitoring network wells. As stated above, several different processes could be responsible for the isotopic signature and although the isotope data indicate evaporation, they do not indicate ground water quality degradation. As stated in the previous ground water reports, any deviations in ground water quality, if present, are too small to be accurately quantified.

In addition, based on the isotopic data, the site is not impacting Huntington Creek. The data indicates that the Upgradient Creek water and the Downgradient creek water are the same quality within the accuracy and precision of the analytical method. As shown on Figure 3, the upstream sample and UPL-9 plot in the same location on the figure, indicating no significant isotopic difference between the two samples, thus no degradation of the stream water.

In summary, the isotope analysis supports the conclusions that:

1. Irrigation and Farm practices do not adversely affect water quality in NH-8W,
2. Irrigation and Farm practices do not appreciable affect Huntington Creek between the upper sample location (H-2) and the lower sample location (UPL-9), and
3. Evaporative effects along ground water flowpaths under the Research Farm are detectable using stable isotope analysis, but would most likely be present and detectable regardless of the water source, given the current high ET irrigation strategy.

5.0 REFERENCES

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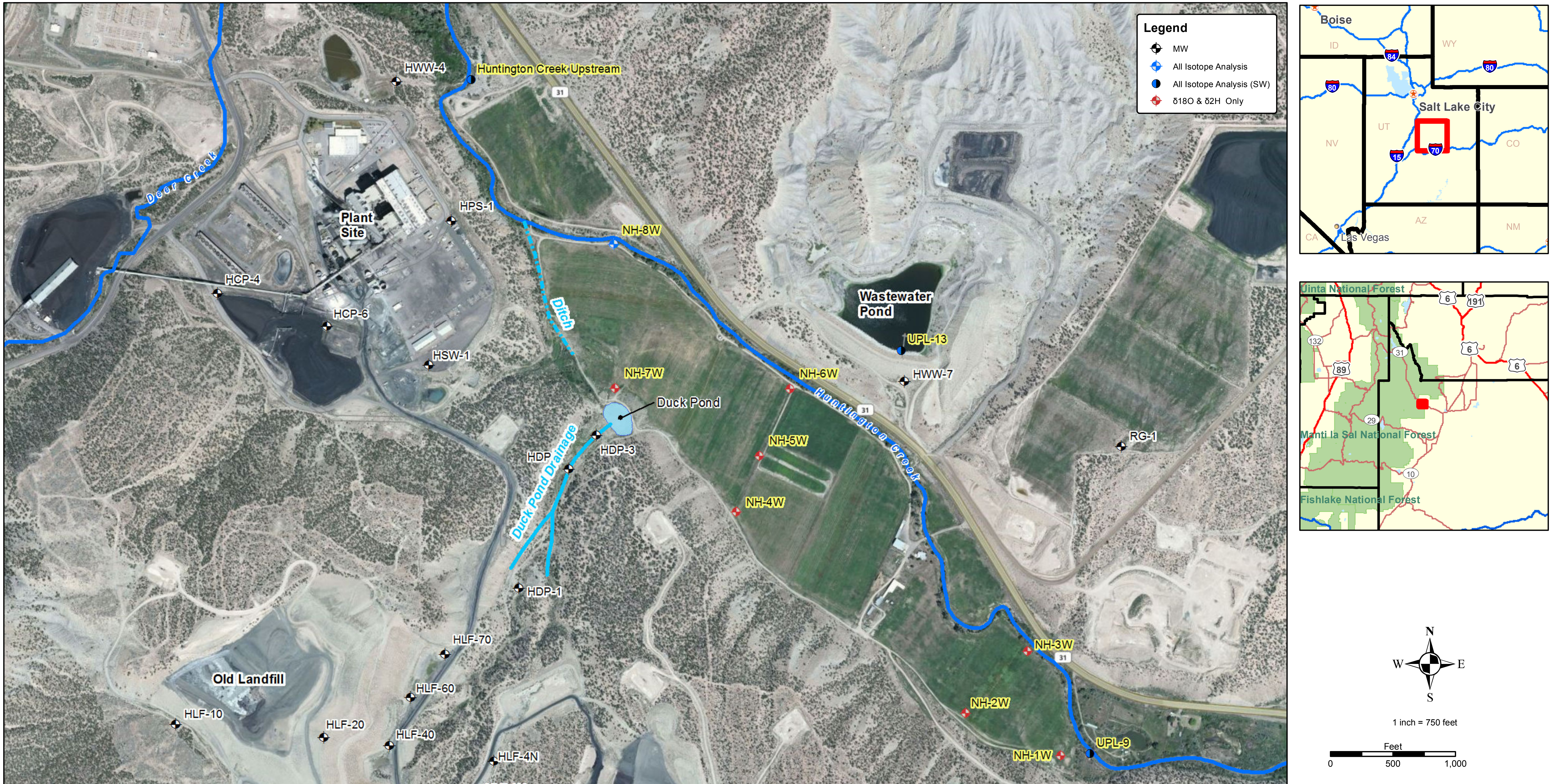
Figures



PACIFICORP

Water & Environmental TECHNOLOGIES

HUNTINGTON POWER PLANT

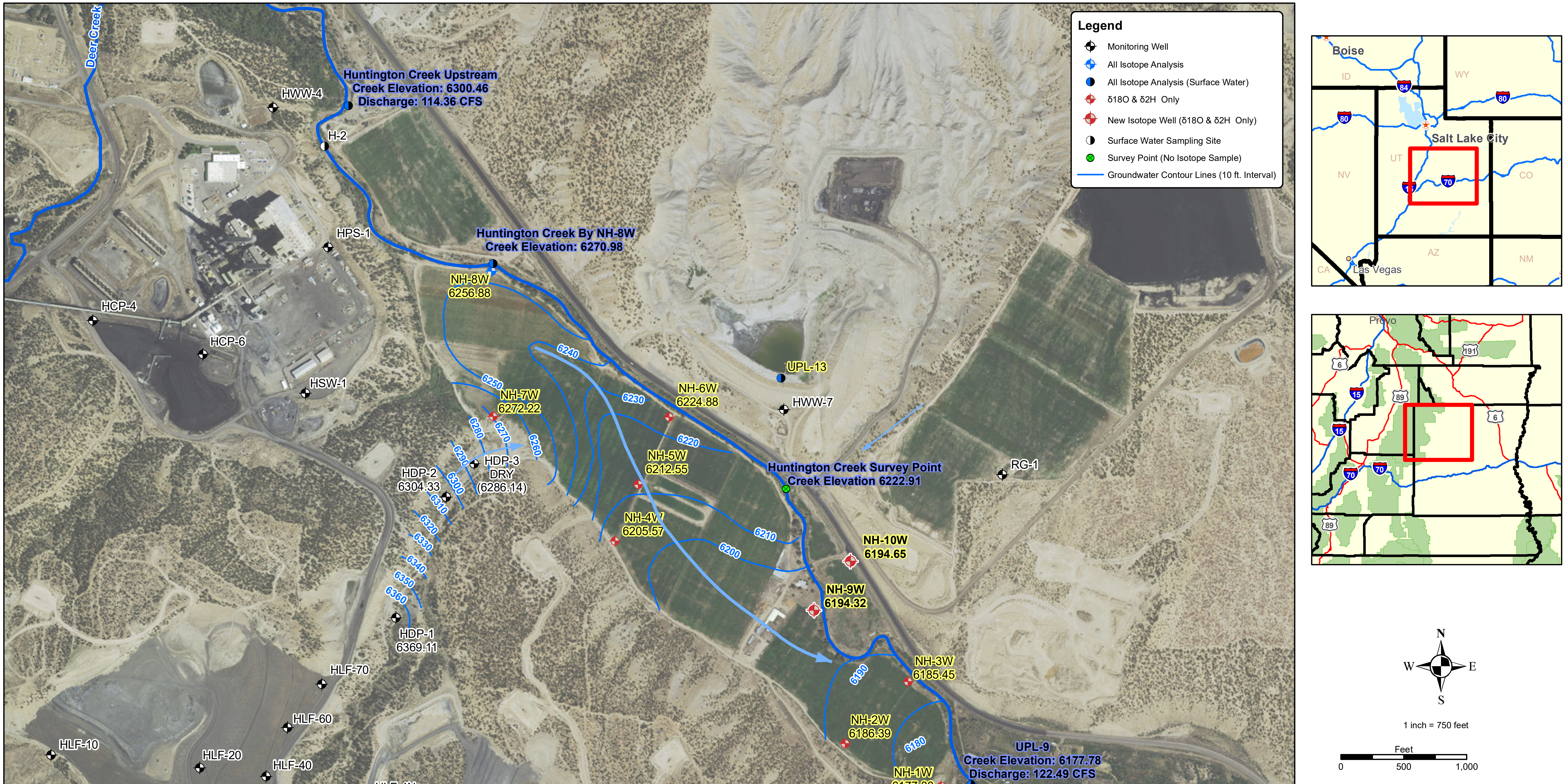
Isotope Sampling Locations

Job#: PERCM73

Date: 9/14/2016

FIGURE 1

Path: \\wetfs\maps\Huntington\2016 ISOTOPE SAMPLING.mxd, Author: jleprowse



PACIFICORP

Water & Environmental TECHNOLOGIES

Huntington Power Plant

June 2016 Groundwater Elevations

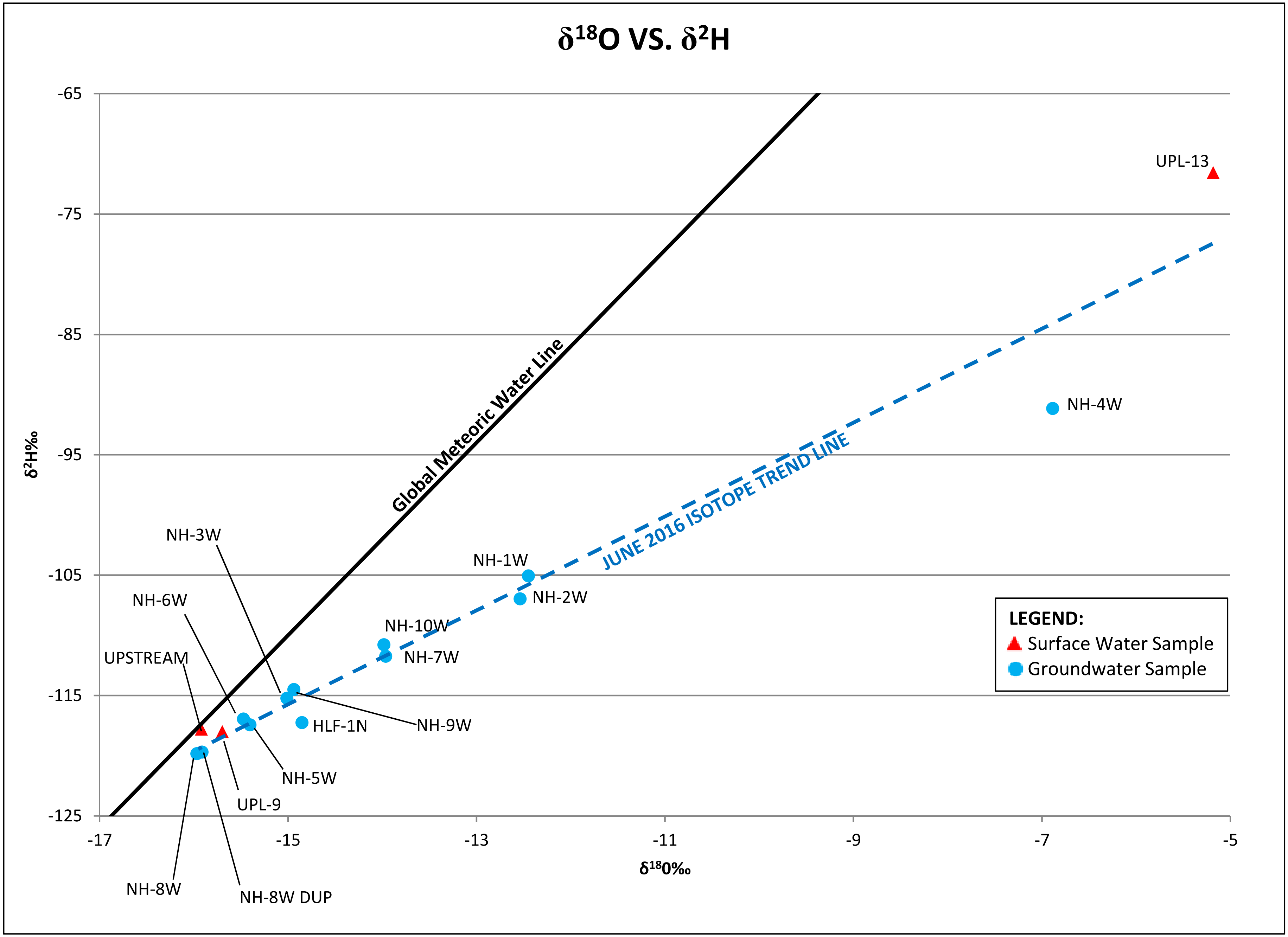
PERCM73

Date: 8/26/2016

FIGURE 2

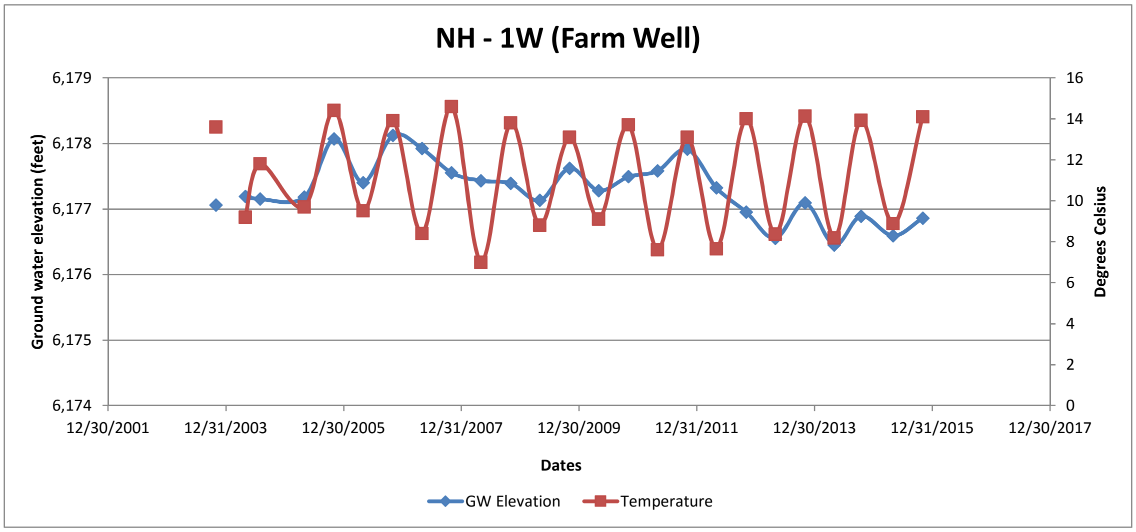
M:\Huntington\June 2016 Elevations.mxd

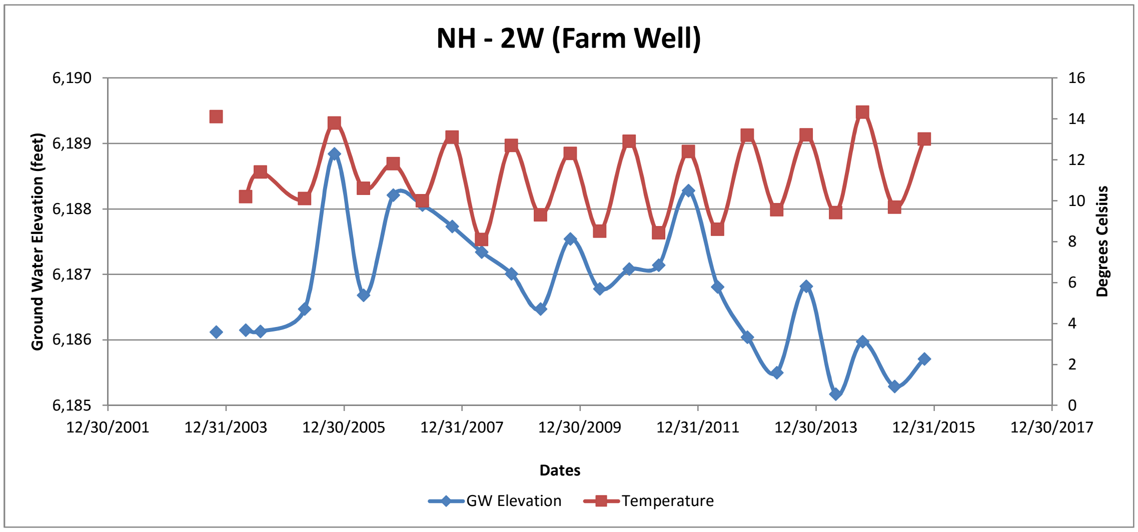
Figure 3



δ18O VS. δ2H
-65
-75
-85
-95
-105
-115
-125
δ2H‰
-17
-15
-13
-11
-9
-7
-5
δ180‰
Global Meteoric Water Line
JUNE 2016 ISOTOPE TREND LINE
UPL-13
NH-4W
NH-1W
NH-2W
NH-10W
NH-7W
NH-3W
NH-6W
UPSTREAM
HLF-1N
NH-9W
NH-5W
UPL-9
NH-8W
NH-8W DUP
LEGEND:
▲ Surface Water Sample
● Groundwater Sample

Appendix A. Water Quality Graphs


NH - 1W (Farm Well)
Ground water elevation (feet)
6,179
6,178
6,177
6,176
6,175
6,174
Degrees Celsius
16
14
12
10
8
6
4
2
0
12/30/2001
12/31/2003
12/30/2005
12/31/2007
12/30/2009
12/31/2011
12/30/2013
12/31/2015
12/30/2017
Dates
GW Elevation
Temperature


NH - 2W (Farm Well)
Ground Water Elevation (feet)
6,190
6,189
6,188
6,187
6,186
6,185
Degrees Celsius
16
14
12
10
8
6
4
2
0
12/30/2001
12/31/2003
12/30/2005
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12/30/2017
Dates
GW Elevation
Temperature

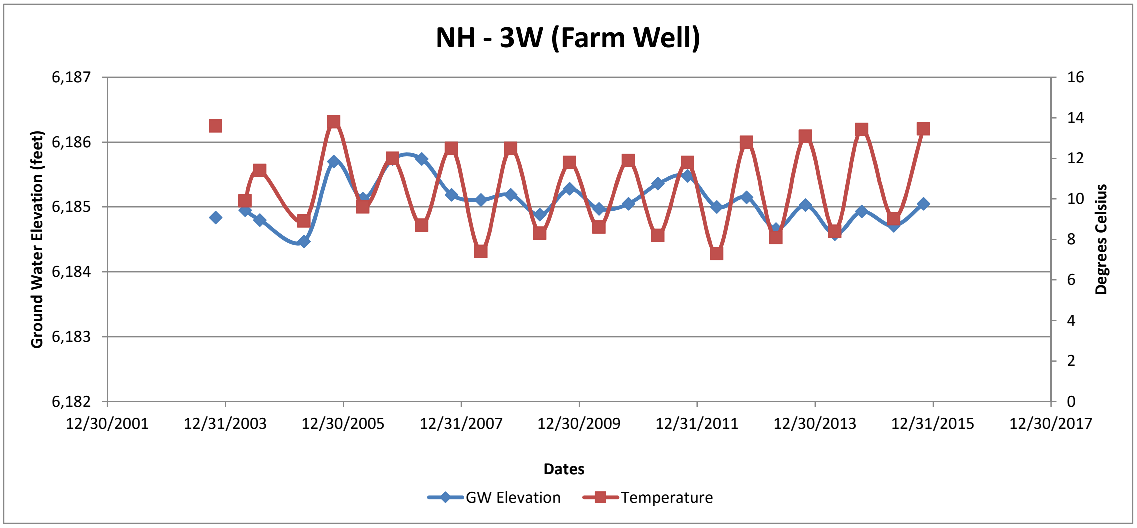
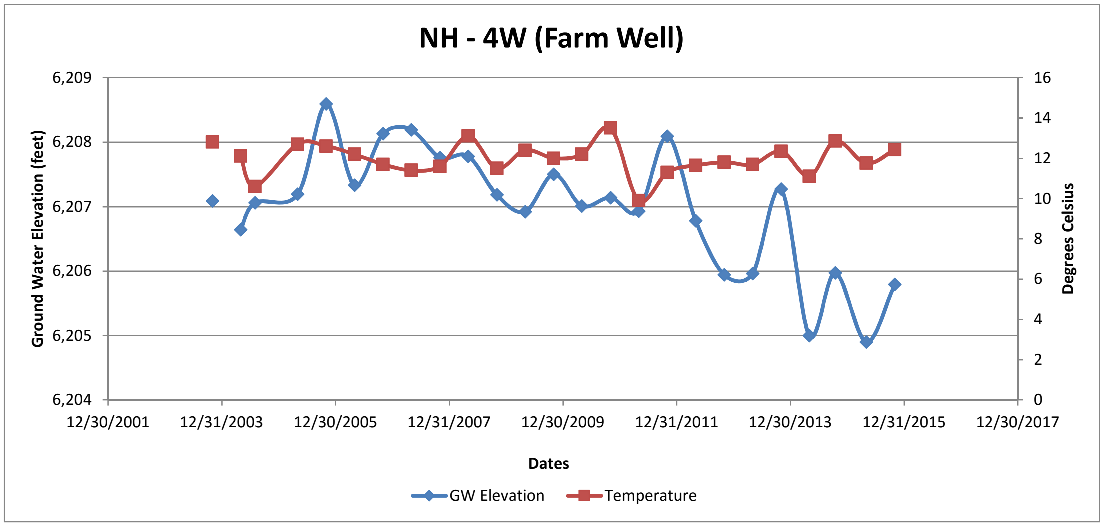

NH - 3W (Farm Well)
Ground Water Elevation (feet)
6,187
6,186
6,185
6,184
6,183
6,182
Degrees Celsius
16
14
12
10
8
6
4
2
0
12/30/2001
12/31/2003
12/30/2005
12/31/2007
12/30/2009
12/31/2011
12/30/2013
12/31/2015
12/30/2017
Dates
GW Elevation
Temperature

Figure A-1


NH - 4W (Farm Well)
Ground Water Elevation (feet)
6,209
6,208
6,207
6,206
6,205
6,204
Degrees Celsius
16
14
12
10
8
6
4
2
0
12/30/2001
12/31/2003
12/30/2005
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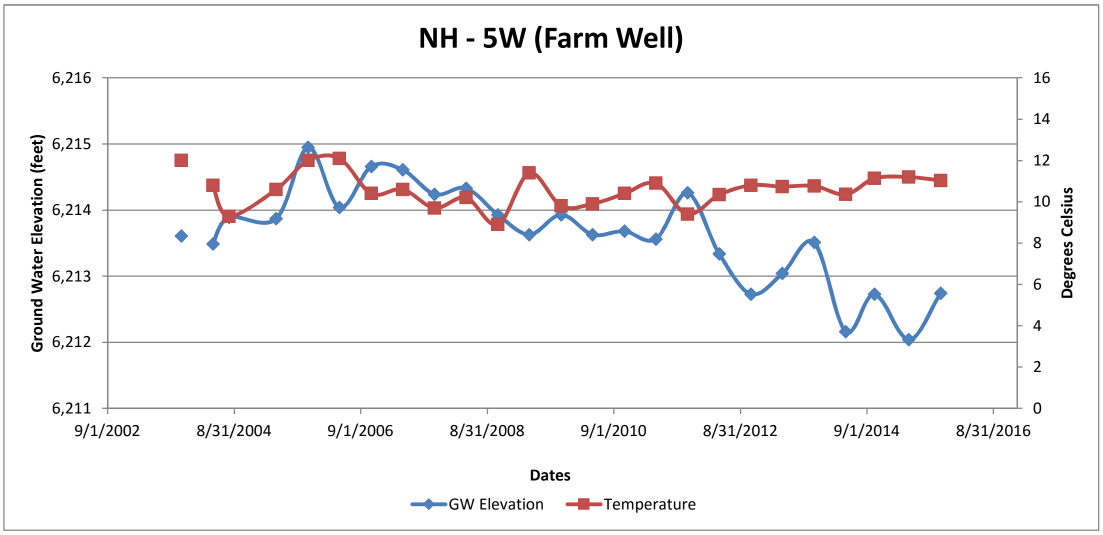
12/30/2009
12/31/2011
12/30/2013
12/31/2015
12/30/2017
Dates
GW Elevation
Temperature


NH - 5W (Farm Well)
Ground Water Elevation (feet)
6,216
6,215
6,214
6,213
6,212
6,211
Degrees Celsius
16
14
12
10
8
6
4
2
0
9/1/2002
8/31/2004
9/1/2006
8/31/2008
9/1/2010
8/31/2012
9/1/2014
8/31/2016
Dates
GW Elevation
Temperature

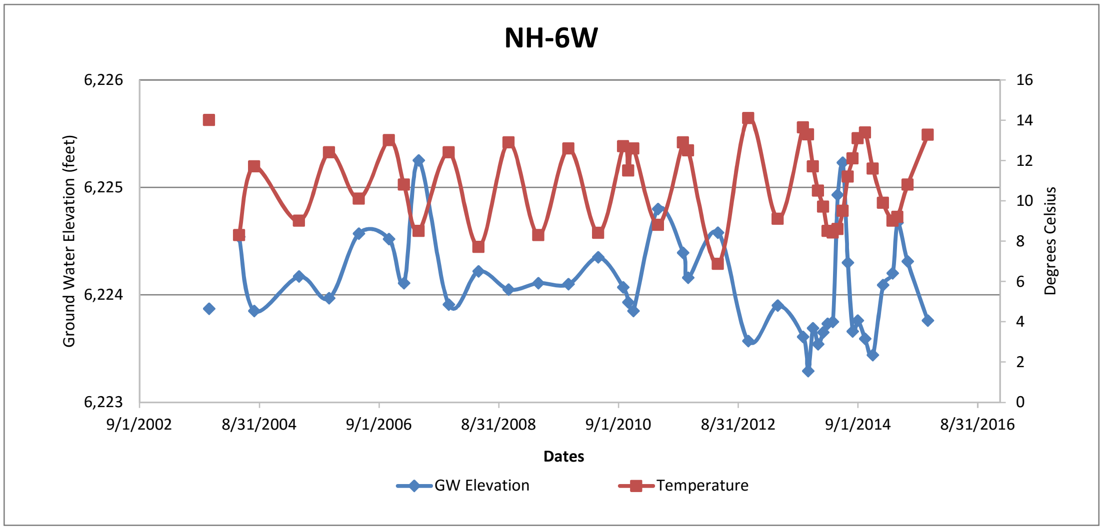
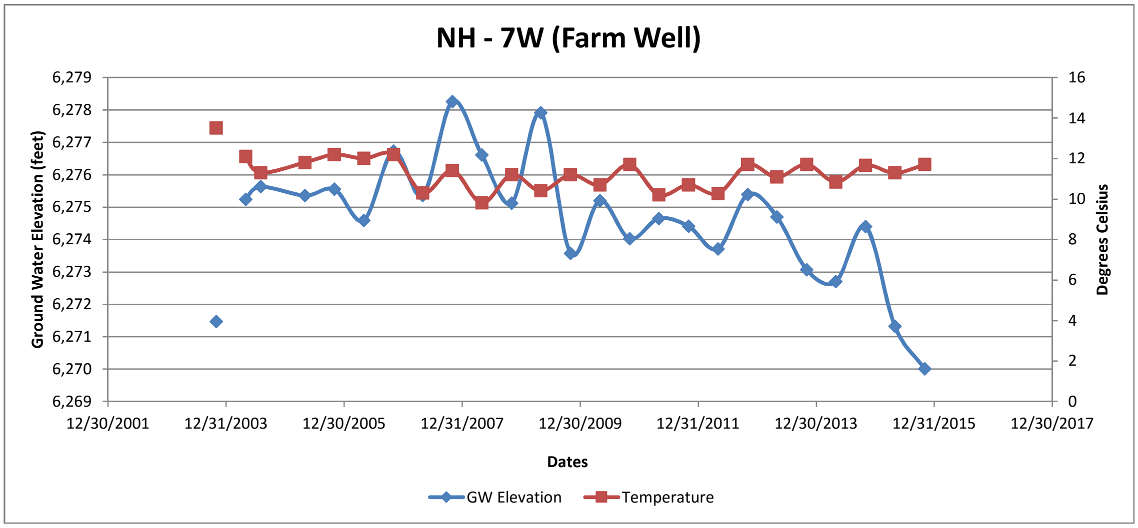

NH-6W
Ground Water Elevation (feet)
6,226
6,225
6,224
6,223
Degrees Celsius
16
14
12
10
8
6
4
2
0
9/1/2002
8/31/2004
9/1/2006
8/31/2008
9/1/2010
8/31/2012
9/1/2014
8/31/2016
Dates
GW Elevation
Temperature

Figure A-2


NH - 7W (Farm Well)
Ground Water Elevation (feet)
6,279
6,278
6,277
6,276
6,275
6,274
6,273
6,272
6,271
6,270
6,269
Degrees Celsius
16
14
12
10
8
6
4
2
0
12/30/2001
12/31/2003
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12/30/2017
Dates
GW Elevation
Temperature

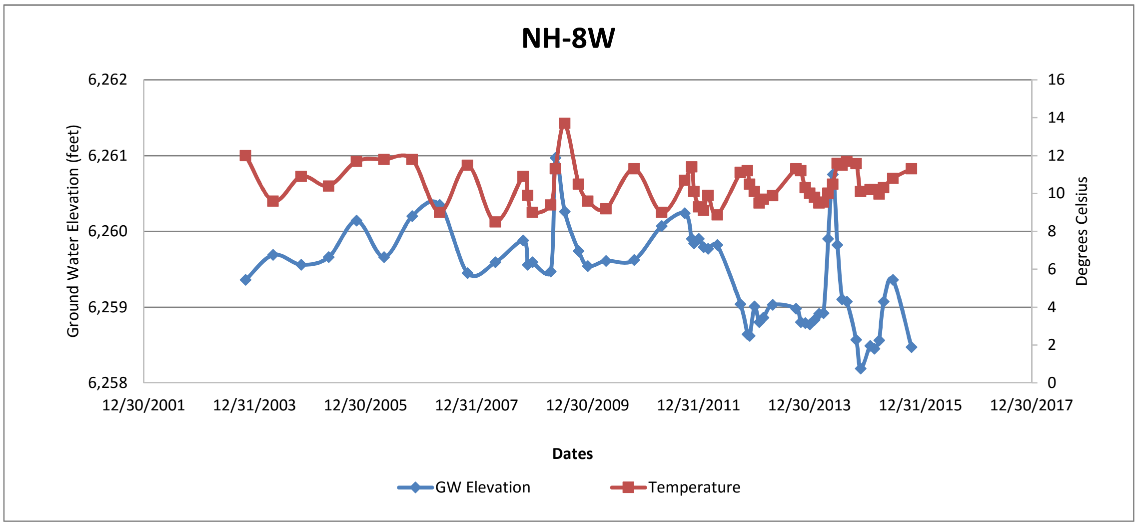
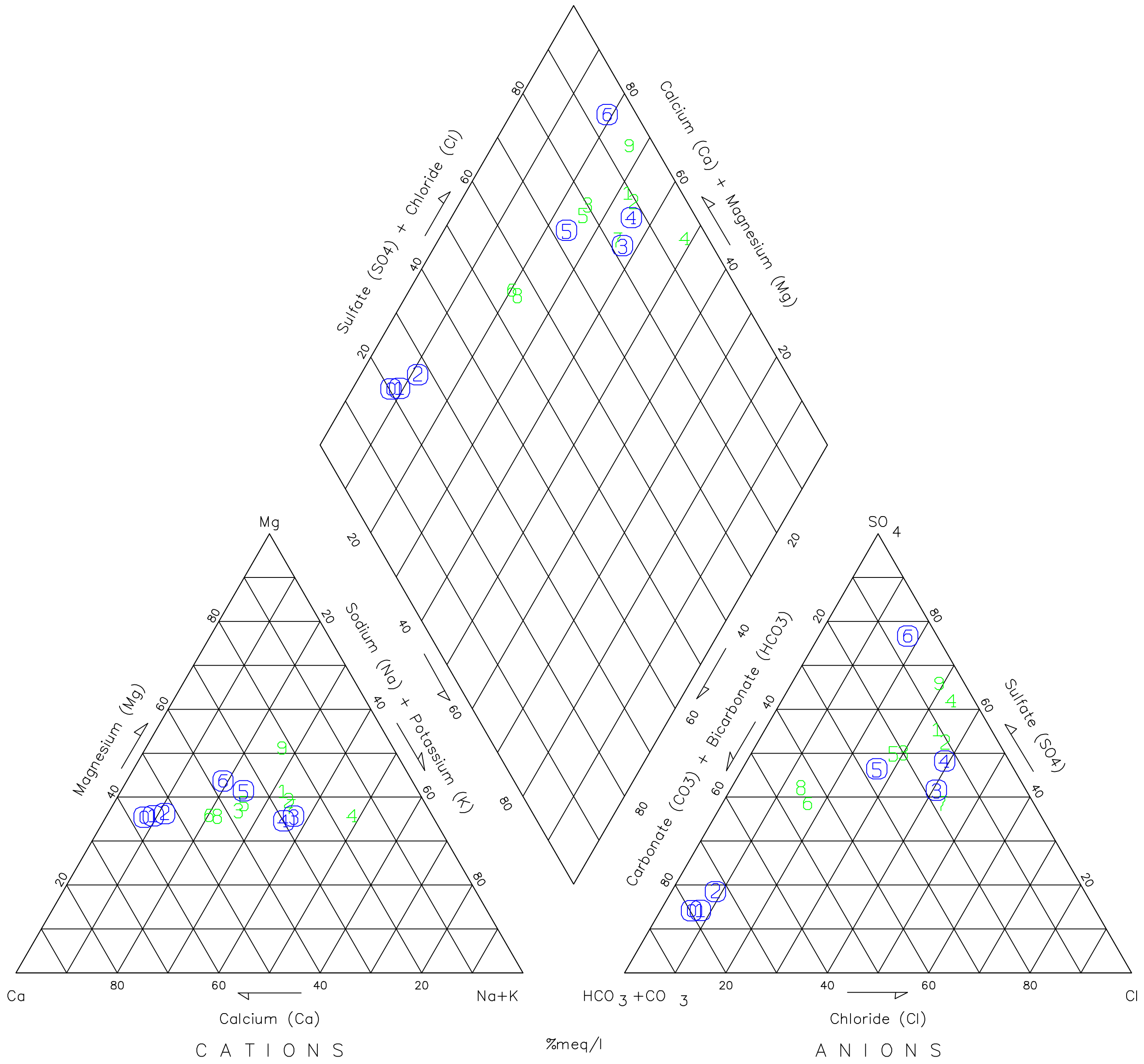

NH-8W
Ground Water Elevation (feet)
6,262
6,261
6,260
6,259
6,258
Degrees Celsius
16
14
12
10
8
6
4
2
0
12/30/2001
12/31/2003
12/30/2005
12/31/2007
12/30/2009
12/31/2011
12/30/2013
12/31/2015
12/30/2017
Dates
GW Elevation
Temperature

Figure A-3

Appendix B. Trilinear Diagrams



LEGEND:

1 NH1W
2 NH2W
3 NH3W
4 NH4W
5 NH5W
6 NH6W
7 NH7W
8 NH8W
9 RG−1W
⓪ H−1
① H−2
② UPL−9
③ H−11 Spring
④ H−12 Duckpond
⑤ HG−FD
⑥ UPL−13

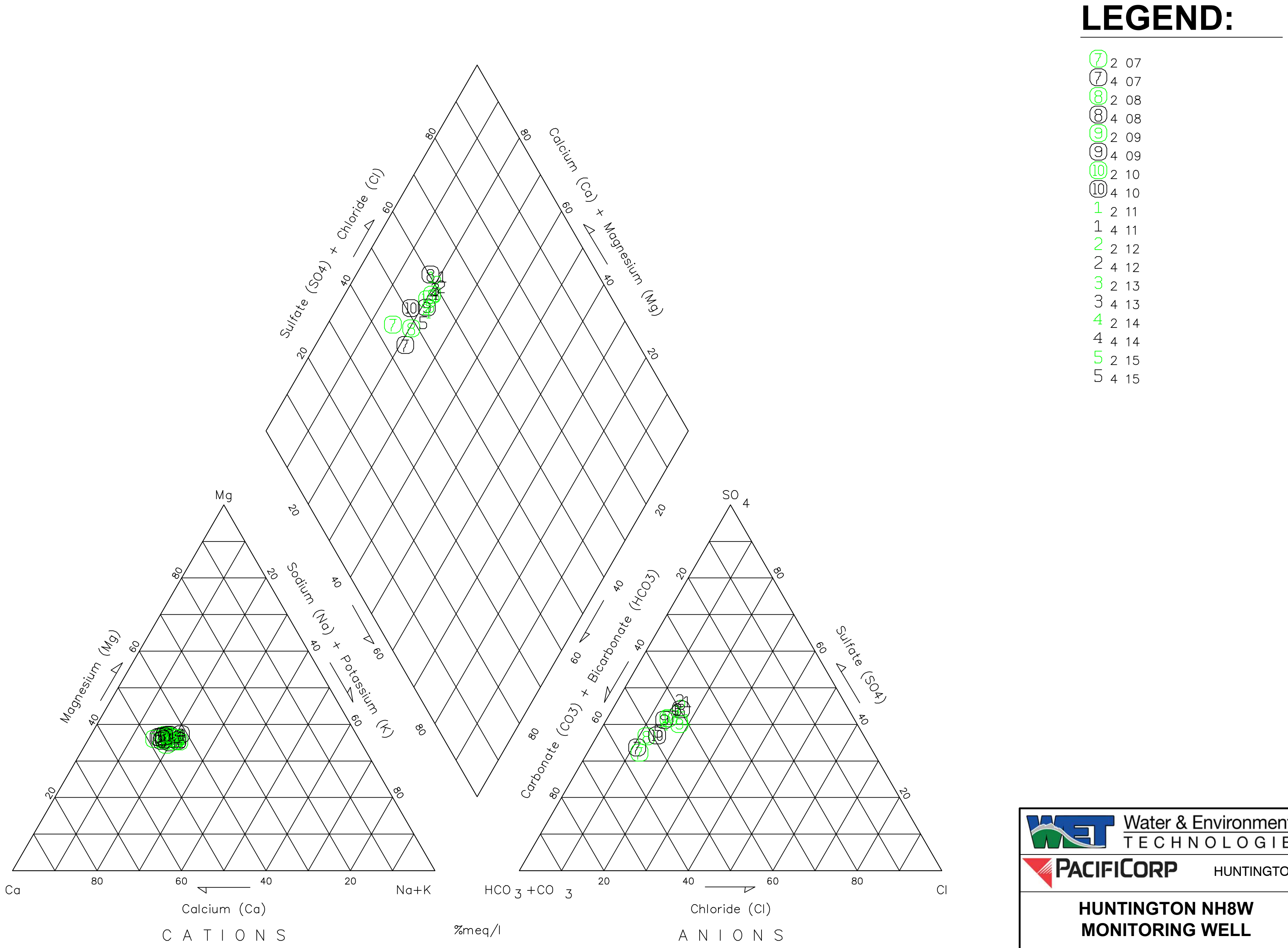
Water & Environmental
TECHNOLOGIES

PACIFICORP
HUNTINGTON

SPRING 2015
FARM MONITORING WELLS

PERCM43
DATE: 08/26/2016

FIGURE B-1



Water & Environmental TECHNOLOGIES

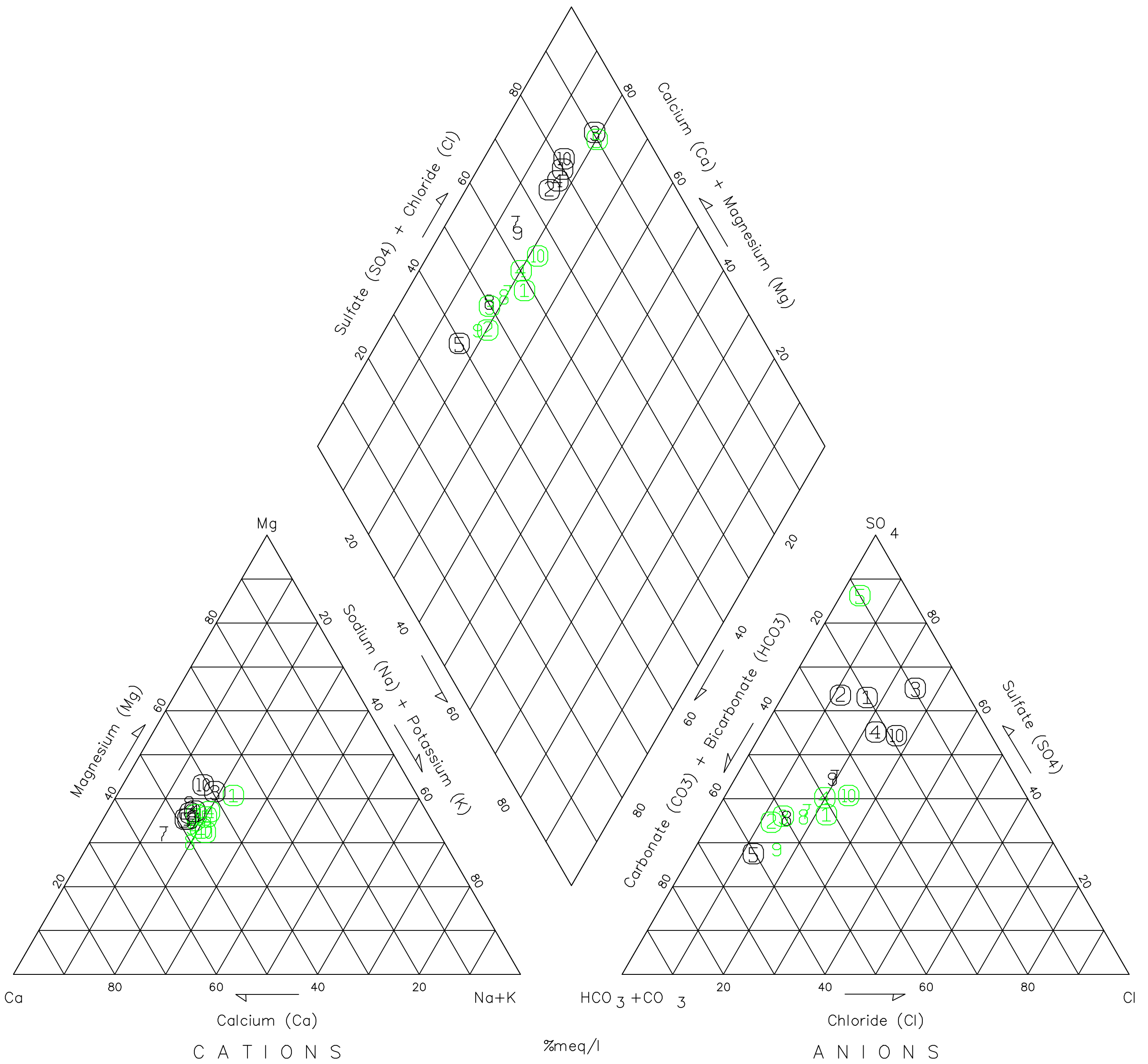
PACIFICORP

HUNTINGTON

HUNTINGTON NH8W
MONITORING WELL

PERCM43
DATE: 12/9/2015

FIGURE B-2



LEGEND:

7 2 07
7 4 07
8 2 08
8 4 08
9 2 09
9 4 09
⑩ 2 10
⑩ 4 10
① 2 11
① 4 11
② 2 12
② 4 12
③ 2 13
③ 4 13
④ 2 14
④ 4 14
⑤ 2 15
⑤ 4 15

WET Water & Environmental TECHNOLOGIES

PACIFICORP HUNTINGTON

HUNTINGTON NH6W
MONITORING WELL

PERCM43
DATE: 12/9/2015

FIGURE B-3

Appendix C. Isotope Analysis Results

Client: Shirley
Water and Environmental Technologies
Project #: PERCM

ISO# 2016291
Location:
15 for 18O, 2H,
5 for 34S+18O,SO4,
15N+18O.NO3, 15N,NH4

Environmental Isotope Lab
8/26/2016
1 of 1

#	Sample	Date	Lab#	$\delta^{18}O$	Result	Repeat	$\delta^{2}H$	Result	Repeat	$\delta^{18}O$	Result	Repeat	$\delta^{34}S$	Result	Repeat	$\delta^{15}N$	Result	Repeat	$\delta^{18}O$	Result	Repeat	$\delta^{15}N$	Result	Repeat	pH	EC	Chloride	Nitrite	Nitrate	Sulfate
				H_2O	VSMOW ± 0.2‰		H_2O	VSMOW ± 0.8‰		SO_4	VSMOW ± 0.4‰		SO_4	VCDT ± 0.3‰		NO_3	AIR ± 0.3‰		NO_3	VSMOW ± 0.8‰		NH_4	AIR ± 0.5‰				mg/L	mg/L	mg/L	mg/L
1	NH-7W	6/8/2016	365968	X	-13.96		X	-111.76																						
2	UPL 9	6/8/2016	365969	X	-15.70		X	-118.00		X			X			X			X			X					7.02	< 0.1	0.65	26.18
3	UPL-13	6/8/2016	365970	X	-5.18		X	-71.57		X			X			X			X			X					605.55	4.02	51.79	2909.12
4	Upstream	6/8/2016	365971	X	-15.92		X	-117.81		X			X			X			X			X					4.59	< 0.1	0.40	19.94
5	NH-10W	6/8/2016	365972	X	-13.98	-14.02	X	-110.29	-110.79																					
6	NH-8W	6/8/2016	365973	X	-15.97		X	-119.84		X			X			X			X			X					51.86	< 0.1	1.38	180.23
7	HLF-1N	6/7/2016	365974	X	-14.85		X	-117.26																						
8	NH-1W	6/7/2016	365975	X	-12.45		X	-105.07																						
9	NH-8W Dup	6/8/2016	365976	X	-15.91		X	-119.70		X			X			X			X			X					51.21	< 0.1	1.11	180.12
10	NH-9W	6/9/2016	365977	X	-14.94	-14.86	X	-114.51	-114.35																					
11	NH-4W	6/8/2016	365978	X	-6.88	-6.66	X	-91.17	-91.73																					
12	NH-3W	6/7/2016	365979	X	-15.01		X	-115.25																						
13	NH-2W	6/8/2016	365980	X	-12.54		X	-106.98																						
14	NH-5W	6/8/2016	365981	X	-15.40		X	-117.44																						
15	NH-6W	6/6/2016	365982	X	-15.47	-15.40	X	-116.95	-117.59																					

Note:
Samples #2, #3, #4, #6 and #9 require chemical analysis:
1 gallon jug of raw water for Chemical Analysis - require SO4, Cl, NO3, NO2 and NH4 concentrations.

Glass vials:
Sample names on some of the glass vials wiped off on the bubble wrap.
Not able to identify all the sample vials.

Estimated pH and conductivity to be done.

Received sample chemistry July 5, 2016.

18O/2H Results from LGR Laser

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Hydrologic Reconnaissance of the Wasatch Plateau-Book Cliffs Coal-Fields Area, Utah

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2068

Prepared in cooperation with the
U.S. Bureau of Land Management
and the U.S. Environmental
Protection Agency

U.S. DEPARTMENT OF THE INTERIOR

Hydrologic Reconnaissance of the Wasatch Plateau-Book Cliffs Coal-Fields Area, Utah

By K. M. WADDELL, P. KAY CONTRATTO, C. T. SUMSION, *and*
J. R. BUTLER

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METRIC CONVERSION FACTORS

Most measurements in this report are given in the inch-pound system of units. The conversion factors for computing metric equivalents are shown below.

Inch-pound system			*Metric system*	
Unit (Multiply)	*Abbreviation*	(by)	*Unit* (to obtain)	*Abbreviation*
Acre		0.4047	Square hectometer	hm^2
		.004047	Square kilometer	km^2
Acre-foot	acre-ft	.001233	Cubic hectometer	hm^3
		1233	Cubic meter	m^3
Cubic foot per second	ft^3/s	.02832	Cubic meter per second	m^3/s
Foot	ft	.3048	Meter	m
Gallon per minute	gal/min	.06309	Liter per second	L/s
Inch	in.	25.40	Millimeter	mm
		2.540	Centimeter	cm
Mile	mi	1.609	Kilometer	km
Square mile	mi^2	2.590	Square kilometer	km^2

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.

Chemical concentrations in terms of ionic interacting values is given in milliequivalents per liter (meq/L). Meq/L is numerically equal to the equivalents per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation: °F = 1.8(°C) + 32.

HYDROLOGIC RECONNAISSANCE OF THE WASATCH PLATEAU-BOOK CLIFFS COAL-FIELDS AREA, UTAH

By K. M. Waddell, P. Kay Contratto, C. T. Sumsion,
and J. R. Butler

ABSTRACT

Data obtained during a hydrologic reconnaissance in 1975–77 in the Wasatch Plateau-Book Cliffs coal-fields area of Utah were correlated with existing long-term data. Maps were prepared showing average precipitation, average streamflow, stream temperature, ground- and surface-water quality, sediment yield, and geology. Recommendations were made for additional study and suggested approaches for continued monitoring in the coal-fields areas.

During the 1931–75 water years, the minimum discharges for the five major streams that head in the area ranged from about 12,000 to 26,000 acre-feet per year, and the maximum discharges ranged from about 59,000 to 315,000 acre-feet per year. Correlations indicate that 3 years of low-flow records at stream sites in the Wasatch Plateau would allow the development of relationships with long-term sites that can be used to estimate future low-flow records within a standard error of about 20 percent.

Most water-quality degradation in streams occurs along the flanks of the Wasatch Plateau and Book Cliffs. In the uplands, dissolved-solids concentrations generally ranged from less than 100 to about 250 milligrams per liter, and in the lowlands, the concentrations ranged from about 250 to more than 6,000 milligrams per liter.

Most springs in the Wasatch Plateau and Book Cliffs discharge from the Star Point Sandstone or younger formations, and the water generally contains less than about 1,000 milligrams per liter of dissolved solids. The discharges of 65 springs ranged from about 0.2 to 200 gallons per minute. The Blackhawk Formation, which is the principal coal-bearing formation, produces water in many of the mines. The dissolved-solids concentration in water discharging from springs and mines in the Blackhawk ranged from about 60 to 800 milligrams per liter.

In the lowland areas, the Ferron Sandstone Member of the Mancos Shale appears to have the most potential for subsurface development of water of suitable chemical quality for human consumption. Three wells in the Ferron yielded water with dissolved-solids concentrations ranging from about 650 to 1,230 milligrams per liter.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, conducted a reconnaissance from July 1975 to September 1977 which was designed to provide an assessment of the hydrology of the Wasatch Plateau-Book Cliffs coal-fields area in Utah.

The U.S. Environmental Protection Agency also supported the study by providing additional funds for enhancement of the water-quality effort. The coal lands in Utah are largely in the Upper Colorado River Basin (fig. 1). The most active coal-mining areas in 1977 were in the Wasatch Plateau and Book Cliffs area.

The objectives of the study were to (1) establish data bases for hydrologic parameters from existing data supplemented with information gathered as part of this study; (2) describe the water resources, based on the data available; and (3) recommend monitoring programs and additional detailed studies.

Historical data, pertinent to the hydrology of the study area, cover variable periods. A common-base period of the 1931–75 water years[1] was selected for historical records. Data collection during 1975–77 was designed to fill voids where the historical data were not adequate to satisfy the objectives. Temporary data sites were established for direct or indirect measurement of streamflow and measurement of selected water-quality parameters for ground water, streams, and mine discharge. A well inventory was made, and selected wells were monitored for water-level changes. The data collected during 1975–77 and selected data from the 1931–75 water years are given in a report by Waddell and others (1978).

PHYSIOGRAPHY

The Wasatch Plateau ranges from about 9,000 to 12,000 feet above sea level and is approximately 4,000 to 7,000 feet above the lowlands to the east and west. The Book Cliffs range from about 7,000 to 10,000 feet above sea level and are about 2,000 to 5,000 feet above the lowlands to the south and west. The canyon of the Price River forms a physiographic break between the Wasatch Plateau and the Book Cliffs.

Another physiographic feature within the study area, the San Rafael Swell, is of lesser importance to coal development. The San Rafael Swell is an elliptical, asymetrical structural dome (anticline) with a northeast-southwest trend that begins southeast of Price and extends southwest through the study area (fig. 1).

GEOLOGY

The consolidated-rock formations that crop out in the study area are of Pennsylvanian to Tertiary age (pl. 1). The exposed formations include limestone, sandstone, siltstone, shale, conglomerate, and coal.

The principal coal-producing formations are of Cretaceous age. The Dakota Sandstone is the oldest formation that contains coal, but it is

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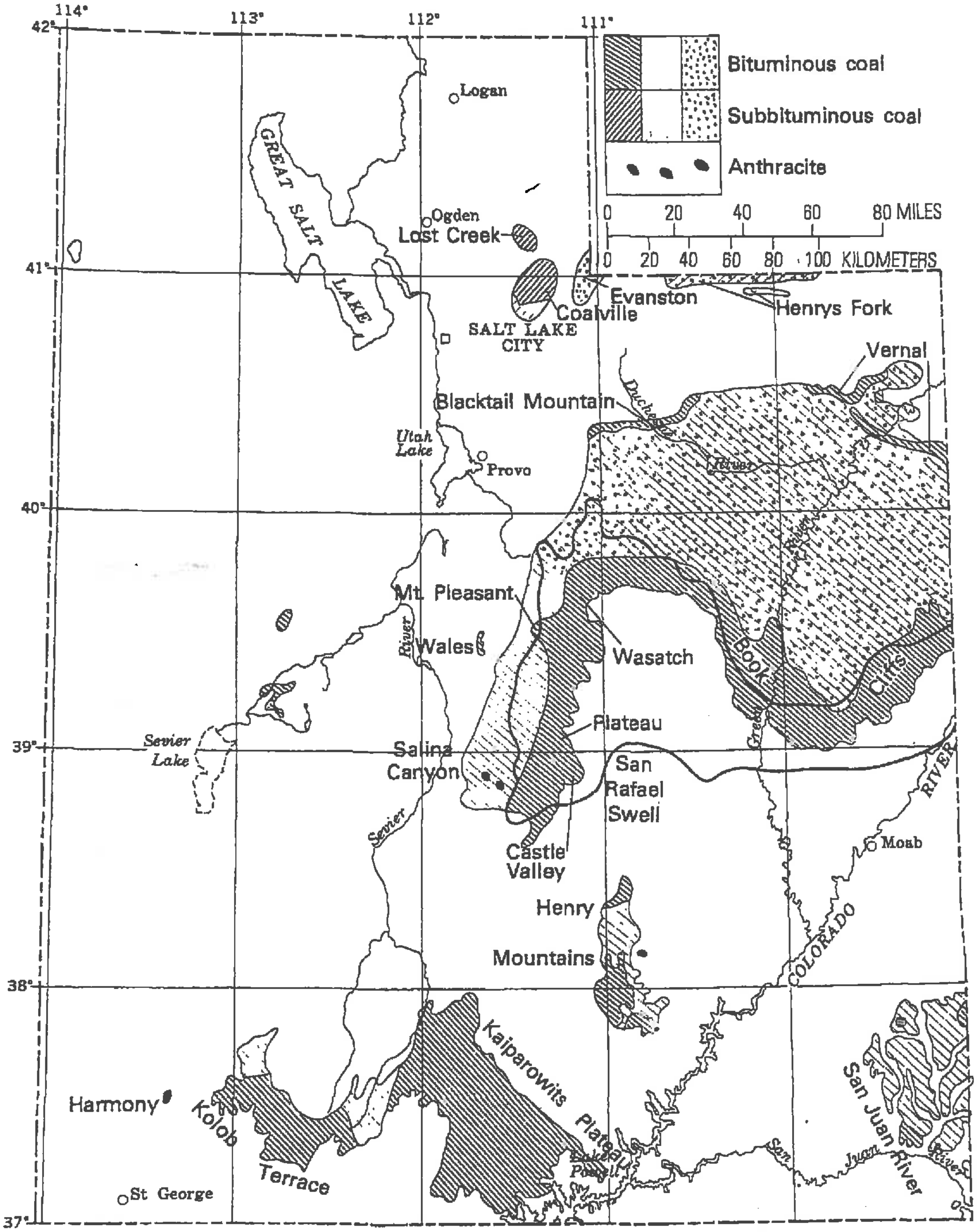
[1] A water year designates the calendar year of the period that ended on September 30 and began October 1 of the previous calendar year.



Dark ruling—Known accessible coal in named coal fields

Light ruling—Thin and discontinuous coal or meager information about the coal

Stippling—Coal-bearing rocks concealed by younger rocks

———— Boundary of study area for this report

FIGURE 1.—Coal fields of Utah (modified from Averitt, 1964, fig. 11).

not an important coal-producing zone in the study area. The Dakota crops out around the northern part of the study area.

The Mancos Shale overlies the Dakota Sandstone. The most noteworthy member of the Mancos, in terms of coal production and water resources, is the Ferron Sandstone Member. The Ferron crops out in the lowlands several miles from the Wasatch Plateau and Book Cliffs. The Ferron outcrop generally parallels the uplands but is farther removed from the front of the Book Cliffs than from the edge of Wasatch Plateau. In the vicinity of Emery, coal is being mined (underground) in the Ferron, but coal production from the Ferron is small in relation to that from the Blackhawk Formation (Mesaverde Group) in the Wasatch Plateau and the Book Cliffs. Strip mining of coal in the Ferron has been proposed for the area south and southeast of Emery.

The outcrop of the Blue Gate Member of the Mancos Shale generally marks the beginning ~~of~~ the lowlands, and it crops out along streams several miles upstream from the mouths of most canyons. Shales in the Mancos typically have low permeability, are easily erodible, and contain large quantities of soluble salts, including gypsum ($CaSO_42H_2O$), mirabilite ($Na_2SO_410H_2O$), and thenardite ($NaSO_4$). Ground-water seepage contributes large quantities of dissolved salts to all the streams in the study area where they cross the outcrops of the shales. Most dissolved constituents are contributed to streams where the Blue Gate is widely exposed along the eastern base of the Wasatch Plateau.

The shales also have a profound influence on topography and landscape because of their ease of erodibility; their salts, which limit plant growth; and their low permeability, which causes most of the precipitation to run off directly into streams. The high percentage of runoff, the rapid weathering due to expansion and contraction resulting from seasonal hydration and dehydration of salts, and the softness of the shales stimulates erosion and development of badlands.

The Mesaverde Group overlies the Mancos Shale in the Wasatch Plateau and the western Book Cliffs. The Blackhawk Formation of the Mesaverde is the most important coal-producing formation in Utah. The Blackhawk is composed of sandstone, shale, and coal, and coal beds as thick as 20 feet are found locally in the lower part of the formation (U.S. Geological Survey, 1964, p. 45).

The North Horn Formation of Tertiary and Cretaceous ages and younger formations that overlie the Mesaverde Group are not important coal producers. However, they yield large quantities of freshwater to numerous springs and seeps that flow into streams at the higher altitudes of the Wasatch Plateau and Book Cliffs.

CLIMATE

PRECIPITATION

The average annual precipitation exceeds 40 inches at the higher altitudes of the Wasatch Plateau, as compared to a maximum of about 20 inches in the Book Cliffs (pl. 2). The precipitation varies widely across the study area, generally reflecting variations in altitude. South of the town of Green River, where the low point of the study area is about 4,100 feet above sea level, the average annual precipitation is less than 6 inches.

The average annual precipitation in the study area was shown by isohyetal lines by the U.S. Weather Bureau (no date) for 1931–60. The average annual precipitation for 1931–60 and 1931–75 was compared for 10 stations in and near the study area to determine if adjustments to the Weather Bureau isohyetals would be necessary in order to be representative of 1931–75 averages (table 1). The comparison indicated that precipitation at the 10 stations was, on the average, about 3 percent greater during 1931–75 than during 1931–60. The small increase showed no pattern of consistency; therefore, the 1931–60 isohyetals were accepted as representative of 1931–75 and are shown on plate 2.

The annual distribution of precipitation in the study area during 1931–75 is shown in figure 2 for a representative site—Scofield Dam. The U.S. Weather Bureau precipitation record for Scofield Dam begins in 1951, but the record was extended back to 1931 by correlation with the records at three other sites in and near the study area.

According to figure 2, the annual precipitation at Scofield Dam during 1931–75 ranged from 6.77 to 32.03 inches and averaged 16.0 inches. Plate 2, however, indicates that the average annual precipitation at Scofield Dam is about 23 inches. The difference may be due to a combination of several factors—difference in base periods, errors of

TABLE 1.—*Comparison of average annual precipitation for 1931–60 and 1931–75 for selected sites in Utah in and near the study area*

[Sites are shown on pl. 1]

Site	1931–60 (A)	1931–75 (B)	Ratio (B/A)
Emery	7.23	7.14	0.99
Hanksville[1]	5.07	5.25	1.04
Hiawatha	12.89	12.94	1.00
Manti[1]	11.94	12.29	1.03
Moab 4NW [1]	8.19	8.21	1.00
Moroni[1]	9.46	9.44	1.00
Myton[1]	6.39	7.10	1.11
Salina[1]	9.39	9.73	1.04
Spanish Fork Power House[1]	16.75	17.75	1.06
Thompson	8.56	8.46	.99

[1] Outside of study area.

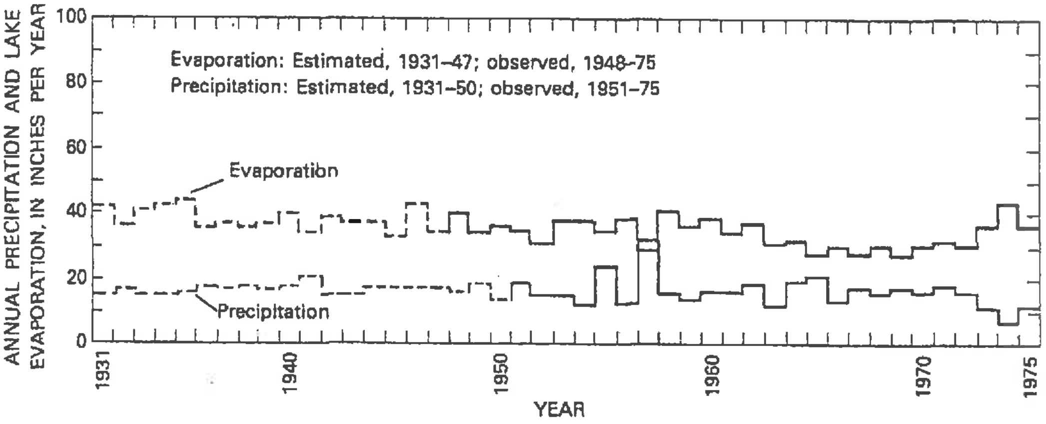


FIGURE 2.—Annual precipitation and lake evaporation at Scofield Dam, 1931–75.

estimates by correlation, location of gage relative to mountain ranges, and local interference.

The seasonal distribution of precipitation at Scofield Dam for 1931–75 is shown in figure 3. The monthly precipitation ranged from 6 percent of the annual average in May, June, and November to 12 percent in January.

EVAPORATION

The evaporation at Scofield Dam for 1931–75 is shown in figure 2. The U.S. Weather Bureau evaporation record for Scofield Dam, which is at an altitude of 7,630 feet, begins in 1947; but the record was extended back to 1931 by correlation with the record of Utah Lake at Lehi. The evaporation at Scofield Dam ranged from 27 to 44 inches per year and averaged about 35 inches during the 1931–75 water years. The average annual evaporation at lower altitudes in the study area, where temperatures are higher, would be greater. For example, at Green River, Utah, which is at an altitude of 4,120 feet, the average annual evaporation was about 42 inches for the 1931–75 water years.

The seasonal distribution of evaporation at Scofield Dam for 1931–75 is shown in figure 3. The monthly evaporation ranged from 1 percent of the average annual in December, January, and February to 17 percent in July.

AIR TEMPERATURE

The average air temperature in the study area ranges from about 35°F at Soldier Summit, which is representative of the higher altitudes of the Wasatch Plateau, to more than 50°F at Thompson in the lowlands to the east. Daily temperatures at Price are shown in figure 8. Although the extremes of daily temperature vary throughout the basin, the thermograph recording for Price is typical of seasonal fluctuations.

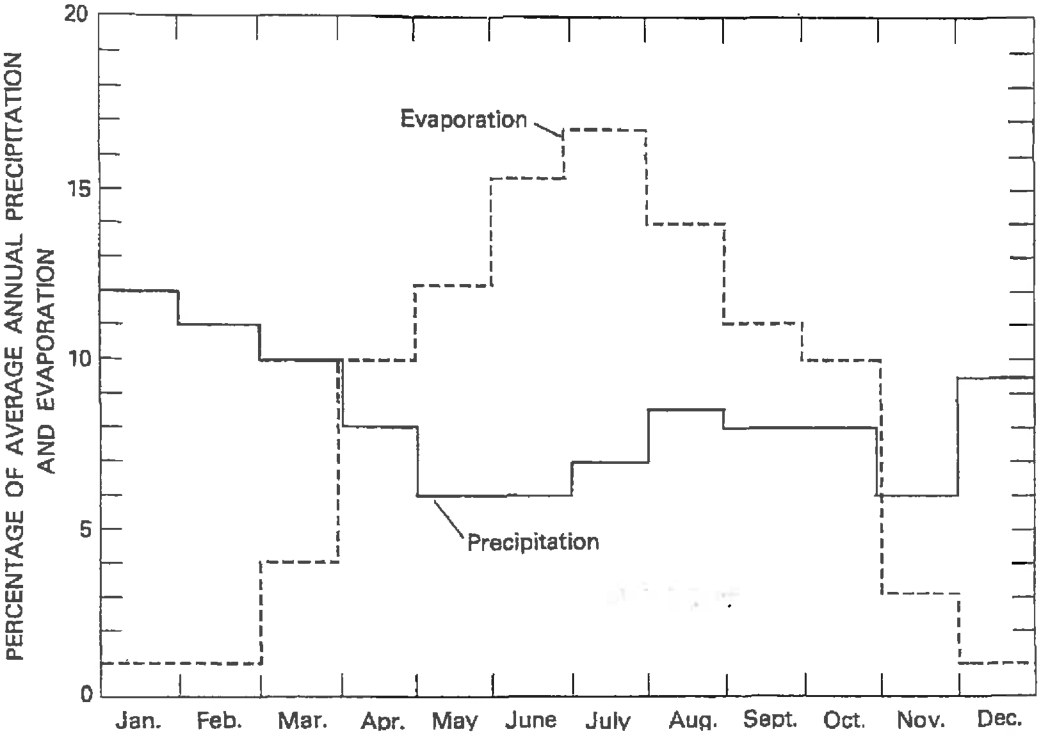


FIGURE 3.—Monthly distribution of precipitation and evaporation at Scofield Dam, 1931–75.

SURFACE WATER

The five major streams whose headwaters originate in the Wasatch Plateau are the Price River and Cottonwood, Ferron, Huntington, and Muddy Creeks. These streams form the headwaters of three drainage basins—the Price River basin (Price River), the San Rafael River basin (Cottonwood, Ferron, and Huntington Creeks), and the Dirty Devil River basin (Muddy Creek). The Price and San Rafael Rivers drain into the Green River, whereas the Dirty Devil River drains into the Colorado River below the mouth of the Green River. (See fig. 1.) The main stem of the Green River cuts through the Book Cliffs in the south-central part of the study area.

The flow in streams that head in the Book Cliffs is extremely small in comparison to the flow of the major streams in the Wasatch Plateau. Most of the streams that drain the Book Cliffs east of the Green River flow into the Colorado River. Many of the streams that head in the Book Cliffs are perennial at higher altitudes, but they become ephemeral as they emerge from the mountains and flow onto the lowlands.

STREAM-DATA NUMBERING SYSTEMS

The U.S. Geological Survey uses a nationwide system of numbering sites on streams,by referring to the position of the site or station in a downstream order in a given major-river basin. The study area is in Part 9, the Colorado River Basin.

Gaging-station numbers are assigned in a downstream direction along the main stems of the major streams, and all stations on a tributary stream that enters above a main-stem station are numbered before that station. A similar order is followed in listing stations on first rank, second rank, and other ranks of tributaries. The numbering system consists of an 8-digit number for each station, for example 09327450. The first two digits (09) represent the "part" number identifying the hydrologic region used by the U.S. Geological Survey for reporting surface hydrologic data. The next six digits represent the position of the location in a downstream order.

For sites on streams where miscellaneous measurements of discharge or chemical quality or other measurements or samples are taken, the station is numbered by using simple reference numbers. The reference numbers are shown on the maps by the appropriate site-location symbol.

STREAMFLOW

AVERAGE DISCHARGE

Average discharges were computed from gaging station records, estimated from channel-geometry measurements, or estimated from discharge-drainage area relationships. Records of streamflow at [illegible]9 stations in the study area are available for the 1931–75 water years (table 2). A few pre-1931 records are available, but most of the streamflow data has been gathered since 1931. Although the gaged sites in the Wasatch Plateau have variable lengths of record, the average annual flows of the major streams were adjusted to the common base period of 1931–75 water years through correlation with stations having records for the missing periods.

Approximately 50–70 percent of the streamflow occurs during May-July (fig. 4). This results from the melting of snow that fell during October–April, particularly above altitudes of 6,000 feet.

The annual variability of flow in Huntington Creek for the 1931–73 water years is shown in figure 5. The annual flow ranged from 25,000 to 150,000 acre–feet and averaged 65,000 acre-feet per year. The annual flows of Huntington Creek correlated with flows of other major streams in the Wasatch Plateau; the Huntington Creek record, therefore, was used to extend the average annual flows of streams having shorter periods of record.

The average annual discharges of ephemeral streams (primarily in the Book Cliffs) were estimated from channel-geometry measurements using a technique described by Fields (1975). These discharges were then correlated with drainage areas, and other estimates of discharge were made at additional sites on the basis of comparison of drainage areas. Table 3 is a summary of estimated discharges and drainage areas of miscellaneous sites on perennial and ephemeral streams. The average discharges for only the larger streams are depicted in plate 3.

DIVERSIONS

Most of the water from the major streams is diverted for irrigation. Figure 4 shows the net change of flow during selected water years resulting primarily from diversions from the Price River and Cottonwood, Ferron, and Muddy Creeks.

EFFECTS OF MINING

Mining may change the distribution of water along a stream. The flow of streams along a particular reach may change, depending upon the relationship of tunneling and the resulting subsidence to aquifers that are hydraulically connected to the stream. In order to determine whether mining is affecting streamflow, measurements are required to define the seasonal and annual variability of the streamflow above and below mining areas.

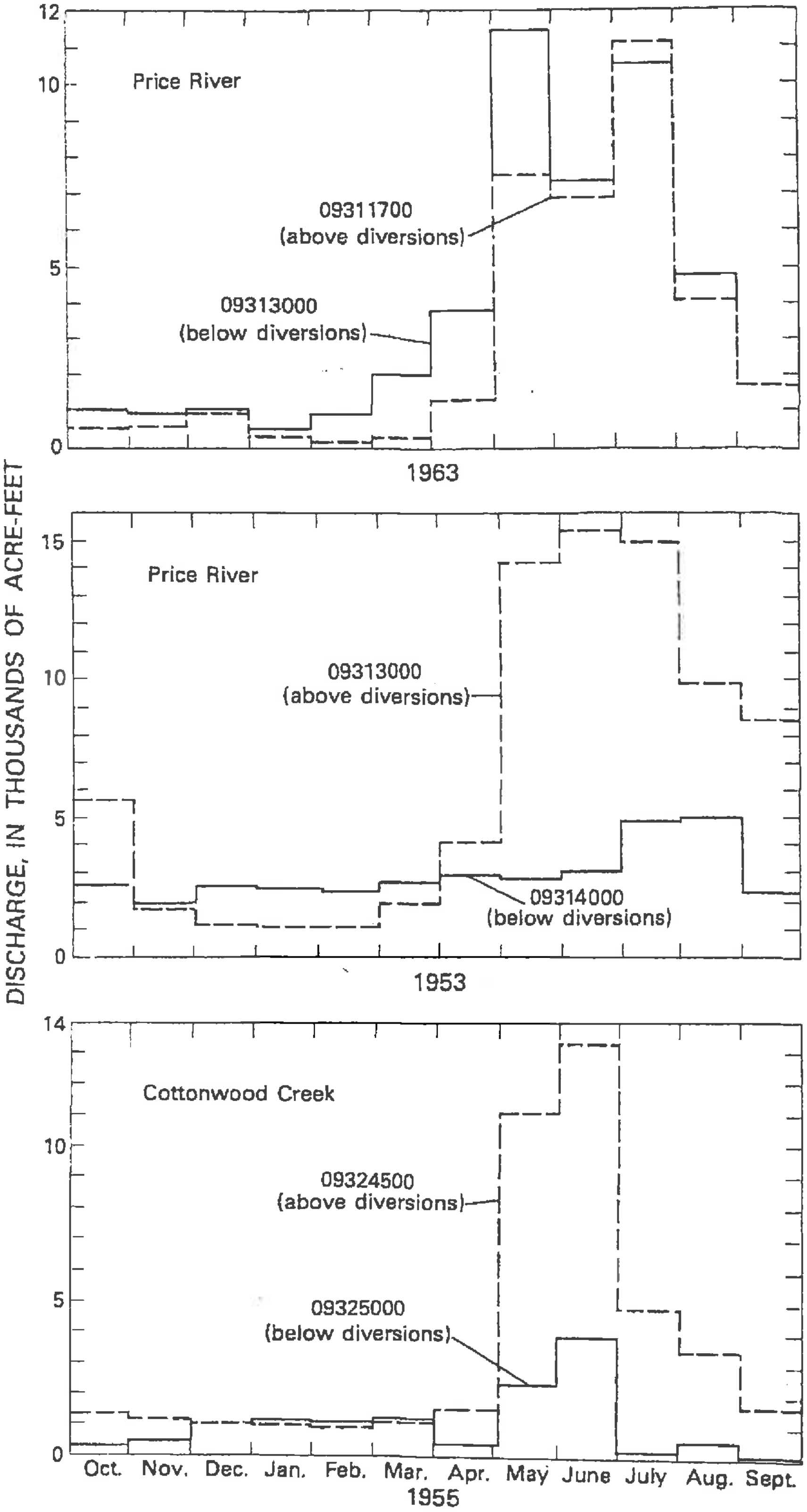


FIGURE 4.—Discharge of Price River and Cottonwood, Ferron, and Muddy Creeks above and below diversions at selected gaging stations for selected water years. (See table 2 for names of gaging stations.)

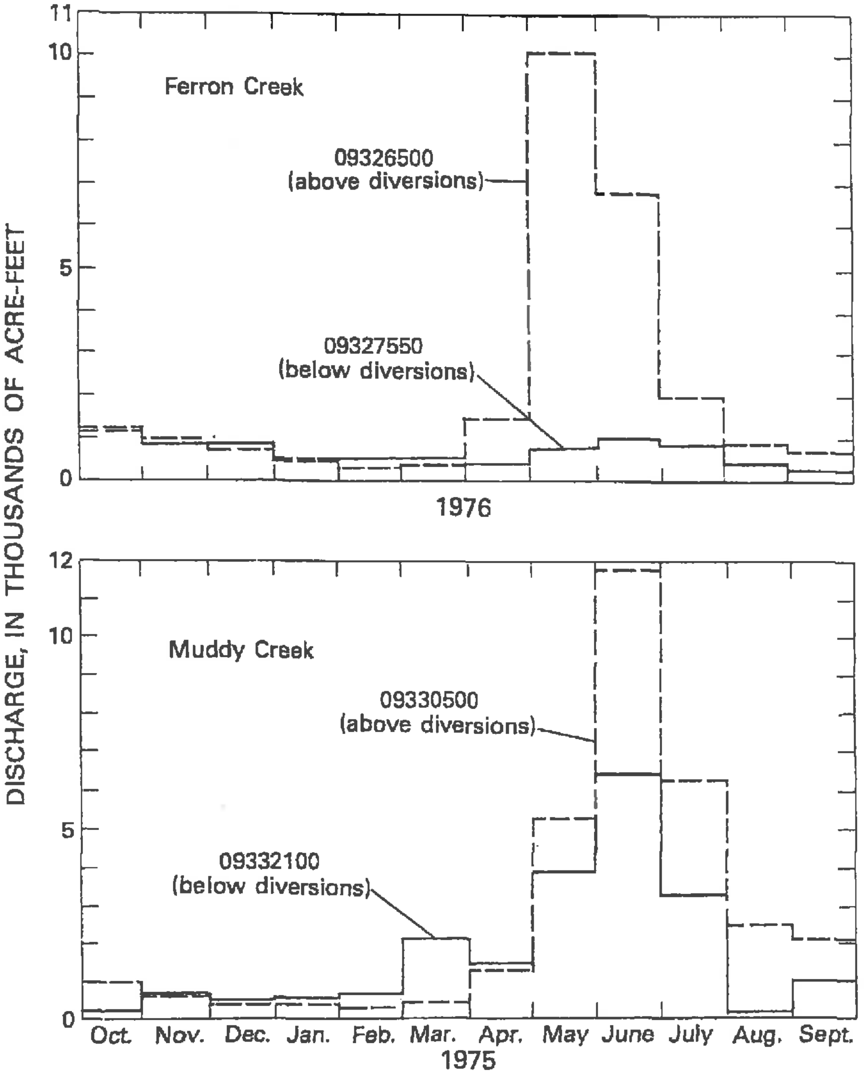


FIGURE 4.—Continued.

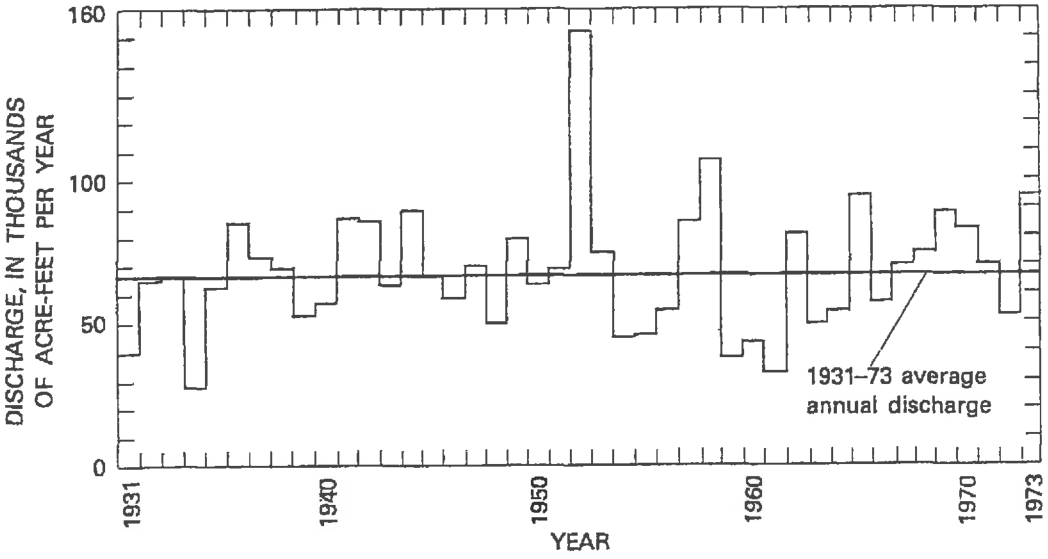


FIGURE 5.—Annual discharge of Huntington Creek (gaging station 09318000), 1931–73, water years.

TABLE 3.—*Estimated average annual discharge and drainage area at miscellaneous sites on ephemeral and perennial streams*

Site No.: See explanation of numbering system in text and plate 3 for location of data sites.
Estimated average annual discharge: From channel-geometry measurements.

Site No.	Ephemeral (E) or perennial (P)	Estimated average annual discharge (acre-feet per year)	Drainage area (square miles)
09163510	E	700	18.20
09163527	E	900	18.10
09163560	P	5,900	158.00
09163570	E	2,200	26.00
09163610	E	1,000	89.60
09163715	P	1,700	48.20
09163717	E	1,700	25.50
09163719	E	800	26.30
09312800	P	6,700	62.00
09312901	P	7,100	80.60
09313021	E	100	4.50
09313025	E	150	3.90
09313027	E	180	8.40
09313041	P	1,600	23.10
09313301	E	70	1.40
09313303	E	90	1.20
09313306	P	90	.62
09313307	P	400	.98
09313308	P	100	.26
09313565	P	14,000	90.10
09313813	E	70	2.60
09313815	E	70	1.60
09313817	E	230	4.80
09313851	E	90	3.60
09313853	E	80	.63
09313855	E	140	4.20
09313964	P	7,200	22.40
09313965	P	9,300	27.90
09313966	E	90	1.30
09313972	P	5,900	11.30
09313973	P	940	3.60
09313976	P	5,600	23.40
09314320	P	2,500	39.90
09314362	E	390	69.30
09314367	P	1,100	5.60
09314368	E	460	43.90
09314369	E	560	113.00
09314374	P	3,600	13.30
09314701	E	2,900	83.30
09315005	E	940	76.50
09328850	E	1,200	30.10
09328900	E	940	23.00
09331827	P	3,800	85.40

Sufficient current (1977) data are not available for direct definition of seasonal and annual variabilites of streamflow in all areas that may be affected by mining. Many years of streamflow records would be required at a site in order to provide an adequate definition of the variation of flow. However, correlation of existing long-term streamflow records with short-term records can aid in obtaining a more accurate estimate of streamflow for a given site.

An example of a correlation follows. Gaging stations on Huntington (site 09318000), Ferron (site 09316500), Cottonwood (site 09324500), and Muddy (site 09330500) Creeks, have been operated for a number of years above diversions near the canyon mouths. Low flows during August-November at the station on Huntington Creek correlate well with streamflow at the other three sites. The best correlation exists for September flows, the standard error of estimate ranging from about 15 to 25 percent of the mean (table 4 and fig. 6).

Correlation between the Huntington and Ferron Creek stations, based on varying lengths of record (fig. 7), also indicate that low-flow records for a 3-year period would allow estimates within about 20 percent of the mean for September flows. These estimates were made using a 15-year sample of observed flows for Huntington and Ferron Creeks and testing all combinations of possible September flows. Thus, if a tributary that might be affected by mining in the Wasatch Plateau were gaged during September for 3 years, while the main-stem stream was also being gaged, the future record of the tributary could be estimated within about 20 percent of the mean of the main-stem record. Ten years of record would reduce the standard error to only about 16-17 percent, and 15 years to about 15 percent. Incorporation of other streamflow characteristics and climatic parameters, such as the distribution of precipitation, might improve the low-flow relationship, especially for smaller drainage basins.

RESERVOIRS AND LAKES

The study area contains 53 reservoirs and lakes with a capacity exceeding 100 acre-feet, all except one being in the Wasatch Plateau. In addition, numerous smaller stock ponds are scattered throughout the area. The locations of the 53 reservoirs and lakes are shown on plate 1,

TABLE 4.—*Statistical summary of low-flow correlations*

		August		
			Standard error of estimate expressed as:	
Site being estimated (dependent variable)	Site used for correlation (independent variable)	Correlation coefficient	Acre-ft	Percent of the mean of the dependent variable
09324500	09318000	0.66	742	25
09326500	09318000	.78	624	24
09330500	09318000	.79	585	24

and the capacities for the four largest are listed below. The storage capacities of even the largest reservoirs are small in relation to the average annual flow of the streams concerned.

Name	Drainage	Total capacity (acre-ft)	Usable storage (acre-ft)
Scofield Reservoir	Price River	73,780	65,780
Joes Valley Reservoir	Cottonwood Creek	62,460	54,670
Electric Lake	Huntington Creek	31,272	30,528
Mill Site	Ferron Creek	19,200	16,700

QUALITY OF SURFACE WATER

TEMPERATURE

Water temperature has a direct influence on the use of water for domestic supply, fish and wildlife, assimilation of wastes, industry, and agriculture. Temperature influences almost every process that takes place in water, including most chemical reactions and all biological organisms in the aquatic community (Stevens and others, 1975).

The primary controlling factor that influences stream temperature in most areas is generally the climate, particularly the air temperature. Other influencing factors are shading, ground-water inflow, reservoir storage and release, stream orientation, diversions, and effluents from industrial and other uses.

Plate 4 shows the estimated ranges of stream temperature in the study area. The temperature ranges were compiled from data collected primarily at water-quality sampling sites and gaging sites. Temperature data collected during 1944–70 were reported by Whitaker (1970, 1971).

The minimum temperature of all stream water in the study area is the freezing point of freshwater—0°C. The maximum temperature ranges from about 18°C at the higher altitudes of the Wasatch Plateau to 30°C in the lowlands. Water in most of the streams within the mountainous areas drops to 0°C during October and November, whereas in the lowlands it may be December or January before 0°C is reached.

for selected sites in the Wasatch Plateau

September			October			November		
Correlation coefficient	Standard error of estimate expressed as:		Correlation coefficient	Standard error of estimate expressed as:		Correlation coefficient	Standard error of estimate expressed as:	
	Acre-ft	Percent of the mean of the dependent variable		Acre-ft	Percent of the mean of the dependent variable		Acre-ft	Percent of the mean of the dependent variable
0.82	294	16	0.76	280	17	0.65	259	18
.81	343	25	.80	236	24	.62	165	25
.82	249	19	.78	231	24	.81	128	20

Most of the changes in stream temperature shown on plate 4 are related to the climatic transgression that typically affects streams as they emerge from the Wasatch Plateau and enter the lowland areas.

By relating miscellaneous water-temperature measurements to mean air temperature, thermographs were generated for sites 09318000 and 09318450 on Huntington Creek (fig. 8). This method can be used to generate seasonal water thermographs for any stream site where miscellaneous water temperatures and concurrent air temperatures have been collected. Site 09318000 is downstream from a coal-fired powerplant and 3 miles upstream from the mouth of Huntington Canyon. Site 09318450 is about 20 miles downstream from the canyon mouth and below all major diversions. The estimated thermographs are similar, but the temperatures at the downstream site are about 5° to 10°C higher during the spring and summer.

SELECTED CHEMICAL AND BIOLOGICAL PARAMETERS

Samples for chemical and biological analyses were collected at 16 stream sites at approximately bimonthly intervals during 1975–76. (See table 5.) Data were collected at many other sites during the study. A comprehensive tabulation of water-quality data collected during and prior to 1975–77 is given in Waddell and others (1978). Most of the pre-1975 data include only inorganic chemical parameters.

During 1975–76, emphasis was concentrated on the major streams where the greatest water-quality degradation was suspected. Sites were selected to bracket reaches where water-quality change was most likely to occur. Samples were collected during 1- or 2-day periods on each stream to define changes that occurred.

Most water-quality degradation occurred along the mountain fronts where water diversion, waste disposal, consumptive use, and geologic environment all had a pronounced effect. This is demonstrated in plate 5, using dissolved-solids concentration as an index of water quality from the standpoint of dissolved inorganic constituents.

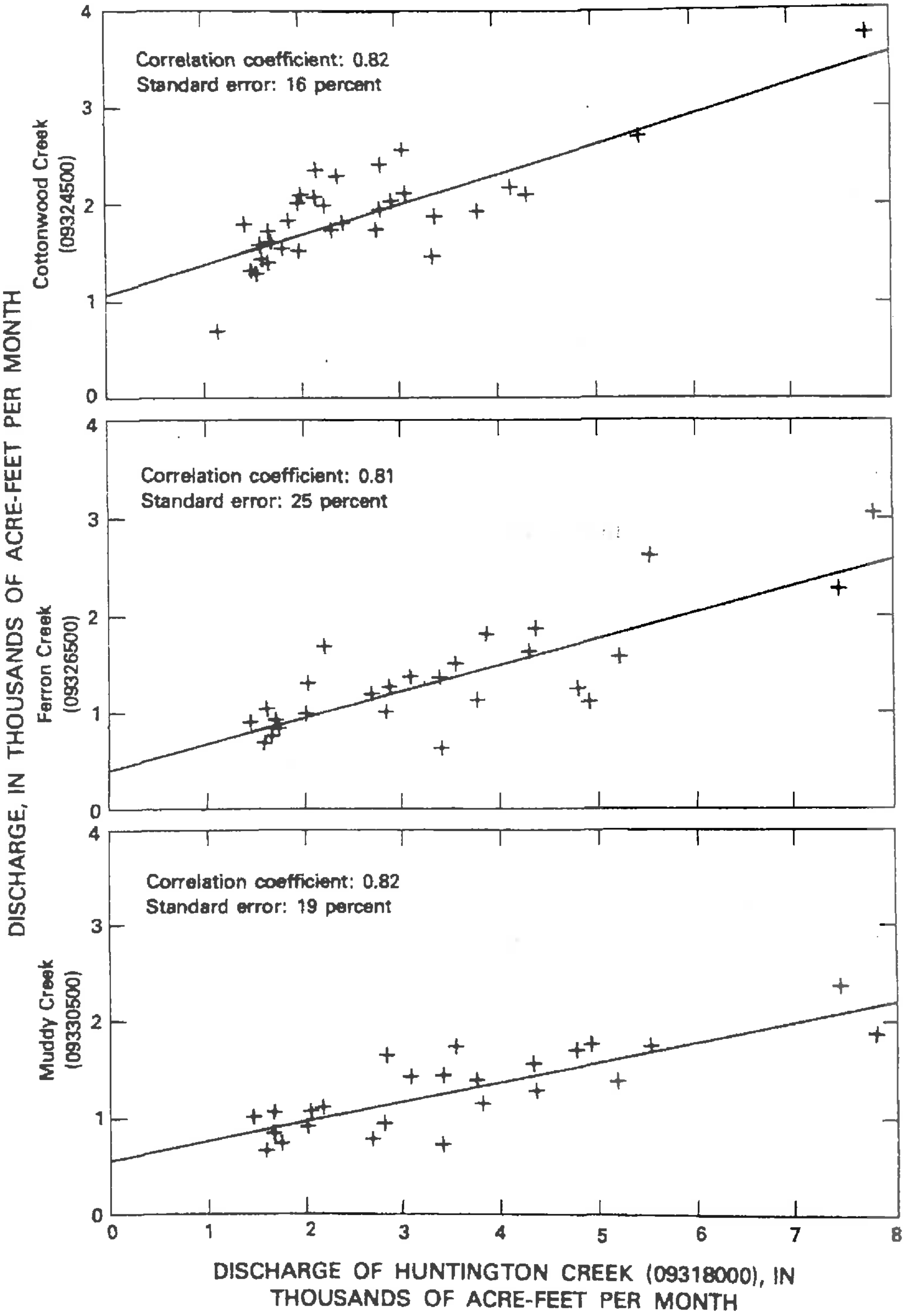


FIGURE 6.—Relationship of September flows at Huntington Creek to sites on Cottonwood, Ferron, and Muddy Creeks. Numbers in parentheses are gaging-station locations.

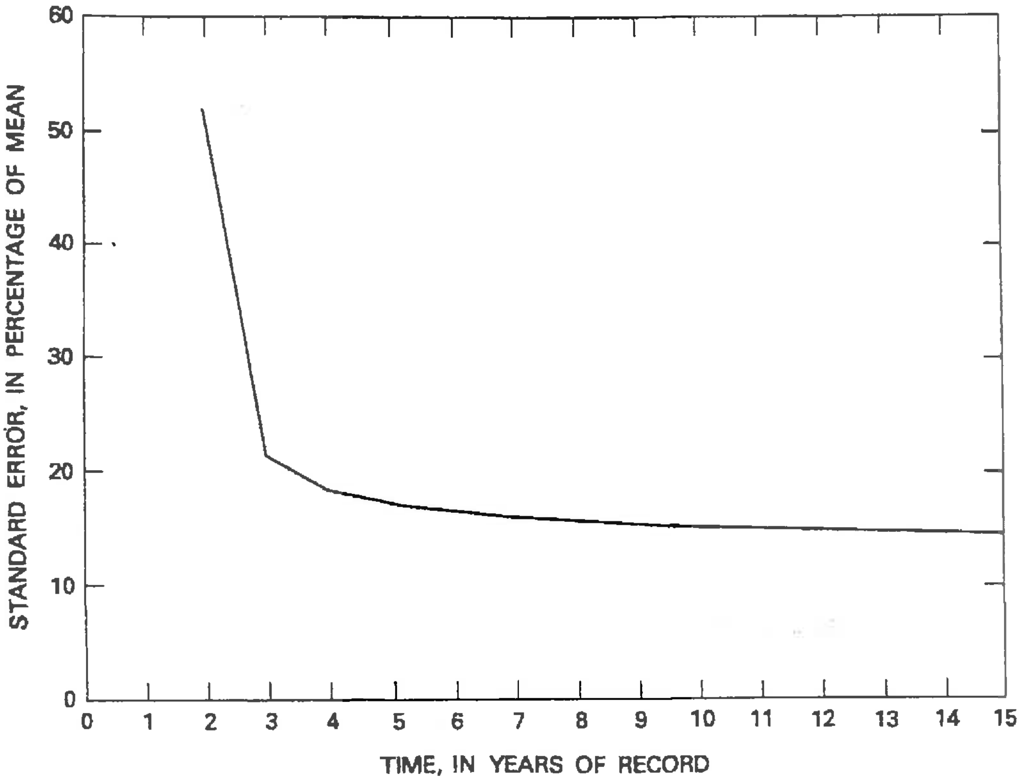


FIGURE 7.—Relationship of the standard error of estimate of low-flow correlations to varying years of record. Correlations are between September flows on Huntington Creek (09318000) and Ferron Creek (09316500).

Plate 5 is based on data in Waddell and others (1978), Mundorff (1972), and unpublished data collected by the U.S. Bureau of Reclamation. About 4,000 chemical analyses from 170 sites and over 25 years of daily water-quality records for site 09314500 on the Price River were used in the preparation of plate 5.

The lowest dissolved-solids concentrations are at the higher altitudes; the concentrations increase markedly as the streams emerge from the mountains. The lowest concentrations generally occur during high flows resulting from snowmelt; whereas, the highest concentrations generally occur during the late summer, fall, and winter months when the streamflow is maintained primarily by ground-water seepage. The smallest seasonal changes occur at higher altitudes, and the largest changes occur in the lowlands.

In most streams, at the higher altitudes in the Wasatch Plateau, the minimum concentration of dissolved solids is less than 100 mg/L, and the maximum concentration is less than 250 mg/L. At the higher altitudes, the rocks consist primarily of limestone or other rocks that contain only small amounts of readily soluble materials. The ratio of

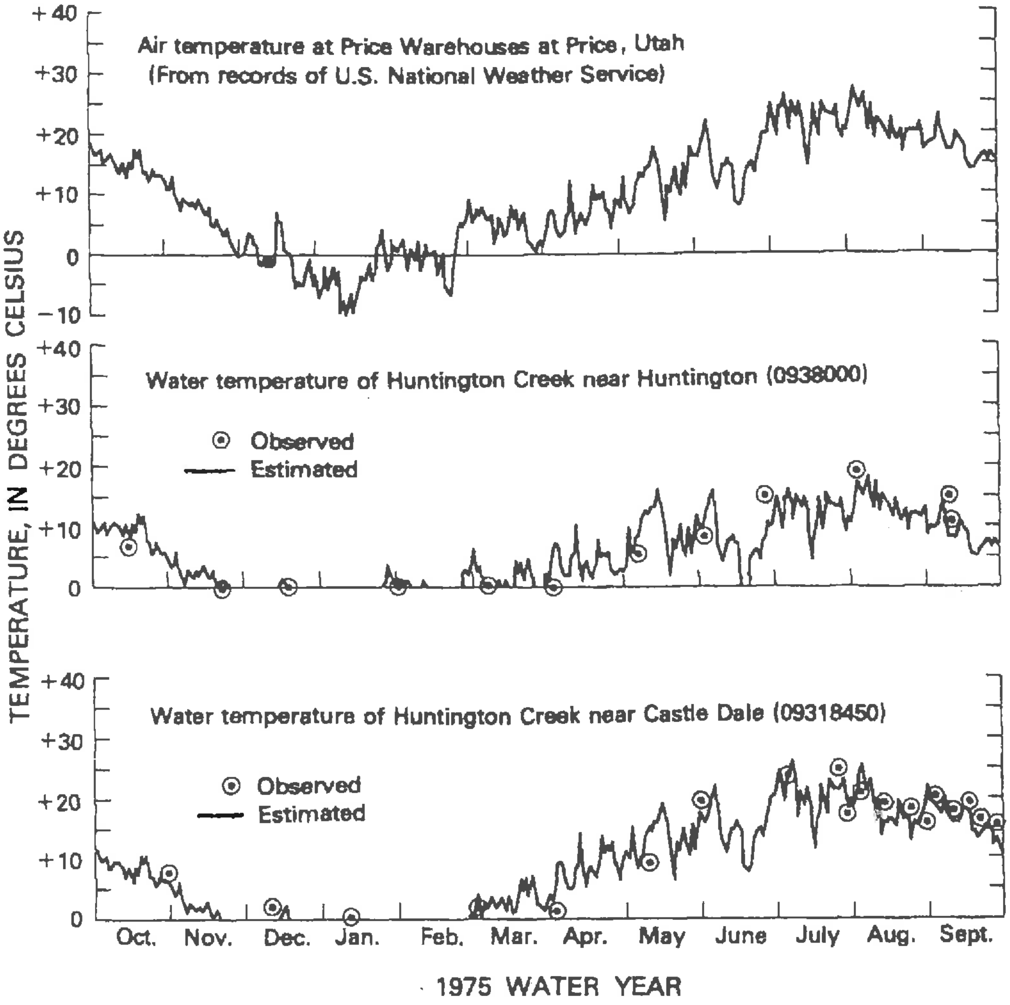


FIGURE 8.—Daily air temperature at Price and observed and estimated water temperatures at two sites on Huntington Creek.

dissolved calcium to dissolved magnesium (both in milliequivalents per liter) in water draining those rocks generally ranges from 1:1 to 3:1, and the combined concentration of calcium and magnesium approximates that of bicarbonate.

At lower altitudes below diversions, the water changes to a sodium-sulfate type and the dissolved-solids concentrations increase, ranging from about 250 to more than 6,000 mg/L. These changes are caused mainly by drainage from areas underlain by the Mancos Shale, which contains large amounts of soluble materials. The marked increase of dissolved-solids concentrations below diversions is accentuated by irrigation of relatively impermeable, moderately to highly saline, soils developed on the Mancos. (See pl. 1.) Evapotranspiration concentrates salts in the soils or as efflorescences on the soil surface. These salts are dissolved by water seeping through the soils or by surface runoff. Some of this water eventually seeps or flows back into the streams or into ditches that empty into the streams, resulting in increased concentrations of dissolved solids.

PRICE RIVER

The most upstream site on the Price River that was sampled in 1975–76 was site 09312780 which is above most diversions and populated areas (pl. 3). The most downstream site was 09314250, which is below most diversions and populated areas that have potential to provide pollutant inflows. During each sampling run the concentrations of dissolved-solids increased downstream; the overall increase ranged from 700 to almost 1,200 percent (table 5).

Organic nitrogen, which includes all dissolved nitrogenous organic compounds, is sometimes a good indicator of pollutant inflows such as fertilizer, sewage, barnyard seepage, and effluent from some industrial processes. The concentrations of organic nitrogen generally increased downstream; the largest increase usually occurred between site 09313950 at Wellington and site 09314250 below Miller Creek. The maximum-observed concentration, however, was only 1.90 mg/L, which is below the recommended maximum limits of the U.S. Environmental Protection Agency (1976, p. 5). Total Kjeldahl nitrogen which represents the total nitrogenous content of dissolved and suspended material in the water also showed a general increase downstream, and a marked change was observed between the two lowest sites.

Phosphorus, which has its source in rocks, soils, fertilizers, sewage, and industrial effluent, is sometimes an indication of pollution; it is a nutrient that promotes algal growth. Orthophosphate (dissolved phosphorus) increased significantly between the two lowest sites in the

TABLE 5.—*Summary of selected chemical and biological water-quality parameters for selected stream sites*

[Gaging-station number: See explanation of numbering system in text. Date: Samples are grouped together by date in downstream order to show progressive changes in discharge and water quality. Dissolved solids: e, estimated]

Gaging-station No.	Date	Discharge (ft^3/s)	Temperature (°C)	pH	Specific conductance (micromhos per centimeter at 25°C)	Milligrams per liter										Phenols (µg/L)	Fecal coliform (col/100 mL)	Fecal streptococci (col/100 mL)	Benthic-invertebrates (diversity index)
						Dissolved solids (sum of determined constituents)	Dissolved oxygen	Dissolved nitrite plus nitrate (N)	Dissolved organic nitrogen (N)	Dissolved Kjeldahl nitrogen (N)	Total Kjeldahl nitrogen (N)	Orthophosphate as P	Total phosphate as P	Dissolved organic carbon (C)	Oil and grease				
Price River																			
09312780 --	10-23-75	32	1.5	--	465	278	11.8	0.03	--	--	0.53	0.00	0.00	--	--	--	--	--	--
09313550 --	10-23-75	33	4.0	8.5	750	479	12.1	.14	--	--	.30	.00	.00	--	--	--	--	--	--
09313750 --	10-23-75	8.2	7.0	8.3	2,220	1,770	10.7	.67	--	--	.52	.00	.00	--	--	--	--	--	--
09313950 --	10-23-75	18	7.0	8.2	3,100	2,800	11.1	.59	--	--	.68	.00	.00	--	--	--	--	--	--
09314250 --	10-23-75	35	6.0	8.4	3,400	3,050	--	.65	--	--	2.30	.20	--	--	--	--	--	--	--
09312780 --	12-15-75	24	0.0	8.3	540	320e	11.6	.20	1.40	1.50	1.60	.01	--	--	--	3	<1	24	--
09313550 --	12-15-75	28	0.5	8.3	970	625e	12.5	1.0	.72	.76	.76	.01	--	--	--	2	60	244	--
09313750 --	12-15-75	47	0.5	8.3	1,500	1,075e	11.6	.76	.66	.69	.72	.01	--	--	--	3	0	102	--
09313950 --	12-15-75	43	0.0	8.2	2,000	1,600e	11.4	.46	--	--	.77	.01	--	--	--	4	12	80	--
09314250 --	12-16-75	30	0.0	8.5	2,900	2,550e	10.9	.69	1.90	3.50	3.50	.01	--	--	--	4	16	102	--
09312780 --	2-24-76	24	1.0	8.7	600	360e	11.0	.23	.29	.30	--	.00	--	12.0	--	2	<1	<1	--
09313550 --	2-24-76	19	5.0	8.6	800	500e	11.7	.37	.37	.38	--	.00	--	9.9	--	2	24	<1	--
09313750 --	2-24-76	22	6.5	8.2	1,400	950e	9.5	.49	.13	.16	.22	.00	--	6.2	--	2	28	12	--
09313950 --	2-25-76	27	0.5	8.2	2,190	1,750e	10.8	.55	.37	.40	--	.00	--	11.0	--	4	79	65	--
09314250 --	2-25-76	48	1.5	8.3	2,900	2,550e	10.8	.90	.99	1.90	2.80	.25	--	14.0	--	4	6	1,640	--
09312780 --	4-21-76	51	6.5	8.6	540	319	9.5	.02	.18	.21	.28	.00	--	2.7	--	2	1	6	--
09313550 --	4-21-76	23	10.5	8.5	700	483	9.5	.11	.13	.16	.61	.00	--	2.6	--	5	300	100	--
09313750 --	4-21-76	8.8	17.5	8.2	1,900	1,480	9.5	.17	.13	.16	.30	.00	--	3.1	--	2	0	160	--

09313950	--	4-21-76	17	15.0	8.1	2,600	2,310	--	.16	.20	.22	.38	.00	--	5.4	--	1	44	920	--
09314250	--	4-22-76	35	9.5	8.2	2,700	2,240	8.2	.81	.67	.97	1.20	.23	--	--	--	1	--	840	--
09312780	--	6-29-76	--	19.5	8.2	350	200e	7.1	.02	.69	.72	--	.00	--	2.5	--	0	9	40	--
09313550	--	6-30-76	267	15.0	8.3	420	250e	8.2	.06	--	.50	.53	.00	--	3.1	--	2	180	260	--
09313750	--	6-30-76	24	19.5	8.3	1,420	950e	8.9	.17	--	.28	--	.00	--	--	0	0	800	1,448	--
09313950	--	6-30-76	61	22.0	8.2	2,100	1,700e	10.3	.21	--	.56	--	.00	--	--	0	0	97	300	--
09314250	--	6-30-76	35	22.5	8.6	2,600	2,250e	9.9	.04	--	.69	.72	.16	--	--	0	1	4	24	--
09312780	--	9- 2-76	122	12.0	8.4	360	194	8.4	.09	.35	.35	--	.00	--	4.0	0	0	18	132	1.59
09313550	--	9- 2-76	63	14.0	8.8	460	261	8.4	.18	.50	.50	.57	.00	--	3.9	0	2	50	216	.98
09313750	--	9- 2-76	6.8	13.0	8.1	1,650	1,250e	8.7	.47	.93	1.00	--	--	--	3.6	0	2	620	840	1.00
09313950	--	9- 2-76	17	19.0	8.3	2,700	2,360	13.8	.14	.68	.70	2.00	.03	--	9.8	0	2	68	228	.75
09314250	--	9-10-76	28	18.0	8.3	2,600	2,250e	6.9	1.4	.82	1.00	1.20	.28	.69	7.6	0	2	--	--	--

Grassy Trail Creek

09314320	--	9-12-75	0.50	14.5	8.5	608	366	--	0.00	--	--	--	0.00	--	--	--	--	--	--	--
09314320	--	10-24-75	.13	0.0	8.6	700	451	10.5	--	--	--	0.02	.00	0.00	--	--	--	--	--	--
09314340	--	10-24-75	.78	0.0	8.7	1,700	1,280	11.2	.09	--	--	.30	.00	.00	--	--	--	--	--	--
09314320	--	1-13-76	.04	0.5	8.0	690	425e	10.6	.07	0.19	0.32	--	.01	--	--	--	0	1	4	--
09314340	--	1-13-76	.66	6.0	8.5	2,400	2,000e	11.3	.38	.69	--	1.30	.01	--	--	--	4	0	12	--
09314340	--	2-25-76	.77	9.9	8.6	2,300	1,925e	10.0	.37	.28	.30	.69	.02	--	6.4	--	4	12	80	--
09314320	--	4-22-76	.12	7.0	8.2	650	380	9.2	.01	.13	.16	.22	.01	--	1.4	--	0	0	65	--
09314340	--	4-22-76	1.40	9.5	8.6	2,200	1,450	8.6	.34	.11	.15	1.20	.01	--	6.0	0	2	0	124	--
09314320	--	7- 1-76	1.00	12.5	8.6	431	250e	7.5	.02	.52	.63	--	.01	--	3.9	--	1	40	196	--
09314340	--	7- 1-76	6.00	20.0	8.6	--	--	7.0	.08	.09	.10	.37	.00	--	3.0	--	0	16	536	--
09314320	--	9-10-76	.15	13.5	8.7	580	350e	7.8	.06	.02	.03	.15	.01	.00	12.0	0	1	--	160	1.76
09314340	--	9-10-76	1.50	16.5	8.9	1,650	1,250e	8.1	.10	.10	.11	.82	.01	.01	15.0	0	0	--	500	.59

Huntington Creek

09317950	--	11- 4-75	46.00	4.5	8.4	350	184	9.8	0.02	0.12	0.12	--	0.00	--	--	--	--	--	--	--
09318450	--	11- 4-75	25.00	4.5	8.4	3,600	3,440	9.8	.09	.44	.46	0.60	.00	--	--	--	--	40	436	--
09317950	--	1-15-76	29.00	0.5	8.7	470	275e	11.2	.26	.36	.40	--	.00	--	--	--	3	8	2	--
09318450	--	1-15-76	9.30	0.5	7.9	5,000	3,050e	10.6	.85	.87	1.10	--	.00	--	--	--	10	36	184	--
09317950	--	3-16-76	62.00	1.5	8.4	420	250e	10.4	.16	1.70	1.70	1.70	.00	--	1.9	--	0	2	25	--
09318450	--	3-16-76	14.00	7.0	8.3	4,500	3,950e	11.0	.62	.59	.67	1.30	.00	--	6.2	--	0	0	28	--
09317950	--	7- 7-76	250.00	11.5	8.5	280	150e	8.5	.13	.10	.11	--	.00	--	3.2	--	0	19	32	--
09318450	--	7- 7-76	25.00	24.5	8.3	3,000	2,650e	7.5	.14	.67	.70	--	.00	--	7.6	--	0	280	220	--
09317950	--	8-31-76	90.00	14.5	8.7	230	125e	7.9	.10	1.20	1.30	--	.01	--	--	1	2	2	4	1.99
09318450	--	8-31-76	10.00	24.0	8.3	4,350	3,540	8.2	.21	1.20	1.20	--	.01	--	--	0	3	200	330	1.23

TABLE 5. —*Summary of selected chemical and biological water-quality parameters for selected stream sites*—Continued

						Milligrams per liter													
Gaging-station No.	Date	Discharge (ft³/s)	Temperature (°C)	pH	Specific conductance (micromhos per centimeter at 25°C)	Dissolved solids (sum of determined constituents)	Dissolved oxygen	Dissolved nitrite plus nitrate (N)	Dissolved organic nitrogen (N)	Dissolved Kjeldahl nitrogen (N)	Total Kjeldahl nitrogen (N)	Orthophosphate as P	Total phosphate as P	Dissolved organic carbon (C)	Oil and grease	Phenols (µg/L)	Fecal coliform (col/100 mL)	Fecal streptococci (col/100 mL)	Benthic-invertebrates (diversity index)
									Cottonwood Creek										
09324500 --	11- 4-75	15.0	8.5	8.5	460	249	9.2	0.05	0.05	0.07	0.12	0.00	--	--	--	--	0	50	--
09325000 --	11- 4-75	11.0	9.5	8.3	2,500	2,160	9.6	.00	.27	.30	.48	.00	--	--	--	--	260	264	--
09324500 --	1-15-76	6.5	0.5	8.4	530	300e	11.6	.18	.40	.44	--	.00	--	--	--	0	0	2	--
09325000 --	1-15-76	7.4	0.5	7.9	2,400	2,025e	9.2	.62	1.10	1.70	--	.06	--	--	--	10	1,960	3,000	--
09324500 --	3-17-76	9.5	3.5	8.4	510	300e	10.6	.12	.28	.30	.30	.00	--	1.5	--	0	2	7	--
09325000 --	3-17-76	5.8	8.5	8.2	3,200	2,850e	11.6	.18	1.90	2.00	--	.00	--	21.0	--	1	80	0	--
09324500 --	7- 7-76	200.0	12.0	8.5	380	225e	8.4	.14	.14	.17	--	.00	--	2.3	--	1	2	38	--
09325000 --	7- 8-76	21.0	20.0	8.2	2,000	1,600e	8.2	.08	.50	.50	.51	.00	--	14.0	5	2	80	110	--
09324500 --	9- 1-76	164.0	14.5	8.7	390	210	8.5	.20	.61	.63	--	.01	--	--	1	1	7	51	1.29
09325000 --	9- 1-76	6.9	14.5	8.1	2,200	2,160	7.6	.07	.61	.61	--	--	--	--	0	2	44	96	1.53
									Ferron Creek										
09326500 --	9-10-75	30.0	8.0	8.9	570	350e	--	0.10	--	--	--	0.00	--	--	--	--	--	--	--
09327550 --	9-10-75	--	22.0	8.3	2,300	1,980	--	.70	--	--	--	.00	--	--	--	--	--	--	--
09326500 --	11- 5-75	13.0	6.5	8.2	540	331	9.7	.11	.24	0.25	--	.00	--	--	--	--	0	4	--
09327550 --	11- 5-75	18.0	9.0	8.3	3,080	2,450	9.4	.35	.47	.49	0.67	.00	--	--	--	--	--	56	--

09326500	--	1-14-76	10.0	0.5	8.3	600	375e	11.4	.44	.10	.14	.27	.00	--	--	--	4	6	1	--
09327550	--	1-14-76	8.7	0.5	8.2	2,700	2,210	10.8	1.20	.70	.78	--	--	--	--	--	0	10	72	--
09326500	--	3-17-76	9.0	10.0	8.8	600	375e	9.0	.25	.95	.96	1.00	.00	--	6.1	--	0	0	1	--
09327550	--	3-17-76	11.0	12.0	8.3	3,500	3,100e	9.5	1.10	1.30	1.30	1.40	.00	--	5.6	--	0	0	24	--
09326500	--	7- 8-76	34.0	20.0	8.6	460	275e	7.0	.10	.08	.11	.16	.01	--	14.0	4	0	6	10	--
09327550	--	7- 8-76	16.0	21.5	8.3	2,400	2,025e	7.2	.14	1.30	1.30	--	.01	--	13.0	6	0	192	760	--
09326500	--	9- 1-76	8.0	19.5	8.7	500	300	7.3	.06	.67	.68	--	.01	--	--	0	3	4	48	1.55
09327550	--	9- 1-76	7.1	26.0	8.2	2,700	2,380	7.1	.04	.56	.57	--	.00	--	--	0	2	28	800	.84

Muddy and Ivie Creeks

09330500	--	9-10-75	39.0	19.0	8.7	390	211	--	0.35	--	--	--	0.00	--	--	--	--	--	--	--
09332100	--	9-10-75	4.0	--	--	4,000	3,450	--	3.50	--	--	--	.00	--	--	--	--	--	--	--
09330500	--	11- 5-75	13.0	7.5	8.9	420	240	9.8	.27	0.00	0.00	0.12	.00	--	--	--	--	0	6	--
09332000	--	11- 5-75	5.6	7.0	8.9	3,700	3,270	9.7	2.90	.29	.30	1.10	.00	--	--	--	--	32	650	--
09332100	--	11- 5-75	10.0	3.5	9.1	3,600	3,140	10.6	3.50	.08	.08	1.40	.00	--	--	--	--	60	850	--
09330500	--	1-14-76	8.5	0.0	8.5	440	250e	11.4	.61	.12	.16	--	.01	--	--	--	2	0	8	--
09332000	--	1-14-76	8.0	0.5	8.2	2,950	2,600e	10.8	2.80	.74	.82	1.10	.01	--	--	--	2	10	250	--
09332100	--	1-14-76	13.0	0.5	8.2	2,400	2,025e	11.2	1.90	.69	.78	--	.00	--	--	--	4	2	180	--
09330500	--	3-18-76	6.0	4.0	8.4	420	250e	10.2	.47	.91	.96	1.60	.00	--	2.1	--	0	4	84	--
09332000	--	3-18-76	14.0	11.5	8.4	1,900	1,500e	8.3	2.30	1.70	1.80	1.80	.00	--	3.7	--	6	860	940	--
09332100	--	3-18-76	14.0	13.0	8.4	2,100	1,700e	7.9	2.30	.76	.78	.88	.00	--	4.3	--	1	960	448	--
09330500	--	7- 8-76	37.0	20.5	8.6	360	200e	7.1	.44	.29	.29	--	.00	--	2.3	--	0	5	41	--
09332000	--	7- 9-76	.34	28.0	8.5	4,500	3,950e	6.6	4.80	.63	.69	--	.00	--	7.3	34	4	16	28	--
09332100	--	7- 9-76	--	29.0	8.5	4,600	4,025e	6.1	4.30	.75	.75	--	.01	--	15.0	3	0	52	308	--
09330500	--	9- 9-76	13.0	11.5	8.6	380	225e	--	.37	.19	.20	--	.01	.00	1.5	0	1	--	88	1.34
09332100	--	9- 9-76	.43	21.5	8.3	3,500	3,175e	7.0	6.50	.62	.63	--	.00	.00	7.6	0	1	--	283	.06

Price River. Dissolved phosphorus was less than 0.02 mg/L at the upper three sites, but it increased to as much as 0.28 mg/L at the lower site. Total phosphorus (suspended plus dissolved) showed a maximum of 0.69 mg/L at the lower site. Phosphorus is not toxic at these concentrations.

Phenols, which may be indicative of pollutive effluents from industrial processes, impart undesirable taste and odor to water supplies; the threshold level is in the range of 0.01-0.1 μg/L. A concentration of 5.0 μg/L is considered harmful to many species of fish (U.S Federal Water Pollution Control Administration, 1968). Phenol concentrations ranged from 0 to 5 μg/L, with the maximum of 5 μg/L occurring at site 09313550 near Spring Glen. Water discharging at a rate of approximately 10–20 gal/min was observed flowing into the Price River from Hardscrabble Canyon, just north of Spring Glen. About 15–20 percent (by weight) of the total water discharge was finely ground coal. It is not known if phenolic wastes were associated with this effluent, but it was the only visible source of surface inflow immediately upstream from site 09313550.

Dissolved organic carbon (DOC) may be indicative of waste effluent from industrial and agricultural processes. DOC is not specific for any organic compound, but when found in concentrations exceeding about 4 μg/L, more exhaustive tests to pinpoint a specific organic pollutant may be warranted. The maximum concentration of DOC observed was 14.0 μg/L at site 09314250. The maximum concentration occurred at this site during all but one of the sampling runs.

Bacteriological analyses were made for fecal coliform and fecal streptococci bacteria, both of which are indications of water contamination. Fecal coliform bacteria may indicate recent and possibly dangerous contamination as they are found in the gut or feces of warm-blooded animals. The normal habitat of fecal streptococci bacteria is in the intestine of man (Slack and others, 1973, p. 59).

The ratio of fecal coliform to fecal streptococci bacteria (Fc/Fs) can be used as an indication of the origin of bacterial wastes (Millipore Corp., 1973, p. 38–39). If Fc/Fs is greater than or equal to 4, it is strong evidence that the pollution is derived from human wastes. If Fc/Fs is less than or equal to about 0.7, the pollution probably is derived predominantly from the wastes of warm-blooded animals (including livestock) other than humans. If Fc/Fs is between about 0.7 and 4, it is less definitive of the pollutant origin and may be from mixed sources.

The bacterial counts at the uppermost site (09312780) were generally low. The maximum count was 132 colonies of fecal streptococci bacteria per 100 mL, but counts were 40 colonies per 100 mL or less during the other observations. At the other four sites no downstream consistency was observed, but high counts were observed at the lower three sites where the maximum fecal streptococci bacteria count was

1,640 colonies per 100 mL, and the maximum fecal coliform bacteria count was 620 colonies per 100 mL. Fc/Fs was generally less than 0.7 at all sites, suggesting that most of the bacterial pollution is from nonhuman wastes.

HUNTINGTON, COTTONWOOD, FERRON, AND MUDDY CREEKS

Huntington, Cottonwood, Ferron, and Muddy Creeks were each sampled at an upper site above major diversions and a lower site below major diversions and most populated areas. The upper sites are near the canyon mouths, upstream from where the streams emerge from the Wasatch Plateau. Irrigated lands, which are developed primarily on the Mancos Shale, lie between the upper and lower sites.

The dissolved-solids concentrations during 1975–76 in the four streams at the upper sites ranged from 125 to 375 mg/L and at the lower sites from 1,600 to 4,025 mg/L (table 6). Thus, the overall increase ranged from 500 to 1,000 percent. The dominant ions in the water at the upper sites were generally calcium, magnesium, and bicarbonate, whereas sodium and sulfate become more predominant at the lower sites. The downstream changes were primarily due to the combined effects of (1) diversion of water containing low dissolved-solids concentrations, (2) subsequent irrigation and return drainage from moderate to highly saline soils, (3) ground-water seepage, and (4) inflow of sewage and pollutants from the communities between the upper and lower sites.

In the reaches between the upper and lower sampling sites on the four streams, there was also a pronounced increase in the concentration of most of the organic and biological water-quality parameters that are indicative of pollutants.

Organic forms of nitrogen generally increased from the upper to lower sites on the four streams. The maximum observed concentration, however, was only 2.0 mg/L of dissolved Kjeldahl nitrogen, and it occurred at the lower site on Cottonwood Creek (09325000).

Dissolved phosphorus was almost nonexistent, as all except one sample had less than 0.02 mg/L at all sampling sites on the four streams.

Concentrations of DOC and phenols and bacteria counts indicated significant sources of pollutants at the lower sampling sites, especially on Huntington and Cottonwood Creeks. On Huntington Creek, for example, DOC increased from 1.9 to 6.2 mg/L between sites 09317950 and 09318450 during March 1976 and from 3.2 to 7.6 mg/L during July 1976. During January 1976, phenols increased from 3 to 10 μg/L between the two sites. Fecal streptococci bacteria counts at the upper site were less than 40 colonies per 100 mL, but at the lower site counts were as high as 436 colonies per 100 mL. The sources of the pollutants are probably irrigation return flows and stock that graze within the affected reach—Fc/Fs was generally less than about 0.7.

On Cottonwood Creek, DOC increased from 1.6 to 21 mg/L between sites 09324500 and 09325000 during March 1976 and increased from 2.3 to 14 mg/L between the sites during July 1976. The concentration of phenols increased from 0 to 10 µg/L between the sites during January 1976. Fecal streptococci bacteria counts increased from 2 to 3,000 colonies per 100 mL between the sites during January 1976. Several small inflows were observed discharging into Cottonwood Creek at the community of Castle Dale. Here inflows may contain pollutants that contribute to the water-quality deterioration between the sampling sites. Also, another possible source of pollutant inflow is mine discharge into Grimes Wash, which joins Cottonwood Creek between the two sampling sites.

Biological determinations are not available for the discharge from Grimes Wash, however, and it is not known if the high concentrations of DOC and phenols and the high fecal streptococci bacteria counts at the lower site on Cottonwood Creek are from this source.

On Ferron and Muddy Creeks, bacteria counts at the upper sites (09326500 and 09330500) were generally less than about 50 colonies per 100 mL. However, the counts increased markedly to 760 colonies per 100 mL of fecal streptococci bacteria at the lower site (09327550) on Ferron Creek and to 960 colonies per 100 mL of fecal coliform bacteria at the lower site (09332100) on Muddy Creek. Fc/Fs was generally less than 0.7 at both sites, suggesting that most of the bacterial pollution is originating from nonhuman wastes. Most of the increase of bacteria in Muddy Creek is attributed to inflow from Ivie Creek, which was sampled at site 09332000 near its confluence with Muddy Creek. Ivie Creek had bacteria counts close to or exceeding those of Muddy Creek at site 09332100 below the confluence, at times when the flow of Ivie Creek represented either all or a large percentage of the flow at the lower sampling site on Muddy Creek.

GRASSY TRAIL CREEK

Grassy Trail Creek was sampled at sites 09314320 and 09314340 in Whitmore Canyon, above and below the Sunnyside Mine. The mine, which obtains coal from the Blackhawk Formation, intermittently discharges water into Grassy Trail Creek between the two sites, and mine discharge is often a significant part of the streamflow at the lower site. The dissolved-solids concentration of a mine-discharge sample on July 1, 1976, was about 1,600 mg/L. Such a high dissolved-solids concentration suggests that some of the water may be derived from the Mancos Shale, which intertongues with the Blackhawk in the area.

The discharge from the mine affects the water quality at the lower site on Grassy Trail Creek and probably indirectly affects the groundwater system below the canyon mouth because of stream seepage into alluvium. The dissolved-solids concentration ranged from 250 to 451 mg/L at the upper site and from 1,250 to 2,000 mg/L at the lower site (table 5). Part of the increase in dissolved solids is due to intermittent discharge from the mine. The predominant ions in the water at the upper site in Whitmore Canyon are calcium, magnesium, and bicarbonate, whereas at the lower site sodium, bicarbonate, and sulfate are the predominant ions—typical of Mancos Shale influence.

Dissolved nitrite plus nitrate and the total Kjeldahl nitrogen increased from the upper to lower site, but the maximum total nitrogen was only 1.3 mg/L. Concentrations of phosphorus were small at both sites, with a maximum recorded concentration of orthophosphate of only 0.02 mg/L.

Concentrations of dissolved organic carbon were generally higher at the lower site than at the upper; the concentration ranged from 1.4 to 12 mg/L at the upper site and from 3.0 to 15 mg/L at the lower site. No oil and grease were detected in two samples at the lower site, and the maximum phenol concentration was 4 μg/L at the lower site.

Fecal coliform bacteria counts at both sites were 40 colonies per 100 mL or less, but fecal streptococci bacteria ranged from 4 to 196 colonies per 100 mL at the upper site as compared to a range of 12 to 536 colonies per 100 mL at the lower site. For all concurrent samples at the two sites, an appreciable increase in fecal streptococci bacteria occurred from the upper to the lower sampling site.

Water samples from Whitmore Spring, (D-15-13)1ddc-S1, and from well (D-15-13)2dad-1, both of which discharge from alluvium near the mouth of Whitmore Canyon, had dissolved-solids concentrations and chemical compositions similar to samples obtained from Grassy Trail Creek at the lower site. This probably reflects the influence of seepage from Grassy Trail Creek into the alluvium near the canyon mouth.

BENTHIC INVERTEBRATES

Benthic invertebrates are used as an indication of prior water-quality conditions in a stream, whereas most chemical parameters are indicative of water-quality conditions only at the time of sampling. The invertebrates are bottom dwellers; they have a lifespan of months or years; and, in some cases they have only slight mobility, which restricts them to a particular environment. A diversity index is often used as an indication of the variety of taxa and the number of individuals per taxon at a sampling site (Slack and others, 1973, p. 24). The higher the index number, the more diverse the groups of taxa, and the more likely that the water quality has been good for a significant period of time.

A benthic-invertebrate survey was made during the fall of 1976. Although one survey cannot describe seasonal variations, the results showed significant decreases in the diversity of the fauna from upper to lower sites on the Price River and Huntington, Ferron, Muddy, and Grassy Trail Creeks (table 5). These decreases in the diversity indexes are related to increases in temperature, dissolved-solids concentration, and concentration of other water-quality parameters between the upper and lower sites. Cottonwood Creek was an exception, and it is not known why the diversity index did not decrease between the upper and lower site on that Creek. An unusually low diversity index of 0.06 occurred at the lower site on Muddy Creek (09332100). This was probably due to poor water-quality conditions but, in particular, to the presence of very fine sediment that covers the streambed. An abundance of very fine sediment has been observed in the bed material of Ivie Creek, which discharges into Muddy Creek immediately upstream from the sampling site.

TRACE ELEMENTS

Trace-element analyses were made of samples collected at the 16 stream sites (table 6). Many of the elements shown in table 6 can be in coal wastes; therefore, the analyses were made to provide background information on trace elements in the study area for the level of coal mining existent in 1975–76.

The concentrations of boron, lithium, and strontium generally increase downstream in amounts proportional to the increase of dissolved solids in the streams. The greatest increases occur after most of the water draining from the mountain block is diverted. This is to be expected, however, because irrigation-return flows, seepage from the Mancos Shale, and local inflow of sewage and other pollutants sustain the base flow of the streams in the lower reaches.

SEDIMENT

Estimated sediment yields for the study area are shown in plate 6, which was adapted from a map prepared by the U.S. Department of Agriculture (1973).

The estimated sediment yields are based largely on the geology of the study area. The yields range from 0.1 to 3 acre-feet per square mile per year. The lower yields generally are from the higher parts of the Wasatch Plateau and Book Cliffs, where the exposed rock types are predominantly limestone and dolomite; the higher yields generally are from the lowlands, where rock types are predominantly shale and sandstone.

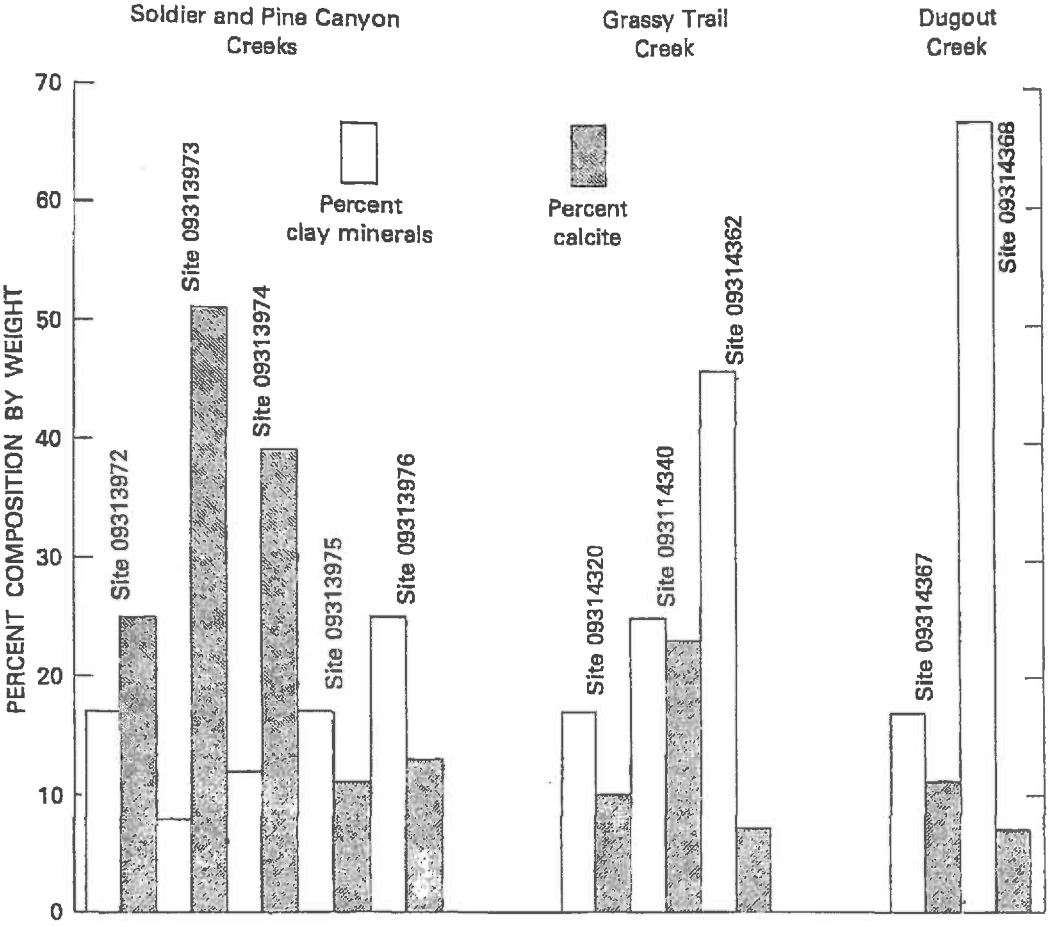


FIGURE 9.—Mineralogic composition of bed material at sites on selected streams.

A large percentage of the total sediment yield occurs during infrequent storms; therefore, no attempt was made during the 1975–77 reconnaissance to determine suspended-sediment yields. Bed-material samples, however, were obtained at many stream sites to provide background information about the size and mineralogic character of existing bed material. The sampling sites are shown in plate 6 and the laboratory analyses are given by Waddell and others (1978, table 13). Similar data were collected from representative rock outcrops in the Wasatch Plateau and Book Cliffs (pl. 6) to provide background information that might aid in future studies. (See Waddell and others, 1978, table 14.)

On most of the major streams, clay minerals constitute less than about 20 percent (by weight) of the bed material. On ephemeral streams, particularly at lowland sites several miles from the mountains, clay minerals often constitute more than 20 percent of the bed material.

TABLE 6. – *Trace-element analyses of water from selected stream sites*

[Gaging-station number: See explanation of numbering system in text]

Gaging-station No.	Date	Temperature (°C)	Discharge (ft³/s)	Micrograms per liter																			
				Dissolved arsenic (As)	Dissolved barium (Ba)	Dissolved beryllium (Be)	Dissolved boron (B)	Dissolved chromium (Cr)	Dissolved cobalt (Co)	Dissolved copper (Cu)	Dissolved iron (Fe)	Dissolved lead (Pb)	Dissolved lithium (Li)	Dissolved manganese (Mn)	Dissolved molybdenum (Mo)	Dissolved nickel (Ni)	Dissolved mercury (Hg)	Dissolved selenium (Se)	Dissolved silver (Ag)	Dissolved strontium (Sr)	Dissolved tin (Sn)	Dissolved vanadium (V)	Dissolved zinc (Zn)
Maximum limits ^{1,2}				50 ^{1}	1,000 ^{1}	--	--	50	--	1,000 ^{2}	300	50 ^{1}	--	--	--	--	2 ^{1}	10 ^{1}	50 ^{1}	--	--	--	5,000 ^{2}
Price River																							
09312780	10-23-75	1.5	32.0	1	80	<2	30	<7	<7	<2	0	<7	10	10	4	<7	--	0	<1	370	<7	<7.0	10
	4-21-76	6.5	51.0	2	100	<2	60	<8	<8	2	--	<8	20	10	<4	<8	--	1	<1	370	<10	<8.0	0
	9- 2-76	12.0	122.0	0	80	<1	30	0	<5	3	--	1	10	10	4	<5	--	0	<1	190	<7	<5.0	0
09313550	10-23-75	4.0	33.0	1	90	<2	110	<10	<10	4	50	<10	20	20	6	<10	--	2	<1	420	<10	<10	10
	4-21-76	10.5	23.0	3	100	<2	110	<10	<10	3	--	<10	30	10	<5	<10	--	1	<1	560	<15	<10	0
	9- 2-76	14.0	63.0	0	100	<3	60	0	<7	3	--	6	10	0	<7	<7	--	1	<2	270	<7	<7.0	0
09313750	10-23-75	7.0	8.2	0	40	<1	270	<30	<30	<7	10	<30	110	190	20	<80	--	5	<4	1,600	<30	<30	20
	4-21-76	17.5	8.8	0	50	<6	230	0	<25	<6	--	4	90	160	<12	<25	--	2	<3	1,500	<40	<25	0
	9- 2-76	13.0	6.8	0	40	<6	260	0	<25	<6	--	2	110	100	<10	<25	--	2	<3	1,700	<40	<25	0
09313950	10-23-75	7.0	18.0	1	40	<10	420	<45	<45	<10	0	<45	240	260	30	<45	--	7	<5	2,200	<45	<45	10
	4-21-76	15.0	17.0	0	40	<10	260	<40	<40	<10	--	<40	200	190	<20	<40	--	3	<5	2,400	<60	<40	0
	9- 2-76	19.0	17.0	0	40	<20	380	0	<40	<8	--	9	210	40	<40	<40	--	3	<8	2,600	<40	<40	0
09314250	10-23-75	6.0	35.0	1	50	<10	400	<50	<50	<10	20	<50	240	180	30	<50	--	7	<6	2,500	<50	<50	10
	4-22-76	9.5	35.0	1	60	<10	300	<40	<40	<10	--	<40	190	80	<20	<40	--	4	<5	2,100	<60	<40	0
Grassy Trail Creek																							
09314320	10-24-75	0.0	.13	1	70	<3	60	<10	<10	<5	10	<10	<10	<10	5	<10	--	0	<2	230	<10	<10	20
	4-22-76	7.0	.12	0	70	<2	60	<10	<10	<2	--	<10	0	<10	<5	<10	--	0	<1	280	<15	<10	0

09314840	4-22-76	9.5	1.4	1	30	<7	250	0	<30	<7	--	4	50	<80	<15	<80	--	0	<4	340	<30	<30	0
	9-10-76	16.5	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Huntington Creek

09317950	7- 7-76	12.0	250.0	1	70	<2	0	0	<5	8	--	0	5	10	3	<5	--	0	<1	140	<5	<5.0	0
	8-31-76	14.5	90.0	0	60	<2	20	0	<4	4	--	35	0	40	<4	<4	--	0	<1	140	<4	<4.0	10
09318450	11- 4-75	4.5	25.0	1	40	<10	290	<60	<60	<12	--	<60	360	140	30	<60	--	5	<6	2,500	<60	<60	10
	7- 7-76	24.5	25.0	1	40	<20	300	10	<50	<10	--	2	320	80	35	<50	--	8	<7	2,700	<50	<50	5
	8-31-76	24.0	10.0	0	30	<10	310	0	<60	<12	--	2	370	20	<30	<60	--	3	<6	3,100	<80	<60	0

Cottonwood Creek

09324500	11- 4-75	8.5	15.0	1	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	--	--	--
	7- 7-76	12.0	200.0	1	80	<1	20	0	<3	1	--	0	10	0	3	<3	--	0	0	290	<3	<3.0	0
	9- 1-76	14.5	164.0	0	100	<2	20	0	<6	2	--	2	10	20	5	<6	--	0	<1	310	<8	<6.0	0
09325000	11- 4-75	9.5	11.0	1	40	<8	270	<40	<40	<8	--	<40	200	70	<20	<40	--	1	<4	1,600	<40	<40	<10
	7- 8-76	20.0	21.0	2	40	<10	250	0	<30	<7	--	2	160	90	20	<30	--	1	<4	1,800	<30	<30	0
	9- 1-76	14.5	6.9	0	30	<8	310	0	<40	<8	--	1	210	40	20	<40	--	0	<4	2,300	<50	<40	0

Ferron Creek

09326500	11- 5-75	6.5	13.0	1	20	<3	20	<7	<7	10	--	<7	20	10	5	<7	--	0	<1	770	<7	<7.0	<10
	7- 8-76	20.0	34.0	1	100	<2	10	0	<7	2	--	2	20	20	5	<7	--	0	<1	730	<10	<6.0	0
	9- 1-76	19.5	8.0	0	100	<3	40	0	<8	3	--	2	30	0	<8	<8	--	0	<2	780	<8	<8.0	0
09327550	11- 5-75	9.0	18.0	0	40	<9	280	<40	<40	<9	--	<40	240	<40	20	<40	--	8	<5	2,200	<40	<40	20
	7- 8-76	21.5	16.0	2	40	<10	270	0	<35	<8	--	3	190	20	20	<35	--	2	<5	2,600	<50	<30	0
	9- 1-76	26.0	7.1	1	40	<10	340	0	<40	13	--	2	260	20	20	<40	--	3	<4	3,200	<60	<40	0

Muddy and Ivie Creeks

09330500	11- 5-75	7.5	13.0	2	30	<2	10	<5	<5	20	--	<5	.20	5	4	<5	--	0	<1	420	<5	<5.0	<10
	7- 8-76	20.5	37.0	1	<200	<2	4	0	6	2	--	2	20	0	4	<6	--	0	<1	410	<8	<5.0	0
	8-12-76	10.5	15.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	9- 9-76	11.5	13.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
09332000	11- 5-75	7.0	5.6	0	40	<10	390	<60	<60	<15	--	<60	210	<60	30	<60	--	8	<7	2,600	<60	<60	<10
	7- 9-76	23.0	.34	1	<40	<20	530	0	<70	15	--	2	310	60	49	<70	--	11	<10	3,900	<100	<60	5
09332100	11-19-75	0.0	10.0	2	0	--	250	--	1	--	--	6	180	30	1	--	0.0	7	--	1,900	--	--	10
	7- 9-76	20.0	--	1	40	<30	590	0	<75	<15	--	4	320	70	40	<75	--	9	<10	4,000	<100	<60	5
	8-11-76	25.0	.10	0	0	--	620	--	2	--	--	2	300	20	2	--	.0	8	--	4,100	--	--	0

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[1] Maximum permissible level stated by the U.S. Environmental Protection Agency (1976, p. 5).

[2] Maximum recommended level stated by the National Academy of Sciences and National Academy of Engineering (1974, p. 50–94).

Soldier, Grassy Trail, and Dugout Creeks all head in the Book Cliffs and have similar geologic and physiographic settings. Selected reaches of these streams were chosen for more detailed study in order to determine trends of bed-material characteristics. Bed material in the three creeks generally increased in clay-mineral content and decreased in calcite content between upper and lower sampling sites (fig. 9).

Soldier Creek was sampled at four sites, and a major tributary, Pine Canyon Creek, was sampled near its confluence with Soldier Creek. The clay-mineral content of bed material in Soldier Creek above Pine Canyon Creek (site 09313972) was 17 percent, in Pine Canyon Creek at the mouth (site 09313973) it was 8 percent, and below the confluence of the two streams (site 09313974) it was 12 percent. At successive sites downstream from the confluence (09313975 and 09313976), the clay-mineral content increased to 17 and 25 percent.

At the upper site on Soldier Creek (09313972), calcite was 25 percent of the bed material, at the mouth of Pine Canyon (site 09313973) calcite was 51 percent, and below the confluence (site 09313974) calcite was 39 percent. At successive sites downstream (09313975 and 09313976), the calcite dropped to 11 and 13 percent (pl. 6). The general trend of decreasing calcite content and increasing clay-mineral content reflects the geologic transition along the reach where the rock types change from predominantly limestone and dolomite to shale and sandstone.

A similar change in the mineralogic character of the bed material occurred on Grassy Trail Creek and a tributary, Dugout Creek. The clay minerals increased from 17 percent at the upper site on Grassy Trail Creek (09314320), to 25 percent near the canyon mouth (site 09314340), to 46 percent about 15 miles from the canyon mouth in the lowlands (site 09314362). Dugout Creek was sampled at the canyon mouth in the Book Cliffs (site 09314367) and just above its confluence with Grassy Trail Creek (site 09314368). The clay-mineral content increased from 17 percent at the upper site to 67 percent at the lower site. The calcite content showed an overall decrease downstream at Grassy Trail and Dugout Creeks, but the trend was not as pronounced as at Soldier Creek. The latter drains a larger area underlain by limestone and dolomite above the upper sampling site than Grassy Trail and Dugout Creeks do above their upper sampling sites. Changes along stream reaches affected by future mining activities could be monitored relatively inexpensively by means of particle-size analyses and determinations of bed-material mineralogy.

MINE EFFLUENT

Effluents from several mines in the study area directly or indirectly affect the quality of water in the streams. Listed below are selected mines and a comparison of the dissolved-solids concentrations of the mine effluent and of the stream water into which the mines discharge. The average discharges of the mines is not known, but all have been observed discharging more than 100 gal/min. Some discharge continuously and others intermittently.

Analyses were made on several of the mine effluents for selected dissolved metals (table 8). The concentrations of arsenic, chromium, lead, mercury, and selenium did not exceed the recommended maximum contaminant levels set by the U.S. Environmental Protection Agency (1976, p. 5). Analyses also made for total metals (dissolved plus undissolved) in the outflow from the Utah No. 2 Mine indicated that the concentrations of some of the undissolved (suspended) metals were several times greater than those of the dissolved metals. Dissolved arsenic was 0 μg/L as compared to 11 μg/L total; dissolved iron, 20 μg/L as compared to 2,600 μg/L total; and dissolved lead, 0 μg/L as compared to 100 μg/L total. The dissolved and undissolved concentrations of lithium, zinc, and selenium were about the same. The undissolved metals are relatively harmless as long as physical parameters such as pH and redox potential of the water do not allow the toxic metals, such as arsenic and lead, to dissolve. If the undissolved material eventually

Location	Mine	Dissolved-solids concentration in mine effluent (mg/L)	Stream and sampling site	Dissolved-solids concentration in stream above mine[1] (mg/L)
(D-13-7)8dac	Utah No. 2	482	Pleasant Valley Creek (Price River tributary), site 09310691.	230
(D-14-14)20dcc	Sunnyside	1,600	Grassy Trail Creek (Price River tributary), site 09314320.	255-820
(D-16-8)8dda	King No. 2	671	Cedar Creek (Huntington Creek tributary).	671[2]
(D-17-7)27abb	Wilberg	551	Grimes Wash (Cottonwood Creek tributary), site 09324500.	141-666
(D-22-4)12bda	Convulsion Canyon	276	Quitchupah Creek (Muddy Creek tributary); site 09331805.	421
(D-22-6)29ddd	Emery (Browning)	5,100	Christiansen Wash (Muddy Creek tributary).	(3)

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[1] Ranges are for samples collected during 1975-77; single entries are for samples collected concurrently with samples of mine effluent.

[2] All flow from mine.

[3] No sample collected.

migrates into an anaerobic zone, as may exist in the bottom of reservoirs or lakes, the metals may dissolve. The undissolved material, although relatively harmless in that state, may pose a future threat if the proper solubility criteria are induced into the water.

GROUND WATER

Ground-water data in the Wasatch Plateau and Book Cliffs consists largely of discharge measurements and water-quality analyses for spring flow and mine effluents. In the lowland areas, however, water wells were the source of most subsurface information, including well yields, well logs, water-level measurements, and chemical analyses. In addition, well logs and water-quality information from petroleum tests were used to construct stratigraphic sections of the lowland areas.

Mining and resulting subsidence may cause changes in the flow of springs. In extreme cases, springs may disappear or new ones may appear. Discharge and water-quality measurements were made at 65 selected springs in order to initiate a monitoring record that could be used to determine seasonal and long-term variability of flows and quality. The variability of these factors that are due to climatic changes must be established in order to distinguish changes that might occur because of mining. A summary of the discharge measurements and dissolved-solids concentrations as related to a geologic source is included in table 7, and selected water-quality parameters, including trace metals, are included in table 8. Tables 7 and 8 also include data for selected wells and mines in the study area.

NUMBERING SYSTEM USED FOR WELLS, SPRINGS, AND MINES

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres;[2] the letters a, b, c, and d indicate, respectively, the northeast, northwest,

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[2] Although the basic land unit, the section, is theoretically 1 mi^2, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

TABLE 7.—*Summary of ground-water discharge, dissolved-solids concentrations, and related geologic sources*

Range of discharge: Springs only.
Predominant in organic chemical constituents: Ca, calcium; Cl, chloride; HCO_3, bicarbonate; Mg, magnesium; Na, sodium; SO_4, sulfate.
Range of discharge: Measurements made in 1975–76.

	Number of wells and mines sampled	Number of springs sampled	Range of discharge (gal/min)	Range of dissolved-solids concentration (mg/L)	Predominant inorganic chemical constituents
Quaternary alluvium	2	2	168–206	778–1,790	$MgCaSO_4HCO_3$
Green River Formation					
Flagstaff Limestone Member	—	20	.19–30	142–662	$CaMgHCO_3$
Wasatch Formation	—	2	.66–2.7	325–745	$CaNaHCO_3$
Colton Formation	—	1	11	—	$MgCaHCO_3$
North Horn Formation	—	18	.20–121	148–469	$CaMgHCO_3$
Price River Formation	—	11	.22–120	122–792	$CaMgNaHCO_3$
Castlegate Sandstone	2	1	.25	315–806	$CaHCO_3$
Blackhawk Formation	9	6	.30–18	63–796 [1]	$CaMgHCO_3SO_4$
Star Point Sandstone	—	2	1.3–50	335–391	$CaMgHCO_3SO_4$
Mancos Shale					
Masuk Member	—	1	28	304	$CaMgHCO_3$
Blue Gate Member	1	—	—	4,040	$CaMgHCO_3SO_4$
Ferron Sandstone Member	3	—	—	652–1,230 [2]	$NaSO_4HCO_3$
Summerville Formation	—	1	.5	3,280	$MgCaSO_4$
Entrada Sandstone	1	—	—	6,810	$CaNaSO_4Cl$
Carmel Formation	1	—	—	3,550	$CaMgSO_4$

[1] One other sample from the Blackhawk Formation contained 1,600 mg/L, but some of the water may be derived from the Mancos Shale.

[2] Two other samples from the Ferron Sandstone Member contained 5,100 and 3,450 mg/L respectively, but the samples are probably a mixture of water from the Blue Gate and Ferron Sandstone Members.

southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tracts; the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus (D-12-7)3bcc-1 designates the first well constructed or visited in the SW1/4SW1/4NW1/4 sec. 3, T. 12 S., R. 7 E. Mine sites where hydrologic data were collected are numbered in the same manner, but three letters are used after the section number and no serial number is used. The numbering system is illustrated in figure 10.

WASATCH PLATEAU AND BOOK CLIFFS

Most springs in the Wasatch Plateau and Book Cliffs issue from the Star Point Sandstone or younger formations. The yields of the springs measured during 1975-76 ranged from about 0.2 to 200 gal/min. The dissolved-solids concentration of the spring water was generally less than 1,000 mg/L; thus, the water is suitable for most uses. Plate 7 shows the approximate ranges of dissolved-solids concentration for ground water in the Wasatch Plateau and Book Cliffs. The figure is based primarily upon water-quality data collected from springs during 1975-76 and may not be representative of water in aquifers at various depths within a designated area.

TABLE 8.—*Selected water-quality data for wells, springs, and mines*

Location: See explanation of numbering system in text.
Water type: Ca, calcium; HCO_3, bicarbonate; Mg, magnesium; Na, sodium; SO_4, sulfate.

Location	Date	Discharge (gal/min)	Temperature (°C)	Dissolved solids (sum of determined constituents) (mg/L)	pH	Micrograms per liter										Water type	
						Dissolved arsenic (As)	Dissolved boron (B)	Dissolved chromium (Cr)	Dissolved iron (Fe)	Dissolved lead (Pb)	Dissolved lithium (Li)	Dissolved mercury (Hg)	Dissolved selenium (Se)	Dissolved strontium (Sr)	Dissolved zinc (Zn)	Cations	Anions
Wells and mines																	
(D-12-7)8bcc-1	9-19-75	--	--	--	--	0	20	--	320	6	--	--	0	--	210	Ca	HCO_3
10bcd-1	9-19-75	--	9.5	362	--	0	30	--	20	2	10	--	2	--	110	Ca	HCO_3
10dcb-1	9-19-75	--	--	246	--	0	80	--	1,300	4	20	--	0	--	30	Mg Ca	HCO_3
(D-13-7)5cab-1	9-19-75	--	8.0	280	7.1	0	30	--	620	7	10	--	0	--	40	Ca Mg	HCO_3
8dac [1]	9-19-75	--	--	482	7.5	1	70	--	20	4	10	--	0	--	40	Ca Mg	HCO_3
(D-13-8)4bbb-1	9-17-76	50	6.0	315	7.1	0	30	0	10	0	20	0.0	0	340	0	Ca	HCO_3
12aba	10-19-76	5	6.0	796	7.5	0	120	0	30	0	30	.0	0	680	10	Ca Mg	HCO_3 SO_4
(D-13-9)25add-1	9-24-75	--	12.5	4,040	7.6	0	610	--	9,000	2	350	--	0	--	40	Mg Ca	SO_4
25dcc-1	9-18-75	--	17.5	778	--	0	210	--	80	2	30	--	5	--	30	Mg Ca	SO_4 HCO_3
(D-13-14)24dba-1	7-15-66	--	--	327	8.2	--	--	--	--	--	--	--	--	--	--	Ca Mg	HCO_3
(D-15-13)2dad-1	9-17-75	--	14.0	1,790	7.4	0	210	--	100	7	10	--	9	--	590	Mg Ca	SO_4
(D-16-8)8dda	9-18-75	300	12.5	671	7.3	0	100	--	20	5	20	--	0	--	40	Ca Mg	HCO_3 SO_4
(D-17-7)11bcd	4-20-76	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Ca Mg	HCO_3
27abb	9-29-76	--	29.0	551	7.8	0	70	0	10	20	20	.0	1	450	--	Mg Ca	HCO_3 SO_4
(D-19-10)15bac-1	10-21-76	20	14.0	3,550	7.1	0	1,000	0	60	2	70	.0	0	1,000	240	Ca Mg	SO_4
(D-19-21)29dbc-1	8-14-72	--	--	6,810	7.1	--	4,100	--	1,600	--	--	--	--	--	--	Ca Na	SO_4 Cl
(D-22-4)12bda	9-27-76	224	10.0	276	8.3	1	130	0	10	0	0	.0	1	430	10	Mg Ca	HCO_3
(D-22-6)4cab-1	3-18-66	--	--	756	7.8	--	80	--	--	--	--	--	--	--	--	Ca	SO_4 HCO_3
	4-12-66	--	--	--	7.8	--	330	--	--	--	--	--	--	--	--	Mg Ca	SO_4 HCO_3
	4- 4-67	--	--	798	7.8	--	220	--	--	--	--	--	--	--	--	Mg Ca	SO_4 HCO_3
	6- 1-67	--	--	808	7.8	--	--	--	--	--	--	--	--	--	--	--	SO_4
	3-24-71	--	--	800	7.7	--	290	--	--	--	--	--	--	--	--	Mg Ca	SO_4 HCO_3

	9-10-75	75	26.5	759	7.6	0	200	--	--	6	80	--	0	--	80	Ca Mg	HCO_3 SO_4
17abc-1	9-10-75	--	--	652	8.7	1	190	--	--	4	40	--	0	--	20	Mg	HCO_3 SO_4
29ddd	9-16-76	200	12.0	5,100	--	1	770	0	10	0	250	.6	0	9,300	20	Mg	SO_4
31dab-1	10- 7-76	12	13.0	1,280	7.9	0	280	10	120	0	50	.0	0	2,300	10	Ca Na	SO_4
33bdc	1-23-53	--	--	3,454	--	--	--	--	--	--	--	--	--	--	--	Mg Ca	SO_4
Springs																	
(D-11-7)29aaa-S1	10-21-76	0.82	8.0	--	7.2	--	--	--	--	--	--	--	--	--	--	--	--
36bdb-S1	10-21-76	121.00	6.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(D-12-7)1bcb-S1	10-21-76	5.00	5.0	--	8.1	--	--	--	--	--	--	--	--	--	--	--	--
(D-12-9)1ccc-S1	8- 6-76	2.80	12.0	338	7.7	0	40	10	10	4	10	7.2	2	770	0	Ca Mg	HCO_3
(D-12-10)34aad-S1	8- 4-76	4.50	13.5	311	8.3	0	40	10	20	9	10	.0	8	360	0	Ca Mg	HCO_3
35dbc-S1	8- 4-76	4.50	12.0	326	7.9	0	30	10	10	4	10	.1	1	280	0	Ca Mg	HCO_3
(D-12-11)20aaa-S1	8- 4-76	2.30	10.5	420	7.2	1	60	10	10	4	10	.1	1	340	0	Ca	HCO_3
20aaa-S2	8- 4-76	3.00	20.0	--	7.6	--	--	--	--	--	--	--	--	--	--	--	--
21aca-S1	8- 5-76	3.00	10.0	336	7.1	0	40	0	0	12	10	.1	1	310	0	Ca Mg	HCO_3
21bab-S1	8- 5-76	.79	22.0	374	8.2	1	70	10	20	2	10	.1	0	320	0	Ca Mg	HCO_3
36aad-S1	7-28-76	.33	17.0	325	7.9	1	40	0	40	1	20	.0	1	360	0	Ca Mg	HCO_3
(D-12-12)30dcc-S1	7-28-76	5.40	12.0	323	7.5	1	40	10	0	1	20	.0	0	390	0	Ca Mg	HCO_3
(D-13-7)17cdd-S1	10- 1-76	50.00	9.0	335	7.4	0	80	0	780	0	10	.0	0	170	0	Ca Mg	HCO_3
(D-13-12)9ddc-S1	7-15-76	4.30	7.5	--	7.4	1	--	0	30	2	10	.0	1	280	10	Ca Mg	HCO_3
10abb-S1	7-14-76	11.00	16.5	--	8.4	1	--	0	20	6	10	.0	1	310	0	Ca Mg	HCO_3
10adb-S1	7-14-76	3.00	6.5	271	7.1	0	--	0	30	4	0	.0	1	330	0	Ca	HCO_3
11acd-S1	7-15-76	12.00	7.5	--	7.8	0	--	0	30	4	10	.0	1	370	10	Ca Mg	HCO_3
12adb-S1	7-14-76	11.00	9.0	--	7.8	1	--	0	30	5	0	.0	3	220	10	Mg Ca	HCO_3
12cbb-S1	7-14-76	2.00	9.0	--	7.8	1	--	0	30	9	10	.0	1	340	20	Ca Mg	HCO_3
13aaa-S1	7-20-76	3.50	10.0	282	7.4	0	--	10	20	4	0	.0	1	260	0	Ca Mg	HCO_3
(D-13½-12)4bdc-S1	7-14-76	2.40	14.0	--	8.6	1	--	0	0	5	10	.0	3	380	10	Mg Ca	HCO_3
5cbc-S1	7-14-76	2.10	11.5	--	7.8	1	--	0	40	2	20	.0	0	540	0	Mg Ca	HCO_3
(D-13-13)18bac-S1	7-20-76	38.00	16.0	350	8.3	0	--	10	10	2	10	.0	1	410	0	Ca Mg	HCO_3
(D-14-6)26caa-S1	8-20-76	2.50	4.0	230	8.2	0	20	10	20	10	0	.0	0	110	0	Ca	HCO_3
(D-14-7)7dbc-S1	8-27-76	5.00	5.5	206	7.0	0	10	10	10	6	0	.0	1	120	0	Ca	HCO_3
15bca-S1	8-25-76	1.00	4.5	63	7.1	0	40	0	20	4	0	.0	0	60	0	Ca Mg	HCO_3
30bac-S1	8-20-76	28.00	12.0	304	7.4	0	40	10	40	9	10	.0	0	270	0	Ca Mg	HCO_3
(D-15-7)12dba-S1	8-26-76	.38	10.5	148	7.9	0	10	10	40	7	0	.0	0	110	0	Ca	HCO_3
15abd-S1	8-26-76	5.00	13.0	210	7.4	0	10	10	0	6	0	.0	0	180	20	Ca Mg	HCO_3
34bab-S1	8-19-76	.66	8.0	325	7.7	0	80	0	30	6	10	.0	1	250	0	Ca	HCO_3
(D-15-13)1ddc-S1	9-12-75	206.00	16.0	1,380	8.3	2	190	--	--	3	10	--	2	--	10	Mg Ca	SO_4 HCO_3
18caa-S1	9-17-75	168.00	13.0	1,080	7.6	0	120	--	30	3	10	--	13	--	30	Mg	SO_4 HCO_3
(D-16-6)13aab-S1	8-18-76	15.00	4.0	323	7.6	0	30	0	20	8	10	.0	0	260	10	Ca Mg	HCO_3
(D-16-7)1acb-S1	8-26-76	11.00	5.5	248	7.5	0	10	10	10	3	10	.0	0	200	0	Ca Mg	HCO_3
9cbd-S1	8-18-76	120.00	8.5	332	7.6	0	80	0	40	12	10	.0	0	260	0	Ca Mg	HCO_3

TABLE 8.—*Selected water-quality data for wells, springs, and mines*—Continued

						Micrograms per liter										Water type	
Location	Date	Discharge (gal/min)	Temperature (°C)	Dissolved solids (sum of determined constituents) (mg/L)	pH	Dissolved arsenic (As)	Dissolved boron (B)	Dissolved chromium (Cr)	Dissolved iron (Fe)	Dissolved lead (Pb)	Dissolved lithium (Li)	Dissolved mercury (Hg)	Dissolved selenium (Se)	Dissolved strontium (Sr)	Dissolved zinc (Zn)	Cations	Anions
Springs—Continued																	
(D-16-7)17ccb-S1	8-18-76	1.50	8.0	--	7.5	--	--	--	--	--	--	--	--	--	--	--	--
(D-17-7)7aca-S1	7-13-76	7.50	5.0	271	--	--	0	--	10	--	--	--	--	--	--	Ca Mg	HCO_3
21dcd-S1	10-22-76	.62	5.6	469	7.4	0	50	0	30	3	20	.5	2	490	10	Ca Mg	HCO_3
27aca-S1	9-29-76	1.20	10.0	750	7.3	0	100	0	20	1	30	.1	1	780	10	Mg Ca	SO_4 HCO_3
28bad-S1	10-22-76	2.70	3.5	332	8.5	1	20	10	30	8	10	.3	1	320	10	Ca Mg	HCO_3
(D-18-4)22aac-S1	9-30-76	.44	9.0	142	8.3	1	10	0	20	0	10	.0	1	460	0	Ca Mg	HCO_3
22bdb-S1	9-30-76	15.00	5.5	185	8.5	2	20	0	10	0	20	.3	1	1,800	0	Mg Ca	HCO_3
(D-18-5)35dda-S1	9-28-76	1.00	14.0	294	8.0	0	60	0	20	0	30	.3	2	560	0	Mg Ca	HCO_3
(D-18-6)31dca-S1	9-28-76	1.20	9.0	662	7.5	1	90	0	10	0	40	.0	5	470	10	Mg Ca	HCO_3
(D-19-4)9cdb-S1	9-27-76	.66	5.5	200	7.8	1	10	0	20	5	30	.0	1	330	10	Mg Ca	HCO_3
21dba-S1	9-27-76	30.00	8.5	231	7.5	0	10	0	30	0	10	.0	1	380	0	Ca Mg	HCO_3
26aaa-S1	9-28-76	4.60	3.0	314	7.7	0	30	0	10	0	20	.0	0	610	0	Mg Ca	HCO_3
33bbd-S1	9-25-76	8.10	3.0	195	7.9	1	20	0	10	12	10	.0	1	300	0	Ca Mg	HCO_3
(D-19-6)6aad-S1	9-28-76	.19	14.0	560	8.4	3	100	0	30	0	40	.1	1	460	0	Mg Ca	HCO_3
20dba-S1	9-28-76	2.70	8.5	745	8.8	1	200	0	140	0	20	.0	1	100	10	Na Ca	HCO_3
(D-19-9)26cab-S1	9-11-75	0.5	15.5	3,280	8.1	2	600	--	--	11	240	--	10	--	20	Mg Ca	SO_4
(D-19½-5)34bac-S1	9-26-76	.20	9.5	269	8.3	1	30	0	60	12	20	.0	1	730	10	Ca Mg	HCO_3
(D-20-5)4dac-S1	9-26-76	26.00	4.5	249	7.6	1	30	0	20	5	10	.0	1	300	10	Mg Ca	HCO_3
11add-S1	9-26-76	36.00	5.0	250	7.8	1	30	0	10	0	20	.0	2	400	10	Mg Ca	HCO_3
31abd-S1	9-25-76	.99	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
32bbc-S1	9-25-76	.24	13.0	450	7.3	0	60	0	20	6	30	.0	1	450	30	Ca Mg	HCO_3
(D-20-20)28bbb-S1	10-10-76	18.00	8.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
(D-21-4)22bdb-S1	9-17-76	1.60	8.0	792	8.6	6	140	0	120	6	70	3.2	0	710	0	Mg Ca	HCO_3
34bcd-S1	9-16-76	2.80	10.0	786	7.7	1	80	0	10	0	20	.3	0	770	0	Ca Mg	HCO_3
(D-22-4)16dcd-S1	9-17-76	.25	12.5	806	7.3	1	110	0	20	5	10	1.0	0	960	0	Ca Mg	HCO_3

24bac–S1	9–17–76	.22	13.5	122	6.8	1	40	0	80	9	0	1.1	0	130	0	Ca Mg	HCO_3
32dbb–S1	9–16–76	.23	20.0	489	7.5	1	70	0	10	7	30	1.8	2	870	30	Ca Mg	HCO_3
(D–23–4)16bab–S1	9–16–76	.30	15.5	230	6.8	0	40	0	10	10	10	1.2	0	290	10	Ca Mg	HCO_3 SO_4
21add–S1	9–16–76	.32	12.5	192	6.7	1	40	0	10	11	0	1.2	2	220	0	Ca	HCO_3
36bad–S1	9–16–76	1.30	8.0	391	7.4	1	70	0	80	7	30	1.4	0	540	0	Ca Mg	HCO_3 SO_4

---

[1] Total dissolved plus suspended constituents, in micrograms per liter, arsenic, 12; iron, 2,600; lead, <100; lithium, 10; selenium, 0; zinc, 40.

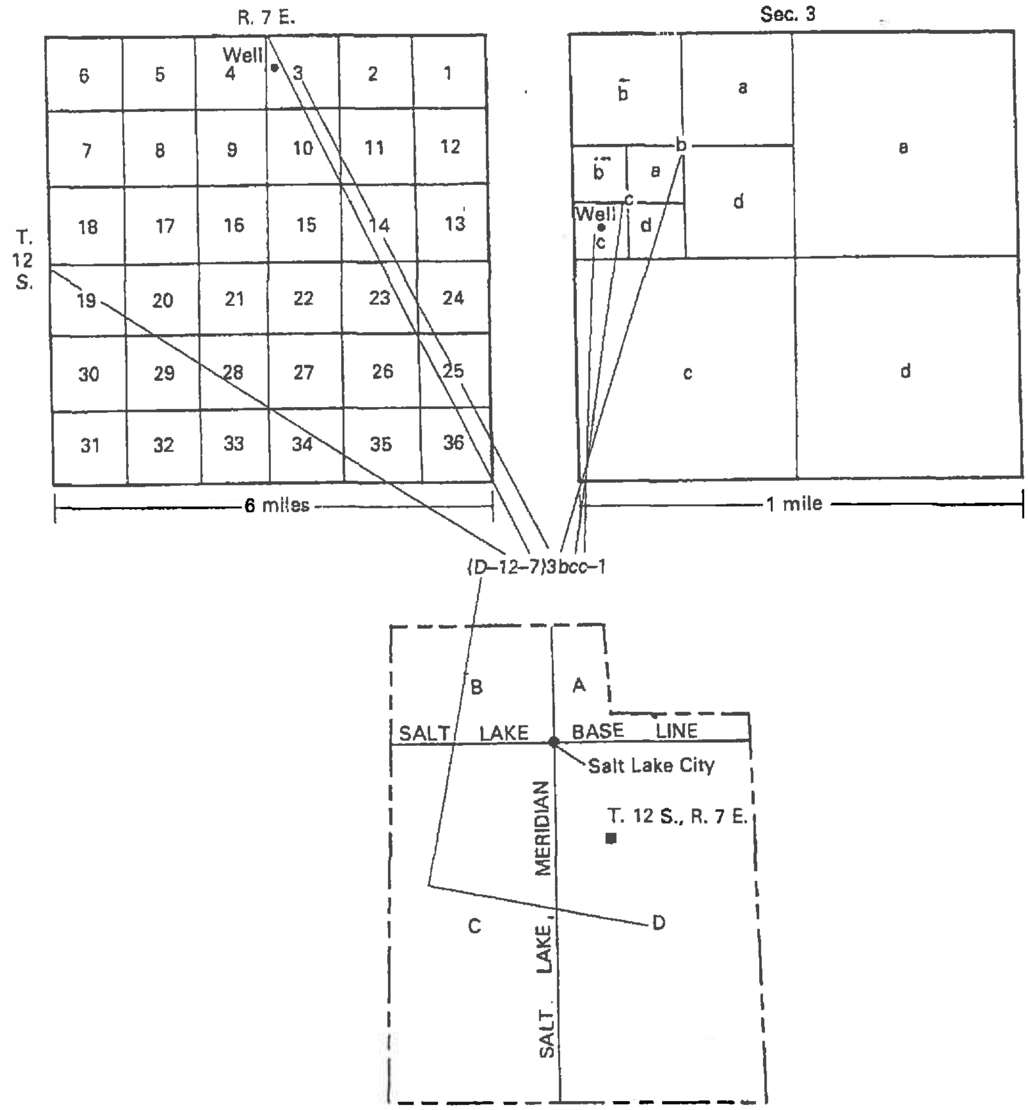

FIGURE 10.—Well- and spring-numbering system used in Utah.

Samples of water were obtained from two springs discharging from the Star Point Sandstone. The dissolved-solids concentrations were 335 and 391 mg/L, and the principal chemical constituents in both samples were calcium, magnesium, bicarbonate, and sulfate.

The floor of the Wilberg Mine, which is at the base of the Blackhawk Formation, rests on the Star Point Sandstone. Seeps from the floor and the roof of the mine were sampled, and the chemical composition of water from both sources was similar. The concentration of dissolved solids from the floor seepage was 572 mg/L as compared to 551 mg/L from the ceiling seepage, and the principal dissolved-chemical constituents were calcium, magnesium, bicarbonate, and sulfate in both samples.

The Blackhawk Formation produces water in many of the mines, including the Convulsion Canyon, King No. 2, Utah No. 2, and Sunnyside Mines. The mining companies have not kept records of total annual discharge. Discharges of several of the mines were measured during 1975–77; but most of the mines are pumped intermittently, and the measurements are not representative of average annual discharge.

With the exception of the Sunnyside Mine, the water from 12 mines and springs discharging from the Blackhawk Formation had dissolved-solids concentrations ranging from about 60 to 800 mg/L; the principal dissolved constituents were calcium, magnesium, bicarbonate, and sulfate. The water from the Sunnyside Mine had a dissolved-solids concentration of about 1,600 mg/L. It is not known why water from the Sunnyside Mine is so highly mineralized, but some of the mine water may be derived from Mancos Shale. In this area of the Book Cliffs, the Mancos commonly intertongues with the Blackhawk, and water in the Mancos is usually highly mineralized.

Samples of water were obtained from three points of discharge from the Castlegate Sandstone. The dissolved-solids concentration ranged from 313 to 806 mg/L, and the principal constituents were calcium and bicarbonate.

In 11 samples of spring water obtained from the Price River Formation, the dissolved-solids concentration ranged from 122 to 792 mg/L. Samples with the lower dissolved-solids concentrations contained predominantly calcium, magnesium, and bicarbonate, but the waters containing the higher dissolved-solids concentrations were predominantly sodium and bicarbonate types.

Thirty-eight samples were obtained from springs issuing from the Flagstaff Limestone Member of the Green River Formation of Tertiary age and the underlying North Horn Formation. The dissolved-solids concentrations ranged from 142 to 662 mg/L. The springs issue mainly from limestone, and thus the principal dissolved constituents were calcium, magnesium, and bicarbonate.

LOWLAND AREA

Little is known about the amount of water that can be obtained from wells in most of the formations that underlie the lowland area. The approximate range of dissolved-solids concentrations in ground water in the lowlands, however, is indicated in the stratigraphic fence diagram (pl. 8).

The ranges of dissolved-solids concentrations are based largely on the dominant lithology of the various formations and, where available, on chemical analyses of water obtained from water wells and petroleum tests. All formations are not water bearing in all areas, and the actual quality of water in any given formation at any given location can be determined only by drilling.

Most of the subsurface water in the lowlands contains more than 2,000 mg/L of dissolved solids, and the water is not suitable for public use. Much of the water contains less than 35,000 mg/L of dissolved solids, however, and it could be used for selected industrial purposes.

The Ferron Sandstone Member of the Mancos Shale is the shallowest aquifier in the area with water of suitable chemical quality for human consumption and for future development for public use. The public supply for the city of Emery is obtained from well (D–22–6)4cab–1, developed in the lower part of the Ferron.This well is pumped at rates of 150 to 250 gal/min; the water contains about 790 mg/L of dissolved solids. The Kemmerer Coal Co. drilled well (D–22-6)17abc–1 to the lower part of the Ferron about 1.5 miles south of Emery. The water from this well is similar in chemical quality to the water from the Emery well.

Several test holes were drilled into the upper part of the Ferron Sandstone Member a few miles southeast of Emery by Consolidation Coal Co. These test holes were not constructed to hydraulically separate the upper part of the Ferron from other possible overlying water-bearing zones. Water levels in the test holes are typically above the top of the Ferron and within a few feet of the land surface. It is not known whether the water levels in these test holes are representative of the potentiometric surface in the upper part of the Ferron or the water table in the overlying Blue Gate Member of the Mancos Shale.

The Ferron Sandstone Member may lose water by seepage to streams and mines, but the quantities involved are unknown. Approximately 200 to 300 gal/min is discharged from the Emery (Browning) Mine, (D–22–6)29ddd, which is about 4 miles south of Emery. Coal is mined from the upper part of the Ferron, but some of the mine water is believed to be coming from the Blue Gate which overlies the Ferron. The concentration of dissolved solids in water from the Browning Mine was 5,100 mg/L on September 16, 1976.

Three samples from wells (D–22–6)cab–1, (D–22–6)17abc–1, and (D–22–6)31dab–1, believed to be representative of water in the Ferron Sandstone Member, had dissolved-solids concentrations ranging from 652 to 1,230 mg/L; the principal constituents were sodium, sulfate, and bicarbonate. The water in the Ferron, although of marginal chemical quality for public consumption, is probably the best obtainable from aquifers within depths of 2,000 feet along margins of the uplands.

Water levels were monitored in 19 wells in the study area during 1975–77. Hydrographs for six wells in the Ferron Sandstone Member near Emery are shown in plate 9. Water levels in most of these wells declined, probably reflecting below-normal precipitation during 1976–77. Although the length of record available is not adequate to attribute the declines solely to climatic variations, this is suggested by the general decline of water levels observed in many of the eight other observation wells that tap different aquifers in other parts of the study area (pl. 9).

Water levels are an aid in interpreting ground-water conditions in an area, in constructing potentiometric-surface maps, and in determining changes in aquifer storage in response to climatic variations and man-made withdrawals. Any stress imposed on a ground-water system usually is reflected in ground-water levels. Thus, through monitoring of water levels, one may detect future changes in either recharge or discharge to aquifers. Unfortunately, most of the wells available for monitoring in the study area are completed in only a few aquifers and are concentrated in small areas.

SUMMARY AND RECOMMENDATIONS

This study was designed to provide an assessment of the hydrology of the Wasatch Plateau-Book Cliffs coal-fields area in Utah. The objectives of the study were to establish data bases for hydrologic parameters, to describe the water resources based on available data, and to recommend monitoring programs and additional detailed studies that might be needed.

The principal coal-producing formations are of Cretaceous age. Coal production is from the Ferron Sandstone Member of the Mancos Shale and the Blackhawk Formation of the Mesaverde Group, which is the most important coal-producing formation in Utah.

Five major streams have headwaters that originate in the Wasatch Plateau. They are the Price River and Cottonwood, Ferron, Huntington, and Muddy Creeks. No major streams originate in the Book Cliffs. During the 1931–75 water years, the minimum discharge for the five major streams ranged from about 12,000 to 26,000 acre-feet per year, and the maximum discharge ranged from 59,000 to 315,000 acre-feet per year. Approximately 50–70 percent of the streamflow occurs during May–July, resulting from melting of snow that fell during October–April. Most of the water from the major streams is diverted for irrigation.

Most water-quality degradation in streams occurred along the flanks of the Wasatch Plateau and Book Cliffs where water diversion, waste disposal, consumptive use, and geologic environment all had a pronounced effect. In most streams at higher altitudes in the Wasatch Plateau, the minimum concentration of dissolved solids is less than 100 mg/L, and the maximum concentration is less than 250 mg/L. At lower altitudes, below diversions, the concentration ranged from about 250 mg/L to more than 6,000 mg/L.

Mining may change the distribution of water along a stream. The flow of streams along a reach may change, depending upon the relationship of tunneling and the resulting subsidence to aquifers that are hydraulically connected to the stream. In order to determine whether mining is affecting streamflow, measurements are required to determine the seasonal and annual variability of the streamflow above and below mining areas. Correlations indicate that 3 years of low-flow records at stream sites in the Wasatch Plateau would allow the development of relationships with long-term sites that can be used to estimate future low-flow records within a standard error of about 20 percent.

1. The low flow of streams below areas that are being mined or are proposed for mining should be continuously monitored. The best period for monitoring low flows is during August–November.
2. Low-flow monitoring sites should be supplemented with seepage studies which extend from below to above the coal-development areas.
3. The flow of selected springs in areas with no mining activity should be monitored in order to determine seasonal and long-term natural variability of flow.
4. Water quality at stream sites below coal-development areas should be monitored for inorganic, organic, and biologic parameters which will aid in the detection of possible water-quality degradation.
5. Bed-material characteristics of stream channels should be monitored above, through, and below potential mining areas. Sampling should extend from the Castlegate Sandstone downstream through the Blackhawk Formation and into the upper members of the Mancos Shale. The frequency of sampling should be keyed to periods of significant runoff. Bed-material analyses should include mineralogic and size analyses.
6. Subsurface information that will aid the interpretation of groundwater hydrology should be collected from on-going drilling operations of private companies and other Federal agencies.
7. Comprehensive basin studies should be initiated to enable the construction of accurate water budgets and to develop the capability to accurately predict the effects of coal mining on the various components of the hydrologic system.
8. Initiate a study to determine the areal extent of the aquifer in the Ferron Sandstone Member of the Mancos Shale; the potential of the Ferron as a source of water supply; and the effect that proposed strip mining might have on flows of affected streams, the potentiometric surface of the aquifer, and the production of existing wells.
9. Monitoring of water levels in wells should be continued, and selected wells should be added to the network, as they become available, to improve the areal distribution of monitoring sites.
10. A subsidence-monitoring program should be initiated under the guidance of State and Federal agencies charged with this responsibility.

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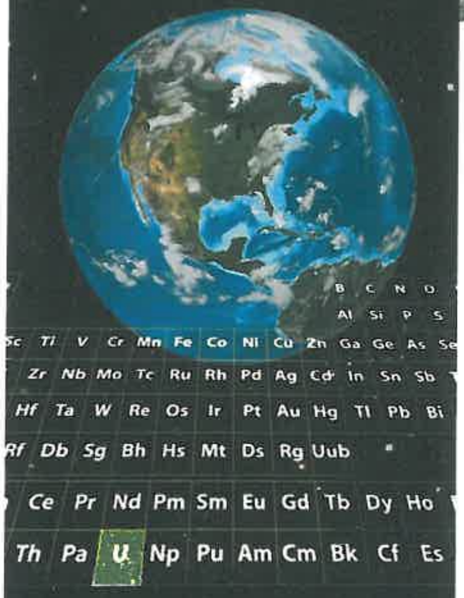

Natural Contamination from the Mancos Shale

April 2011

Prepared for

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Cover Photo: Mancos Shale Near Loutsenhizer Arroyo.

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Natural Contamination from the Mancos Shale

April 2011

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Appendixes

Appendix A Site Information
Appendix B Calculation of Water Density from Specific Conductivity
Appendix C Analytical Data

Abbreviations

General

AR	activity ratio (of U-234 to U-238)
DOC	dissolved organic carbon
DOE	U.S. Department of Energy
g/cm^3	grams per cubic centimeter
gpm	gallons per minute
ICP	inductively coupled plasma
kg	kilogram
KPA	kinetic phosphorescence analysis
m^2/g	square meters per gram
meq/100 g	milliequivalents per hundred grams
mg/L	milligrams per liter
mg/kg	milligrams per kilogram
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
NURE	National Uranium Resource Evaluation
NWIS	National Water Information Service
pCi/L	picocuries per liter
SC	specific conductivity
USGS	U.S. Geological Survey

Sampling Locations

BAS	Bert Avery Spring
BCWL	Bostwick Canal West Lateral
BGS	Blue Gate Spring
BPS	Buen Pastor Spring
BSCS	Bitter Spring Creek Seep
BSCUS	Bitter Spring Creek Upper Spring
BWS	Browns Wash Seep
CAS	Cato Springs
CCS	Cedar Creek Seep
CIS	Cisco Springs

CWCS	Cottonwood Creek Spring
D9S	Ditch 9 Spring
DAR	Daly Reservoir
DARS1	Daly Reservoir Spring 1
DARS2	Daly Reservoir Spring 2
DR	Delta Reservoir
DRDS	Delta Reservoir Dam Spring
DRS1	Delta Reservoir Seep 1
DRS3	Delta Reservoir Seep 3
DTS1	Devils Thumb Seep 1
DTS2	Devils Thumb Seep 2
DTS3	Devils Thumb Seep 3
DWS	Dutchmans Wash Seep
EF-22	Many Devils Wash EF-22
ETFW	East Tributary Floy Wash
ETFWD	East Tributary Floy Wash Downstream
GRCRS	Green River Canal Return Seep
HGRP	Houston Gulch Red Pool
HGS	Houston Gulch Seep
HGSE	Houston Gulch Seep East
KCFS	Kannah Creek Flowline Spring
LGW	Little Grand Wash
LGWS	Little Grand Wash Seep
LOUT3	Loutsenhizer 3
LOUT8	Loutsenhizer 8
LUOT9	Loutsenhizer 9
LOUT11	Loutsenhizer 11
LOUT11W	Loutsenhizer 11 in Wash
LOUT12L	Loutsenhizer 12 Lower
LOUT12U	Loutsenhizer 12 Upper
LOUT13	Loutsenhizer 13
LOUT14	Loutsenhizer 14
MS	Mud Spring
MWS	Mathis Wash Seep

PCS	Point Creek Seep
S36	Section 36 Spring
SCWS	Salt Creek Wash Seep
SL	Sweitzer Lake
SNGC	Sweitzer Lake NE Garnet Canal
SNS	Sweitzer NE Seep
SNS1	Sweitzer NE Seep 1
SNS2	Sweitzer NE Seep 2
SNS3	Sweitzer NE Seep 3
SRP	Sweitzer Red Pool
TWS	Town Wash Spring
TWSP	Town Wash Spring Pool
UENAS	Upper Eagle Nest Arroyo Spring
UFWS	Upper Floy Wash Spring
UFWS1	Upper Floy Wash 30 ft from Spring
UFWS2	Upper Floy Wash 50 ft from Spring
US1	USGS Seep 1
WCTS	Whitewater Creek Tributary Seep
WCTSP1	Whitewater Creek Tributary Seep Pool 1
WCTSP2	Whitewater Creek Tributary Seep Pool 2
WD2S	Whitewater Ditch No. 2 Seep
WD2	Whitewater Ditch No. 2
WFFW	West Fork Floy Wash
YHS	Yucca House Spring

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Executive Summary

Uranium mill tailings disposal cells in Colorado and New Mexico have been constructed on dark-gray shale bedrock of the Upper Cretaceous Mancos Shale, and a new disposal cell is being constructed on Mancos Shale in Utah. It has long been known and discussed by many researchers that the Mancos Shale is a source of salts, selenium, and trace metals. These constituents can in turn contribute to groundwater contamination. There is a need to consider the release of potential contaminants by natural processes when evaluating the progress of groundwater remediation efforts at disposal sites built on Mancos Shale.

We sampled Mancos Shale groundwater at 51 locations in Colorado, New Mexico, and Utah, mostly from shale beds but also from some sandstones and alluvial gravels. Because the Mancos Shale does not typically yield much groundwater, most samples were collected from seeps and springs. Many of the groundwater samples were highly saline, as indicated by specific conductivity values ranging from 418 to 70,002 microsiemens per centimeter (µS/cm) with a geometric mean of 9,226 µS/cm. Samples collected at nine locations had specific conductivity values of more than 30,000 µS/cm. Nitrate concentrations exceeded 250 milligrams per liter (mg/L) at 13 locations, and selenium concentrations exceeded 1,000 micrograms per liter (µg/L) in eight samples. Uranium concentrations were also high, having a range of 0.2 to 1,922 µg/L with a geometric mean of 48.8 µg/L, and samples from 18 locations had concentrations more than 100 µg/L. At several locations, seep water was colored yellow to red; the coloration was caused by dissolved organic carbon concentrations up to 280 mg/L. Boron concentrations exceeding 1,000 µg/L were common in groundwater from shale beds, but lower values were found in groundwater from sandstone.

All uranium-234 to uranium-238 activity ratios (ARs) were greater than the secular equilibrium value of 1.0. All but three of the AR values were more than 1.5, and about half of the values exceeded 2.0. Thus, high AR values may be a common characteristic of groundwater that has interacted with Mancos Shale.

The results indicate that high concentrations of boron, major ions, nitrate, selenium, and uranium are likely to occur as a natural process of interaction between groundwater and Mancos Shale. The high concentrations are apparently limited to groundwater associated with shale beds, and concentrations of these constituents in groundwater associated with sandstone were much lower. High contaminant concentrations occurred throughout the study areas and were not correlated with geographic area, stratigraphic position, or source of water. Some of the samples were influenced by irrigation, but others were collected from locations in remote areas with no significant anthropogenic input.

In a few well-characterized areas, it was possible to define the source of recharge water and the groundwater flow path to the seeps. Seeps in several areas were fed from man-made ponds or reservoirs, and had historical documentation that allowed accurate assessments of the timing of the formation of the seeps. At one area, historical data were sufficient to determine that the groundwater flow rate through the shale beds of Mancos exceeded 8 feet per day.

A literature review of the solid-phase composition of Mancos Shale indicated that the shale is composed of quartz, feldspar, illite, smectite, interlayered clays, carbonates, sulfates, organic matter, and pyrite. Uranium and nitrate likely reside in or are closely associated with organic

matter, and selenium substitutes for sulfur in pyrite. Conceptually, major ion chemical reactions are dominated by calcite dissolution following proton release from pyrite oxidation and subsequent exchange by calcium for the sodium residing on clay mineral exchange sites. This conceptual model was tested numerically using a reaction progress approach. The modeling indicated that these reactions were able to explain the general features of groundwater chemical evolution.

1.0 Introduction

We define natural contamination as a process by which constituents are transferred from geologic materials (in this case, rock of the Mancos Shale) to groundwater in concentrations that could be harmful to human health or the environment. For this definition, the source of the groundwater may be anthropogenic but the water must be of a reasonably high quality prior to contacting the geologic source of the natural contamination. Although there are many factors that should be considered when relating concentrations of a dissolved constituent to the risks to human health or the environment, in this study we consider contaminants as concentrations that exceed regulated standards. Contaminants with concentrations that exceed standards by an order of magnitude or more, which for this study included uranium, selenium, and nitrate, are of special interest (Table 1). Although Table 1 presents national drinking water standards, other standards exist. For example, an aquatic life standard of 4.6 micrograms per liter (µg/L) has been established for selenium (Thomas 2009) and the State of New Mexico has a livestock drinking water standard of 100 µg/L for vanadium (Thomas et al. 1998).

Table 1. Contaminants Exceeding 10 Times the Maximum Contaminant Levels for Drinking Water in Seep and Spring Samples Analyzed for This Study(40 E-CFR 141)

	Drinking Water Standard	Range Measured In This Study	Geometric Mean
Uranium (µg/L)	30	0.2–1,922	49.7
Selenium (µg/L)	50	0.14–4,700	51.5
Nitrate (mg/L)	44	0.5–3,614	33.7

mg/L = milligrams per liter

Natural contamination of surface drainages, including the Colorado River, by salts and selenium from irrigation on marine shale formations in semiarid lands is well known (Laronne 1977; Wagenet and Jurinak 1978; Whittig et al. 1982, 1983, 1986; Laronne and Schumm 1982; Jackson and Julander 1982; Deyo 1984; Rao et al. 1984; Evangelou 1981; Evangelou et al. 1984; Wright and Butler 1993; Butler et al. 1991, 1994, 1996; Zielinski et al. 1995; Butler and Leib 2002; Kakouros et al. 2006; Thomas et al. 2008; Tuttle and Grauch 2009). A study of natural contamination was conducted by Littke et al. (1991) on black shale of the Jurassic Posidonia Shale in Germany. They developed a mass and volume balance that estimated constituent loss (potentially transferred to groundwater) during the weathering process and concluded that shale may significantly increase sulfur and organic carbon concentrations in the groundwater over those levels derived from local anthropogenic sources.

A goal of this project was to determine the distribution of natural contamination in Mancos Shale groundwater by measuring chemical concentrations in Mancos Shale seeps and springs from samples collected throughout much of its depositional basin. This information is directly relevant to evaluation of groundwater contamination at uranium mill tailings disposal sites that were constructed on the Mancos Shale. Because uranium is an important contaminant at U.S. Department of Energy (DOE) former uranium milling sites and tailings disposal sites, it is a contaminant of principal interest to this study. It is important to understand the possible contribution of natural uranium to background concentrations at these cleanup sites to ensure realistic cleanup standards and to evaluate the progress of site cleanup. Relatively few data exist on uranium concentrations in surface water or groundwater influenced by Mancos Shale.

Uranium mill tailings disposal cells were built on Mancos Shale near Grand Junction, Colorado, and Shiprock, New Mexico. These sites are administered by DOE's Office of Legacy Management. Under another program, DOE is currently (2011) relocating uranium tailings from a former milling site near Moab, Utah, to a disposal cell built on Mancos Shale at Crescent Junction, Utah (Figure 1).

Less-direct reasons for studying Mancos Shale groundwater chemistry include its role in the understanding of (1) contaminant loading to surface water, particularly the Colorado River, (2) uranium ore genesis, and (3) influence of natural carbon releases on the global carbon budget. These three secondary objectives are discussed briefly as follows:

(1) Many studies have focused on the release of salt and selenium from the Mancos Shale and its effects on salt loading to the Colorado River. Notable research has been conducted by personnel at the U.S. Geological Survey (USGS) (Butler et al. 1991, 1994, 1996; Wright 1995, 1999; Butler and Leib 2002; Grauch et al. 2005; Tuttle et al. 2005, 2007; Thomas et al. 2008; Tuttle and Grauch 2009; Stillings et al. 2005), University of California, Davis, (Whittig et al. 1982, 1983, 1986; Deyo 1984; Evangelou et al. 1984, 1985), Utah State University (Jurinak et al. 1977; Wagenet and Jurinak 1978; Rao et al. 1984), Colorado State University (Laronne 1977; Ponce and Hawkins 1978; Sunday 1979; Laronne and Shen 1982; Laronne and Schumm 1982), and others (Jackson and Julander 1982). These studies are important because of issues with deteriorating water quality for downstream users, particularly in California and Mexico. Data collected for most of these studies are predominantly from samples of surface waters (streams, lakes, and canals) that flow to the Colorado River. Groundwater contribution of salt and selenium have also been investigated (e.g. Butler et al. 1994), but to a far lesser extent.

(2) Although most theories of the origin of sandstone-type uranium ore deposits in the Colorado Plateau Province do not invoke a contribution from the Mancos Shale, Shawe (1976) proposed that uranium ore deposits in the Slick Rock District in southwest Colorado were formed by uranium-bearing groundwater that flowed downward from the Mancos Shale during burial compaction, depositing uranium in the organic-carbon-rich Morrison Formation. Shawe (1976) suggested that the fluids migrating from the Mancos were reducing, with uranium kept in solution by dissolved carbonate.

(3) Petsch et al. (2000) determined that between 60 and 100 percent of the total organic carbon present in black shale can be released during weathering. Oxidation during weathering depletes oxygen from and adds carbon dioxide to the atmosphere. As shown in Figure 1, the Mancos Shale crops out over approximately 1,250 square miles in the Four Corners states. The vast area of Mancos and equivalent gray marine shale outcrops that are in Arizona, Colorado, Kansas, Montana, Nebraska, New Mexico, North Dakota, South Dakota, Utah, and Wyoming may provide sufficient carbon dioxide release to have an impact on the global carbon budget.

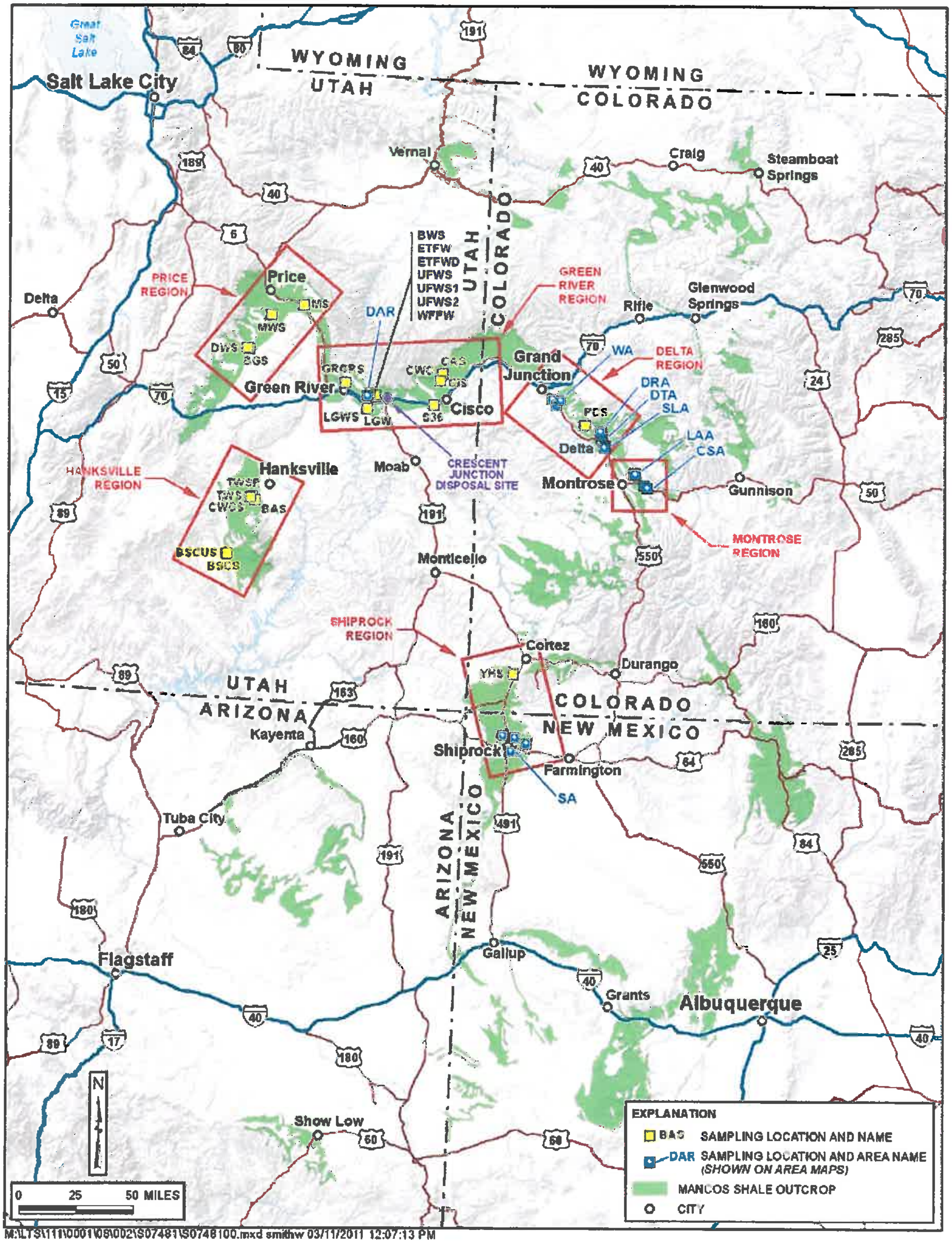

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Figure 1. Locations of Sampling Regions and Mancos Shale Outcrops

CSA = Cerro Summit Area (Figure 10), DAR = Daly Reservoir Area (Figure 9), DRA = Delta Reservoir Area (Figure 2), DTA = Devil's Thumb Golf Course Area (Figure 4), LAA = Loutsenhizer Arroyo Area (Figure 11), SA = Shiprock Area (Figure 12), SLA = Sweitzer Lake Area (Figure 5), WA = Whitewater Area (Figure 6)

2.0 Geology of the Study Area

The Mancos Shale was deposited during the Late Cretaceous Epoch in the offshore and open-marine environment of the epicontinental Western Interior Seaway. The seaway corresponded to the Rocky Mountain foreland basin, an area of downwarping that developed as a result of active thrusting along the Sevier orogenic belt to the west (Johnson 2003). For about 13 to 15 million years, the slowly subsiding foreland basin accumulated sediment and ash-fall deposits from periodic uplift and volcanic activity in the Sevier highland to the west (Matthews et al. 2003).

The exposed formation reaches as much as 4,150 ft thick in west-central Colorado and east-central Utah (Fisher et al. 1960). Named by Cross and Purington (1899) for exposures in the valley around Mancos, Colorado, the Mancos Shale in that area is considerably thinner—only 2,238 ft, as measured in a section by Leckie et al. (1997).

The Mancos Shale represents the interplay of transgressive and regressive episodes of the seaway. Shale, mudstone, claystone, and limestone were deposited during transgressions, and sandstones were deposited during regressions. The lithologic variation around the depositional basin, reflecting the proximity to sediment sources in the Sevier highland, created a complicated nomenclature for the Mancos—Berman et al. (1980) referred to the nomenclature as "burdensome." Mancos Shale, as recognized in the Colorado Plateau and Southern Rocky Mountains, represents only part of the marine rocks formed in the western part of the seaway. Other formations represent these seaway deposits to the east and north. As thrusting progressed eastward in the Sevier orogenic belt with time, the west part of the seaway filled, and marine conditions shifted eastward where the Pierre Shale was deposited in eastern Colorado and in adjoining states to the east and north.

Mancos Shale nomenclature varied significantly across the Colorado Plateau in the six regions where samples were collected for this study. Figure 2 shows the various members of Mancos Shale for each of the sampled regions (Delta and Montrose Regions were combined because their Mancos Shale members are similar). Also shown in Figure 2 is a nomenclature column of Mancos-equivalent marine deposits for eastern Colorado where the Pierre Shale is present. In western Colorado, the upper part of the Mancos Shale is equivalent to the lower part of the Pierre Shale (Berman et al. 1980). For the Delta-Montrose and Shiprock Regions, much of the nomenclature is imported from the open-marine facies (and members) recognized in eastern Colorado.

Immediately underlying the Mancos Shale in the study area is the Dakota Sandstone, which was deposited during the initial transgression of the seaway. The maximum transgression of the seaway corresponding to its greatest depth is characterized by the deposition of fine-grained carbonates of the Bridge Creek, Fort Hays Limestone, and Greenhorn Limestone Members (Kauffman 1969). As the sea gradually regressed in cycles, the shoreline moved generally from the northwest to southeast across the study area. During the seaway regression, the Mancos typically intertongues with marginal-marine rocks in the overlying Mesaverde Group. Basal Mesaverde Group regressive coastal deposits in the study area include the Castlegate, Point Lookout, and Star Point Sandstones. The basal coastal deposit and equivalent to the basal Mesaverde in eastern Colorado overlying the Pierre Shale is the Fox Hills Sandstone.

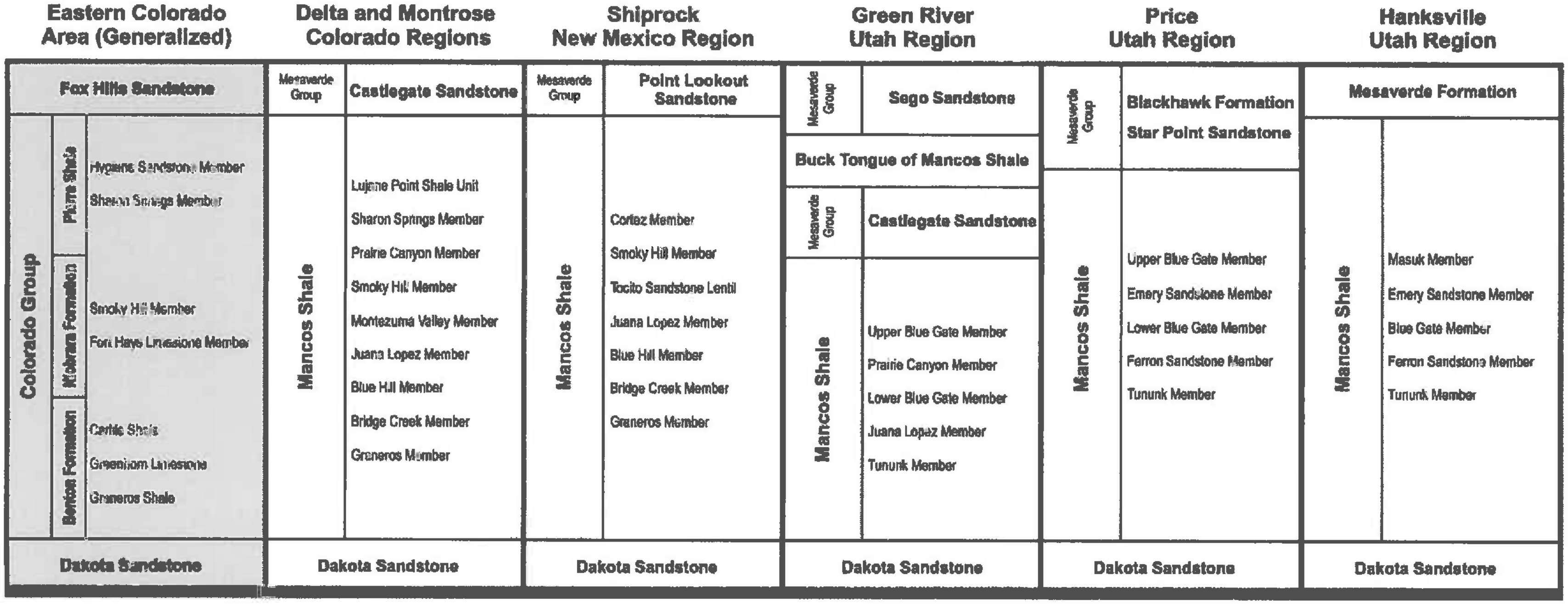

Figure 2. Mancos Shale Nomenclature for the Six Sampled Regions and Eastern Colorado Area

Mancos Shale generally consists of clayey to sandy to calcareous silt-shale with minor limestone, marlstone, bentonite, concretions, and sandstone beds (Noe et al. 2007a). These rocks represent muddy, shallow shelf deposits, and they typically form badland-style topography. A good example of this geomorphic expression is in the area of the South Branch of Loutsenhizer Arroyo in the Montrose, Colorado, Region (shown in the cover photo). Here, as in many other places of exposed Mancos, the shale is covered with a thin skin of residual or colluvial mud, as a result of in-place weathering (Noe et al. 2007a). Weathering commonly imparts a "popcorn" texture in calcareous shales of the thick Smoky Hill Member. Other characteristics of the Smoky Hill are the presence of *Inoceramus* shell fragments and its tendency to weather to a lighter gray or yellow-golden color. The overlying Prairie Canyon Member, is generally noncalcareous and organic-rich, and it contains very fine-grained, bioturbated, thin sandstone beds that weather out into small plates.

As used in this study, weathered Mancos Shale is defined as those portions of Mancos that have undergone significant chemical changes related to weathering processes, chiefly pyrite oxidation to iron hydroxide minerals and significant oxidation and loss of organic matter. This definition of weathering is consistent with that used by Berner (1987). These geochemical reactions are likely accompanied by mineralogical changes to the clay fraction, and manifest themselves in various ways including a change in the color of Mancos Shale from dark gray to yellowish gray and the production of a popcorn texture at the ground surface. Various terms have been used in the literature, but not well defined, for features that we presume to correlate with this definition of weathered Mancos Shale: Mancos Shale residuum (Wright and Butler 1993; Butler et al. 1994), shale residuum (Wright 1995, 1999), surficial Mancos Shale (Laronne 1977), weathered Mancos (Laronne and Shen 1982; Laronne 1977), weathered zone (Stillings et al. 2005), weathered shale (Wright 1995; Evangelou 1981), and partially weathered Mancos (Evangelou et al. 1984, 1985; Evangelou 1981). Similarly, our definition of unweathered Mancos Shale is probably mostly equivalent to Mancos Shale bedrock (Butler et al. 1994), competent Mancos (Laronne 1977), and less-weathered shale (Stillings et al. 2005). Mancos Shale hills are in most places capped by weathered shale that has a light-gray or yellow color. Another characteristic of weathered Mancos Shale is the presence of gypsum ($CaSO_4 \cdot 2H_2O$) and calcite ($CaCO_3$); the amounts of both decrease with increasing depth. However, weathering of Mancos Shale can apparently occur without any obvious change in appearance. In a study of the weathering of organic matter in the Mancos Shale, Leythaeuser (1973) found that core samples with a similar dark-gray appearance had significantly lower concentrations of organic carbon in the shallowest zones, likely due to weathering. In a study of black shale in Germany, Littke et al. (1991) also showed that organics can be weathered without a significant change in macroscopic appearance.

Thin bentonite beds have been identified in most members of the Mancos Shale. Thicknesses of the beds range from a fraction of an inch to as much as 5 ft and most commonly are 1 to 6 inches. Bentonite was first defined to be a highly colloidal, plastic clay found in Cretaceous rocks near Fort Benton, Wyoming (Knight 1898). Later definitions of bentonite limited it to clays composed mostly of montmorillonite produced by the alteration of volcanic ash. Approximately 400 to 450 distinct bentonite beds have been identified in the Western Interior Seaway deposits, and many of the bentonite beds extend for hundreds of miles across the depositional basin (Kauffman 1977). Radiometric dates of the bentonites correlate well with index fossils and provide a detailed geochronology for the seaway. Further definition of bentonite (in common usage, and in this report) classifies it as a rock derived from wind-transported volcanic ash, predominantly vitric in character, that fell into a body of water, and then settled to form a discrete bed (Schultz et al. 1980). Glassy ash shards are altered most commonly to smectite, and phenocrysts in the ash are typically preserved. The rock is considered a bentonite if the ash-fall origin is recognizable. This definition was used by Schultz et al. (1980) for description of bentonite beds in the Pierre Shale, an eastern equivalent of the Mancos Shale. Numerous bentonite beds as much as 5 ft thick (but typically less than 1 ft thick) in the upper Pierre Shale just west of Denver, Colorado, are described by Noe et al. (2007b). Mineralogy of these bentonites indicates they are calcium bentonites and do not have as much swelling capacity as the very highly expansive sodium bentonites that occur in northern Wyoming.

During this study, bentonite beds were observed as light gray to white, thin layers in several exposures of Mancos Shale, particularly in the Montrose and Delta Regions. In the Delta Region, bentonite beds several inches thick were present at the Delta Reservoir seeps in the lower part of the Prairie Canyon Member. In the Montrose Region, bentonite beds were seen in the Prairie Canyon Member in areas investigated along a tributary to Loutsenhizer Arroyo. Also in the Montrose and Delta Regions, just above the Prairie Canyon Member, bentonite beds were observed in the Sharon Springs Member.

3.0 Site Descriptions

In November and December 2010, samples were collected from 69 sampling locations over a broad geographic area on the Colorado Plateau encompassing much of the Mancos Shale depositional basin (Figure 1). Latitude and longitude coordinates and geologic units for each sampling location are provided in Appendix A. For ease of discussion, these locations were grouped into six sampling regions named after the nearby towns of Delta, Green River, Hanksville, Montrose, Price, and Shiprock (Figure 1). Where there were clusters of sampling locations, the regions were subdivided into sampling areas. Some of the locations were in irrigated areas, whereas others were remote with little chance for anthropogenic impacts. Seeps were sampled at 51 of these locations and surface water at 18 locations. Seeps are surface expressions of groundwater with insignificant flow, whereas springs are the same but with sufficient flow to form a stream of water. These definitions were used in the location names (Appendix A), but for simplicity in the document, we use the terms "seep" and "spring" interchangeably.

Areas with known groundwater occurrences were identified using the USGS National Water Information Service (NWIS) Web Interface (USGS 2011a). Other areas likely to have groundwater seepage were identified using aerial photography in Google Earth and from data from DOE's National Uranium Resource Evaluation (NURE) program (USGS 2011b). Field reconnaissance investigations identified additional sampling locations.

Of the surface water locations, 12 were small streams and pools receiving water from the seeps or springs. At the other six surface locations, water bodies were identified as the source of water for the groundwater that surfaced at the seep sampling locations. These six surface locations are Whitewater Ditch No. 2 (WD2) that feeds Whitewater Ditch No.2 seep (WD2S); Bostwick Canal West Lateral (BCWL) that feeds the Loutsenhizer Area seeps; Sweitzer NE Garnet Canal (SNGC) that feeds the seeps northeast of Sweitzer Lake; Sweitzer Lake (SL) that feeds Buen Pastor Spring (BPS); Delta Reservoir (DR) that feeds Delta Reservoir Seep 1 (DRS1), Delta Reservoir Seep 3 (DRS3), and Delta Reservoir Dam Spring (DRDS); and Daly Reservoir (DAR) that feeds Daly Reservoir Spring 1 (DARS1) and Daly Reservoir Spring 2 (DARS2).

Many of the seep locations were conspicuous by the presence of extensive white efflorescent salt coatings on the ground surface. At a few locations, particularly those at the Sweitzer Lake Area and Dutchmans Wash Seep, the efflorescence was intense and formed several acres of crystalline salt crusts as much as one inch thick. Using samples collected from the West Salt Creek watershed near Grand Junction, Colorado, and the Miller Creek watershed near Price, Utah, Whittig et al. (1982) identified the mineral assemblage in efflorescence as gypsum ($CaSO_4 \cdot 2H_2O$), epsomite ($MgSO_4 \cdot 10H_2O$), hexahydrite ($MgSO_4 \cdot 6H_2O$), pentahydrite ($MgSO_4 \cdot 5H_2O$), starkeyite ($MgSO_4 \cdot 4H_2O$), kieserite ($MgSO_4 \cdot H_2O$), loewite ($Na_4Mg_2(SO_4)_4 \cdot 5H_2O$), bloedite ($Na_2Mg(SO_4)_2 \cdot 4H_2O$), mirabilite ($Na_2SO_4 \cdot 10H_2O$), and thenardite ($Na_2SO_4$). Bloedite, thenardite, and sideronatrite [$Na_2Fe(SO_4)_2(OH) \cdot 3H_2O$] were identified in efflorescent salts at DOE's Shiprock, New Mexico, disposal site (DOE 2000).

Shale beds were the source of the groundwater seeps, with the exception of nine locations. At BAS, BSCS, BSCUS, CWCS, TWS, and YHS the groundwater issued from sandstone beds in the Mancos Shale. At GRCRS, LGWS, and MS, groundwater issued from gravel alluvium. In the following discussion, we refer to these nine sites as "sandstone" seeps.

Each location is described individually and organized alphabetically by region.

3.1 Delta, Colorado, Region

3.1.1 Delta Reservoir Area and Devil's Thumb Area (Delta Reservoir Locations DR, DRDS, DRS1, DRS3 and Devil's Thumb Locations DTS1, DTS2, and DTS3)

Delta Reservoir (Figure 3) is located about 4 miles north of Delta, Colorado, and about 1 mile north of Devil's Thumb Golf Course. Sources for historical information about these areas include discussions with Mr. Andy Mitchell (City of Delta) and an unpublished report prepared by Golder Associates for Delta County (Golder Associates 2004). Delta Reservoir occupies 3.2 acres and is fed by a pipe from Doughspoon Reservoir high on the southwest side of Grand Mesa. Because Delta Reservoir is fed from the Grand Mesa, its water is pristine, as indicated by our sample collected on November 8, 2010, that had a low specific conductance of 114 µS/cm. Seeps DRS1 and DRS3 are located about 1,400 ft east of and hydraulically downgradient of Delta Reservoir. Seep DRS3 (Figure 3) emerges from the side of a steep hillside outcrop where two lines of tamarisks mark seepage (Figure 4). To reach seeps DRS1 and DRS3, the water must recharge into the Mancos Shale beneath Delta Reservoir and then travel along fractures and bedding planes. Several bentonite layers are present in the Mancos that appear to exert local control on the groundwater flow. The seeps sampled at DRS1 and DRS3 occur just above bentonite beds and had specific conductivity values of 27,250 and 22,840 µS/cm, respectively. Sampling location DRDS was established just downstream of the Delta Reservoir dam where water flowed down a small stream at more than a few gpm. The water emerging at DRDS would have had minimal residence time in the dam material, which appeared to be composed of alluvium and broken-up Mancos bedrock.

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Figure 3. Delta Reservoir Area and Sampling Locations

Figure 4. View Northeast Toward Two Lines of Tamarisk That Mark Seepage along Two Separate Bentonite Beds. DRS3 is located just above the lower bentonite bed.

Devil's Thumb Golf Course is about 3 miles north of Delta and was constructed in 2000 (Figure 5). Delta Reservoir was used as the water supply for the City of Delta through 1990, after which the reservoir was drained and remained empty until 1998 when refilling was initiated to supply water for the planned Devil's Thumb Golf Course. Images from Google Earth confirm that the reservoir was dry in September 1993. Water was conveyed through pipes from Delta Reservoir to four unlined ponds on the Devil's Thumb Golf Course starting in August 2000. Initially, the course was irrigated with as much as 1 million gallons of water per day to establish the turf.

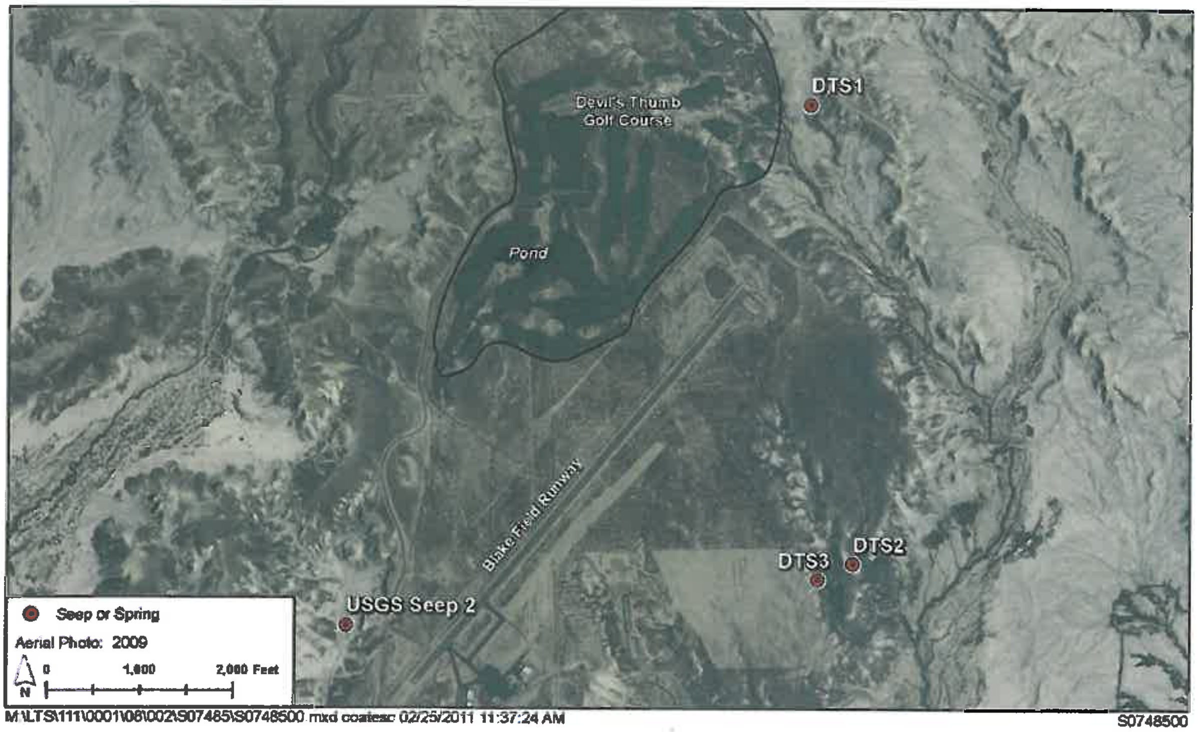

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Figure 5. Devil's Thumb Golf Course Area and Sampling Locations

Shortly after the golf course opened, groundwater seeps started to appear in nearby areas. In November 2001, USGS personnel sampled a seep at location USGS Seep 2, also referred to in the NWIS database (USGS 2011a) as 384657108041901. This seep is 4,200 feet (ft) from the Devil's Thumb Golf Course pond and receives groundwater that has flowed through the Mancos Shale (Figure 5). Using the time period from the filling of the ponds in August 2000 to the first documented seepage at USGS Seep 2 in November 2001 and a flow distance of 4,200 ft, we estimated a minimum flow velocity through the shale of 8 ft per day. USGS Seep 2 was flowing at about 9 gallons per minute (gpm) at the time of the USGS sampling and had high concentrations of major ions, selenium, and uranium (Table 2). Concentration data for nitrate in this seep were not available in the NWIS database (USGS 2011a).

Table 2. Composition of Devil's Thumb USGS Seep 2 on November 28, 2001

Constituent	Concentration	Constituent	Concentration
Sp. Conductance	26,000 µS/cm	pH	7.9
Alkalinity	526 mg/L as $CaCO_3$	Selenium	18,700 µg/L
Calcium	435 mg/L	Sulfate	12,900 mg/L
Magnesium	1,220 mg/L	Chloride	1,240 mg/L
Sodium	5,730 mg/L	Arsenic	1,020 µg/L
Potassium	38.3 mg/L	Uranium	139 µg/L
Boron	634 µg/L	Nitrate	no value in NWIS

Source: USGS 2011a
µS/cm = microsiemens per centimeter

Largely because of the high selenium concentrations, efforts were undertaken by the City of Delta to minimize seepage from the golf course ponds. The four ponds were consolidated into a single, 2.9-acre pond prior to 2004. This larger pond (labeled "pond" on Figure 5) was lined with bentonite, and later, polyacrylic acid potassium (PAM) was applied to slow the recharge. On January 21, 2003, the seep was still flowing at a rate of about 14 gpm (USGS 2011a). A photograph taken in 2003 by Kenneth Leib (written communication) of USGS indicated that the seep had created a marsh area. Because neither the bentonite liner nor the PAM treatment was successful in eliminating recharge from the pond, in 2004 the pond was lined with plastic. Soon after the pond was lined with plastic, USGS Seep 2 dried up (Andy Mitchell, personal communication). It was dry at the time of our study and had apparently been dry for some time based on the difficulty we had in determining the location of the former marsh area. The rapid loss of the seepage at USGS Seep 2 following the pond lining confirmed that the golf course pond was the source of the seep water and that groundwater can move at high velocity through the Mancos.

3.1.2 Point Creek Seep (Location PCS)

Point Creek Seep (PCS) is an isolated seep flowing from shale in the Mancos Shale along the bank of Point Creek on the southwest flank of Grand Mesa about 9 miles northwest of Delta, Colorado (Figure 1). It was identified as location 385043108112901 in the NWIS database and was sampled by U.S. Bureau of Land Management personnel on April 18 and May 13, 1980, at which times it had specific conductivities of 7,380 and 7,480 µS/cm, respectively (USGS 2011a).

Several days prior to sample collection, we placed a sampling pipe in the seep by hand digging. At the time of sampling on November 8, 2010, the seep had a specific conductivity of 10,739 µS/cm. No obvious sources of surface water that might supply this seep were identified. The area is remote and there is no irrigation in the vicinity.

3.1.3 Sweitzer Lake Area (Locations BPS, SL, SNGC, SNS, SNS1, SNS2, SNS3, SRP, and US1)

Sweitzer Lake is located about 2 miles southeast of Delta, Colorado. The lake is fed from a diversion ditch off the Garnet Canal on the east side of the lake (Butler et al. 1991). Sweitzer Lake has long been known to have elevated concentrations of selenium. Butler et al. (1991) reported selenium concentrations ranging from 5 to 45 µg/L in the lake water.

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Figure 6. Sampling Locations for Sweitzer Lake Area

We collected surface water samples from Sweitzer Lake at location SL and from the Garnet Canal at location SNGC. At the time of sampling on November 4, 2010, the water level in the Garnet Canal had dropped several feet from the week prior because it was near the end of the irrigation season. Samples were collected from locations SNS, SNS1, SNS2, and SNS3 on November 30, 2010, from hand-dug holes in a seepage area heavily encrusted with efflorescence along a tributary draining into Sweitzer Lake about 1,000 ft northeast of the lake (Figure 6). These seep samples had some of the highest concentrations of salts and trace metals of any samples collected for our study, with specific conductivity values as high as 68,114 µS/cm, and the water samples were deep yellow or red from dissolved organic carbon (DOC). Another seep (US1) located about 750 ft east of Sweitzer Lake and cited in Thomas (2009) was sampled from a hand-dug hole. A nearby pool of deep-red water (SRP) was also sampled. Buen Pastor Spring (BPS) is located about 800 ft south of Sweitzer Lake and was sampled from a sampling pipe placed about 2 ft into the ground.

3.1.4 Whitewater Area (Locations KCFS, WCTS, WCTSP1, WCTSP2, WD2, and WD2S)

The Whitewater Area is between Delta and Grand Junction, Colorado, about 6 miles southeast of Grand Junction (Figure 7). Efflorescence is common over several square miles in the Whitewater Area. Kannah Creek Flowline Spring (KCFS) was sampled in the nearly dry creek bed at the farthest upstream point where water starts seeping into the drainage. Efflorescence was abundant in the KCFS seepage area, and the specific conductivity was 26,250 µS/cm. Another seep (WD2S), located adjacent to U.S. Highway 50, had an unusually low pH of 4.15 and a specific conductivity of 14,285 µS/cm. Water supplying seep WD2S was sampled at location WD2 from Whitewater Ditch No. 2, which runs nearly parallel to U.S. Highway 50. As with location KCFS, the vicinity at and near WD2S and WD2 had an extensive cover of efflorescence. A third seep (WCTS) was sampled in a tributary to Whitewater Creek. Specific conductivity of this seep was not measured, but samples from two nearby pools at locations WCTSP1 and WCTSP2 that were fed from the seep had high specific conductivity values of 47,655 and 67,474 µS/cm, respectively. This area is also characterized by widespread efflorescence.

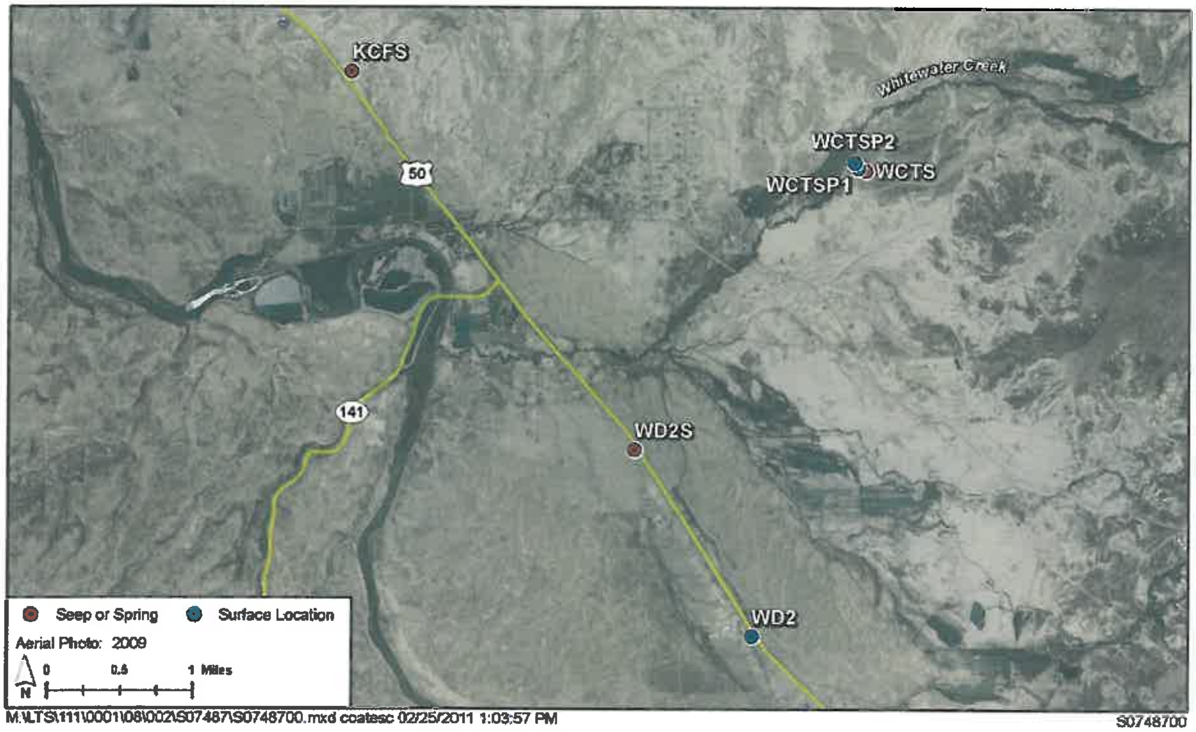

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Figure 7. Sampling Locations at the Whitewater Area

3.2 Green River, Utah, Region

3.2.1 Cisco Area (Locations CAS, CIS, CWC, and S36)

Location CAS is at Cato Springs about 42 miles east-northeast of Green River, Utah, and about 10 miles north of the unincorporated community of Cisco, Utah (Figure 1). The spring issued from a stream bank and was marked by red ferric oxyhydroxide deposits having a slimy appearance that might have been due to the presence of algae (Figure 8). This red coloration is distinctly different from the dissolved red coloration at some locations that is caused by DOC, such as at location HGS in the Montrose, Colorado, Region (Figure 9). The precipitates formed from reduced groundwater carrying ferrous iron at a concentration of 2.03 milligrams per liter (mg/L) that was exposed to atmospheric oxygen at the spring. The sample from CAS was collected from a hand-dug hole and had a relatively low specific conductivity of 2,184 µS/cm. A stream sample was collected at location CWC in Cottonwood Wash about 30 ft from location CAS.

Figure 8. Red Color Caused by Ferric Oxyhydroxide. Photo taken at Cato Springs, October 12, 2010.

Figure 9. Red Pool of Water Formed from Seep at Houston Gulch. The red color is caused by dissolved organic carbon.

Seep location CIS was at Cisco Springs, about 3 miles southwest of Cato Springs. The seep is in a wash adjacent to outcrops of gray shale in the Mancos. Cattails are prominent in the immediate area of the sampling location and a prominent tamarisk stand was present about 100 ft upstream. The sample was collected from a pool in the stream bank and had a specific conductivity of 3,947 µS/cm.

Section 36 Seep (S36) is located about 200 ft south of Interstate 70 (I-70) and about 5 miles southwest of Cisco, Utah (Figure 1). The sample was collected from a hand-dug hole in the bank of a drainage that appeared to have been straightened during construction of I-70. Shale beds of the Mancos Shale underlie the area, and it was apparent that the seepage had originated in the Mancos. However, the sampling hole did not quite reach bedrock and was terminated in colluvium. Efflorescence coated much of the streambed. The sample, collected on November 11, 2010, had a specific conductivity of 24,522 µS/cm.

3.2.2 Daly Reservoir Area and Browns Wash Seep (Locations BWS, DAR, DARS1, and DARS2)

Daly Reservoir in Grand County, Utah, was built for range improvement in April 1983 (verbal communication from Becky Dolittle, Moab Field Office, U.S. Bureau of Land Management). It fills from an unnamed drainage that drains northwest to Browns Wash and has an area of 2.4 acres. Daly Reservoir was sampled from the dam at location DAR, and had a specific conductance of 1,720 µS/cm. Daly Reservoir Springs 1 and 2 (DARS1 and DARS2) were sampled at locations 230 and 360 ft from the reservoir, respectively (Figure 10). The springs were flowing from an embankment of gray shale of the Mancos into a small arroyo. Samples were collected from hand-dug holes in the bank of the arroyo. Efflorescence was abundant on the banks and in the bottom of the arroyo. Specific conductivity values in samples from seeps DARS1 and DARS2 were 9,187 and 15,377 µS/cm, respectively.

Sampling location Browns Wash Seep (BWS) is about 1.4 mile northeast of Daly Reservoir (Figure 1). Much of Browns Wash near BWS is eroded down to shale of the Mancos bedrock, but portions are covered by thin bars and lenses of alluvial gravel. Browns Wash Seep (BWS) was sampled from a sampling pipe emplaced about 1 ft deep in an alluvial lens. The sample had a specific conductivity of 10,798 µS/cm. Efflorescence in this area was minimal.

3.2.3 Floy Wash Area (Locations ETFW, ETFWD, UFWS, UFWS1, UFWS2, and WFFW)

West Fork Floy Wash (WFFW) is about 4 miles northeast of exit 175 on I-70 (Figure 1). The entire area is underlain by shale of the Mancos, and seepage appeared to be emanating from a series of locations along the wash. Specific conductivity was measured at six locations in pools along a 1,000 ft stretch of the wash; values ranged from 6,000 to 22,000 µS/cm. Pools with high specific conductivity had a yellow color. One sample from one pool (WFFW) was analyzed only for uranium, and it had a uranium concentration of 57.4 µg/L.

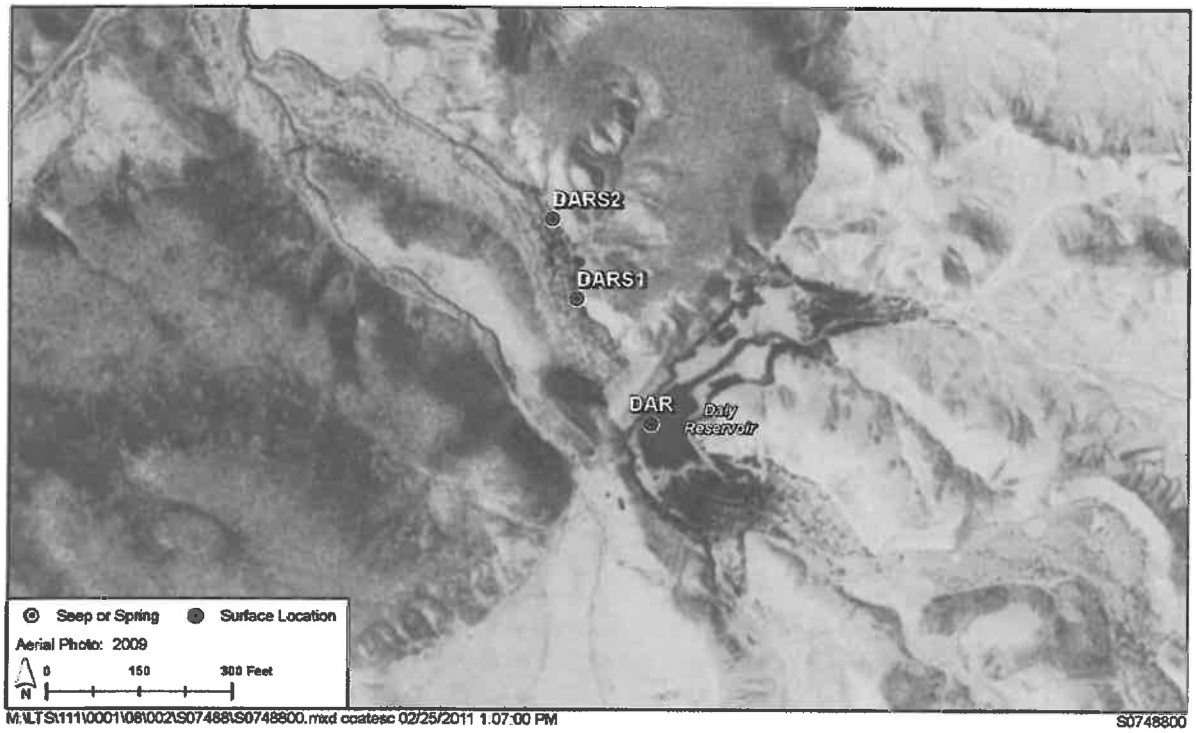

Figure 10. Sampling Locations at Daly Reservoir

Locations East Tributary Floy Wash (ETFW) and Upper Floy Wash Spring (UFWS) are about 1 mile south of location WFFW (Figure 1). Location ETFW was at the farthest upstream appearance of water in the wash, and although mostly concealed, it was probably formed from a seep. The pools that formed were red from precipitation of ferric iron, and cattails were abundant. Specific conductivity of the water at ETFW was 21,315 µS/cm, and specific conductivity in a pool about 50 ft downstream (location ETFWD) was 6,300 µS/cm. Samples were collected from a sampling pipe inserted about 2 ft into the ground at location UFWS, and the water had a specific conductivity of 6,514 µS/cm. Water in both of two hand-dug, 1 ft deep holes located 30 ft (UFWS1) and 50 ft (UFWS2) downstream had a specific conductivity of 2,236 µS/cm. Sediment in these holes was black and had an odor that indicated chemical reduction. Ferric iron coated portions of the stream and was likely derived from dissolved ferrous iron that had oxidized as it contacted the atmosphere at the seeps.

3.2.4 Green River Canal Return Seep (Location GRCRS)

This seep is referred to as SP-3 in Gerner et al. (2006) and is shown on Figure 1. USGS personnel collected samples from the seep between June and September 2004 to help determine salt loading from agricultural practices in the Green River, Utah, area (Gerner et al. 2006). Dissolved solids concentrations in the USGS samples ranged from 4,280 to 4,640 mg/L; our sample collected on November 11, 2010, had a specific conductivity of 3,847 µS/cm.

The seep is located on the bank of an irrigation return canal about 850 ft from its entry to the east side of the Green River. The sample was collected from a 2 ft deep hole that was dug by hand into the bank of the canal. Lithologic relationships are somewhat concealed, but the seep appears to result from water that had infiltrated from the canal to the Green River floodplain alluvium and then surfaced at or near the contact with the underlying Mancos Shale bedrock. Thus, the chemistry of this seep may be influenced by contact with both alluvium and Mancos Shale, and by irrigation.

3.2.5 Little Grand Wash (Locations LGW and LGWS)

The seep sample from site LGWS was collected from a sampling pipe inserted about 1.5 ft into the stream bank of Little Grand Wash (Figure 1). A stream sample was collected 2 ft from the seep in a pool composed mostly of seep water. The stream was partially frozen and was flowing at less than 1 gpm. The stream sample could have been affected by exclusion of some ions from the ice during freezing. Specific conductivity values measured on November 12, 2010, for the seep and wash samples were 1,637 and 1,326 μS/cm. respectively.

The seep appears to result from water that flowed through Little Grand Wash alluvium and then surfaced at or near the contact with the underlying Lower Blue Gate Member of Mancos Shale bedrock. Thus, the chemistry of the seep could be influenced by contact with both alluvium and Mancos Shale.

3.3 Hanksville, Utah, Region

3.3.1 Town Wash Spring (Locations TWS and TWSP)

Town Wash Spring location TWS is in the Henry Mountains Basin about 9 miles southwest of Hanksville, Utah, (Figure 1) and is listed in the NWIS database as location 381721110505401 (USGS 2011a). The sample from location TWS was collected from a 2 ft deep sampling pipe. At the time of our sampling on November 17, 2010, the specific conductivity was 10,018 μS/cm. A pool, sampled at location TWSP in Town Wash about 20 ft south of the TWS sampling pipe, had a specific conductivity of 5,630 μS/cm. Water emerging at the spring originated from flow through sandstone in the Ferron Sandstone Member of the Mancos at the contact with the underlying Tununk Member of the Mancos Shale.

3.3.2 Cottonwood Creek Spring (Location CWCS)

Cottonwood Creek Spring location CWCS is in the Henry Mountains Basin about 9 miles southwest of Hanksville, Utah, (Figure 1) and is listed in the NWIS database as location 381739110513801 (USGS 2011a). The sample from location CWCS was collected from a small pool that was fed from the seep. At the time of our sampling on November 17, 2010, the specific conductivity was 5,965 μS/cm. Water emerging at the spring originated from flow through sandstone in the Ferron Sandstone Member of the Mancos at the contact with the underlying Tununk Member of the Mancos Shale.

3.3.3 Bert Avery Spring (Location BAS)

Bert Avery Spring location BAS is in the Henry Mountains Basin about 9 miles southwest of Hanksville, Utah, (Figure 1) and is listed in the NWIS database as location 381603110491901 (USGS 2011a). The sample from location BAS was collected from a 2 ft deep sampling pipe placed at the base of a 30 ft thick sandstone cliff. At the time of our sampling on November 17, 2010, the specific conductivity was 418 µS/cm. Water emerging at the spring originated from flow through sandstone in the Ferron Sandstone Member of the Mancos at the contact with the underlying Tununk Member of the Mancos Shale.

3.3.4 Bitter Spring Creek (Locations BSCS and BSCUS)

Bitter Spring Creek Seep location BSCS (Figure 1) is southwest of the Henry Mountains in the Henry Mountains Basin about 400 ft east of the Capitol Reef National Park boundary. It is listed in the NWIS database as location 375458111011901 (USGS 2011a). The spring sample at location BSCS was collected from a sampling pipe near the base of a massive sandstone bed in the Emery Sandstone Member of the Mancos Shale. The spring water was depositing iron oxide on the rocks and streambed. Our sample, collected November 18, 2010, had a specific conductivity of 2,037 µS/cm. The upper spring sample at location BSCUS was collected from a shallow stream pool at the farthest upgradient location of seepage and had a specific conductivity of 1,079 µS/cm. This area is characterized by steep sandstone cliffs, and the intermittent stream has formed a series of falls up to 20 ft high. The groundwater flows through sandstone in the Emery Sandstone Member of the Mancos, and the springs emerge near the base of the Emery Sandstone at the contact with the underlying Blue Gate Member of the Mancos Shale.

3.4 Montrose, Colorado, Region

3.4.1 Cerro Summit Area (Locations CCS, HGS, HGSE, and HGRP)

Cedar Creek Seep location CCS is about 70 ft south of U.S. Highway 50 and about 2 miles northwest of Cerro Summit (Figure 11). The seep flows from the north side of a dirt road from the Highway 50 embankment, and efflorescence is apparent (Figure 11 inset). The groundwater sample was collected from a hand-dug hole in the highest-elevation portion of the seepage area. The water had a dark-yellow color and a specific conductivity of 16,409 µS/cm. The radon-222 concentration was 1,625 picocuries per liter (pCi/L), which was the highest value measured in our study. The source of the water feeding the seep was not determined.

Location HGS (Figure 11) in Houston Gulch is along Highway 50 about 1.7 miles northwest of location CCS and about 100 ft north of the highway. The sample was collected from a sampling pipe inserted about 1.5 ft into the seepage area. Groundwater issuing from the seep was red due to DOC and had a specific conductivity of 22,790 µS/cm. Sampling location HGSE was a hand-dug hole 30 ft southeast of HGS. The groundwater at location HGSE was also red and had a specific conductivity of 21,658 µS/cm. Red water flowed from the seepage area down a small stream (Figure 9). The stream at location HGRP had a specific conductivity of 45,645 µS/cm.

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Figure 11. Sampling Locations at Cerro Summit Area. Inset is a September 28, 2010, photo of Cedar Creek Seep.

3.4.2 Loutsenhizer Arroyo Area (Locations BCWL, LOUT3, LOUT8, LOUT9, LOUT11, LOUT11W, LOUT12L, LOUT12U, LOUT13, LOUT14)

According to the USGS 1:24,000 topographic map of the Olathe quadrangle, the main portion of Loutsenhizer Arroyo runs northwest along the eastern side of the Uncompahgre River valley floor starting about 5 miles north of Montrose, Colorado. Our sampling was conducted in one of the upper reaches of Loutsenhizer Arroyo, which is unnamed on the USGS topographic maps but is referred to as South Branch of Louzenhizer [sic] Arroyo by Butler and Leib (2002). For ease of discussion, we will use the name Loutsenhizer Arroyo to refer to the South Branch and its tributaries in the area of our sampling (Figure 12). Bostwick Canal runs along the upper reach of Loutsenhizer Arroyo (Figure 12) and is likely the source for the seepage in the arroyo. Location BCWL, on the West Lateral of the Bostwick Canal with a similar water supply, had a specific conductivity of 197 µS/cm.

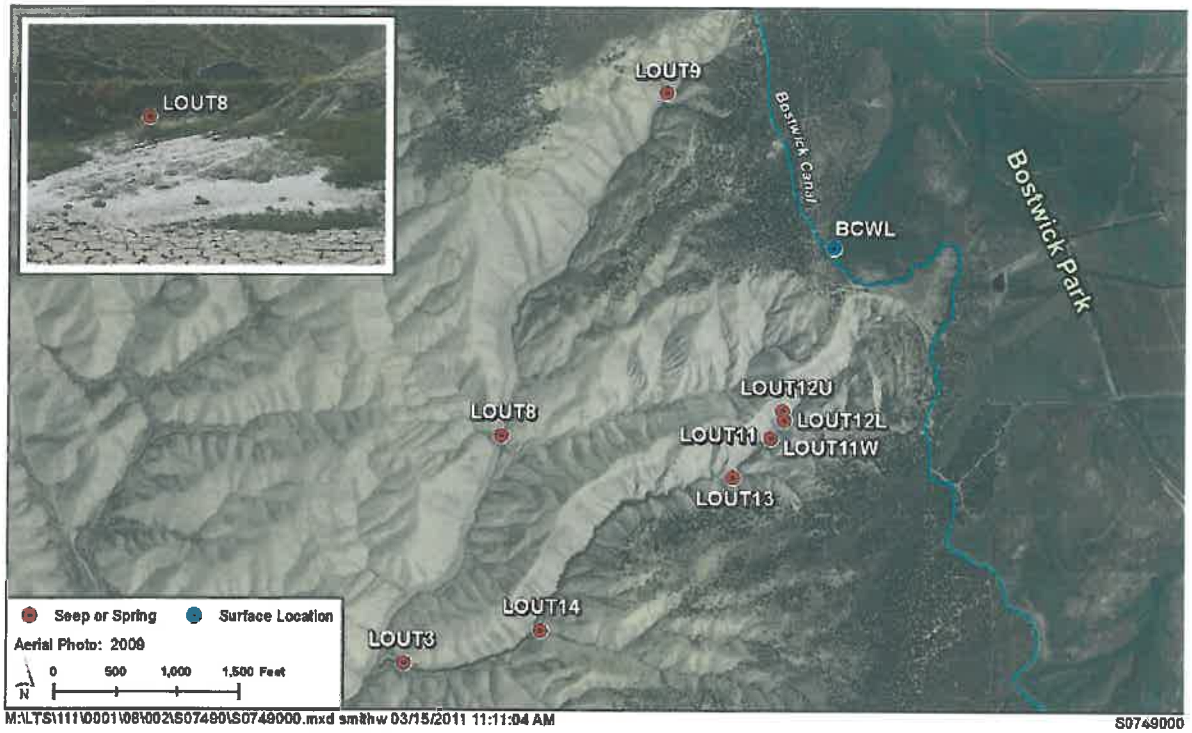

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Figure 12. Sampling Locations at Loutsenhizer Arroyo Area and Location of the West Lateral of Bostwick Canal (labeled Bostwick Canal). Insert photo is LOUT8 seep looking southwest.

A spring with a high uranium concentration of 113.8 µg/L was discovered on September 26, 1977, during sampling for the NURE program in the Montrose 1° × 2° quadrangle (Broxton et al. 1979). Additional chemical data for this seep, from samples collected on May 15, 2000, are available in the NWIS database where it is listed as "Upper Seep, S. Branch Loutsenhizer Arroyo" with the index number 383307107464701 (USGS 2011a). On this date it had a specific conductivity of 10,600 µS/cm. The NWIS (USGS 2011a) database lists another seep in Loutsenhizer Arroyo as "Lower Seep, S. Branch Loutsenhizer Arroyo" with the index number 383242107470402 that has data for October 5, 2000, at which time the specific conductivity was 42,800 µS/cm. Our locations LOUT9 and LOUT8 are the same as the NWIS (USGS 2011a) locations Upper Seep and Lower Seep, respectively.

Efflorescence was common at the Lower seep, LOUT8 (Figure 12, inset), but efflorescence was minimal at LOUT9. Samples collected from locations LOUT9 and LOUT8 on November 4, 2010, had specific conductivity values of 8,844 and 22,130 µS/cm, respectively. Location LOUT11 was sampled from a shallow, hand-dug hole in a small tributary to Loutsenhizer Arroyo, and location LOUT11W was in the wash about 9 ft away. Samples of LOUT11 and LOUT11W had specific conductivity values of 11,600 and 315 µS/cm, respectively. Location LOUT12U was a seep dripping from a plant rootlet bedded in gray shale in a small ravine on the side of a steep Mancos hillside. Another seep was sampled at location LOUT12L near the bottom of the same ravine as LOUT12U, near where the ravine intersected the main arroyo. Specific conductivity values for samples at LOUT12U and LOUT12L were 5,190 and 6,220 µS/cm, respectively. Locations LOUT13 and LOUT14 were downstream from LOUT11 in the same tributary and were sampled to test chemical variability along the tributary.

Seep water measured in hand-dug holes at locations LOUT13 and LOUT14 had specific conductivity values of 5,880 and 17,700 µS/cm, respectively. Seep location LOUT3 was farther down the tributary and was sampled from a sampling pipe in a grassy area where seepage emerged from the Mancos Shale. Specific conductivity at this location was 15,330 µS/cm.

3.5 Price, Utah, Region

3.5.1 Mud Spring (Location MS)

At location MS, clear water was flowing up and out of an existing vertical PVC pipe, and the sample was collected by pumping water from the pipe. The spring is listed as Mud Spring on the USGS 1:24,000 map of the Sunnyside Junction quadrangle and is listed in the NWIS database as location 393103110315901 (USGS 2011a) (Figure 1). The site had plumbing that appeared to have been used to convey water from the spring to animal feeding areas, indicating that the spring had been flowing for some time. Specific conductivity measured on November 16, 2010, was 1,659 µS/cm. This spring appears to result from groundwater flowing through the alluvial fan extending outward (westward) from the mouth of Whitmore Canyon at the base of the Book Cliffs. Mud Spring is one of many springs in the area where groundwater emerges from the base of the alluvial fan material at the contact of the pediment surface on the underlying Mancos Shale.

3.5.2 Dutchmans Wash Seep and Blue Gate Spring (Locations DWS, BGS)

Dutchmans Wash Seep is located about 27 miles southwest of Price, Utah, on the western slope of the San Rafael Swell (Figure 1). The sampling location (DWS) was within a large, flat, open area with abundant efflorescence. Irrigated areas are nearby to the northwest, but it is unclear whether they supply water to this area. Specific conductivity of the seep water was 48,519 µS/cm on November 16, 2010.

Blue Gate Spring (BGS) is located about one mile east of location DWS and is listed in the NWIS database as site 391315110570301. The seep issues from the dark-gray shale of the Blue Gate Member and had a sulfurous odor. Ferric oxide deposits were visible along the seepage area. Specific conductivity of the seep water was 6,203 µS/cm on November 16, 2010.

3.5.3 Mathis Wash Seep (Location MWS)

Location MWS is about 11 miles south of Price, Utah, and is about 20 ft west of Upper Miller Creek Road (Figure 1). This location is within a large, irrigated area with abundant efflorescence. Specific conductivity of the seep water was high at 70,002 µS/cm on November 16, 2010. A 6-ft diameter pool of yellow-colored water on the opposite (east) side of Miller Creek Road had a specific conductivity of 53,800 µS/cm.

3.6 Shiprock, New Mexico, Region

3.6.1 Ditch 9 Spring (Location D9S)

Location D9S is about 375 ft west of Farm Road within a marshy area that extends about 75 ft along the base of a steep shale hill of Mancos bedrock (Figure 13). On December 2, 2010, the spring water had a specific conductivity of 4,045 µS/cm. Samples were collected from a hole hand dug about 2 ft into the weathered Mancos. Scattered areas of efflorescence are in the vicinity of the spring.

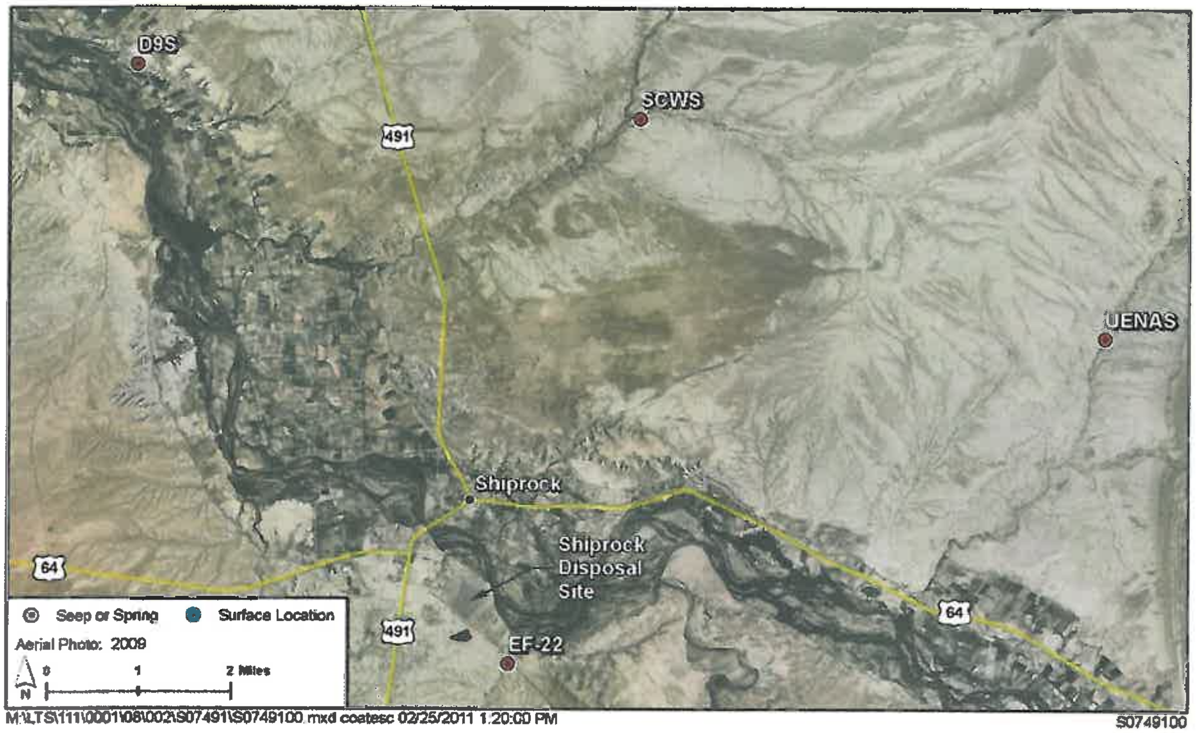

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Figure 13. Sampling Locations in the Shiprock Area.

3.6.2 Many Devils Wash (Location EF-22)

Many Devils Wash is an arroyo that feeds into the San Juan River about 1.5 miles south of Shiprock, New Mexico. The wash is within about 0.5 mile of DOE's Shiprock uranium mill tailings disposal site, and DOE is currently remediating a portion of the wash by pumping groundwater and surface water to an evaporation pond (Figure 13). Groundwater with specific conductivity values ranging from about 20,000 to 35,000 µS/cm enters Many Devils Wash from seepage from a tributary called the East Fork (DOE 2000) at a relatively constant flow rate, estimated visually as 1 gpm. The seepage contains elevated concentrations of sulfate, nitrate, selenium, and uranium and is thought to originate as infiltration to groundwater derived from the uranium milling (DOE 2000). Because the suite of contaminants is similar to that observed as natural contamination from the Mancos Shale, it is reasonable to suggest that some or all of the contamination may be of a natural origin instead of related solely to the mill site.

Location EF-22 is in East Fork about 100 ft from its confluence with Many Devils Wash (Figure 13). A sample was collected at this location from a sampling pipe inserted to a depth of 2 ft. The area of East Fork about 50 ft downstream of EF-22 is saturated most of the time; thus, location EF-22 is near the surface emergence of the groundwater system. The area is often covered by efflorescence. This is the only site sampled during the study that is located relatively close (0.5 mile) to a known source of anthropogenic uranium contamination.

3.6.3 Salt Creek Wash Seep (Location SCWS)

Sampling location SCWS is about 4 miles northeast of Shiprock, New Mexico (Figure 13). The sample was collected from the first upstream appearance of water along Salt Creek Wash where the wash is bounded on both sides by shale outcrops of Mancos. The shale is weathered to a reddish orange color on the surface in places but still contains scattered black organic material. The sample was collected from a hole dug by hand to a depth of about 2 ft within the wash where the water was issuing from the shale. The water was saline with a specific conductivity of 48,639 µS/cm. Where the water pooled in the arroyo bed, it had a yellow to red color and a DOC concentration of 183 mg/L.

The source of the groundwater feeding SCWS was not identified; the site is in a remote area and there are no obvious nearby reservoirs, canals, or other standing bodies of water. Location SCWS is in the vicinity of the Salt Creek Dakota Oil Field and at least 47 test holes have been drilled within 1 mile of the sampling location, many of them hydraulically upgradient. Some of these test holes became oil wells that produce from a depth of about 1,100 ft in the Cretaceous Dakota Sandstone, just below the Mancos Shale (Jacobs and Fagrelius 1978). If any of these wells were incompletely sealed, groundwater could have migrated to the seeps from deeper horizons.

3.6.4 Upper Eagle Nest Arroyo Spring (Location UENAS)

Upper Eagle Nest Arroyo is about 7 miles northeast of Shiprock, New Mexico, and runs subparallel to and about 2 miles west of The Hogback, a monocline where rocks dip steeply eastward into the San Juan Basin. At sampling location UENAS (Figure 13), the arroyo has incised the Mancos Shale bedrock, which consists of siltstone and shale. The sample was collected in a hand-dug hole at a depth of about 1 ft into the arroyo bed and had a specific conductivity of 26,607 µS/cm. The sample was unusual in that it had a low color index of only 24 color units but having a high DOC value of 161 mg/L. No source of water was identified for the spring, because it is remote and far from irrigation, reservoirs, canals, and oil wells.

3.6.5 Yucca House Spring (Location YHS)

Yucca House Spring (YHS) is located about 30 miles north of Shiprock, New Mexico, and about 10 miles south of Cortez, Colorado, (Figure 1) and is within the boundary of Yucca House National Monument, one of the largest archeological sites in southwest Colorado (NPS 2011). Ancestral Puebloan people used water from the spring from A.D. 1150 to 1300 (NPS 2011).

The site is listed in the NWIS database as location 371500108410801 (USGS 2011a). At the time of our sampling on December 1, 2010, the specific conductivity was 1,442 µS/cm, and the spring was estimated to be flowing at 0.2 to 0.5 gpm. Wright (2006) reported specific conductivity values ranging from 1,260 to 2,050 µS/cm for water sampled from Yucca House Spring during four sampling events from September 2002 to September 2003. During this time, Wright (2006) measured spring discharge at 0.45 to 0.90 gpm, and uranium concentrations ranged from 7.46 to 13.1 µg/L. Wright (2006) also measured a uranium concentration of 485 µg/L in a surface water sample collected from Navajo Wash 0.5 miles to the east.

Although partially concealed, the spring water appears to originate in the Mancos Shale from flow through sandy material in the Juana Lopez Member and emerge at the contact with the underlying Blue Hill Member, composed mainly of shale. During the irrigation season, groundwater may be supplemented by water from the Ute Mountain Ditch. Using infrared aerial photography to identify areas with high densities of phreatophytes, Wright (2006) suggested an area of alluvial and pediment cover located about 1 mile west of Yucca House Spring on the east slope of Sleeping Ute Mountain as the recharge area for the spring. Based on chemical signatures of area springs, Wright (2006) suggested that calcium-bicarbonate groundwater recharging the subsurface in the Ute Mountain area interacted with Mancos Shale to produce the calcium sulfate groundwater issuing from Yucca House Spring. He also suggested that irrigation water contributed to Yucca House Spring.

4.0 Methods

4.1 Sampling

We sampled groundwater seeps from the Mancos Shale over a large portion of its depositional basin (Figure 1). A single round of sampling was conducted during November and December 2010. This period was considered base flow conditions by Tuttle and Grauch (2009), a time when irrigation and runoff are at a minimum. This period of time is within the nonirrigation season that Butler et al. (1991) reported typically lasts from November through March. At all sampling locations, an effort was made to locate the farthest upgradient area of the seep in order to obtain groundwater at its first emergence from the formation. Flow from most seeps was less than 1 gpm.

Groundwater was collected either through a 1 to 3 ft long, vertical, 2-inch-diameter, slotted PVC casing (sampling pipe), or an open hole dug with a hand auger or shovel. The water was pumped from the "well" with a peristaltic pump. Field parameters (pH, specific conductivity, temperature, dissolved oxygen, and oxidation-reduction potential [ORP]) were measured either in a flow-through cell or by placing the sonde directly into the well. In some cases, groundwater flowed from the rock in a manner that a sample could be collected directly into a sampling container. This mode of sampling was used only if the sample could be obtained at the immediate point of groundwater emergence from the outcrop.

At a few of the seep locations, flowing groundwater could be identified mostly by wet or soggy ground conditions. At these sites, care was taken to ensure that groundwater was flowing, and was not simply stagnant water. Typically, the water was pumped from the sampling pipe or open hole until it reached a steady flow rate. At a few locations that had limited groundwater production, the "wells" were pumped down and left for some time (up to several hours) to refill before sampling. Not all analytes were measured at all locations. At some locations we only measured field parameters, and only uranium was analyzed at others.

In all cases, the seep and spring samples clearly represented flowing groundwater. The proximity of the seeps and springs to the ground surface suggested that alteration of the groundwater resulting from upward capillary flow and evaporation was possible in some samples. Evaporation effects were likely to be more dominant in areas covered by efflorescence, such as Sweitzer Lake and Dutchmans Wash. Because the areas with efflorescence had minimal or no plant growth, transpiration of groundwater at these locales was not considered significant. Measurements of radon-222 were made in an effort to help evaluate effects of evaporation.

Samples for chemical analyses were field filtered through 0.45 micrometer in-line filters using a low-flow peristaltic pump. Samples were collected in Nalgene bottles: 1 liter for uranium isotopes, 125 milliliters (mL) for anions, and 125 mL for cations and metals. An unfiltered sample was collected in a 50 mL plastic bottle for analysis of iron-related bacteria. Two samples were collected for radon-222 analyses in 40 mL glass vials with Teflon-lined septa. Samples for anions, radon-222, and bacteria analyses were not preserved but were placed on ice until analysis. All other samples were preserved with sufficient concentrated nitric acid to maintain the pH at less than 2.

4.2 Analysis

Field parameters (pH, ORP, specific conductivity, temperature, and dissolved oxygen) were measured on unfiltered water using a YSI Environmental (Yellow Springs, Ohio) 556 MPS meter and sonde. Measurement of pH employed a glass combination electrode, ORP a platinum electrode, conductivity a four-electrode cell, and dissolved oxygen a steady-state polarographic cell. Alkalinity was determined in the field on filtered samples by titration with sulfuric acid.

Most water analyses were conducted at the DOE Environmental Sciences Laboratory in Grand Junction, Colorado. Samples collected for analysis of arsenic, boron, selenium, uranium isotopes, and vanadium were sent to a commercial laboratory. Color analyses were performed on filtered samples using a Hach (Loveland, Colorado) DR/890 colorimeter, which measures light absorbance at 465 nanometers normalized to a platinum-cobalt standard. One color unit is equivalent to 1 mg/L platinum as chloroplatinate. Concentrations of anions (sulfate, chloride, and nitrate) were determined on a Dionex (Sunnyvale, California) Model ICS-1500 ion chromatograph, and cation (calcium, magnesium, sodium, iron, and potassium) concentrations were measured by flame atomic absorption spectrophotometry on a Perkin Elmer (Waltham, Massachusetts) AAnalyst 300. To minimize possible biodegradation of nitrate, samples were analyzed within 48 hours of collection. Radon-222 concentrations were measured within 48 hours of sample collection on a Beckman (Brea, California) LS6000IC liquid scintillation counter. Samples were rerun several days later to confirm, using decay-rate calculations, that radon-222 was the only significant alpha emitter. Care was taken throughout the sampling and preparation process to minimize exposure to the atmosphere prior to alpha counting. Uranium concentrations were determined by laser-induced kinetic phosphorescence analysis (KPA) using a Chemchek (Richland, Washington) KPA-11. Analysis of iron-related bacteria (bacteria that use iron in their metabolism and can be either iron oxidizing or iron reducing) was conducted on unfiltered samples by incubating the sample at room temperature for up to 9 days (Droycon 2004). Dissolved organic carbon concentrations were determined colorimetrically on filtered samples, after the samples were pretreated at pH less than 2 to remove inorganic carbon, and subsequently heated to a temperature of 105 °C in a Hach DRB 200 reactor.

Samples were analyzed for uranium-234, -235, and -238 by alpha spectrometry; for arsenic, selenium, and vanadium by inductively coupled plasma (ICP) mass spectrometry; and for boron by ICP emission at ALS Laboratory Group (Fort Collins, Colorado). Total uranium concentrations determined from the alpha spectrometry analyses were consistent with those determined by KPA. The results of the KPA analyses are used in this report for discussions of uranium where concentrations are provided in mass units.

4.3 Calculations

Though major ion analytical concentrations were reported in units of mass per liter of solution, geochemical modeling calculations (using the speciation code PHREEQC) required units of molality. Conversion of mass units to molality required corresponding measures of water densities, which were estimated from salinity values and temperature using the empirical equations in several published standard methods in Eaton et al. (1995). The calculation method is presented in Appendix B.

Values of pE used in geochemical modeling were estimated from ORP values per the following formula (Stumm and Morgan 1981):

$$pE = Eh/(2.3\ RTF - 1)$$

where:

$Eh = ORP - ORP_Z + Eh_Z$
ORP_Z = ORP of Zobell standard solution
Eh_Z = theoretical Eh of Zobell standard solution
R = gas constant
T = absolute temperature (K)
F = the Faraday constant (96,490 $C\ mol^{-1}$)
$C\ mol^{-1}$ = coulombs per mole

5.0 Results

Frequency distributions of concentrations in environmental samples collected for groundwater monitoring are often skewed toward low values, but logarithms of the concentrations are usually normally distributed (Gilbert 1987). Thus, the geometric mean is a useful statistic that is often used to describe distributions of environmental concentration data. Groundwater concentration data from our study, transformed to logarithmic base 10 values, were found to be nearly normally distributed. Thus, we use the geometric mean, which is equal to 10^{μ}, where μ is the mean of the logarithmic distribution, to describe the chemical distributions. In following report sections, the results of chemical analyses performed on samples of groundwater seeping from sandstone beds or alluvium (locations BAS, BSCS, BSCUS, CWCS, GRCRS, LGWS, MS, TWS, and YHS) are often distinguished from the results of analyses for all other seep locations, which are mostly associated with shale beds. The results from surface water samples (locations BCWL, DAR, DR, SL, SNGC, WD2) are also singled out, as are the results of groundwater collected from wells installed in deep shale.

We analyzed for constituents including arsenic, nitrate, selenium, sulfate, uranium, and vanadium that are often elevated in groundwater at uranium milling sites, to address the potential for contribution of contaminants from the Mancos Shale at uranium mill tailings disposal sites. We measured pH, oxidation-reduction potential and concentrations of major ions including calcium, carbonate (as alkalinity), chloride, magnesium, potassium, and sodium, for the purpose of tracking salt loads, assessing analytical accuracy using charge balance, to define water types, and to use in geochemical speciation modeling. Iron and dissolved oxygen were analyzed to help evaluate redox potentials. Dissolved organic carbon and color were measured to determine if the red or yellow colors observed in the Mancos Shale waters relate to an organic component. Uranium-234 and uranium-238 activities were analyzed because these isotopes have been used to help determine the sources and chemical evolution of dissolved uranium. Boron was analyzed because it is often enriched in marine black shales and may help to detect a Mancos Shale source. Radon-222 was analyzed mainly to help determine if the water had been altered by evaporation. Appendix C provides a complete listing of the chemical analytical results.

5.1 Arsenic

Of the 36 samples analyzed, only one sample of seep water had an arsenic concentration (12 µg/L) that exceeded the drinking water standard of 10 µg/L listed in 40 e-CFR 141. This sample was collected from location SNS in the Sweitzer Lake Area (Figure 6). Arsenic concentrations in more than 70 percent of the seep samples were less than values in surface water samples (Figure 14).

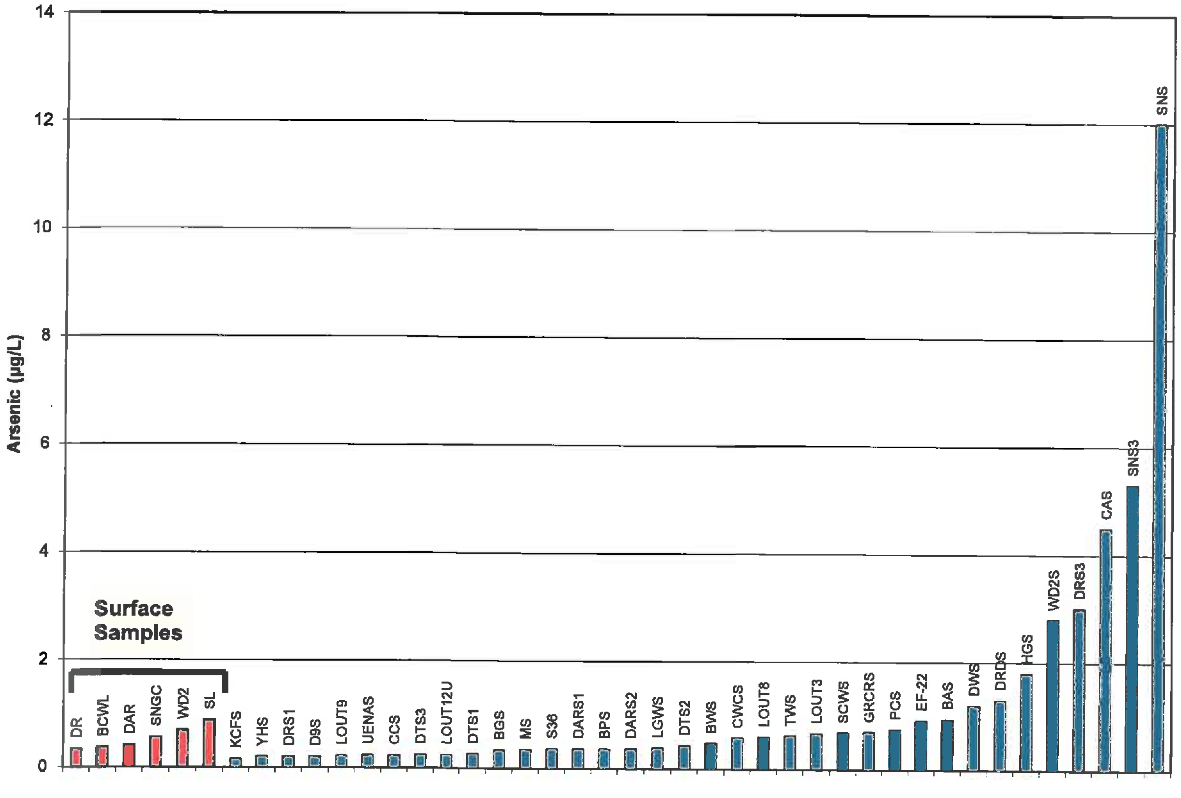

Figure 14. Arsenic Concentrations (µg/L) in Surface Water (Red) and Seep (Blue) Samples

5.2 Boron

Boron concentrations in the six surface water samples ranged from a low value of 3.1 µg/L in Bostwick Canal (BCWL) at the head of Loutsenhizer Arroyo to a high of 530 µg/L at Sweitzer NE Garnet Canal (SNGC). Boron concentrations in seep samples ranged from 16 to 3,200 µg/L with a geometric mean of 441 µg/L (Figure 15). Boron concentrations in seep samples were highest (concentrations of 2,000 and 3,200 µg/L) at two locations in the Sweitzer Lake seepage area. Seep samples with boron concentrations between 1,000 and 1,500 µg/L were collected at Loutsenhizer Arroyo (LOUT3, LOUT8, and LOUT9), Whitewater (WD2S), Point Creek (PCS), and Cedar Creek (CCS). Some of the sandstone seeps had low boron concentrations, including Bert Avery Seep (BAS), Little Grand Wash Seep (LGWS), and Yucca House Spring (YHS). The geometric mean boron concentration for the sandstone seeps was 110 µg/L, which was considerably less than the geometric mean of 692 µg/L for shale seeps.

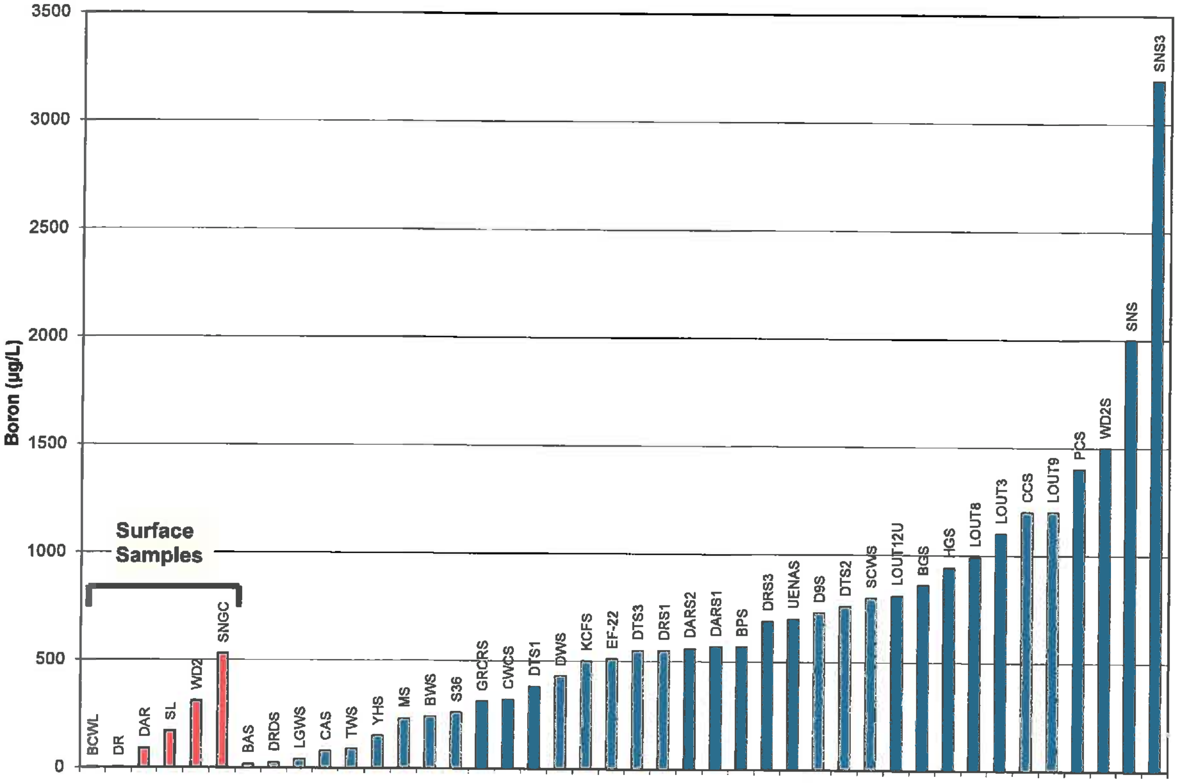

Figure 15. Boron Concentrations (µg/L) in Surface Water (Red) and Seep (Blue) Samples

5.3 Dissolved Organic Carbon (DOC)

DOC concentrations ranged from 2.9 to 265 mg/L in seep samples from the Mancos Shale (Figure 16). Samples from Whitewater Creek tributary (WCTS), Mathis Wash (MWS), and Sweitzer Lake (SNS) had DOC concentrations of more than 260 mg/L. Both locations, UENAS and SCWS, in areas north of Shiprock, New Mexico, had DOC values exceeding 150 mg/L. Samples from Loutsenhizer Arroyo (LOUT3 and LOUT8), Many Devils Wash (EF-22), Houston Gulch (HGS), and Dutchmans Wash (DWS) had DOC concentrations of more than 50 mg/L. DOC concentrations in samples collected at seeps DRS1 and DRS3 east of Delta Reservoir were 16 and 44 mg/L, respectively. At Daly Reservoir, seeps DARS1 and DARS2 had DOC concentrations of 17 and 41 mg/L, respectively. DOC concentrations in the six surface water samples ranged from 3.3 to 31 mg/L.

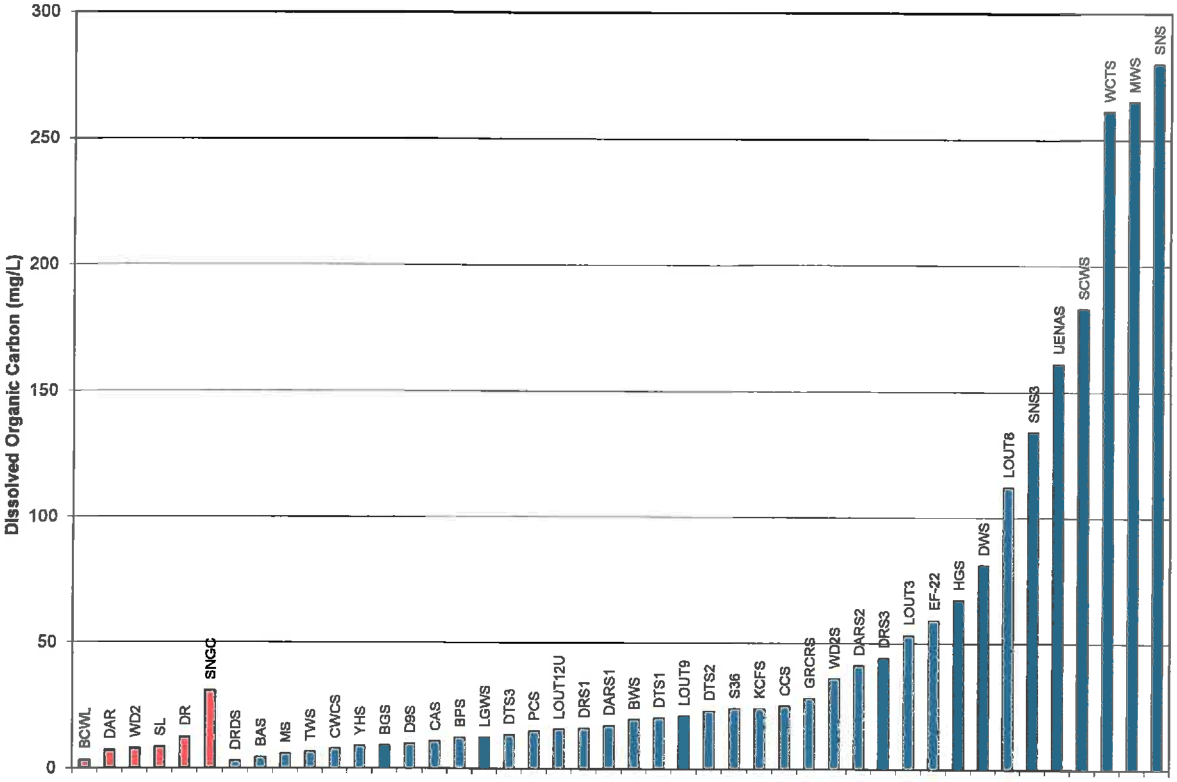

Figure 16. Dissolved Organic Carbon Concentrations (mg/L) in Surface Water (Red) and Seep (Blue) Samples

Much of the groundwater issuing from the Mancos Shale seeps was characterized by a distinctive yellow to deep red color (Figure 9). With the exception of samples from locations SCWS and UENAS in the Shiprock Region, color as measured by light absorbance correlated reasonably well with DOC concentration (Figure 17). Locations SCWS and UENAS showed high DOC concentrations but, for reasons unknown, did not exhibit a yellow or red color and had a low color value. Water color in the streams fed by the colored seepage varies depending on the thickness of the water column. The color is light yellow when the water thickness is less than a few inches, but in thicker pools of water it is deeper shades of yellow and amber, and in pools more than 12 inches deep, the water has a deep-red color (e.g., Figure 9). Curtis and Schindler (1997) in a study of Canadian lakes demonstrated a correlation between DOC concentration and water color as measured by light absorption. Some authors have noted groundwater with similar coloration related to humic material in other environments. Foster (1950) describes yellow to dark-brown water, similar to the color of swamp water, in deep groundwater of the Gulf Coastal Plain in Mississippi that correlates with high concentrations of sodium bicarbonate stemming from interaction with subsurface humic material.

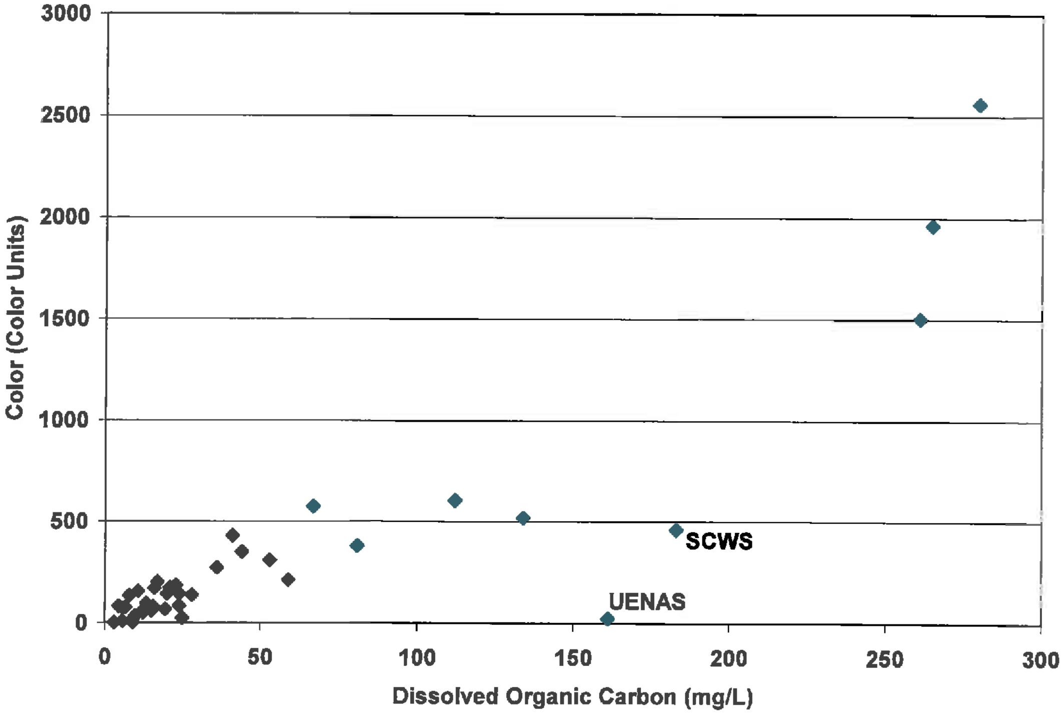

Figure 17. Correlation between DOC Concentration and Water Color in Mancos Shale Seeps

5.4 Major Ions and pH

Many seep samples were highly saline, as indicated by high specific conductivity values. Specific conductivity for the Mancos seeps ranged from 418 to 70,002 µS/cm with a geometric mean of 9,522 µS/cm (Figure 18). Nine seep samples had values exceeding 30,000 µS/cm, and 18 samples had values between 10,000 and 30,000 µS/cm. Specific conductivity values were more than 30,000 µS/cm in seeps associated with large expanses of efflorescence, including Dutchmans Wash (DWS), Many Devils Wash (EF-22), Mathis Wash (MWS), and Sweitzer Lake Area (SNS, SNS1, SNS2, SNS3, US1). Seeps with values of specific conductivity ranging from 15,000 to 30,000 µS/cm were found at Cerro Summit Area (CCS, HGS, HGSE), Daly Reservoir Area (DARS2), Delta Reservoir Area (DRS1, DRS3), Eagle Nest Arroyo (UENAS), Loutsenhizer Arroyo Area (LOUT8, LOUT14, LOUT3), Salt Creek Wash (SCWS), Section 36 Seep (S36), and Whitewater Area (KCFS). Efflorescence was common at most locations that had specific conductivity values more than about 15,000 µS/cm.

Some of the seeps had much lower values of specific conductivity and likely represent conditions other than groundwater issuing from shale. These include Bert Avery Spring (BAS) and Bitter

Spring Creek (BCSUS, BSCS); field observations indicate that these emanate from sandstone of the Ferron Sandstone and Emery Sandstone members of the Mancos Shale, respectively, rather than from shale. Stratigraphic projection suggests that Yucca House Spring (YHS) also issues from sandstone of the Ferron Member, but bedrock is not exposed at that location, and this determination is uncertain. Geometric means of specific conductivity in seeps issuing from shale and sandstone were 11,966 and 2,362 µS/cm, respectively. Six surface water samples, collected from sources of water that likely infiltrated into the Mancos Shale and fed some of the seeps had specific conductivity values ranging from 114 to 6,529 µS/cm (Figure 18).

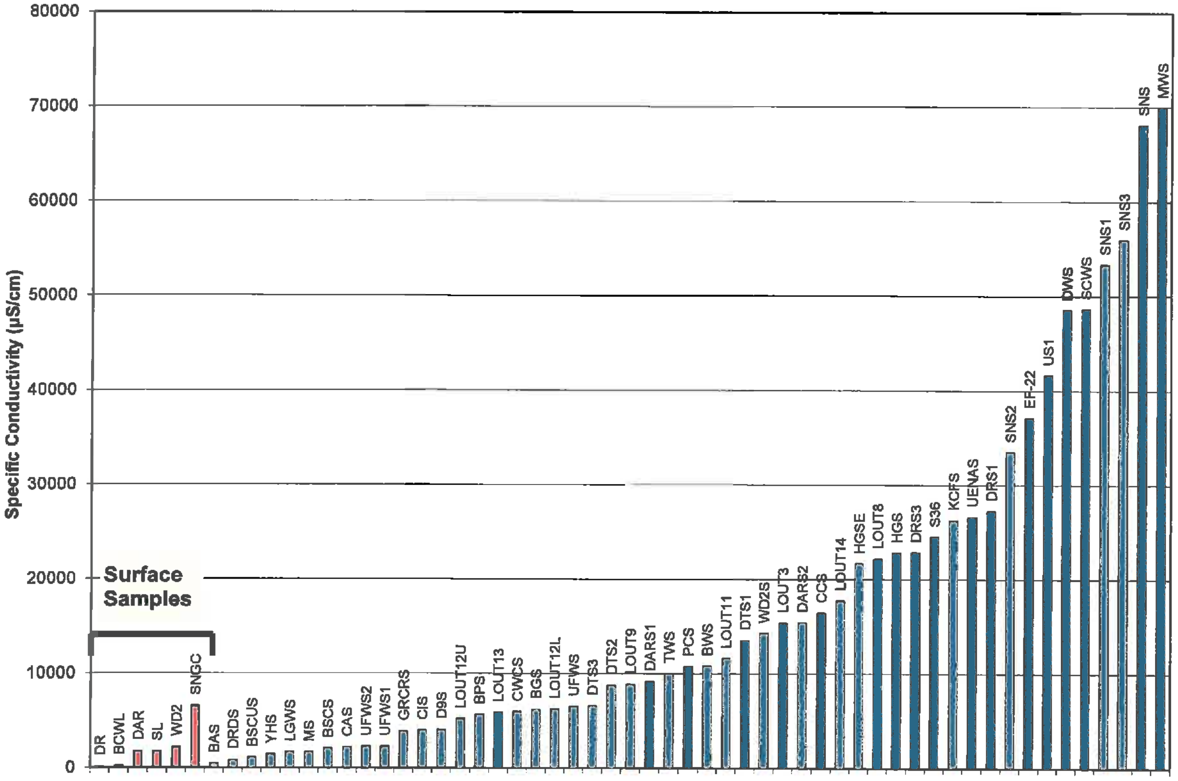

Figure 18. Specific Conductivity (µS/cm) in Surface Water (Red) and Seep (Blue) Samples

Values of pH in the seep samples ranged from 4.15 to 8.45 with a geometric mean of 7.32. Only four seep samples had pH values more than 8; three of these (SNS, SNS2, and US1) were collected in the seepage area at Sweitzer Lake, and the fourth was collected at Dutchmans Wash (DWS). More than half of the seep samples had pH values of less than 7.5. Thus, nearly all the seep samples were lower in pH than the surface water samples (Figure 19). Anomalously low pH values were measured at a tributary to Whitewater Creek, Colorado, where the seep sample (WCTS) had a pH of 4.15, and the surface water sample (WD2S) had a value of 6.57. The cause of these uncharacteristically low pH values is unknown. Surface water samples were typically higher in pH; five of the six surface water samples had a pH of more than 8 (Figure 19).

Concentrations of major cations (calcium, magnesium, sodium, potassium) and anions (carbonate, chloride, and sulfate) are often used to characterize water types and to help evaluate their origins and reactive history (Hem 1985). Groundwater from most seeps had a sodium sulfate composition (Figure 20). Four samples had a significant (more than 30 percent) bicarbonate component, and about half of the samples contained more than 50 percent calcium plus magnesium. As the specific conductivity values of the seeps increased, so did the dominance of sulfate and sodium; however, magnesium was prevalent even in the high-salinity samples (Figure 21).

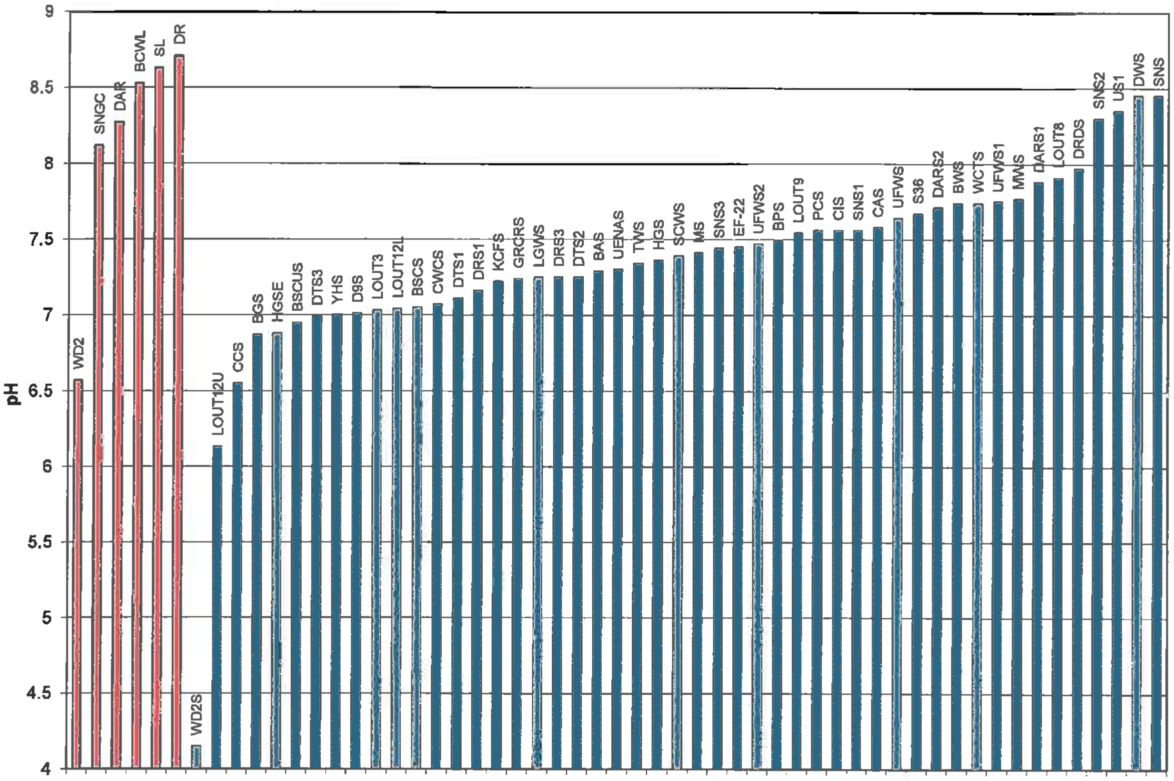

Figure 19. pH Values in Surface Water (Red) and Seep (Blue) Samples

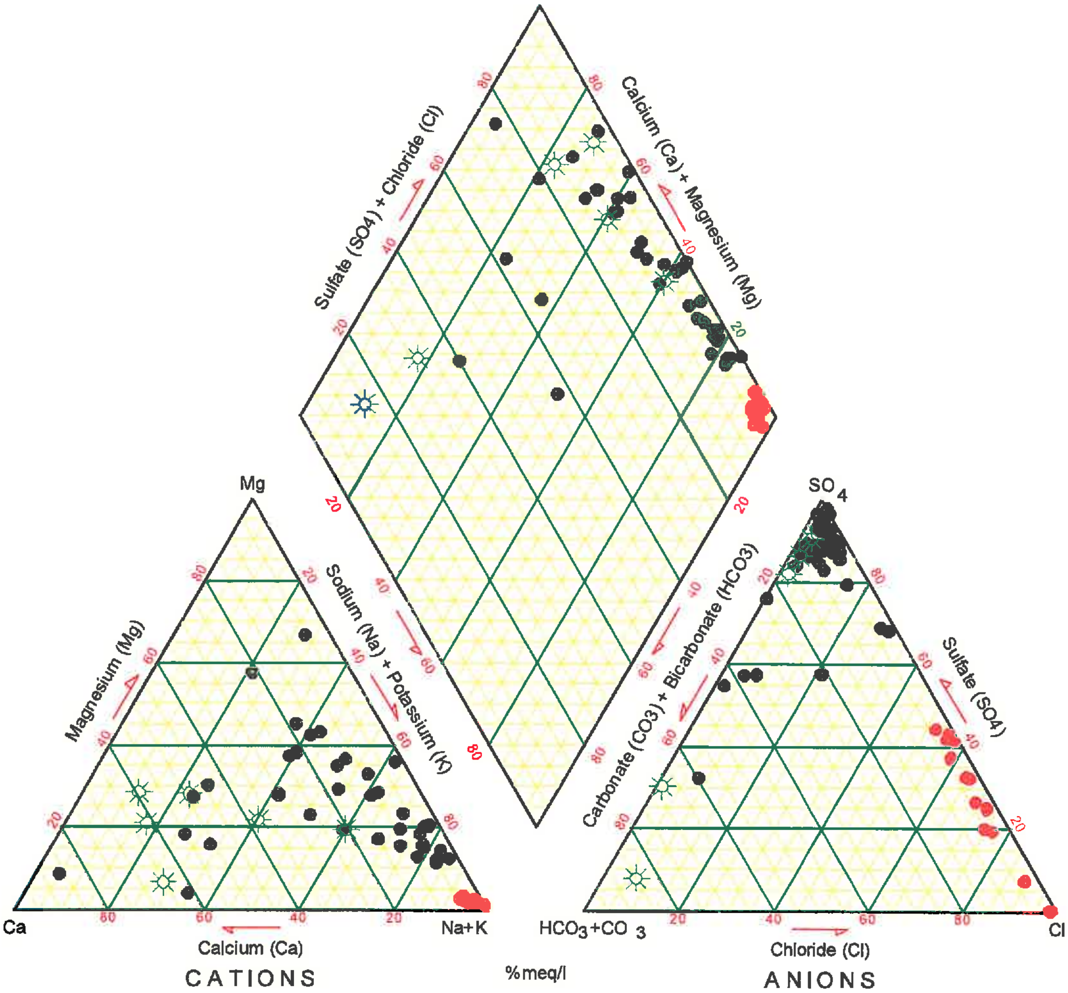

Figure 20. Piper Diagram Showing All Sampled Locations of Mancos Groundwater and Surface Water (black dots = seeps, blue stars = surface water, red dots = deep Mancos wells).

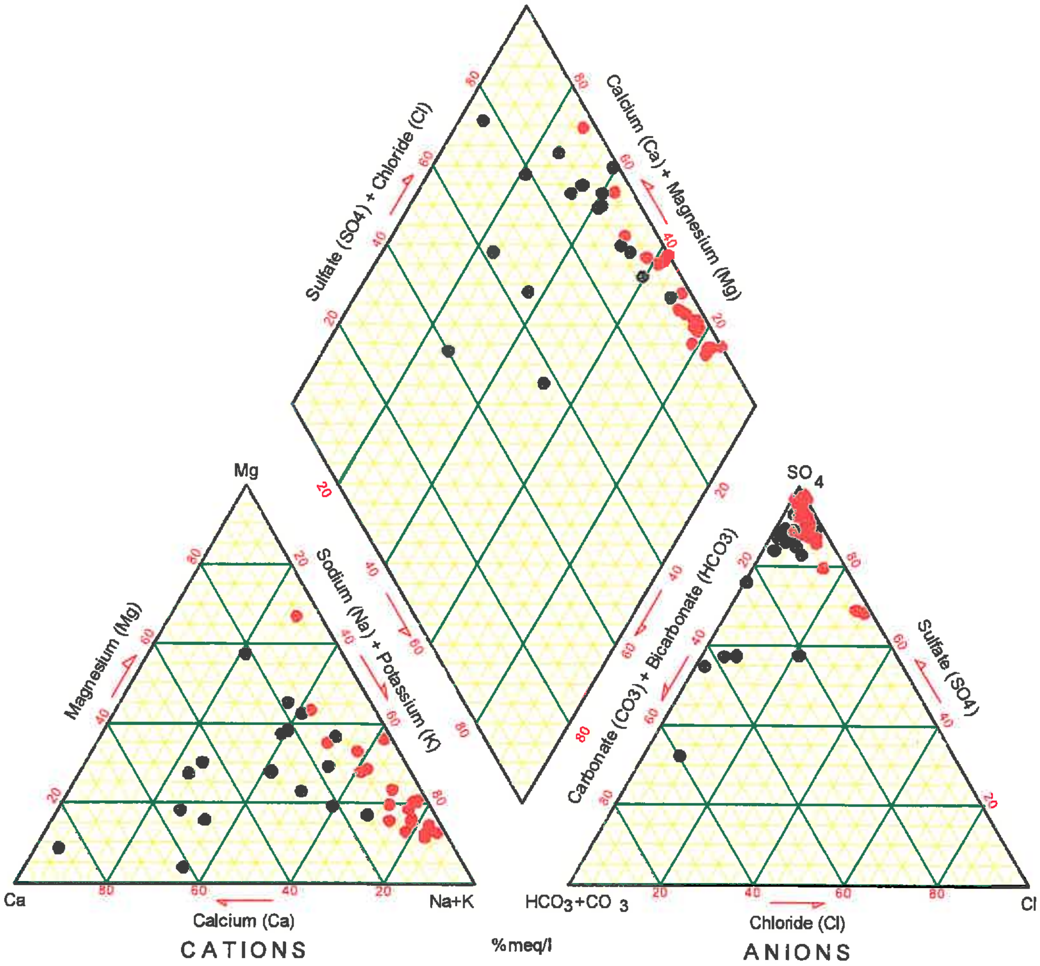

Figure 21. Piper Diagram of Seep Samples Showing Relationship of Seeps to Specific Conductivity. Red dots are samples with specific conductivity higher than 10,000 μS/cm. Black dots are samples with specific conductivity lower than 10,000 μS/cm.

Groundwater data from other studies were used to characterize deep (more than 90 ft below ground surface) horizons in the Mancos Shale. These include analyses of samples collected by DOE from wells used to characterize the geology of a uranium mill tailings disposal site at Crescent Junction, Utah, and from a former uranium mill site at Shiprock, New Mexico (DOE 2007). Groundwater data were also available from a deep Mancos Shale well at the Delta Landfill near the Devil's Thumb Golf Course in Delta County, Colorado, collected and analyzed by Golder Associates (2004). Mancos Shale groundwater samples from 16 deep wells examined for this study had specific conductivity values ranging from 17,030 to 66,120 μS/cm and pH values ranging from 6.84 to 8.2. The groundwater in the deep, unweathered Mancos Shale had a sodium chloride composition, in stark contrast to the sulfate-dominated water in shallow, weathered horizons (Figure 20). In a borehole at DOE's uranium mill tailings disposal site at Crescent Junction, Utah, groundwater flow through shale beds in the unweathered Mancos was confirmed using a downhole camera during which groundwater was observed flowing into the open borehole from fractures.

5.5 Nitrate (as NO_3)

Seeps at three sampling locations had nitrate concentrations of more than 3,000 mg/L, and samples from five additional locations had nitrate concentrations of more than 500 mg/L (Figure 22). Many values are higher than the drinking water standard of 44 mg/L (40 E-CFR 141). Two of the high-nitrate concentrations were from samples collected at locations SCWS and UENAS north of Shiprock, New Mexico, with nitrate concentrations of 1,074 and 3,614 mg/L, respectively. Samples collected from the Section 36 Seep (S36), Houston Gulch Seep (HGS), and Kannah Creek Flowline Spring (KCFS) had nitrate concentrations of more than 800 mg/L. Another area with high nitrate is Loutsenhizer Arroyo, where samples from four locations (LOUT8, LOUT3, LOUT9, and LOUT12U) exceeded 100 mg/L. The two seeps at Daly Reservoir had nitrate concentrations of 150 and 449 mg/L, and two seeps east of Delta Reservoir had concentrations of 76 and 535 mg/L. Two of the seeps near Devil's Thumb Golf Course had nitrate concentrations of 389 and 413 mg/L. Samples collected near the golf course may have some nitrate contributed from fertilizer. Five of the six surface water samples contained less than 3.7 mg/L of nitrate. The sixth sample was collected at the Sweitzer Lake Garnet Canal (SNGC) and had a nitrate concentration of 92 mg/L. Despite the higher concentration of nitrate in the Sweitzer Lake Garnet Canal, the seep samples from sites SNS3 and SNS at the Sweitzer Lake seepage area had relatively low nitrate concentrations of only 4.1 and 18 mg/L, respectively.

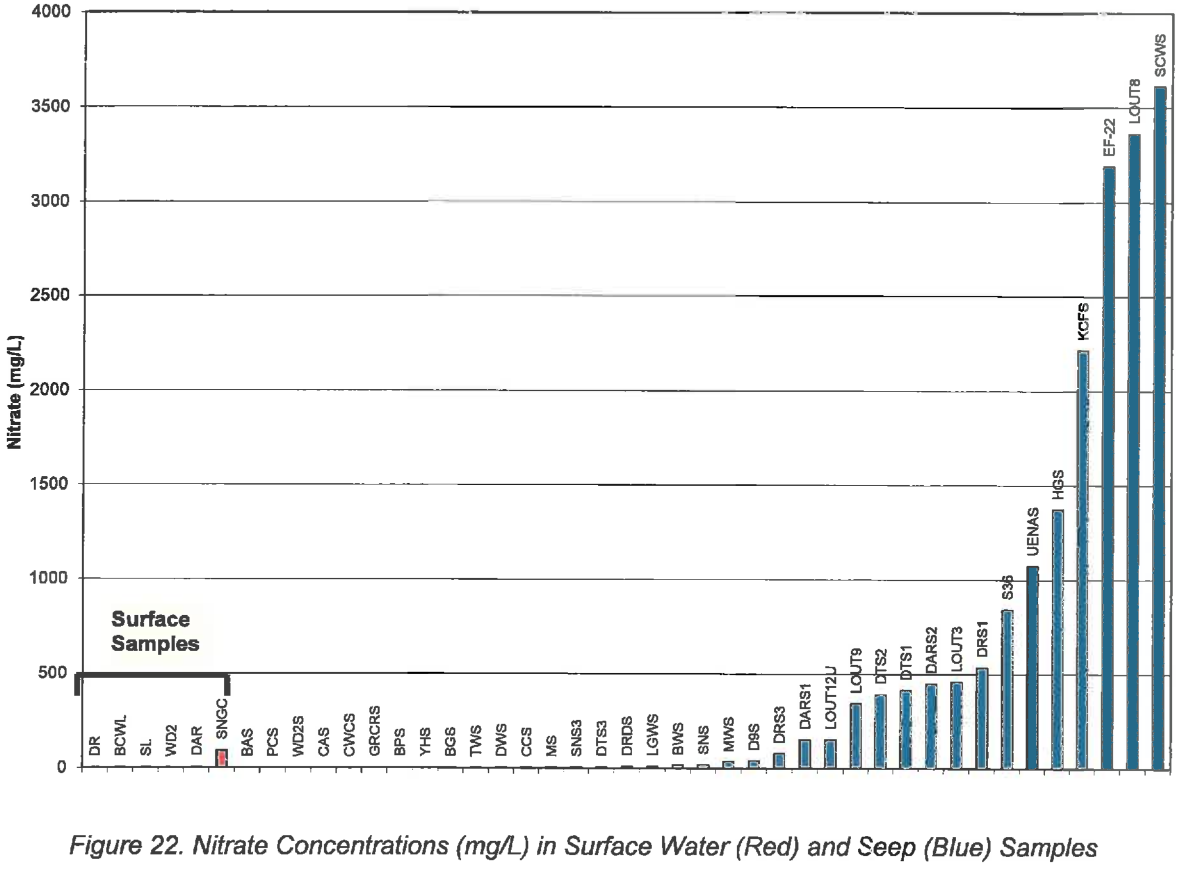

Figure 22. Nitrate Concentrations (mg/L) in Surface Water (Red) and Seep (Blue) Samples

5.6 Radon-222

Two samples were collected for radon-222 analysis at each sampling location, one early during the sampling and another near the end after most other samples had been collected. Generally, the sample collected later had a higher radon-222 value than the earlier one, suggesting that the early water sample had been affected by atmospheric exposure in the borehole, but that less-disturbed formation water was entering the borehole during purging and sampling. The higher of the two values is used for the discussion because the higher value is likely to be most representative of the radon-222 concentration in the formation water.

The highest radon-222 concentration in the six surface samples was 49.8 pCi/L, and all other concentrations were less than 12.6 pCi/L (Figure 23). These low values confirm that radon-222 is released to the atmosphere from standing bodies of water. Seep samples ranged from less than 1 to 1,625 pCi/L. The data show a plateau at about 425 pCi/L and another at about 800 pCi/L (Figure 23), and these values may be indicative of average values for the Mancos Shale. The plateau at 425 pCi/L included three sites in the Loutsenhizer Arroyo Area, and it seems reasonable that this value may represent in situ concentrations for the Mancos Shale in that area. However, the concentration of radon-222 in the groundwater varies from site to site, and data can only be used as a qualitative indicator of atmospheric exposure. The three seep samples (DWS, LGWS, and BGS) with the lowest radon-222 values were collected from water that had flowed along the surface a short distance, and there was opportunity for radon to be lost to the atmosphere.

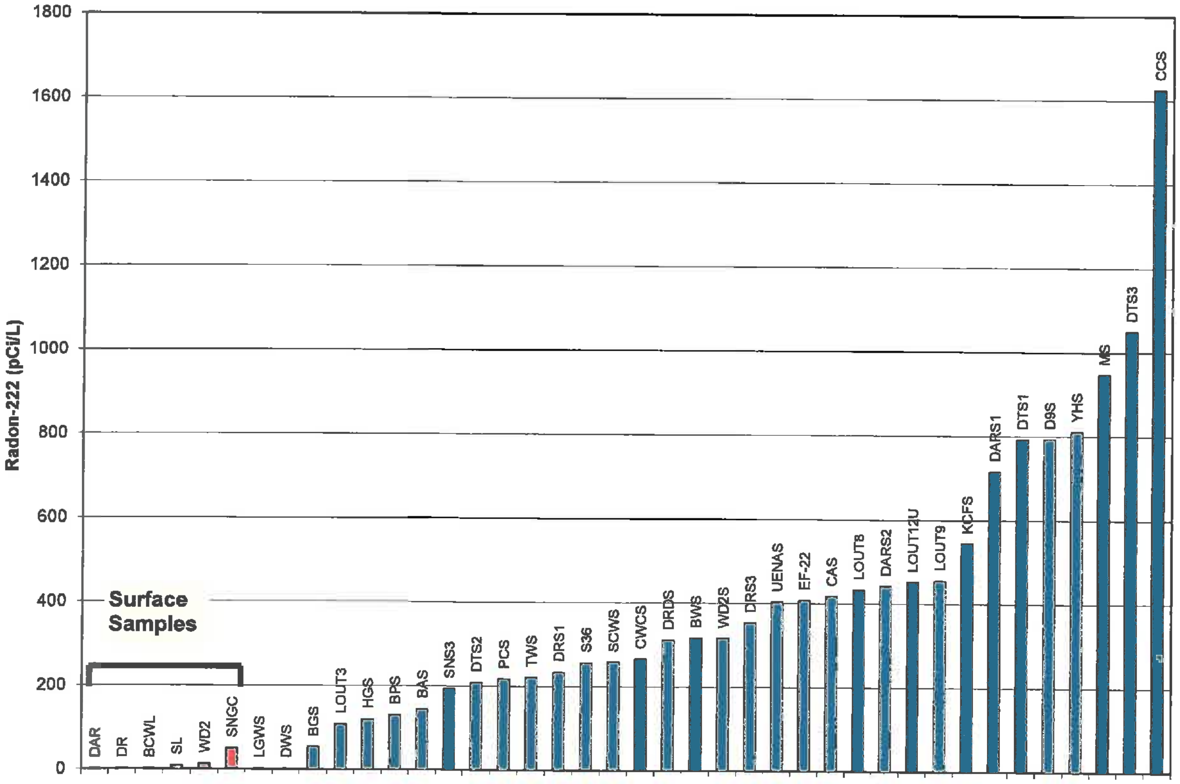

Figure 23. Radon-222 Concentrations (pCi/L) in Surface Water (Red) and Seep (Blue) Samples

5.7 Selenium

Selenium concentrations in seep samples ranged from 0.14 to 4,700 µg/L with a geometric mean of 51.5 µg/L. Many values are higher than the drinking water standard of 50 µg/L (40 E-CFR 141). Four of the sites (LOUT3, LOUT8, LOUT9, and LOUT12U) in Loutsenhizer Arroyo had selenium concentrations of more than 700 µg/L, and the LOUT8 sample had the highest value of 4,700 µg/L (Figure 24). Selenium concentrations of more than 1,000 µg/L occurred in seeps at Section 36 (S36) near Cisco, at EF-22 and SCWS near Shiprock, and at KCFS near Grand Junction. Samples of seeps from two sites at Sweitzer Lake were sampled for selenium; one (SNS) had a high value of 3,500 µg/L, whereas the concentration in the other (SNS3) was only 13 µg/L. The two seeps at Daly Reservoir had selenium concentrations of 110 and 400 µg/L, whereas concentrations in those at Delta Reservoir were 100 and 950 µg/L. All of the seeps associated with sandstone were relatively low in dissolved selenium (a geometric mean of 3.0 µg/L) compared to seeps associated with shale, which had a geometric mean of 124.2 µg/L. Seeps at sites that were elevated in other contaminants but were low in selenium include Point Creek, Dutchmans Wash, and Cedar Creek. Five of the six surface samples had low selenium concentrations (less than 15 µg/L), but the Garnet Canal sample at Sweitzer Lake had 110 µg/L selenium, probably derived from irrigation return flow.

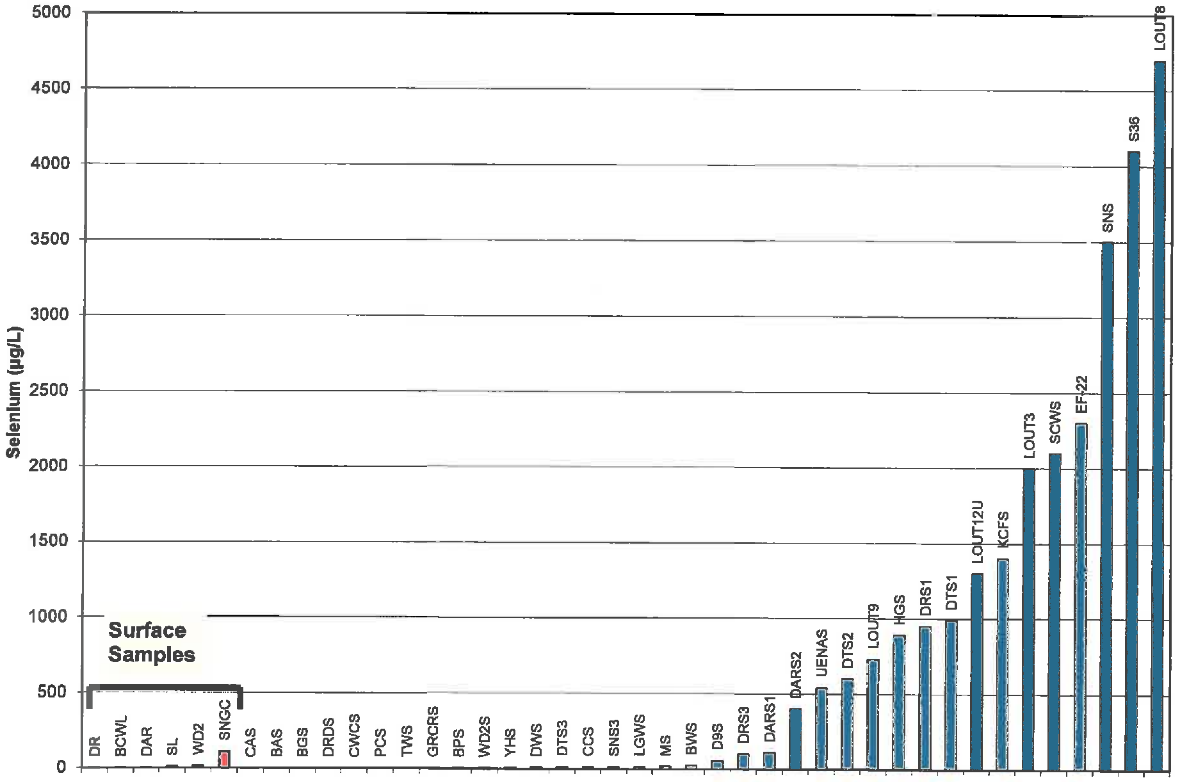

Figure 24. Selenium Concentrations (µg/L) in Surface Water (Red) and Seep (Blue) Samples

5.8 Uranium

Uranium concentrations in groundwater samples collected for this study ranged from 0.2 to 1,922 µg/L and had a geometric mean of 49.7 µg/L (Figure 25). Many values are higher than the drinking water standard of 30 µg/L (40 E-CFR 141). Five samples (SNS, SNS1, SNS2, SNS3, and US1) with uranium concentrations more than 200 µg/L were collected from the seepage east and northeast of Sweitzer Lake. Seepage formed a marsh area covered by thick efflorescence. Thus, although care was taken to ensure that groundwater flowed to each shallow (2 ft deep) sampling hole, upward capillary flow and evaporation may have concentrated dissolved constituents in these samples. Other samples with uranium concentrations more than 200 µg/L were collected at seeps near Whitewater, Colorado (WCTS); Mathis Wash (MWS) and Dutchmans Wash (DWS) near Price, Utah; Houston Gulch (HGS) near Montrose, Colorado; and Point Creek (PCS) near Delta, Colorado. All of these seeps except Point Creek are in or near irrigated areas and are likely fed from irrigation canal water. Point Creek is in a remote area, and no source of water for this seep was apparent during our reconnaissance. Samples from locations near Shiprock (EF-22 and SCWS), Loutsenhizer Arroyo (LOUT3, LOUT8, LOUT9), Delta Reservoir and Devil's Thumb Golf Course Area (DRS3 and DTS1), and Section 36 (S36) had uranium concentrations between 100 and 200 µg/L, which are all well above the mean value of 8.1 µg/L for the Four Corners states (USGS 2011b). Uranium concentrations in seep samples collected from shale beds were higher than those from seeps that discharged from sandstone. The geometric mean of uranium in shale bed seeps was 83.4 µg/L, and the geometric mean for sandstone seeps was 7.3 µg/L. Uranium in samples from the deep, unweathered Mancos Shale had a geometric mean of 7.4 µg/L (Table 3).

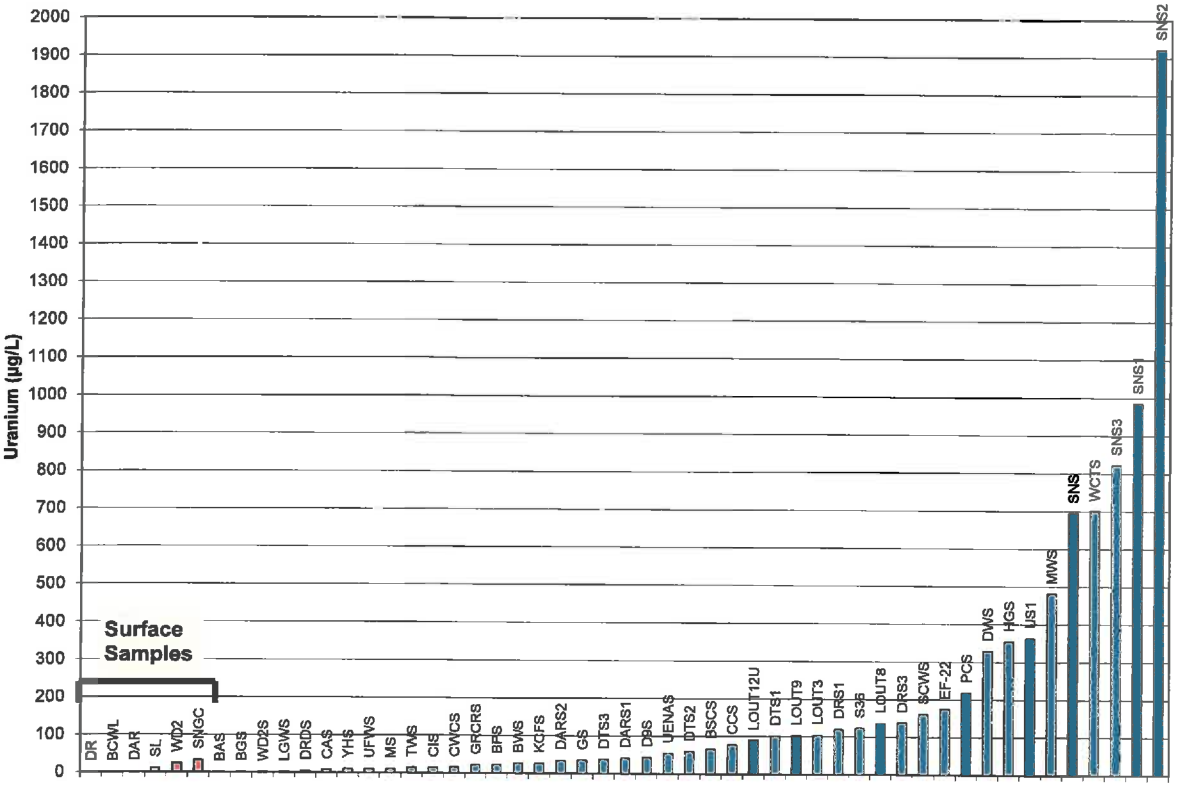

Figure 25. Uranium Concentrations (µg/L) in Surface Water (Red) and Seep (Blue) Samples

Table 3. Uranium Concentration (µg/L) Statistics for Samples from this Study

	Count	Minimum	Maximum	Geometric Mean
All Seeps	45	0.2	1922	49.7
Shale Seeps	38	1.0	1922	83.4
Sandstone Seeps	8	0.2	76.7	7.3
Deep Wells	15	0.23	270	7.4
Surface Water	6	0.20	32.8	2.9

5.9 Uranium Isotopes

Uranium-234 and -238 isotopes were analyzed on all samples that had sufficient sample volume and sufficient uranium concentrations (generally, more than about 0.5 µg/L). Uranium concentrations in samples BGS, WD2S, BAS, and DR were too low to get quantifiable uranium isotopic results with the counting times used. Uranium activity ratios (ARs) of uranium-234 to uranium-238 ranged from 1.22 to 4.08, and uranium concentrations ranged from 1.5 to 822 µg/L (Table 4). AR values ranged from 1.50 to 3.06 at the five surface water sites, and uranium concentrations ranged from 0.40 to 32.8 µg/L.

Table 4. Ranges and Geometric Means of Uranium Concentration (µg/L) and AR for the 38 Samples with Quantifiable Uranium Isotopic Results

	No. of Samples	Range of U Concentration	Geometric Mean U	Range AR Values	Geometric Mean AR
Seeps	33	1.5–822	53.6	1.22–4.08	2.05
Surface Sites	5	0.40–32.8	4.9	1.50–3.06	1.90

Uranium isotopic analyses are often used to help interpret the chemical evolution of groundwater systems (Osmond and Cowart 1976). Because our samples were collected from widely separated areas on the Colorado Plateau and are not from a single aquifer system, it was not possible to interpret groundwater evolution with these data. However, the results can be used to better understand the variation in uranium isotopic signatures in groundwater that interacts with the Mancos Shale. Figure 26 shows the AR values plotted against uranium concentration and displays relative specific conductance values (symbol size) and water-type designation (symbol color). All samples of both seeps and surface water had uranium-234 activities greater than the secular equilibrium values. There was little difference between AR values for seeps from shale and those from sandstone; the geometric means were 2.06 and 1.95, respectively. There were no obvious correlations between AR values and lithology, stratigraphic position, uranium concentration, or groundwater chemistry. A seep sample from the Whitewater Area (KCFS) had the highest AR of 4.08. More than half of the seep samples had AR values greater than 2.0, including samples from the Green River Region (CAS, LGWS, and S36), Hanksville Region (TWS), Delta Area (DRS1, DRS3, DTS1, DTS2, DTS3, Price Region (DWS), Shiprock Region (D9S, EF-22, SCWS, UENAS, and YHS), and Buen Pastor Spring at Sweitzer Lake (Figure 26). AR values of the surface samples were all more than 1.50, and the sample from Daly Reservoir (DAR) had the highest surface water AR value of 3.06. The four samples from Loutsenhizer Arroyo had consistent AR values ranging from 1.71 to 1.87. AR was measured on February 15, 2001, on a single sample from the deep, unweathered Mancos Shale at Shiprock, and this result is plotted on Figure 26 for comparison.

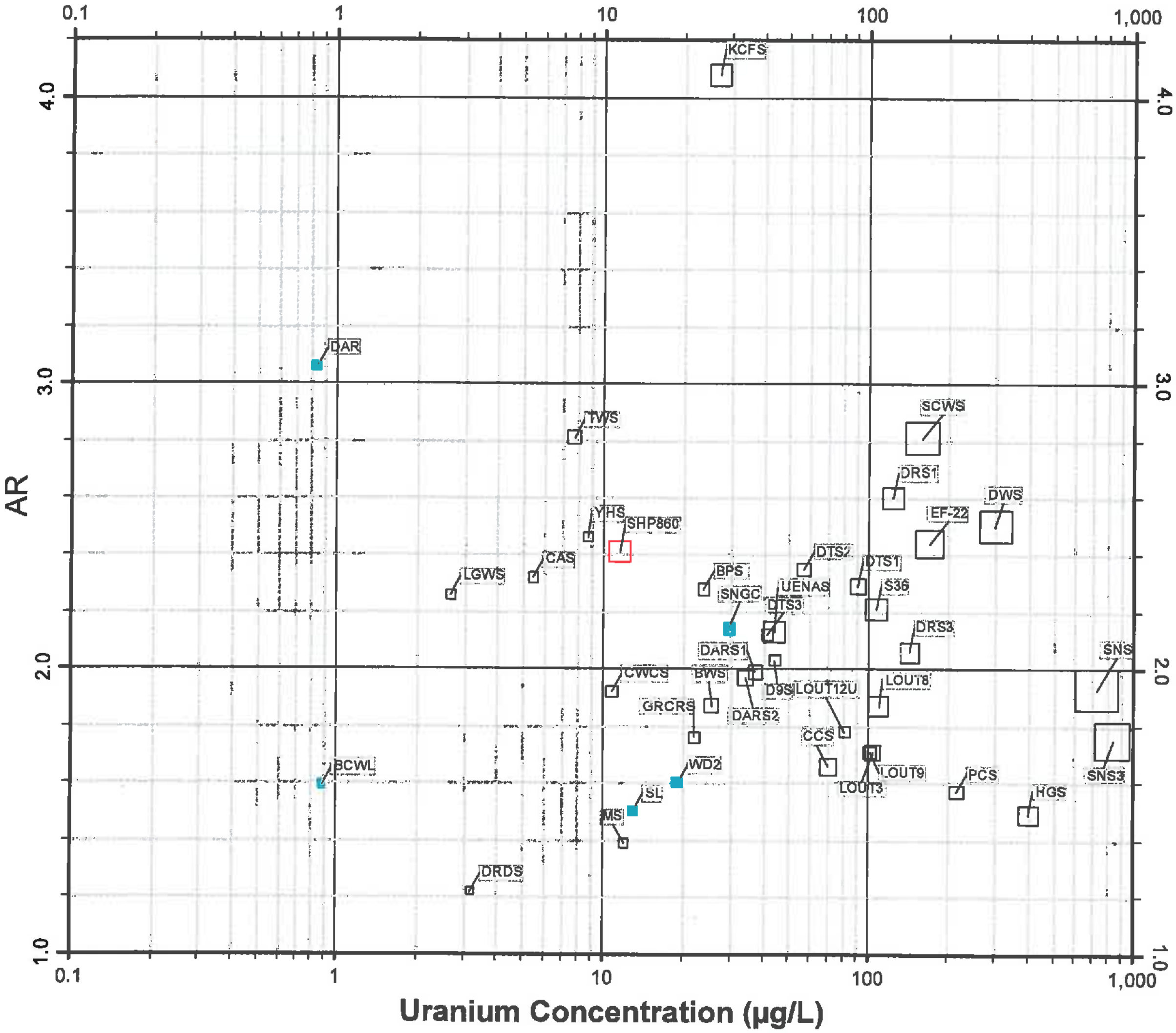

Figure 26. Binary Plot of AR Versus Uranium Concentration for all Samples Analyzed in the Study. Size of square represents relative specific conductivity value. Red, black, and turquoise symbols represent deep well, groundwater, and surface water samples, respectively.

5.10 Vanadium

Vanadium concentrations were low in all samples. The highest value of 19 µg/L was measured in sample SNS from Sweitzer Lake. All other samples had vanadium concentrations less than 3.8 µg/L (Figure 27).

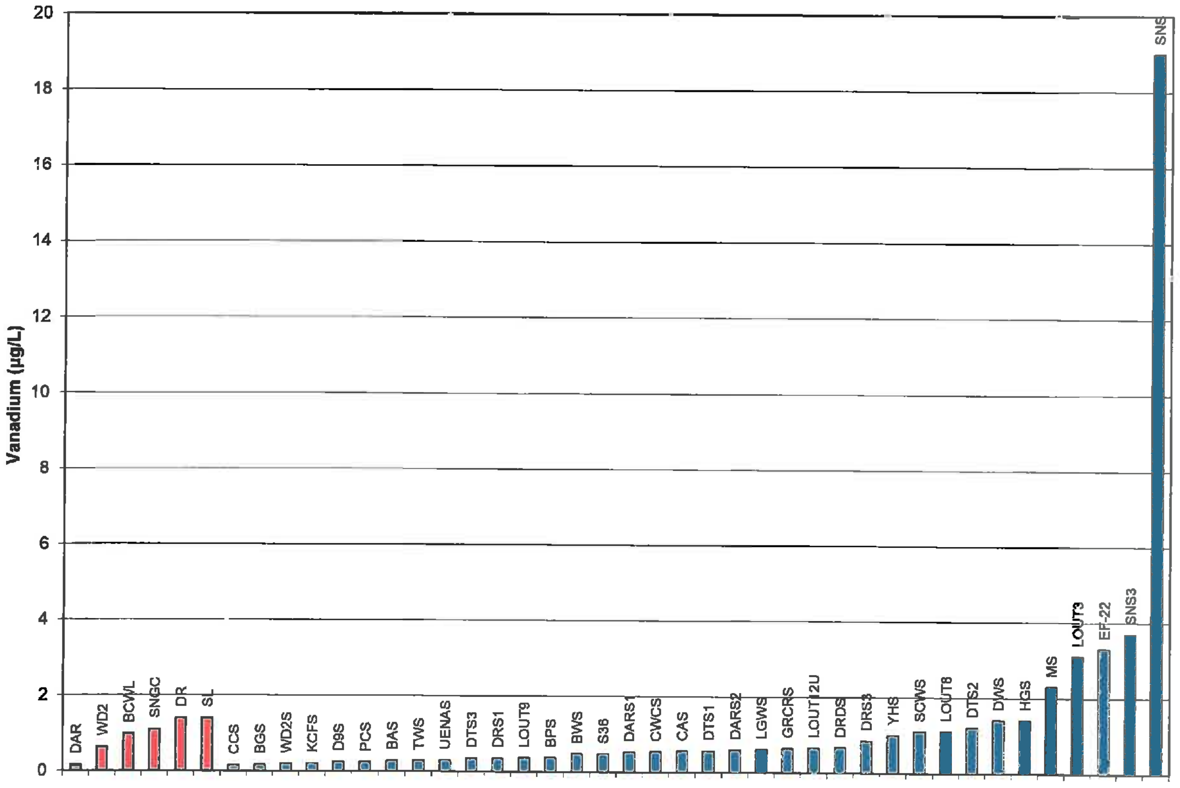

Figure 27. Vanadium Concentrations (µg/L) in Surface Water (Red) and Seep (Blue) Samples

6.0 Discussion

Naturally contaminated seeps develop in areas where water contacts shale of the Mancos Shale and the topography is favorable. The seeps often have specific conductivity values exceeding 15,000 µS/cm, indicating that they have high salinity. Butler et al. (1994) also reported values of high specific conductivity from the weathered Mancos Shale for eight groundwater sampling locations in the Uncompahgre and Grand Valley project areas, where specific conductivity values ranged from 3,650 to 13,900 µS/cm. Groundwater in the weathered Mancos Shale has a sodium sulfate composition, whereas groundwater in the unweathered Mancos Shale has a sodium chloride composition.

Concentrations of nitrate, selenium, and uranium in groundwater from shale beds of Mancos are usually higher than the Safe Drinking Water Act (40 e-CFR 141) drinking water standard, often by a factor of 10. Thus, evaluations of contaminant plumes in Mancos Shale terrain should consider the possible contribution of natural contamination. Because of the wide geographic separation of the sampling locations and the association with various geologic units of the Mancos Shale, we conclude that natural contamination from Mancos Shale is ubiquitous and is not confined to specific areas or specific geologic members. Contaminant concentrations are higher in groundwater flowing through shale than in groundwater flowing through sandstone, as indicated by the geometric means in Table 5.

Table 5. Geometric Means of Mancos Groundwater Concentrations for Shale and Sandstone Aquifers

Analysis	Shale	Sandstone
Uranium (µg/L)	83.4	7.3
Selenium (µg/L)	124.2	3.0
Nitrate (mg/L)	68.2	2.2
Boron (µg/L)	692.1	110.4
Specific Conductivity (µS/cm)	14,086	2,108

Although care was taken to ensure that all of the groundwater samples were collected from active seepage areas, some of the sampling sites were obscured by alluvium or soil, and some could have been affected by fertilizer chemicals. For the following discussion, six key areas were selected that were either isolated from irrigated areas or the source of recharge water was known and was accessible for sampling. These areas are Daly Reservoir, Delta Reservoir, Loutsenhizer Arroyo, Point Creek Seep, Salt Creek Wash, and Upper Eagle Nest Arroyo. The chemistry of samples collected from the seeps at these key areas is a direct result of interaction with the host rock. Because bedrock and seeps are well exposed at these six areas, the exact point where the seeps emerge from dark-gray shale bedrock could be observed, and samples were collected at that point. The construction and water level history of Delta Reservoir (Figure 3) are well known, and the water infiltrating the Mancos Shale is pristine, having been derived from high on the Grand Mesa. Once this water enters the groundwater, it flows through Mancos Shale to the seeps at locations DRS1 and DRS3, located about 1,400 ft from the reservoir. Thus, any constituents dissolved in the seep water must have been derived from chemical transfer from the Mancos Shale to the groundwater.

A similar situation exists at Daly Reservoir (Figure 10) with sampling sites DARS1 and DARS2 located 230 and 360 ft from the reservoir, respectively; however, the infiltrating water is not as pristine, having been derived from ephemeral surface flows in this arid region. Because the composition of the water in Daly Reservoir is known from analysis, the constituents derived from Mancos Shale can be determined by difference. At Loutsenhizer Arroyo (and its tributaries), groundwater emerging as seeps likely is from the upland West Lateral of the Bostwick Canal located about 800 ft (LOUT9) to 4,700 ft (LOUT3) hydraulically upgradient (Figure 12). Bostwick Canal conveys pristine water from the north side of the San Juan Mountains to irrigate agricultural fields in Bostwick Park (Figure 12). Infiltration from the irrigated fields supplies some of the groundwater in Loutsenhizer Arroyo, but infiltration from applied irrigation water is probably minimal compared to the seepage contribution from the canal itself. Bostwick Canal receives irrigation return and thus is not pristine; however, because the composition of the canal water is known from chemical analysis, again the constituent contributions from Mancos Shale can be determined by comparison. The sources of water at Point Creek Seep, Salt Creek Wash, and Upper Eagle Nest Arroyo are unknown; however, there are no obvious anthropogenic water sources in these remote areas.

Because the geologic and hydrologic relationships at these areas are well known, data from them are emphasized in the following discussion of the origin of the seep chemistry. Table 6 shows the composition of natural contaminants in the seeps from the six areas. In all these key areas, concentrations of nitrate, selenium, sulfate, and uranium are elevated, indicating a natural contamination source in the Mancos Shale.

Table 6. Concentrations of Groundwater Constituents in Six Key Areas

Area	Location	Specific Cond. (µS/cm)	SO_4 (mg/L)	NO_3 (mg/L)	U (µg/L)	Se (µg/L)
Daly Reservoir	DARS1	9,187	5,729	150	39.7	110
Daly Reservoir	DARS2	15,377	9,865	449	33.2	400
Delta Reservoir	DRS1	27,250	18,497	534	119.1	950
Delta Reservoir	DRS3	22,840	15,087	76	137.2	100
Point Creek	PCS	10,739	7,282	<0.5	217.6	1.5
Salt Creek Wash	SCWS	48,639	23,800	3,614	160.3	2,100
Upper Eagle Nest Arroyo	UENAS	26,607	12,839	1,074	53	540
Loutsenhizer Arroyo	LOUT3	15,330	8,820	459	102.6	2,000
Loutsenhizer Arroyo	LOUT8	22,130	14,942	3,361	135.2	4,700
Loutsenhizer Arroyo	LOUT9	8,844	5,696	342	101.6	730
	Standard[a]	na	na	44	30	10

[a] Safe Drinking Water Act standard (40 e-CFR 141)
na = not applicable

6.1 Geochemistry and Mineralogy of Marine Black Shale and Mancos Shale

To understand the origin and evolution of groundwater chemistry, it is important to know the mineralogy and chemical exchange capacity of the Mancos Shale with which the groundwater interacts. This section is a summary of the literature containing data on the solid-phase composition and groundwater chemistry of the Mancos Shale, leading to development of a conceptual model for the chemical evolution of the Mancos Shale groundwater. Finally, we numerically simulate processes comprising the conceptual model using a numerical reaction progress modeling approach.

Clay minerals, sulfide minerals, organic matter, carbonate minerals, and sulfate minerals are likely to have an effect on Mancos Shale groundwater chemistry. It is also important to know the solid-phase residences of the chemical constituents. Mass transfer processes likely to be important in controlling groundwater chemistry include ion exchange, mineral dissolution and precipitation, adsorption, and desorption. Table 7 shows a generalized composite of the mineralogical and chemical composition of shale beds in the Mancos Shale based on information presented in the following sections. This generalized composite is used later to help understand the interactions of Mancos Shale with groundwater.

The geochemical and mineralogical contents of the Mancos Shale and some major black shale formations, as discussed herein, were derived from multiple information sources. As part of DOE's siting evaluation for the Crescent Junction uranium mill tailings disposal site, we logged and analyzed core samples collected from 10 borings of the Prairie Canyon and Lower Blue Gate Members of the Mancos Shale (DOE 2007). All 10 borings were cored continuously to a depth of 300 ft below ground surface. Core was logged, and selected samples were analyzed for chemistry and mineralogy. Tuttle et al. (2007) excavated trenches in the Mancos Shale and associated soils in three areas: (1) Elephant Skin Wash located near the upper reach of Loutsenhizer Arroyo about 1.5 miles due west of our location LOUT9, (2) Candy Lane located about 10 miles due north of Montrose, Colorado, and (3) Hanksville, Utah[1]. Butler et al. (1994) analyzed four samples of weathered Mancos Shale, two samples of unweathered Mancos Shale, and two samples of ash beds (bentonite beds) from the Uncompahgre Valley and Grand Valley areas in Colorado[2]. Results from these three studies are presented in this report section along with other literature data from additional sources.

Table 7. Generalized Mineralogical and Chemical Composite of Unweathered Shale in Mancos Shale

Mineralogy	
Carbonate Content	20%
Cation Exchange Capacity	20 meq/100 g
Clay Minerals	mixed-layer illite/smectite, illite, kaolinite
Gypsum Content	present
Minerals Present	calcite, dolomite, feldspar, gypsum, halite, nahcolite, pyrite, quartz, sylvite
Nahcolite, Halite	trace
Pyrite Content	1%
Surface Area	10 m^2/g
Chemistry	
Arsenic	15 mg/kg
Boron	50 mg/kg
Organic Carbon	1% C
Selenium	2 mg/kg
Uranium	3.7 mg/kg
Vanadium	100 mg/kg

meq/100 g = milliequivalents per 100 grams
m^2/g = square meters per gram

6.1.1 Arsenic Content

The average arsenic concentration in 21 samples of shale and marlstone of the Pierre Shale analyzed by Tourtelot (1962) was 14 mg/kg; one additional sample that was particularly rich in organic matter had an anomalously high arsenic content of 41 mg/kg. Schultz et al. (1980) determined the arithmetic mean arsenic concentration of more than 200 shale and siltstone samples of the Pierre Shale to be 14 mg/kg with a standard deviation of 35 mg/kg.

Butler et al. (1994) reported arsenic contents of 2 unweathered shale samples of 10 and 22 mg/kg, ash beds of 20 and 25 mg/kg of arsenic, and 4 samples of weathered shale of 10 mg/kg or less. Tuttle et al. (2007) reported arithmetic means for arsenic concentrations on 72 samples from Elephant Skin Wash, 94 samples from Candy Lane, and 16 samples from Hanksville as 5.82, 11.93, and 4.63 mg/kg, respectively.

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[1] The exact location near Hanksville was not provided. Chemical digestion methods for the core and soil samples were not provided, but we assume the results represent total digestions.

[2] The chemical digestion methods are uncertain, but we presume that the results represent a total digestion, including resistate grains.

6.1.2 Boron Content

Harder (1970) provided mean boron concentrations of 100 mg/kg for clay and shale, 35 mg/kg for sandstone, 27 mg/kg for limestone, and 28 mg/kg for dolomite. Boron occupies tetrahedral sites in mica, and the concentration of boron in illite had been used as an index of paleosalinity, although this concept has not received widespread acceptance (Harder 1970). Boron concentrations in 67 samples of shale and marlstone of the Pierre Shale measured by Tourtelot (1962) ranged from 15 to 150 mg/kg with most values near 30 mg/kg. Schultz et al. (1980) determined the arithmetic mean boron concentration of more than 200 shale and siltstone samples of the Pierre Shale to be 99 mg/kg with a standard deviation of 49 mg/kg. Schultz et al. (1980) found that high boron concentrations were present in both marine and nonmarine shale of the Pierre Shale, and thus, they were not a good indicator of salinity. They also found that boron concentrations did not correlate with organic carbon concentrations.

6.1.3 Carbonate and Sulfate Content

In a detailed study of drill core from the lower 855 feet of Mancos Shale in the Disappointment Syncline near Slick Rock, Colorado, Shawe (1968) analyzed concentrations of calcite from nine vertically separated samples. Calcite concentrations were as high as 40 percent and averaged about 20 percent throughout the core except in the Lower Carlile Shale[3], where it was nearly absent. It is not clear from Shawe's paper whether calcite content is presented as weight or volume percent, but weight percent is most likely based on the analytical method (carbon dioxide release following acid treatment) used. Shawe (1968) did not mention the presence of gypsum in the core.

Evangelou (1981) analyzed carbonate content of weathered and unweathered Mancos Shale at four locations in the West Salt Creek area of the Grand Valley, western Colorado. At each location, three or four samples were analyzed, and results are in weight percent. At three of the locations the arithmetic mean carbonate concentrations in the weathered and unweathered strata were 14.92 and 16.24 percent, respectively. At the fourth area, which was at the base of the Book Cliffs, the carbonate concentrations were lower, with arithmetic means of only 2.58 and 3.07 percent for weathered and unweathered shale, respectively, and dolomite was the only carbonate mineral present. Both calcite and dolomite were present at the other three sampling locations, and gypsum was present at all four locations in the weathered samples.

Evangelou et al. (1985) used column tests to investigate dissolution and desorption rates of carbonate minerals characteristic of weathered Mancos Shale in samples collected from Salt Creek Wash near Grand Junction, Colorado. They concluded that Mancos Shale is an important source of calcium and magnesium loading to surface waters. In column tests, they showed an early release of calcium that exceeded the solubility of calcite. They attributed the calcium release to dissolution of gypsum, but over time, the calcium release rate stabilized, and after a few hours calcium was in equilibrium with calcite. Magnesium release rate was variable but generally increased with time, and dolomite dissolution was thought to be an important source of the magnesium. Evangelou et al. (1985) also speculated that calcite coatings on dolomite may explain the variable magnesium release rates.

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[3] The lower part of the Carlile Shale referred to by Shawe (1968) corresponds to the Graneros, Bridge Creek, and Blue Hill Members of the Mancos Shale, as shown in Figure 13.

Core examination from the Crescent Junction, Utah, uranium mill tailings disposal site indicated that carbonate, mostly in the form of calcite, was present throughout both the weathered and unweathered Mancos Shale but was more concentrated in the weathered zone. Gypsum was common in the upper 50 ft of core but was nearly absent in the deeper unweathered Mancos.

Many authors (e.g., Laronne and Schumm 1982, Whittig et al. 1983, Whittig et al. 1986, Wright 2006) mention the widespread occurrence of gypsum in the Mancos but few data are available with which to quantify its abundance or distribution. Gypsum often occupies fractures and is more abundant in weathered Mancos.

6.1.4 Clay Mineralogy and Cation Exchange Capacity

In a comprehensive study of Mancos Shale clay mineralogy, Nadeau and Reynolds (1981) analyzed 580 samples of shale and bentonite collected at 154 sites throughout the Mancos Shale depositional basin. Samples were analyzed using X-ray powder diffraction on specimens treated (oriented, glycolated, and heated) so as to distinguish clay mineral types (e.g., illite versus smectite), approximate interlayering percentages, and ordering (ordered versus random). They found that the main clay in the shale was mixed layered illite/smectite with 20 to 60 percent illite layers. They suggested that burial metamorphism resulted in increased ordering as smectite layers converted to illite. Uncharacteristic of burial metamorphism was the retention of bentonite beds containing nearly pure smectite. Nadeau and Reynolds (1981) describe a correlation of carbonate content with these bentonites and speculate that the clay alteration was impeded by the presence of carbonate. Kaolinite was found to be a common accessory clay mineral in both bentonite and shale samples, discrete illite was a common accessory in the shale, but chlorite was rarely observed. In a study of clay mineralogy of the Pierre Shale in the northern Great Plains, Schultz (1964) found primarily randomly interstratified illite/smectite containing 20 to 60 percent illite layers, and pure smectitic bentonites.

In a detailed study of a drill core from the lower 855 ft of the Mancos Shale in the Disappointment Syncline near Slick Rock, Colorado, Shawe (1968) logged 24 thin layers of greenish-gray bentonitic shale, particularly in strata equivalent to the Greenhorn Limestone, Carlile Shale, and the lower Niobrara Formation[4]. Pyrite and swelling clays were more abundant in the bentonite-bearing beds. Shawe (1968) stated that the bentonite was likely volcanic ash-fall material. His measured sections of Mancos Shale contained claystone and mudstone beds (some were pyritic) but no bentonite beds, although bentonite was listed occasionally as a component of the claystone beds. Shawe (1968) also described petroliferous odor in some of the mudstone beds, carbonized plant fragments, and numerous observations of carbonates. He described limestone occurring as thin beds in the Mancos Shale, often only a fraction of an inch thick, and the limestone sometimes contained pyrite and/or organic matter.

As part of another DOE project, we measured cation exchange capacity on 20 core samples collected from the Crescent Junction uranium mill tailings disposal site and found a range of 0.54 to 36.29 meq/100 g, with an arithmetic mean of 11.23 meq/100 g. The clay fraction was dominated by mixed-layer (mostly illite-smectite) clays, illite, and kaolinite, with illite layers dominating the mixed-layer clays. Particle surface area was determined by multipoint Brunauer, Emmett, Teller (BET) analysis on 10 samples collected at a depth of 40 ft. The surface area of

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[4] These stratigraphic units are equivalent to the Graneros up through the Smoky Hill Members, as shown in Figure 13.

the 1 to 2 mm fractions of these samples ranged from 8.81 to 13.22 m^2/g with an arithmetic mean value of 11.02 m^2/g. Evangelou (1981) determined that the cation exchange capacity of weathered Mancos Shale samples ranged from 13.14 to 25.15 meq/100 g and provided a single value for unweathered Mancos of 13.02 meq/100 g.

6.1.5 Nitrogen Content

Holloway and Smith (2005) determined nitrogen concentrations of 0.10 to 0.13 percent (as N) on four shale samples of Mancos from the Grand Valley in the Grand Junction, Colorado, area. They found that 58 to 74 percent of the nitrogen was organic, and the rest may have been in ammonium associated with clay minerals and nitrate salts.

6.1.6 Organic Matter

The organic content of geologic materials including marine shale can be classified as sapropelic and humic matter (Vine et al. 1958). Sapropelic material is derived from hydrogen-rich organic matter such as algae, waxes, resins, and spores, whereas humic material is derived from more oxygen-rich plant remains such as lignin and cellulose. Petroleum is a product of sapropelic material, whereas peat, lignite, and coal are products of humic-rich material. Humic acid is soluble in weakly alkaline aqueous solution but forms a gel or precipitate at pH values less than about 4. Dissolved humic acid can impart a yellow or amber color to water similar to the color we observed in the Mancos Shale seeps. Diagenesis of humic acid results in an insoluble compound that can be redissolved under oxidized conditions such as occur during weathering (Vine et al. 1958; Swanson 1961).

Kakouros et al. (2006) determined organic carbon concentrations of 0.44 and 1.34 percent in one sample each from weathered and unweathered shale, respectively, in core samples of the Mancos Shale near Jensen, Utah. Leythaeuser (1973) measured mean organic carbon concentrations of 1.08 percent (11 samples) and 1.58 percent (6 samples) on relatively uniform shallow (21 ft) cores from a highly calcareous core and a noncalcareous core, respectively, in the Tununk Member of the Mancos Shale in Emery County, Utah. Butler et al. (1994) analyzed four samples of weathered Mancos Shale, two samples of unweathered Mancos Shale, and two samples of ash beds (bentonite beds) from the Mancos Shale in the Uncompahgre Valley and Grand Valley, Colorado, areas. The organic carbon contents of the two unweathered shale samples were 1.36 and 1.55 percent, the ash beds had 0.12 and 0.39 percent, and organic carbon in the weathered shale ranged from 0.44 to 0.64 percent with an arithmetic mean of 0.54 percent. Palsey et al. (1989, 1991) measured organic carbon concentrations ranging from 0.49 to 5.29 percent in core and outcrop samples of marine shale from the Mancos Shale just above and below the Tocito Sandstone in the San Juan Basin near Shiprock, New Mexico. Tourtelot (1962) observed that bentonites appeared as lighter-colored beds upon weathering because they are derived from volcanic ash and contain no organic matter. Holloway and Smith (2005) determined organic carbon concentrations of 2.00 to 2.53 percent on four shale samples of Mancos from the Grand Valley in the Grand Junction, Colorado, area. They found that 68 to 83 percent of the carbon in these samples was organic.

Organic carbon concentrations ranged from 0.6 to 7.4 percent in 18 samples of shale and marlstone of the Pierre Shale analyzed by Tourtelot (1962); another 40 samples had organic carbon concentrations less than 0.5 percent. Samples containing organic carbon of more than

1 percent had a distinctively dark color (Tourtelot 1962). Schultz et al. (1980) analyzed more than 200 shale and siltstone samples of the Pierre Shale and determined the arithmetic mean organic carbon concentration to be 0.94 percent with a standard deviation of 1.8 percent. Clayton and Swetland (1978) analyzed 15 samples of unweathered core samples from the Pierre Shale in Boulder County, Colorado, and found a tight range of 0.78 to 0.97 percent.

We found that samples of cores from the Crescent Junction disposal site commonly contained visible organic matter that was present mostly in the deeper unweathered horizons. Organic matter was often found in contact with pyrite and was typically disseminated as black, fine particles coating fracture planes or bedding surfaces.

6.1.7 Pyrite and Accessory Minerals

Although there are many references to the presence of pyrite in shale of the Mancos Shale, few data are available to quantify its abundance. In a detailed study of a drill core from the lower 855 ft of the Mancos Shale in the Disappointment Syncline near Slick Rock Colorado, Shawe (1968) used petrographic methods to determine concentrations of pyrite. The core contained pyrite concentrations up to 10 percent. Based on the methods used, we presume that the pyrite concentrations are in volume percent; however, the authors did not specify whether they are based on weight or volume. The highest pyrite concentrations were in the lower Niobrara Formation, the upper Carlile Shale, and the Greenhorn Limestone[5].

By analogy with typical sapropelic marine environments of today, Shawe (1976) indicated that hydrogen sulfide would be abundant at the bottom of the Mancos sea, but suggests that sulfur might also be derived from volcanic ash. Shawe (1976) observed compaction of bedding around pyrite crystals, indicating that the pyrite had formed earlier than the compaction and was likely formed syngenetically. Shawe (1976) also observed a lack of black opaque minerals such as magnetite and ilmenite in the Mancos Shale that he ascribed to dissolution by pore waters. Using petrographic data from uranium-bearing geologic formations, Adams et al. (1974) demonstrated the alteration of black opaque minerals to titanium oxide minerals by reducing solutions, and even suggested that magnetic susceptibility could be used to detect the loss of magnetite to reveal reducing provinces favorable for formation of uranium ores.

Samples from the Crescent Junction, Utah, cores commonly contained visible pyrite as shallow as 14 ft. Pyrite was noted in both weathered and unweathered Mancos and often was associated with organic matter. Pyrite was often framboidal but also occurred as coatings on fracture planes and as fossil shell replacements. Limonite staining was common in the core descriptions and likely reflected an oxidized product of former pyrite.

Fifty Mancos Shale core samples collected from 40 to 300 ft depths at the Crescent Junction disposal site were also analyzed for water soluble fraction (DOE 2007). Based on chemistry of the water soluble fractions, we deduced that the water soluble mineral suite was dominated by nahcolite, with major amounts of Ca-Na exchange and gypsum. Halite, sylvite, and dolomite occurred in lesser amounts, and calcite was present. X-ray diffraction analysis of 10 samples indicated that the shale was composed dominantly of quartz, with lesser amounts of dolomite and calcite, small amounts of feldspar, and traces of gypsum.

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[5] These stratigraphic units are equivalent, respectively, to the Smoky Hill, Juana Lopez, and Bridge Creek-Graneros Members, as shown in Figure 13.

6.1.8 Selenium Content

Kakouros et al. (2006) analyzed two core samples of Mancos Shale (one each of weathered and unweathered material) collected near Jensen, Utah. They found selenium concentrations in the weathered and unweathered shale samples of 3.0 and 1.9 mg/kg, respectively. Using selective extraction methods, they surmised that most of this selenium resided in the organic fraction.

The average selenium concentration in 21 samples of shale and marlstone of the Pierre Shale analyzed by Tourtelot (1962) was 2 mg/kg. One anomalously high value of 50 mg/kg occurred in a sample that was particularly rich in organic content. Schultz et al. (1980) determined an arithmetic mean selenium concentration for more than 200 shale and siltstone samples of the Pierre Shale to be 3.7 mg/kg with a standard deviation of 15 mg/kg.

Butler et al. (1994) analyzed four samples of weathered Mancos Shale, two samples of unweathered Mancos Shale, and two samples of ash beds (bentonite beds) from the Uncompahgre Valley and Grand Valley, Colorado, areas. The selenium contents of the two unweathered shale samples were 0.8 and 1.6 mg/kg; one sample from the ash beds had less than 0.1 mg/kg selenium, and the other had 3.9 mg/kg. Selenium in the weathered shale ranged from 0.8 to 1.6 mg/kg with an arithmetic mean of 1.1 mg/kg. Tuttle et al. (2007) derived arithmetic means of selenium concentrations for 72 samples from Elephant Skin Wash and 94 samples from Candy Lane in Colorado, and 16 samples from the Hanksville, Utah, area of 2.73, 2.94, and 1.09 mg/kg, respectively.

Thomas et al. (1998) analyzed selenium concentrations in stream bottom sediment and soils in a study of irrigation drainage to the San Juan River in New Mexico. They reported that the arithmetic mean and median selenium contents were 4.6 and 2.2 mg/kg for areas of Cretaceous bedrock, whereas in areas of non-Cretaceous bedrock the arithmetic mean and median contents were only 0.6 and 0.15 mg/kg.

6.1.9 Uranium Content

Because anomalously high uranium concentrations were known to exist in some black shale, an extensive campaign was undertaken in the 1940s and 1950s in the United States to test black shale for uranium content to determine its capacity as a uranium resource (Swanson 1961). Swanson states that, during this period, an estimated 8,000 samples were collected and analyzed from more than 200 geologic formations containing marine black shale. Some black shale formations such as the Chattanooga Shale in the southeast United States and phosphatic black shale in Kansas and Oklahoma have anomalously high uranium concentrations of up to 100 mg/kg (Swanson 1961); however, black shale has yet to be mined for uranium.

The Mancos Shale is composed dominantly of dark-gray shale beds and has been described as containing beds of black shale (Wright 2006). Black shale deposits are extensive in the United States and worldwide and are usually dark gray (N3) or grayish black (N2) with common dark hues of brown (5YR 2/1) and olive (5Y 3/2–2/1) (Swanson 1961). After an extensive review of black shale and modern mud deposits, Swanson (1961) included the requirement of having more than 2 percent organic carbon as part of the definition of black shale. Mancos Shale typically contains less than this and therefore would not be considered black shale by Swanson's definition.

McKelvey et al. (1955) compiled data worldwide on uranium in marine black shale. They described several uraniferous marine black shale formations, including the Upper Cambrian Alum Shale of Sweden, the Devonian and Mississippian Chattanooga shale of Tennessee, and shale in the Pennsylvanian Hartville Formation in Wyoming that contain from 50 to 200 mg/kg uranium. However, they stated that not all black shale is high in uranium. In a study of 287 samples of Paleozoic and Mesozoic black shale, Quinby-Hunt et al. (1989) determined a mean and mode for uranium of 15.2 and 3 mg/kg, respectively. Black shale high in uranium was often found to (1) contain high concentrations of sapropelic relative to humic material, (2) be rich in sulfide minerals and distillable hydrocarbons, (3) be low in fossil content except for plankton and nekton, (4) contain higher than average concentrations of phosphate, and (5) have low carbonate concentrations, although interbeds may have carbonate (McKelvey et al. 1955). The observation by McKelvey et al. (1955) that uranium is associated with sapropelic material seems to contrast with those of others (notably Vine et al. 1958; Swanson 1961) that maintain uranium in marine black shale is associated with humic material. The highest uranium concentrations in the Alum Shale are in lenses of dark bitumen. McKelvey et al. (1955) state that it was widely accepted at that time that the uranium was syngenetic, and seawater was the source of the uranium. It was also thought that reducing conditions were a prerequisite for transfer of uranium from seawater to black shale. A syngenetic origin explains the widespread, relatively even distribution of uranium in shale formations and the lack of deposition along faults and joints. Syngenesis was favored by Swanson (1961) and is still the most widely accepted mode of origin for the occurrence of uranium in marine black shale.

Adams and Weaver (1958) provided data on the concentration of uranium in shale samples collected worldwide, using data from their own analyses and literature compilations. They reported the following arithmetic mean and median values from distributions having reasonably normal distributions: 3.2 and 2.7 mg/kg from 52 samples of gray and green shale, 4.1 and 4.1 mg/kg from 15 composite samples representing 4,795 shale samples from the Russian Platform, and 5.0 and 4.5 mg/kg from 69 samples of bentonite. They also reported that uranium concentrations ranged from 1.4 to 69 mg/kg in 17 samples of black shale with a highly skewed distribution. They concluded that a value of 3.7 mg/kg is appropriate for average shale. The analytical method used by Adams and Weaver (1958) assumes secular equilibrium.

The uranium content of the marine Mancos Shale is low compared to that of many other black shale deposits (Shawe 1976). Shawe (1976) explains that the low uranium content may result from low uranium concentration in the seawater, rapid accumulation of sediment, or loss of uranium during compaction. He rejected the first two ideas: evidence from Swanson (1961) suggested that seawater had not been anomalously low in uranium, and deposition likely took place in the seaway in a subsiding basin for more than 20 million years. Thus, the loss of uranium was favored to explain the low concentration.

Using 102 shale samples collected from the Mancos Shale over much of the same outcrop area as used in the current study, Pliler and Adams (1962) determined arithmetic mean and median uranium concentrations of 3.7 and 3.2 mg/kg, respectively. They found that the Mancos Shale is remarkably uniform in uranium concentration, as evidenced by 19 samples collected at 6 ft intervals at a site located 14 miles west of Shiprock, New Mexico, that had an average uranium concentration of 2.9 mg/kg with a standard deviation of 0.3 mg/kg. They also found little variation among nine samples collected from the same stratigraphic layer (middle Mancos Shale of Spieker and Reeside [1925]) but widely separated along a 50-mile-long traverse southwest of

Price, Utah. Unfortunately, Pliler and Adams (1962) did not provide details of the digestion method used to prepare samples for the chemical analyses or the preparation method used for gamma spectrometry. Because the uranium concentrations in a suite of their samples analyzed using both chemical and gamma spectrometric analyses were similar, we assume that a digestion method capable of complete dissolution of the rock material was used, and as such, the concentrations are those of the total rock, including both easily leachable uranium and that residing in resistate grains.

Butler et al. (1994) analyzed four samples of weathered Mancos Shale, two samples of unweathered Mancos Shale, and two samples of ash beds (bentonite beds) from the Mancos Shale in the Uncompahgre Valley and Grand Valley areas in Colorado. The uranium concentrations were 7.4 and 11.2 mg/kg in the two unweathered shale samples, 8.4 and 13.9 mg/kg in the two ash bed samples, and ranged from 4.1 to 5.4 mg/kg in the four weathered shale samples. The average uranium concentration in 22 samples of shale and marlstone of the Pierre Shale analyzed by Tourtelot (1962) was less than 10 mg/kg. Schultz et al. (1980) determined the arithmetic mean uranium concentration of more than 200 shale and siltstone samples of the Pierre Shale to be 5.8 mg/kg with a standard deviation of 5.2 mg/kg. Tuttle et al. (2007) determined arithmetic means of uranium concentrations on 72 samples from Elephant Skin Wash, 95 samples from Candy Lane, and 16 samples from the Hanksville area as 4.79, 5.71, and 4.65 mg/kg, respectively.

In summary, it appears that shale in the Mancos Shale has a mean uranium concentration of about 3.7 mg/kg, which is similar to mean shale concentrations worldwide. We are not aware of any uranium isotopic analytical results for Mancos Shale rock samples.

6.1.10 Vanadium Content

Butler et al. (1994) analyzed four samples of weathered Mancos Shale, two samples of unweathered Mancos Shale, and two samples of ash beds (bentonite beds) from the Mancos in the Uncompahgre Valley and Grand Valley areas in Colorado. The vanadium concentrations were 13 and 50 mg/kg in the two unweathered shale samples, 4 and 40 mg/kg in the ash bed samples, and ranged from 130 to 180 mg/kg in the four weathered shale samples. Tuttle et al. (2007) determined arithmetic means of vanadium concentrations on 72 samples from Elephant Skin Wash, 95 samples from Candy Lane, and 16 samples from the Hanksville area as 142, 192, and 80 mg/kg, respectively.

6.2 Geochemistry of Groundwater in Mancos Shale

6.2.1 Arsenic

Wright (1995) reported that arsenic concentrations were not high in samples from approximately 50 wells and streams located within Colorado irrigation projects in Mancos Shale terrain. Arsenic concentrations in three of four groundwater samples in weathered Mancos Shale reported by Butler et al. (1994) for the Uncompahgre and Grand Valley, Colorado, areas were less than the detection limit of 1 µg/L, and the concentration in the fourth sample was 2 µg/L. Arsenic concentrations from eight samples of Sweitzer Lake water collected in 1987 and 1988 ranged from less than 1 to 2 µg/L, and concentrations were less than 1 µg/L in four samples of water from the Garnet Canal diversion ditch at Sweitzer Lake (Butler et al. 1991).

The arsenic concentration in Mancos Shale is about 15 mg/kg, which is higher than some other trace elements, including uranium (about 3.7 mg/kg; Table 7). Despite these higher, solid-phase concentrations, arsenic concentrations were less than 2 µg/L in all but five of our groundwater samples. Thus, arsenic must be more tightly bound to the solid phase, perhaps as an organic complex. Because it is not easily released to the groundwater, and only one sample had an arsenic concentration that exceeded the drinking water standard, arsenic is not considered a natural contaminant in the Mancos Shale. Sampling site SNS at Sweitzer Lake was anomalous with an arsenic concentration of 12 µg/L, a result that suggests that this sample was affected by evaporation.

6.2.2 Boron

Boron concentrations were measured in groundwater samples collected during this study, not because it is considered a contaminant, but because boron is known to have high concentrations in marine shale and might be an indicator that groundwater has interacted with Mancos Shale. Deverel and Millard (1988) found that boron concentrations in shallow groundwater of the western San Joaquin Valley, California, correlated with salinity. Butler et al. (1994) reported concentrations of boron from the weathered Mancos Shale for eight groundwater sampling locations in the Uncompahgre and Grand Valley areas; the boron results from representative samples ranged from 220 to 1,200 µg/L and had an arithmetic mean of 648 µg/L. Boron concentrations from eight samples of Sweitzer Lake water collected in 1987 and 1988 ranged from 200 to 390 µg/L, and concentrations in four samples of water from the Garnet Canal diversion ditch at Sweitzer Lake ranged from 180 to 800 µg/L (Butler et al. 1991).

Figure 28 shows a histogram of boron concentrations in water samples (most of which are groundwater samples) collected at 14 DOE remediation sites in the Four Corners states. The boron concentrations range from 2 to 75,000 µg/L but are highly skewed to the lower values; the geometric mean is 163 µg/L. The geometric mean of seep samples collected for this study was 441 µg/L (Section 5.2), and the geometric mean concentration in shale of 692 µg/L is distinctly higher than the geometric mean of 110 µg/L from sandstone. These results coupled with literature data suggest that a boron concentration of more than approximately 500 µg/L is an indication of Mancos Shale interaction.

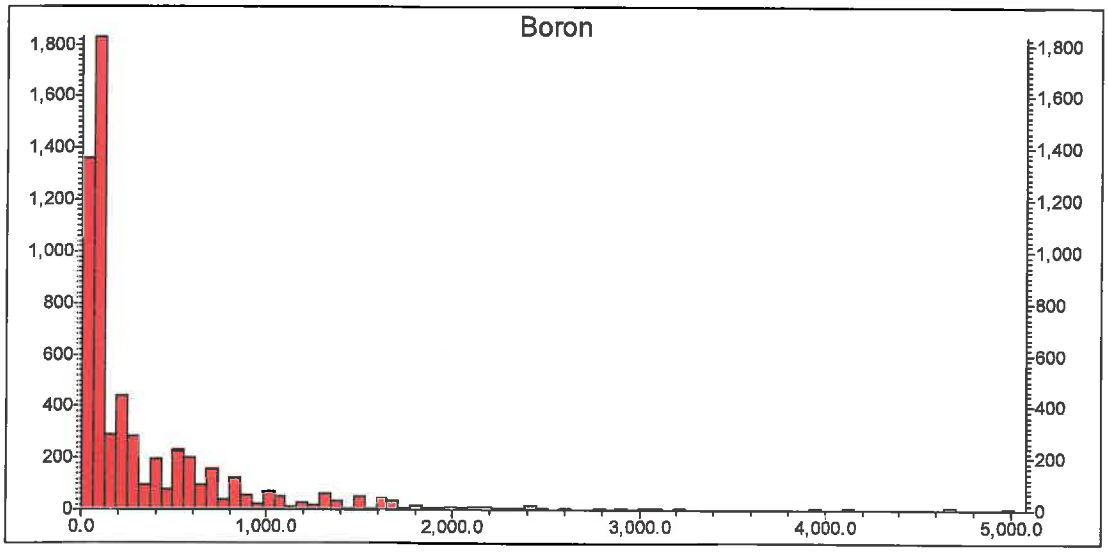

Figure 28. Histogram of Boron Concentrations (µg/L) in Water Samples Collected at DOE Sites in the Four Corners States.Sampling locations are Ambrosia Lake and Shiprock, New Mexico; Durango, Grand Junction, Gunnison, Maybell, Naturita, Rifle, and Slick Rock, Colorado; Mexican Hat, Moab, and Monticello, Utah; and Monument Valley and Tuba City, Arizona.

6.2.3 Dissolved Organic Carbon (DOC)

Natural fresh surface waters typically contain a few milligrams per liter of DOC but can be as high as 50 mg/L in swamps or bogs; DOC in ocean water ranges from about 0.5 to 1.2 mg/L (Stumm and Morgan 1981). In a summary of literature data, Reuter and Perdue (1977) found that most naturally occurring DOC is highly oxidized and similar in composition to soil humic substances, with an origin likely from meteoric water leaching of land-based, plant-derived humus. They report that a DOC concentration of more than 10 mg/L is sufficient to complex and mobilize trace metals, and that DOC concentrations of more than about 20 mg/L impart a distinctive yellow color to the water. Groundwater is generally low in DOC, with concentrations ranging from about 0.1 to 1.3 mg/L (Reuter and Perdue 1977).

DOC has rarely been measured in groundwater associated with Mancos Shale. Leythaeuser (1973) reports that solid-phase total organic carbon was reduced by up to 25 percent in the weathered (10 ft thick) portion of Mancos Shale (Tununk Member, Emery County, Utah), indicating that organic matter is lost from solid kerogen in the shallow weathering zone. In contrast, Clayton and Swetland (1978) analyzed weathered and unweathered core samples of the Pierre Shale in Boulder County, Colorado, and found that there was no loss of organic carbon in the weathered samples. In a study of the Crow Creek Member of Pierre Shale, Tourtelot (1962) indicated that organic carbon had been removed during weathering. Clayton and Swetland (1978) observed that up to 60 percent of the organic carbon was lost from black shale during weathering of the Permian Phosphoria Formation in northeastern Utah.

In situ generation of DOC has been described without the need for near-surface weathering processes. In situ generation of DOC was demonstrated in a study of the Gorleben aquifer in Germany by Buckau et al. (2000), who found that DOC concentrations exceeding 200 mg/L were produced by microbially mediated oxidation of sedimentary organic carbon during sulfate reduction. The recharged DOC was composed mainly of fulvic acid, whereas the in situ–produced DOC had a large component of humic acid. Aravena and Wassenaar (1993) deduced that much of the DOC in glacial sediments in southern Ontario, Canada, is derived by in situ generation.

Swanson (1961) states that the dark brown to black structureless material found in black shale may be humate that precipitated from aqueous humic acid. Humate is soluble in slightly alkaline solution but forms a gel upon acidification. During shale diagenesis, the humic material loses its solubility but becomes soluble again if oxidized (Swanson 1961). Thus, oxidation during Mancos Shale weathering may cause dissolution of organic carbon and produce the high concentrations of DOC we observe.

Holloway and Smith (2005) treated a Mancos Shale sample containing 2.40 percent organic carbon with deionized water for 2 weeks and found that 86 mg of DOC was released per kg of shale, or 0.5 percent of the available organic carbon.

High groundwater concentrations of DOC, up to 265 mg/L as measured in our samples, occur from natural processes in the Mancos Shale. High DOC concentrations imparted yellow to red colors to the groundwater, evidenced by a positive correlation between DOC concentrations and color as measured by light absorbance (Figure 17). We suggest that weathering of humic organic carbon in the Mancos Shale is the source for the DOC observed in the groundwater samples. The presence of the red coloration imparted by the DOC is easily seen in arroyos and is an indicator of natural contamination.

6.2.4 Major Ions

In a study of the contribution of Mancos Shale to salt loading in West Salt Creek, near Grand Junction, Colorado, Evangelou (1981) determined that the salts were derived by dissolving carbonate minerals from the Mancos caused by lowered pH values from biological oxidation of pyrite. Gypsum and magnesium sulfate solid phases were precipitated by the same reactions, and additional ions were dissolved from dolomite, feldspar, and mica. Sodium and magnesium were contributed during cation exchange with unweathered Mancos clays.

Many of the groundwater seeps sampled in this study had high salinities, with specific conductivity values exceeding 20,000 µS/cm at many locations. Cation composition in the Mancos Shale seeps was dominated by sodium and sulfate, and pH values were typically less than 7.5. The major-ion chemistry in the seeps was generally consistent with the major-ion chemical model put forth by Evangelou (1981). Conceptually, oxidation of pyrite and organic matter contribute sulfate, bicarbonate, and protons to the groundwater. Lowering of pH affects carbonate mineral dissolution, adding calcium and, to a lesser extent, magnesium to the groundwater. Sodium is transferred to groundwater as calcium exchanges with sodium on cation exchange sites. Gypsum and other secondary minerals precipitate or dissolve according to constraints of solubility equilibrium.

6.2.5 Nitrate (as NO_3)

Pottorff et al. (2005) sampled surface water and groundwater associated with selenium contamination near the Devil's Thumb Golf Course, Delta, Colorado. They found a positive relationship between selenium and nitrate, which they attributed to oxidation of selenium by nitrate, the source of nitrate being fertilizer applied to the golf course. They reported nitrate concentrations of more than 1,000 mg/L. Wright (1995, 1999) presented data on nitrate (plus nitrite), selenium, and uranium concentrations from about 50 wells and streams selected from samples of Colorado irrigation projects in Mancos Shale terrain. He found that nitrate correlated positively with both selenium and uranium; however, the correlation coefficient for selenium was only 0.50, and although the correlation coefficient for uranium was not provided, the graph showed considerable scatter. Using these correlations, the results of selenium release experiments in batch tests of Mancos Shale treated with variable concentrations of nitrate, and oxidation thermodynamics, Wright (1995, 1999) reasoned that nitrate may play a role in oxidative release of selenium and uranium from the Mancos Shale.

Most of the literature references to high nitrate concentration in the Mancos Shale suggest that fertilizer is the main source of the nitrate. In contrast, Holloway and Smith (2005) found that nitrate could be released naturally from the Mancos Shale. They treated a Mancos Shale sample containing 0.13 percent nitrogen with water for two weeks and found that 2.22 mg of inorganic nitrogen was released per kilogram of shale, or 0.2 percent of the available nitrogen. Our findings also indicate that nitrate can be leached directly from the Mancos Shale at high concentrations without a contribution from fertilizers. Seeps that are unrelated to irrigation and not likely to be significantly affected by evaporation include those at Eagle Nest Arroyo, Salt Creek Wash, Daly Reservoir, and Delta Reservoir; these had nitrate concentrations that ranged from 380 to more than 3,500 mg/L. A possible source for the nitrate is biogenic degradation of humic material during sediment deposition or early burial diagenesis. The nitrate remained associated with the organic matter until released by weathering processes.

6.2.6 Radon

Radon-222 measurements were made to evaluate the extent to which groundwater may have been evaporated by exposure to the atmosphere. Radon is a noble gas and is present in measurable concentrations in most groundwaters. Radon-222 has a half-life of only 3.8 days and is not transported far in groundwater. It is constantly produced in aquifers from the decay of its parent radium-226. Numerous studies of radon-222 in groundwater aquifers indicate that its aqueous concentration is tied to aquifer lithology (Michel 1990). Although large variations exist, radon-222 concentrations in limestone aquifers are typically low, ranging from about from 15 to 90 pCi/L. Radon-222 concentrations in unconsolidated sand aquifers typically range from about 200 to 700 pCi/L, and values from 2,000 to 20,000 pCi/L are common in metamorphic and igneous aquifers. We were unable to locate data regarding radon-222 concentrations in groundwater in shale.

Because it is a gas, radon-222 partitions rapidly into the vapor phase and may indicate whether a sample has been exposed to the atmosphere, either in situ or as a result of sampling. Radon-222 loss can occur without evaporation, so it is a one-sided test—if radon-222 is present in concentrations similar to those in unevaporated formation water, the sample has not been subject to evaporation; however, radon-222 loss could occur without significant evaporation. Unfortunately, few radon-222 concentration data are available for the Mancos Shale, so the concentration expected for formation water must be estimated. Because of these uncertainties, radon-222 data were only used in conjunction with other observations as a qualitative assessment of evaporation effects.

Our results were inconclusive as to whether radon-222 measurements were a useful indicator for atmospheric exposure. All of the surface water samples had low radon-222 signatures, confirming that exposure to the atmosphere depleted radon. Sweitzer Lake sample SNS3 had a relatively low radon-222 signature, consistent with its anomalously high concentrations of other dissolved constituents that might indicate evaporation. The use of radon-222 may have an additional problem if used to indicate evaporation coupled to capillary transport. If groundwater is moving to the ground surface via capillary processes, then it is still in contact with sediment, and the extent of radon emanation from that sediment is unknown. Others have found the water isotopic couple, oxygen-18 and deuterium, to be a useful indicator of evaporation in groundwaters in Mancos Shale terrain (Butler et al. 1996; Golder Associates 2004; Tuttle and Grauch 2009), although Golder Associates (2004) caution that the water isotopes may also be affected by interaction with the Mancos Shale. Perhaps the use of water isotopes in conjunction with radon-222 analyses would provide a more rigorous test of evaporation effects.

6.2.7 Selenium

Nolan and Clark (1997) presented data from more than 600 surface water samples collected in 14 states in the western United States and showed positive correlations of selenium with the presence of Cretaceous sediments, salinity, and irrigated areas. They found median selenium concentrations of 14 µg/L for areas underlain by Cretaceous sediments and less than 1 µg/L for areas underlain by non-Cretaceous sediments. Deverel and Millard (1988) found that selenium concentrations in shallow groundwater of the western San Joaquin Valley, California, correlated with salinity.

Butler et al. (1994) determined aqueous selenium species concentrations for two samples of groundwater collected from weathered Mancos Shale, one each from the Uncompahgre Valley and Grand Valley areas in Colorado. Both samples contained more than 97 percent of the oxidized species $\mathrm{Se^{VI}O_4^{2-}}$, the remainder being the reduced species $\mathrm{Se^{IV}O_3^{2-}}$, suggesting transport of selenium in the oxidized state. Wright and Butler (1993) reported selenium concentrations in groundwater from weathered Mancos Shale in irrigated areas of the Grand Valley and Uncompahgre Valley that ranged from less than 1 to 65 µg/L, but they found higher concentrations, up to 1,300 µg/L, in alluvial groundwater overlying Mancos Shale. Wright and Butler (1993) found that the selenium concentrations in groundwater were somewhat higher during the irrigation season than during the nonirrigated season and found that selenium in weathered Mancos Shale groundwater is negatively correlated with salinity. On the basis of these relationships, they proposed that selenium mobility is controlled predominantly by processes of uptake via reductive precipitation of pyrite and ion exchange on clays. Butler et al. (1996) using a similar database proposed a similar model for selenium migration.

Selenium concentrations in 14 seep samples collected during this study exceeded 500 μg/L, confirming observations by previous researchers that Mancos Shale is a source of elevated selenium concentrations in groundwater. Most of the higher concentrations were in samples that had high concentrations of other constituents, including uranium, DOC, nitrate, and total salinity; although the relative abundances of these constituents varied. The high groundwater concentrations of selenium are not reflected in the solid-phase concentrations. The generalized estimate in this study of solid-phase selenium concentration in the Mancos Shale was 2 mg/kg (Table 7), which was less than each of the solid-phase concentrations of uranium, boron, or arsenic.

Selenium concentrations in groundwater resulting from contact with gray shale beds in the Mancos Shale often exceed 500 μg/L. We propose that selenium is introduced into the Mancos Shale groundwater in a manner consistent with many previous studies. Selenium was adsorbed to humic organic matter and substituted for sulfur in pyrite from seawater during deposition of the Mancos Shale in the Late Cretaceous Western Interior Seaway. Selenium in these solid hosts was in its reduced selenite form. Concentration and redistribution likely occurred during burial diagenesis. As the Mancos Shale was uplifted and became weathered, selenium was oxidized to its more mobile selenate form. Wherever groundwater finds a migration pathway through the Mancos Shale, selenium transfers to the aqueous phase and migrates to the seeps.

6.2.8 Uranium

Data from the NURE program (USGS 2011b) were used to form a basis for comparison with the uranium concentrations encountered in our study. Figure 29 shows a histogram of uranium concentrations in 23,659 groundwater samples collected in the Four Corners states of Arizona, Colorado, New Mexico, and Utah. The NURE samples were obtained from seeps, springs, and wells and represent a wide range of geologic units. The frequency distribution for this set of uranium data is highly skewed with many more observations made at the low end of the concentration distribution; correspondingly, the arithmetic mean and median uranium concentrations were 8.67 and 2.63 μg/L, respectively (Table 8). Several high values skew the distribution but, because the statistics are based on such a large population there was little change to the mean and median values, even when some of the highest uranium concentrations were omitted. If all the uranium concentrations more than 1,000 μg/L uranium are omitted (five values), the mean decreases slightly to 8.13 μg /L, and the median remains the same at 2.63 μg/L (Table 8). Based on this data set, we adopt a value of 8.1 μg/L as a reasonable estimate of the mean.

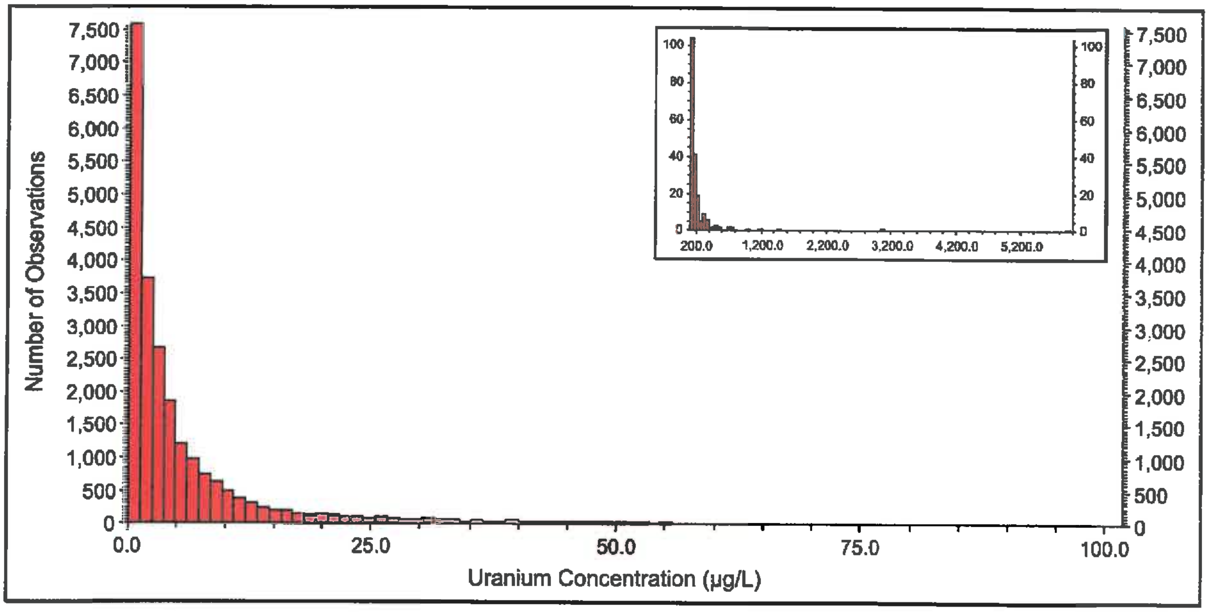

Figure 29. Histogram of Uranium Concentrations (µg/L) in 23,659 Groundwater Samples Collected in the Four Corners States of Arizona, Colorado, New Mexico, and Utah. Inset shows samples with more than 100 µg/L uranium.

Figure 30 provides a map-based representation of all the groundwater uranium concentration data from the Four Corners states, and Figure 31 shows locations that have groundwater uranium concentrations greater than 100 µg/L. There is a dense area of the higher values in an area in northeast Colorado (area A, Figure 31). This area is in the transition from the Rocky Mountains region to the Great Plains region and is characterized geologically by the transition to flat-lying Cretaceous and Tertiary marine and transitional shale-dominated beds, including large areas of strata that are equivalent to the Mancos Shale. Similarly, an area in the transition zone in southeast Colorado has a high density of locations with elevated uranium concentrations with Mancos equivalent strata (area B, Figure 31). Shannon (1979) reported on NURE results of samples collected from the Lamar 1° × 2° quadrangle that is located in eastern Colorado and includes the higher uranium concentrations in area B in southeast Colorado and a portion of the Arkansas River valley (Figure 31). He noted that of all the quadrangles investigated for the NURE program (which includes much of the United States), the Lamar quadrangle had one of the highest mean uranium concentrations in groundwater samples collected from wells. He further noted a correlation of the higher anomalies with units of Upper Cretaceous rocks that are stratigraphically equivalent to the Mancos Shale. Zielinski et al. (1995) reported high uranium concentrations in surface water and groundwater in the Arkansas River valley where the Arkansas River emerges from the Rocky Mountains to the Great Plains, near Cañon City, Colorado (Figure 31). They found concentrations of uranium exceeding 100 µg/L resulting from water contacting marine shale, including Mancos Shale-equivalent strata.

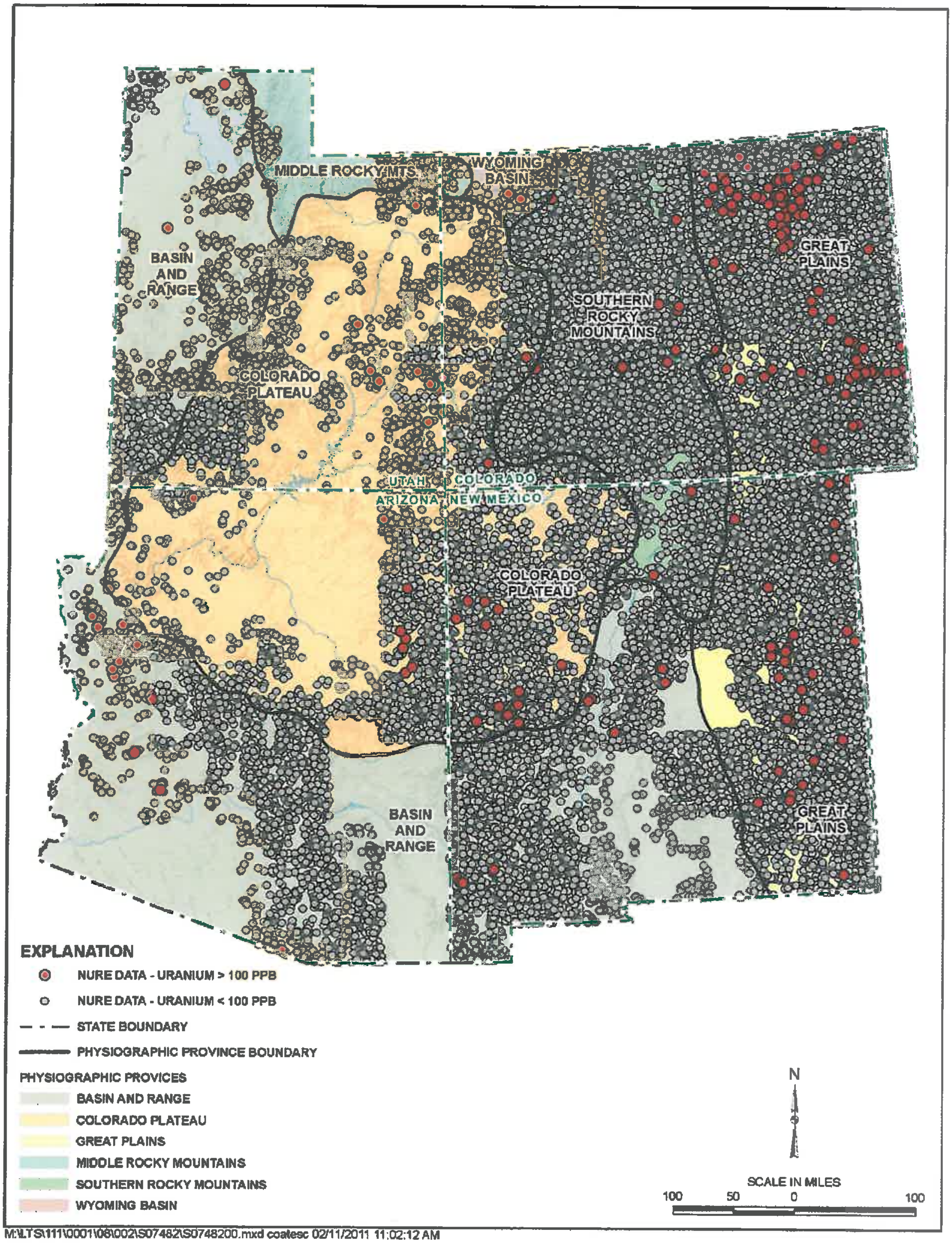

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Figure 30. Uranium Distribution in Groundwater in the Four Corners States. Data from the NURE database from samples collected 1976 through 1979.

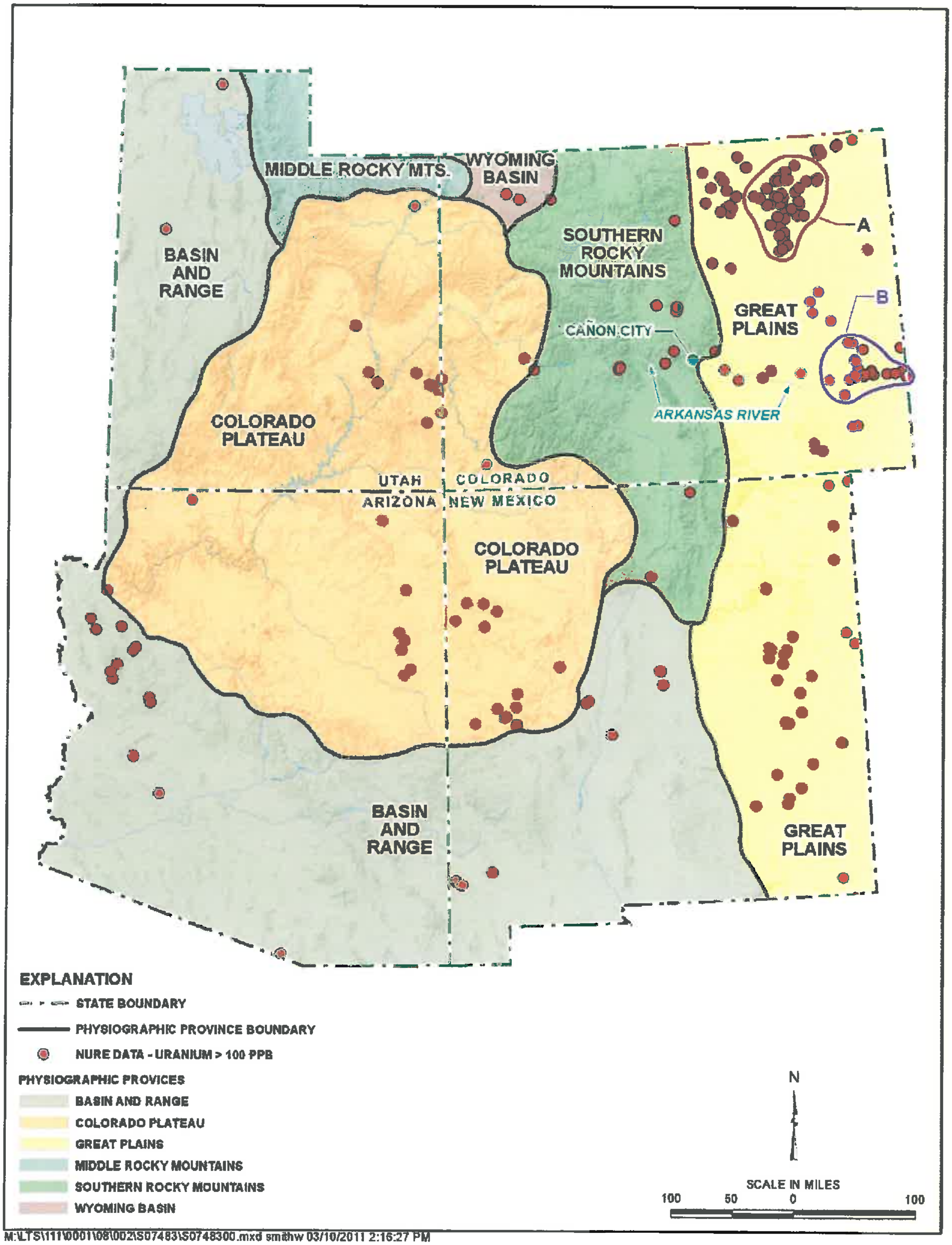

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Figure 31. Groundwater Samples in the Four Corners States with Uranium Concentration more than 100 µg/L. Data from the NURE database from samples collected 1976 through 1979. Areas A and B are discussed in the text.

In many other locations scattered among the Four Corners states that exhibit elevated uranium concentrations (Figure 31), an association with Mancos Shale equivalent strata appears to exist. Note that we did not conduct a critical analysis of the NURE data for the purpose of correlating Mancos Shale with groundwater contamination. Were such an investigation performed, it is likely that some of the high uranium concentrations, particularly solitary high values in outlying areas, would be attributed to anthropogenic activities. Nonetheless, the information presented in this section (e.g. Table 8) suggests that a thorough assessment of the NURE data would enhance an analysis of natural contamination in the Mancos Shale.

Table 8. NURE Statistics of Groundwater Uranium Concentration (µg/L) Data for Arizona, Colorado, New Mexico, and Utah Collected from 1976 to 1979. First row represents all reported data. Second row is based on all data except for the five values that exceed 1,000 µg/L.

	Count	Min.	Max.	Mean[a]	Median	Std Dev
All Values	23,659	0.002	5934	8.67	2.63	51
Minus Highest Five Values	23,654	0.002	748	8.13	2.63	23

[a] Arithmetic mean

In addition to presenting uranium concentration data from seven wells and one spring located in weathered Mancos Shale in the Uncompahgre Valley and Grand Valley areas in Colorado, Butler et al. (1994) presented data from seven wells completed in alluvium overlying weathered Mancos Shale in the same area. Their uranium concentrations for the alluvium ranged from 9 to 72 µg/L and an arithmetic mean of 37 µg/L, as compared to a range of 8 to 75 µg/L with an arithmetic mean of 27 µg/L for the weathered Mancos Shale. A well log obtained from the U.S. Bureau of Reclamation in Grand Junction indicated that one well was screened from alluvium to about 80 ft into the Mancos Shale. Butler et al. (1994) reported that a sample from this well had a uranium concentration of 450 µg/L, which is much higher than two previous values (9.4 and 3.8 µg/L) from the same well. We speculate that this may be an analytical error. Wright (1995) presents uranium concentration data ranging from about 2 to 60 µg/L in 50 water samples collected from wells and streams in western Colorado irrigation projects in Mancos Shale terrain. Some of the data used by Wright (1995) may be the same as those presented in Butler et al. (1994). Uranium concentrations from eight samples of Sweitzer Lake water collected in 1987 and 1988 ranged from 12 to 29 µg/L, and in four samples of water from the Garnet Canal diversion ditch at Sweitzer Lake ranged from 14 to 64 µg/L (Butler et al. 1991).

Uranium concentrations in samples collected from Mancos Shale seeps for this study were relatively high, ranging from 0.2 to 1,922 µg/L. Seeps issuing from shale beds had much higher concentrations (a geometric mean of 83.4 µg/L) than those emanating from sandstone beds (a geometric mean of 7.3 µg/L; see Table 5). Samples from seeps that were apparently unrelated to anthropogenic activity had elevated uranium levels. Uranium concentrations in groundwater contacting gray shale beds in the Mancos Shale often exceed 100 µg/L from natural processes. Uranium is thought to have adsorbed to organic matter from sea water and was reduced to the uranous state at the bottom of the Late Cretaceous sea. Some concentration and redistribution may have occurred during burial diagenesis. As the Mancos Shale was uplifted and weathered, uranium was available for transfer to groundwater in its uranyl state.

6.2.9 Uranium Isotopes

Uranium-234 and -238 both undergo alpha decay with half-lives of 4.468×10^9 and 2.48×10^5 years, respectively (Faure 1977). A closed system requires nearly one million years to achieve secular equilibrium, a condition in which the decay rates of uranium-234 and uranium-238 are equal. Most uranium ores discovered in the Four Corners region are older than this and have achieved secular equilibrium. Individual silicate mineral grains, even those deposited in sediments, are likely to be in secular equilibrium at least in the inner portion that has not been subjected to leaching. There are two principal ways uranium can be transferred to groundwater from solid phases: (1) chemical dissolution, and (2) alpha recoil and associated leaching. Only the second causes fractionation of uranium-234 from uranium-238 (Petit et al. 1985).

Research that began in 1953 in Russia and became widespread in the United States by the mid-1960s recognized that the activity of uranium-234 was higher than the activity of uranium-238 in many groundwaters (Osmond and Cowart 1976; Faure 1977). Uranium-238 decays to thorium-234 by the energetic release of an alpha particle which causes the thorium atom to recoil directly into nearby pore fluid or to become lodged in the mineral crystal lattice (Kigoshi 1971). With a half-life of only 24.1 days, thorium-234 decays rapidly to uranium-234 in a portion of the crystalline lattice that was disrupted by the alpha recoil process. Alpha recoil is also thought to produce oxidation at the site of the newly born uranium-234 atom (Rosholt et al. 1963; Petit et al. 1985; Suksi et al. 2006). When coupled with the lattice disruptions, the oxidized uranium-234 atoms become more amenable to release into the pore fluids than uranium-238. Although there have been several variations on the details of the alpha recoil process and its effect on preferential release of uranium-234, it is well accepted that alpha recoil is the only mechanism that causes fractionation of uranium-234 from uranium-238. Having a single fractionation mechanism can make the interpretation of uranium isotopic signatures more straightforward than interpretations for many of the lighter environmental isotopes (e.g., ^{18}O, ^{2}H, ^{32}S, ^{15}N) that fractionate under a wider range of conditions. Also, fractionations of uranium isotopes are typically larger than those of other environmental isotopes; differences in the percentage range are common, compared to parts-per-thousand differences for many of the other environmental isotopes (Osmond and Cowart 1976). Interpretation of uranium isotopes is further simplified because fractionation is independent of the chemistry of the aqueous phase. Despite these benefits, the use of uranium isotopes still suffers from an incomplete knowledge of the exact fate of thorium-234 and its daughter uranium-234 following alpha decay.

Based on literature surrounding the occurrence of uranium in dark marine shale, we assume that much of the uranium in the Mancos Shale resides in organic matter. Research on preferential release of uranium-234 due to alpha recoil has been universally directed to uranium bound in silicate or carbonate minerals, and we were unable to locate similar research on uranium bound to organic matter. Kigoshi (1971) assumes that the recoil length for thorium-234 is inversely proportional to the density of the material and estimates a 900-angstrom (Å) recoil length for pelagic sediment from experimentally determined recoil lengths of 550 Å for zircon. Presumably, low-density humic matter would have longer recoil lengths, and thus, fractionation due to direct thorium-234 recoil from organic matter would exceed those based on a silica framework. The AR of uranium-234 to uranium-238 has been used in various groundwater studies to help determine the origin of the uranium. The AR is near unity if both isotopes are in secular equilibrium. As alpha recoil processes cause preferential transfer of uranium-234 from the solid to the aqueous phase, the AR increases. AR values up to 2 are common in groundwater, but values up to 9 or more have been reported (Osmond and Cowart 1976; Suksi et al. 2006).

Zielinski et al. (1997) used AR values to help determine the source of uranium in a groundwater uranium plume emanating from a uranium mill site near Cañon City, Colorado. The AR values in the mill effluent were near 1.0 because the uranium ores were in secular equilibrium, and the milling process was sufficiently aggressive to cause essentially congruent mineral dissolution, thus maintaining the isotopic signature. In contrast, Zielinski et al. (1997) reported that AR values in background areas unaffected by the mill-generated plume were between 1.3 and 1.5. The AR values in the groundwater plume correlated well with uranium and molybdenum (another mill contaminant) concentrations, further indicating that AR values could be used to delineate the plume.

Weathering and oxidation processes are often cited to interpret some of the observed AR patterns in nature. Hussain and Krishnaswami (1980) state that intense weathering (presumably caused by congruent mineral dissolution) could result in high uranium concentrations and AR values near 1.0; whereas less-intense weathering (incongruent mineral dissolution) would selectively remove uranium-234 from the oxidized sites created by alpha recoil. Using theoretical modeling of the alpha recoil process, Suksi et al. (2006) concluded that direct alpha recoil to the groundwater is minimal and that uranium-234 fractionation is largely due to preferential oxidation. From this they reasoned that fractionation of uranium-234 only occurs from a reduced substrate. Cowart and Osmond (1977) observed low uranium concentrations with high AR values in groundwater within the reducing zone of uranium ore bodies. They reasoned that oxidized groundwater, high in uranium and with AR near 1.0, transports the uranium to the reduced zone where uranium mineral precipitation caused a sharp decrease in uranium concentration and an increase in AR values due to alpha recoil. In contrast, Maher et al. (2006) matched data from leaching of fine-grained sediment separates with an alpha recoil model based on grain geometry, suggesting that direct alpha recoil loss dominated, and preferential leaching is insignificant in a sediment with slowly dissolving silicates.

All of our uranium isotope data from Mancos Shale seeps show that AR values were more than 1.0 and most exceeded 2.0, indicating that uranium-234 activity regularly exceeds uranium-238 activity in Mancos groundwater throughout its depositional basin. A conceptual model for the groundwater AR values should explain several observations: (1) all samples have excess uranium-234, and many have twice the activity of uranium-234 as uranium-238, (2) these high AR values of near 2.0 are present over wide geographic areas, (3) samples collected from separate locations but within the same local area often have similar AR values, (4) many samples have elevated uranium concentrations, often exceeding 100 µg/L, and (5) groundwater contacting Mancos Shale for as little as one year is sufficient to produce AR values more than 2.0. The last of these observations is based on evidence that USGS Seep 2 near Devil's Thumb Golf Course originated less than a year after the filling of a pond that was the source of the seep water. Uranium isotopic data were not available from this seep, but nearby seeps DTS1, DTS2, and DTS3, which likely formed at the same time, had AR values greater than 2.0.

The apparently short groundwater residence time in the case of USGS Seep 2 seems to refute the possibility that direct recoil of thorium-234 atoms into pore fluids from host organic matter is responsible for the larger AR values that we see in Mancos Shale groundwater. Instead, we suggest that during uplift and erosion of Mancos Shale, perhaps over the last thousand years or so, alpha recoil of thorium-234 into pore fluids was followed by rapid sorption of the recoiled atom to surfaces of oxidized organic matter or minerals formed by the weathering process. The rock matrix at this time was relatively dry. By the time the shale beds were uplifted to within about 50 ft of the surface, uranium-234 preferentially occupied sorption sites on secondary minerals. Once groundwater was able to find pathways through the weathered shale beds, uranium enriched in uranium-234 was desorbed into the groundwater and subsequently transported to the seep locations. This hypothesis remains conjectural until more research can be conducted on the solid-phase AR values, and similar AR values can be produced from controlled laboratory tests. This hypothesis has similarities with the work of Rosholt et al. (1963) who found high variability of uranium isotopic signatures in 28 sandstone uranium ores from the United States; and they found that these ratios did not correlate with the oxidation states of the samples. Rosholt et al. (1963) suggested that uranium-234 was preferentially leached from ores, and then uranium from these fluids reprecipitated to form secondary ores with high uranium-234.

Petit et al. (1985) provided a succinct review and evaluation of the various mechanisms thought to be responsible for the excess of uranium-234 commonly found in groundwater. Importantly, they demonstrated that dissolution of uranium-bearing minerals produces a dilution of the uranium isotopic signature by adding a significant amount of uranium-238 to the groundwater. Their analysis indicated that production of excess uranium-234 by alpha recoil processes to increase the AR value from 1.0 to as little as 1.2 required unrealistically low rates of mineral dissolution. They also suggested that in a situation where water is present in a rock only intermittently, the alpha recoil products are implanted in adjacent grains to be released later when groundwater resaturated the system. The dilution by uranium-238 in the Mancos Shale seep samples investigated in this study would be extreme if mineral dissolution (or desorption) involved uranium that was at secular equilibrium in the shale. Using this reasoning, it is possible that recent groundwater in Mancos Shale released uranium from minerals containing excess uranium-234 that had previously been concentrated on secondary minerals and organic matter over long time periods.

6.2.10 Vanadium

There are few data available to assess vanadium concentrations in Mancos Shale groundwater. Vanadium concentrations from eight samples of Sweitzer Lake water collected in 1987 and 1988 ranged from less than 1 to 7 μg/L, and concentrations in four samples of water from the Garnet Canal diversion ditch (Figure 6) at Sweitzer Lake ranged from less than 1 to 14 μg/L (Butler et al. 1991). Deverel and Millard (1988) found that vanadium concentrations in shallow groundwater of the western San Joaquin Valley, California, correlated with salinity.

Despite its much higher concentration (about 100 mg/kg) than uranium or selenium in the Mancos Shale, vanadium has low concentrations in groundwater. In the seep samples, all but one sample had less than 2 μg/L of vanadium. Sample SNS from Sweitzer Lake was the only exception with a concentration of 19 μg/L, suggesting that this sample was affected by evaporation. We suggest that vanadium is tied up with a more hydrophobic fraction of the shale, perhaps sapropelic-based kerogen, that is not released easily upon contact with an aqueous phase. The affinity of vanadium for petroleum is well documented (Erickson et al. 1954; Hyden 1956).

There is no drinking water standard for vanadium; however, New Mexico has a livestock drinking water standard of 100 µg/L (Thomas et al. 1998). Because all of the groundwater vanadium concentrations measured in the seeps were much below this value, we conclude that vanadium is not a natural contaminant in the Mancos Shale.

6.3 Conceptual Model of Seep Chemistry

Clay and silt particles were deposited as mud at the bottom of the broad shallow Western Interior Seaway during the Late Cretaceous Epoch. Later lithification of these mud deposits became the shale of the Mancos Shale. Calcium carbonate precipitation in the shallow sea resulted in sporadic but substantial beds of limestone. Chemically reducing conditions caused by microbial degradation of organic compounds at the sea bottom caused formation of pyrite. Uranium from seawater was incorporated into organic matter by adsorption and reductive precipitation. Uranium concentrations in seawater may have been increased by devitrification of volcanic ash that periodically fell into the sea. Uranium isotopic signatures reflected those in seawater, which currently has a fairly constant AR of about 1.15 (Faure 1977). Selenium substituted for sulfur in pyrite, and some was adsorbed to organic matter. Nitrate production accompanied biodegradation, and nitrate was concentrated with organic matter. Pore water chemistry reflected the high sodium chloride composition of sea water. Chemical reduction continued during shallow burial, accompanied by minor redistribution of selenium, uranium, and other natural contaminants. Boron, which occurred in seawater at concentrations that were relatively high, was adsorbed by settling mud but was subsequently incorporated in phyllosilicate tetrahedral sites during diagenesis. Calcium carbonate was also redistributed, resulting in calcareous cementation. During burial diagenesis, the original clay and silt deposited during the Late Cretaceous was compacted to about a third to a tenth of its original water-saturated volume by the time it was buried to 10,000 ft in Tertiary time (Shawe 1976). By this time, a large proportion of smectite layers in illite-smectite clay minerals had been transformed to illite, and the Mancos Shale had become lithified. For reasons yet to be determined, nearly pure smectite in bentonite beds went unaltered. Pore fluids were dominated by sodium chloride, and cation exchange sites were occupied by sodium.

During the Neogene, the Mancos Shale was uplifted and became exposed over large areas of the Colorado Plateau, and erosion was coupled to uplift such that the Mancos Shale continually supplied unweathered shale and natural contaminants to the weathering horizon. Chloride minerals are highly soluble, and some chloride was lost from the system before the beds reached the weathering horizon. Oxidation of pyrite and organic matter in the weathering horizon caused formation of gypsum, lowering of pH, and dissolution of some organic matter. The contrast between the sodium-chloride chemistry of the deep, unweathered Mancos Shale groundwater and the sodium-sulfate composition of the shallow, weathered Mancos Shale is caused by the contribution of sulfate by oxidation of pyrite in the weathering horizon. Lowering of pH was buffered by dissolution of calcite, which was abundant in the Mancos Shale. The transfer of calcium from carbonate minerals to the aqueous phase made it available to exchange with sodium on cation exchange sites and to combine with sulfate to form gypsum. Sodium dominated the ion exchange sites as indicated by high sodium concentrations in both weathered and unweathered Mancos Shale. Although shales of the Mancos Shale are mostly dry, they contain an abundance of soluble matter that can be released whenever water is applied. The main elements of major ion chemistry as proposed by this conceptual model were simulated using a numerical model, as discussed in the next section.

6.4 Reaction Progress Model of Seep Chemistry

Groundwater can flow at high rates through the Mancos Shale, as demonstrated at the Devil's Thumb Golf Course, where groundwater flow rates of 8 ft per day were observed. It is likely that flow in the shallow Mancos Shale follows fractures, bedding planes, and other structural or weathered features and is not likely to be accurately portrayed using traditional models invoking porous media flow. Because of the uncertainty of the flow system, we elected not to model flow; rather, we used a reaction progress model to simulate the main chemical features of the shallow groundwater system. Reaction progress modeling is well suited to simulating mass transfer of chemicals between Mancos Shale and groundwater. This type of modeling uses a set of irreversible reactions to produce changes to a chemical system, with all other chemical reactions evolving in local equilibrium. An excellent example of the usefulness of reaction progress modeling is provided by Helgeson (1979), who modeled the progressive evolution of hydrothermal vein minerals driven by irreversible feldspar hydrolysis.

We conceptualize a system in which relatively clean water infiltrates into the Mancos Shale and migrates along fractures, bedding planes, and bentonite layers to seeps or springs. Seeps commonly occur along the strike of the Mancos Shale beds, indicating that bedding planes, and in some cases bentonite beds, exert a major control on groundwater flow. At most sites, the flow regime is relatively shallow and mostly within the weathered Mancos Shale. Based on the core data from the Crescent Junction site and reports of Mancos chemistry and mineralogy from the literature, we assume that the Mancos contains gypsum, calcite, pyrite, and organic matter. Pyrite, calcite, and organic matter are weathered products of marine deposition and shallow (several hundred feet) burial diagenesis, whereas gypsum and ferric oxyhydroxide are oxidation products of pyrite. Pyrite and organic matter are closely associated, whereas gypsum and calcite commonly occur in mineralized fractures or other secondary features, having been mobilized some distance from their source. Of importance, the presence of high concentrations of sodium on ion exchange sites is critical to producing the sodium sulfate major ion compositions that are ubiquitous in many Mancos Shale seeps.

Our conceptual model for the release of constituents from the Mancos Shale involves the irreversible incongruent dissolution of organic matter, the irreversible dissolution of pyrite, and the addition of sodium-filled ion exchange sites (NaX). Equilibrium is maintained among all aqueous speciation, ion exchange, and mineral precipitation and dissolution reactions. Reaction progress modeling can be thought of by considering a liter of water in a beaker to which we gradually add small increments of solid components (pyrite, organic matter, and shale with ion exchange sites) and compute the chemical composition at each addition. This has a similar effect as considering the evolution of water chemistry as this liter of water migrates along a flow path in the Mancos Shale and progressively reacts with the aquifer solids. Because we lack knowledge of the flow regime and have no groundwater data from various locations along a flow path, we cannot explicitly test chemical interactions in a predictive way. However, the model is useful in providing a numerical (and thermodynamically consistent) verification of the reasonableness of our conceptual model. Reaction progress modeling used the PHREEQC computer code (Parkhurst and Appelo 1999).

Thermodynamic data for all aqueous complexation, ion exchange, and mineral precipitation/dissolution reactions are from the database provided with the PHREEQC program. For computational simplicity, solid-phase organic matter in geologic systems is often presented as CH_2O (Stumm and Morgan 1981), and we used that simplification. We also simplify the dissolved organic phase as carboxyl ion; thus, the following equation depicts the irreversible hydrolysis of organic matter:

$$CH_2O + H_2O = HCOO^- + 3H^+ + 2e^-$$

where $HCOO^-$ is used as a proxy for DOC. Because the groundwater is in the near-surface weathered Mancos Shale, oxygen was maintained at equilibrium with 10^{-7} atmosphere of O_2 (approximately 8 mg/L dissolved oxygen). Iron oxyhydroxide was simulated with amorphous $Fe(OH)_3$. Calcite, gypsum, and $Fe(OH)_3$ were maintained at equilibrium throughout the simulation. Ion exchange sites are considered to be highly charged with sodium, as indicated by the presence of concentrated sodium chloride groundwater in the deep borings of unweathered Mancos Shale. Our chemical analysis of a pristine (specific conductivity of 114 µS/cm) Delta Reservoir (DR) water sample on November 8, 2010, was used as the initial solution. Our goal was to seek a reasonable match to the seep chemistry at Delta Reservoir seeps DRS1 and DRS3 by adjusting the phase mixture within reasonable limits. A mixture of pyrite, CH_2O, and NaX in the molar amounts 0.0008, 0.0003, and 1.0, respectively, provided a reasonable match as shown in Table 9. This mixture was added in 1,000 steps of 0.005 mole each to the initial solution. The modeled value for sodium is higher than observed, because only sodium was considered to occupy ion exchange sites; calcium, potassium, and magnesium loading on ion exchange sites was probably minimal and was ignored. As an additional simplification, the carbon contained in DOC was not allowed to exchange with inorganic carbon. This condition is justified by the observation that DOC is at high concentrations in many of the groundwater samples despite oxidizing conditions that would cause its complete conversion to CO_2 if it reacted to thermodynamic equilibrium.

Table 9. Delta Reservoir Reaction Progress Model Results Compared to Chemistry Measured in Samples from Seeps DRS1 and DRS3, November 8, 2010 (mg/L). Five moles of reactive mixture were added.

	DIC	DOC	SO_4	Na	Fe	pH
DRS1	222	44	18,497	7,600	<1	7.16
DRS2	251	2.9	15,087	5,900	<1	7.25
Model	199	18	18,453	8,884	<1	7.17

DIC = dissolved inorganic carbon; DOC = dissolved organic carbon

Figure 32 shows the trends in constituent concentrations as the model progresses toward the final values shown in Table 9. Proton generation from the addition of pyrite, oxidized by the oxygenated atmosphere, causes a gradual decrease in pH. The pH would decrease much faster if not buffered by calcite dissolution. Iron generated by pyrite dissolution is taken up by $Fe(OH)_3$ precipitation. Calcium generated by calcite dissolution exchanges with sodium on the Mancos clay minerals; the lack of dissolved calcium prevents precipitation of gypsum. Thus, the system evolves to a dominantly sodium sulfate system.

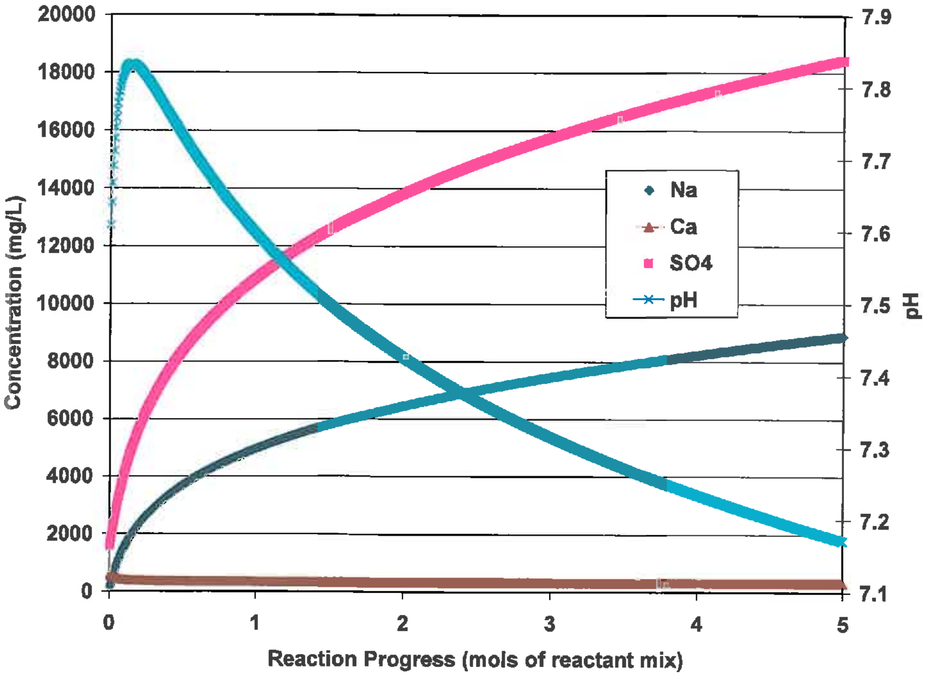

Figure 32. Calculated Concentrations for a Reaction Progress Model Simulation of the Delta Reservoir Seeps. Reaction progress is defined by a mixture of 1, 0.0008, and 0.0003 mole of NaX, pyrite, and CH$_2$O, respectively.

Uranium and other trace constituents were not modeled because too little is known about their mode of occurrence both in the solid and dissolved states. Based on literature data presented above, it is likely that uranium resides in the organic matter and is perhaps complexed by DOC in the aqueous phase.

7.0 Conclusions and Recommendations

This study identified groundwater seeping from the Mancos Shale that was contaminated by naturally occurring processes. The results indicate that high concentrations of major ions, nitrate, selenium, and uranium are likely to occur as a natural process of interaction between groundwater and Mancos Shale. The high concentrations are apparently limited to groundwater associated with shale beds, and concentrations of these constituents in groundwater associated with sandstone were much lower. High contaminant concentrations occurred throughout the study areas and were not correlated with geographic area, stratigraphic position, or source of water. Some of the samples were influenced by irrigation, but others were collected from locations in remote areas with no significant anthropogenic input. In the interest of developing reasonable and achievable cleanup goals, the effects of naturally occurring concentrations of nitrate, selenium, and uranium should be considered when evaluating groundwater contaminant plumes beneath and downgradient of disposal cells constructed on Mancos Shale.

Groundwater contacting shale beds of Mancos Shale can have concentrations of nitrate, selenium, and uranium that exceed regulatory standards. Many of the groundwater samples were highly saline, as indicated by specific conductivity values ranging from 418 to 70,002 µS/cm with a geometric mean of 9,226 µS/cm. Samples collected at nine locations had specific conductivity values of more than 30,000 µS/cm. Nitrate concentrations exceeded 250 mg/L at 13 locations, and selenium concentrations exceeded 1,000 µg/L in eight samples. Uranium concentrations were also high, having a range of 0.2 to 1,922 µg/L with a geometric mean of 48.8 µg/L, and samples from 18 locations had concentrations more than 100 µg/L. The groundwater can also have DOC concentrations exceeding 100 mg/L, which commonly colors the water yellow to red. Boron (a possible indicator of marine shale) concentrations exceeding 1,000 µg/L were common in groundwater from shale beds, but lower values were observed in groundwater from sandstone. Vanadium and arsenic concentrations were low in the seep samples, and thus are not natural contaminants in the Mancos.

All uranium-234 to uranium-238 AR values were greater than the secular equilibrium value of 1.0. All but three of the AR values were more than 1.5, and about half of the values exceeded 2.0. Thus, high AR values may be a common characteristic of groundwater that has interacted with Mancos Shale.

Chemical reactions driven by the irreversible oxidation of organic matter and pyrite offer a plausible explanation for the evolution of groundwater chemistry. Pyrite oxidation generates sulfate, selenium, and protons, whereas organic matter yields DOC and liberates nitrate and uranium. These reactions occurred after the Mancos Shale had been uplifted sufficiently such that atmospheric oxygen was available to drive weathering processes.

The current study is based on a single set of samples from a wide geographic area encompassing much of the Mancos Shale depositional basin. It would be useful to sample the same seeps at least one additional time, during the main irrigation season, to help evaluate seasonal variation. Because of time limitations, several large areas of Mancos Shale outcrops were not investigated in the field. It would be beneficial to extend the study to include groundwater sampling in these areas. These areas include the Kaiparowits Plateau; Black Mesa Basin; areas of the southern San Juan Basin near Gallup, New Mexico; an area near Show Low Arizona; and areas in Colorado near Steamboat Springs and Pagosa Springs; and area near Vernal, Utah. Extending the investigation to include the Pierre Shale, Niobrara Formation, and other Mancos equivalent strata in eastern Colorado, Kansas, Montana, Nebraska, South Dakota, and Wyoming would also be of interest.

The main purpose of the current study was to evaluate groundwater chemistry in the Mancos Shale caused by natural processes. To meet this purpose, a limited set of chemical parameters was selected for study. Because some seeps were relatively nonproductive, obtaining a suitable volume of groundwater for extensive chemical analysis was not possible. However, most locations produced groundwater in sufficient quantity to facilitate additional analyses. Potentially useful data that were not included in this study are $\delta^{18}O$ and δD, which could help confirm the sources of groundwater and provide a more quantitative assessment of evaporation effects. More detailed work, including coring and analysis and installation of a groundwater monitoring array in an area that has well-defined groundwater control such as Daly Reservoir could help to understand groundwater chemistry as it evolves along flow lines. Determination of the nature of the DOC could lead to a better understanding of the processes responsible for its occurrence in the groundwater.

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Appendix A

Site Information

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Location	ID	Latitude	Longitude	USGS Site No.	Geologic Unit	Region	Area
Seeps and Springs							
Bert Avery Spring	BAS	38.26847466	-110.8225768	381603110491901	Ferron Sandstone	Hanksville	
Blue Gate Spring	BGS	39.2207617	-110.9513918	391315110570301	Blue Gate	Price	
Buen Pastor Spring	BPS	38.70697125	-108.0353522		middle Smoky Hill	Delta	Sweitzer Lake
Bitter Spring Creek Spring	BSCS	37.91682206	-111.0217921	375458111011901	Emery Sandstone	Hanksville	
Bitter Spring Creek Upper Spring	BSCUS	37.916988	-111.021816		Emery Sandstone	Hanksville	
Browns Wash Seep	BWS	38.98516015	-109.9522626	385906109570601	Upper Blue Gate	Green River	
Cato Springs	CAS	39.13246669	-109.3674558	390758109220201	Upper Blue Gate	Green River	
Cedar Creek Seep	CCS	38.458021	-107.673677		upper or middle Mancos	Montrose	Cerro Summit
Cisco Springs	CIS	39.08870947	-109.3822425	390519109230001	Prairie Canyon	Green River	
Cottonwood Creek Spring	CWCS	38.27976	-110.861307	381639110513801	Ferron Sandstone	Hanksville	
Ditch 9 Spring	D9S	36.85511911	-108.7483559		Cortez	Shiprock	Shiprock
Daly Reservoir Spring 1	DARS1	38.97021006	-109.9710173		upper Prairie Canyon	Green River	Daly Reservoir
Daly Reservoir Spring 2	DARS2	38.97056543	-109.9711552		upper Prairie Canyon	Green River	Daly Reservoir
Delta Reservoir Dam Spring	DRDS	38.809687	-108.069081		Prairie Canyon	Delta	Delta Reservoir
Delta Reservoir Seep 1	DRS1	38.810393	-108.063758		Prairie Canyon	Delta	Delta Reservoir
Delta Reservoir Seep 3	DRS3	38.808375	-108.064455		Prairie Canyon	Delta	Delta Reservoir
Devils Thumb Seep 1	DTS1	38.79759965	-108.0544136		upper Smoky Hill	Delta	Devil's Thumb Golf Course
Devils Thumb Seep 2	DTS2	38.78388498	-108.053317		middle Smoky Hill	Delta	Devil's Thumb Golf Course
Devils Thumb Seep 3	DTS3	38.78344064	-108.0546702		middle Smoky Hill	Delta	Devil's Thumb Golf Course
Dutchmans Wash Seep	DWS	39.22153704	-110.9688968		Blue Gate	Price	
East Tributary Floy Wash	ETFW	38.96177	-109.904612		upper Blue Gate	Green River	
Green River Canal Return Seep	GRCRS	39.04252778	-110.1511944	390233110090401	upper Blue Gate	Green River	
Houston Gulch Seep	HGS	38.471966	-107.700601		upper or middle Mancos	Montrose	Cerro Summit
Houston Gulch Seep East	HGSE	38.471886	-107.700554		upper or middle Mancos	Montrose	Cerro Summit
Kannah Creek Flowline Spring	KCFS	39.006019	-108.462288		lower Smoky Hill	Delta	Whitewater
Little Grand Wash Seep	LGWS	38.88477648	-109.9658041		lower Blue Gate	Green River	
Loutsenhizer 11	LOUT11	38.544654	-107.7773699		upper or middle Mancos	Delta	Loutsenhizer Arroyo
Loutsenhizer 12 Lower	LOUT12L	38.5450158	-107.776946		upper or middle Mancos	Delta	Loutsenhizer Arroyo

Location	ID	Latitude	Longitude	USGS Site No.	Geologic Unit	Region	Area
Loutsenhizer 12 Upper	LOUT12U	38.545237	-107.776984		upper or middle Mancos	Delta	Loutsenhizer Arroyo
Loutsenhizer 13	LOUT13	38.543799	-107.778448		upper or middle Mancos	Delta	Loutsenhizer Arroyo
Loutsenhizer 14	LOUT14	38.540524	-107.784051		upper or middle Mancos	Delta	Loutsenhizer Arroyo
Loutsenhizer 3	LOUT3	38.5399	-107.787952		upper or middle Mancos	Delta	Loutsenhizer Arroyo
Loutsenhizer 8	LOUT8	38.544899	-107.784986	383242107470401	upper or middle Mancos	Delta	Loutsenhizer Arroyo
Loutsenhizer 9	LOUT9	38.55241793	-107.7799697	383307107454701	upper or middle Mancos	Delta	Loutsenhizer Arroyo
Many Devils Wash EF-22	EF-22	36.759505	-108.678292		Cortez	Shiprock	Shiprock
Mud Spring	MS	39.51934353	-110.5325294	393103110315901	middle Mancos	Price	
Mathis Wash Seep	MWS	39.44309801	-110.7881307		Blue Gate	Price	
Point Creek Seep	PCS	38.84549654	-108.1921318	385043108112901	upper Prairie Canyon	Delta	
Section 36 Spring	S36	38.93193402	-109.4255796		middle Blue Gate	Green River	
Salt Creek Wash Seep	SCWS	36.84469614	-108.6501375		Cortez	Shiprock	Shiprock
Sweitzer NE Seep	SNS	38.71654655	-108.0231702		upper Smoky Hill	Delta	Sweitzer Lake
Sweitzer NE Seep 1	SNS1	38.71649529	-108.0238606		upper Smoky Hill	Delta	Sweitzer Lake
Sweitzer NE Seep 2	SNS2	38.71656063	-108.0235525		upper Smoky Hill	Delta	Sweitzer Lake
Sweitzer NE Seep 3	SNS3	38.71684347	-108.0231466		upper Smoky Hill	Delta	Sweitzer Lake
Town Wash Spring	TWS	38.28946022	-110.84917	381721110505401	Ferron Sandstone	Hanksville	
Upper Eagle Nest Arroyo Spring	UENAS	36.80853481	-108.560075		Cortez	Shiprock	Shiprock
Upper Floy Wash Spring	UFWS	38.96103007	-109.9056714	385738109541901	upper Blue Gate	Green River	
USGS Seep 1	US1	38.71211716	-108.02314	*	upper Smoky Hill	Delta	Sweitzer Lake
Whitewater Creek Tributary Seep	WCTS	38.99507784	-108.3979729		Smoky Hill	Delta	Whitewater
Whitewater Ditch No. 2 Seep	WD2S	38.96777266	-108.4276475		Blue Hill	Delta	Whitewater
Yucca House Spring	YHS	37.250161	-108.686194	371500108410801	Juana Lopez	Shiprock	
Surface Water Bodies (Sources of Seeps or Springs)							
Bostwick Canal West Lateral	BCWL	38.54883569	-107.7753634		upper Mancos	Delta	Loutsenhizer Arroyo
Daly Reservoir	DAR	38.96965	-109.970598		upper Prairie Canyon	Green River	Daly Reservoir
Delta Reservoir	DR	38.810042	-108.068961		Prairie Canyon	Delta	Delta Reservoir
Sweitzer Lake	SL	38.711165	-108.033135		upper Smoky Hill	Delta	Sweitzer Lake
Sweitzer NE Garnet Canal	SNGC	38.716557	-108.02296		upper Smoky Hill	Delta	Sweitzer Lake
Whitewater Ditch No. 2	WD2	38.948979	-108.413333			Delta	Whitewater

Location	ID	Latitude	Longitude	USGS Site No.	Geologic Unit	Region	Area
Pools and Washes Near Seeps and Springs							
Cottonwood Wash at Cato Springs	CWC	39.132553	-109.367508		upper Blue Gate	Green River	
East Tributary Floy Wash Downstream	ETFWD	38.96161	-109.904595		upper Blue Gate	Green River	
Houston Gulch Red Pool	HGRP	38.471794	-107.700532		upper or middle Mancos	Montrose	Cerro Summit
Little Grand Wash	LGW	38.884758	-109.965785		lower Blue Gate	Green River	
Loutsenhizer 11 in Wash	LOUT11W	38.54464	-107.777341		upper or middle Mancos	Delta	Loutsenhizer Arroyo
Sweitzer Red Pool	SRP	38.71186071	-108.0233965		upper Smoky Hill	Delta	Sweitzer Lake
Town Wash Spring Pool	TWSP	38.289408	-110.84918		Ferron Sandstone	Hanksville	
Upper Floy Wash-30 ft from Spring	UFWS1	38.96095	-109.905626		upper Blue Gate	Green River	
Upper Floy Wash-50 ft from Spring	UFWS2	38.960901	-109.90559		upper Blue Gate	Green River	
Whitewater Creek Tributary Seep Pool 1	WCTSP1	38.995092	-108.397974		Smoky Hill	Delta	Whitewater
Whitewater Creek Tributary Seep Pool 2	WCTSP2	38.995119	-108.398076		Smoky Hill	Delta	Whitewater
West Fork Floy Wash	WFFW	38.974718	-109.90538	385829109541601	upper Blue Gate	Green River	

* USGS site referenced in Thomas (2009)

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Appendix B

Calculation of Water Density from Specific Conductivity

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Calculation of Water Density from Specific Conductivity

Salinity was derived from a relationship based on conductivity, which was in turn estimated from measurements of specific conductivity collected in the field. Conductivity is a direct measure of the ability of a solution to carry an electrical current normalized to the area of the conductor, whereas specific conductivity is conductivity that the solution would have at 25 °C.

Specific conductivity (SC) was converted to conductivity (C_t) using a relationship in Standard Method 2510 B:

$C_t = SC \times [1 + 0.0191 \times (T - 25)]$, where T is temperature in °C.

Salinity (S) was then calculated from conductivity using:

$$S = a_0 + a_1 R_t^{1/2} + a_2 R_t + a_3 R_t^{3/2} + a_4 R_t^2 + a_5 R_t^{5/2} + f(T) \times (b_0 + b_1 R_t^{1/2} + b_2 R_t + b_3 R_t^{3/2} + b_4 R_t^2 + b_5 R_t^{5/2}) - a_0/(1 + 1.5X + X^2) - b_0 f(T)/(1 + Y^{1/2} + Y^{3/2})$$

where: $a_0 = 0.0080$, $a_1 = -0.1692$, $a_2 = 25.3851$, $a_3 = 14.0941$, $a_4 = -7.0261$, $a_5 = 2.7081$,
$b_0 = 0.0005$, $b_1 = -0.0056$, $b_2 = -0.0066$, $b_3 = -0.0375$, $b_4 = 0.0636$, $b_5 = -0.0144$, and
$R_t = C_t/(r_0 + r_1 T + r_2 T^2 + r_3 T^3)$
$X = 400R_t$
$Y = 100R_t$
$f(T) = (T - 15)/[1 + 0.0162(T - 15)]$

where: $r_0 = 30332$, $r_1 = 844.33$, $r_2 = 3.8331$, $r_3 = -0.0282$

The constants r_0, r_1, r_2, and r_3 were determined in our laboratory from the temperature dependency of conductivity measured with our field sonde in artificial seawater simulated by a potassium chloride (KCl) solution containing 32.4356 g in a mass of 1 kilogram (kg) of solution (Standard Method 2520 B).

Density (ρ) in grams per cubic centimeter (g/cm^3) was calculated from salinity (S) using Standard Method 2520 C:

$$\rho = (\rho_0 + aS + bS^{3/2} + cS^2)/1{,}000$$

where:

$$\rho_0 = 999.842594 + 0.06793952T - 0.00909529T^2 + 1.001685 \times 10^{-4}T^3 - 1.120083 \times 10^{-6}T^4 + 6.536332 \times 10^{-9}T^5$$

$$a = 0.824493 - 0.0040899T + 7.6438 \times 10^{-5}T^2 - 8.2467 \times 10^{-7}T^3 + 5.3875 \times 10^{-9}T^4$$

$$b = -0.00572466 + 1.0227 \times 10^{-4}T - 1.6546 \times 10^{-6}T^2$$

$$c = 0.00048314$$

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Appendix C

Analytical Data

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ID	Sample Date/Time	Temp deg C	pH	Sp Cond uS/cm	ORP mV	DO mg/L	Alk mg/L*	Cl mg/L	NO3 mg/L	SO4 mg/L	NH3-N mg/L	U µg/L	Fe mg/L	Ca mg/L	Na mg/L	Mg mg/L	K mg/L	IRB CFU/mL	DOC mg/L	Color pt units	pH	222Rn pCi/L	Se ug/L	As ug/L	B ug/L	V ug/L	U233+234 pCi/L	U235 pCi/L	U238 pCi/L
ACS	11/15/10 0:00	7.78	6.94	16362	**244**	0.3																							
BAS	11/17/10 14:00	10.75	7.29	418	**-28**	2.35	129	12	**0.5**	67		0.2	1.55	48	26	9.8	1.4	500	4.4	81	7.12	144	0.18	0.94	16	0.28	**0.284**	0.246	0.322
BCWL	11/4/10 12:30		8.53	197	201		64	0.9	1.7	27		0.4	**0.2**	22.1	5.8	4.6	2.4	35000	3.3	7	7.79	1.2	0.18	0.37	**3.1**	0.98	0.472	**0**	0.296
BGS	11/16/10 11:30	7.68	6.87	6203	**-30**	7.16	58	287	2.3	3911		**1**	0.57	412	780	400	14.8	9000	9.1	16	6.88	53	0.37	0.33	860	0.16	0.637	**0.169**	**0.081**
BPS	11/30/10 14:14	4.61	7.49	5639	**33**	7.09	365	62	1.9	3707		22.6	**2**	376	1200	210	15.8	35000	12.2	59	7.38	130	3.8	0.36	570	0.37	18.2	**0.168**	7.98
BSCS	11/18/10 13:40	8.58	7.05	2037	307	0.45						65.3																	
BSCUS	11/18/10 13:28	9.56	6.95	1079	198	2.1																							
BWS	11/12/10 10:20	4.78	7.74	10798	245	2.76	359	267	15	9853		26.6	**1**	468	3000	720	1.2	140000	19.5	65	7.67	316.3	25	0.48	240	0.47	16	0.484	8.54
CAS	11/11/10 10:25	10.97	7.58	2184	-65	0.34	625	21	1.7	762		7.6	2.03	73.2	355	135	3.8	9000	10.7	156	7.34	416.9	0.14	4.5	79	0.56	4.25	**0.0641**	1.83
CCS	11/3/10 10:30	10.85	6.55	16409	228	4.32	644	1430	2.9	9933		76.7	**1**	454	3300	1000	26.6	35000	25	23	7.32	1624.5	12	0.23	1200	**0.15**	38.9	1.44	23.5
CIS	11/11/10 12:18	9.28	7.56	3947	88	1.5						13.5																	
CWC	11/11/10 10:25	2.27	8.46	1112	218	12.38																							
CWCS	11/17/10 13:12	7.18	7.07	5965	**-92**	0.89	390	137	1.7	3532		15.4	0.79	392	870	210	4.1	35000	7.8	133	7.27	266	1.3	0.58	320	0.54	6.98	0.484	3.64
D9S	12/2/10 15:45	13.28	7.01	4045	174	1.66	329	33	38	2459		42	**0.2**	478	310	200	13.2	150	9.8	34	7.21	793	54	0.2	730	0.24	30	0.783	14.8
DAR	11/12/10 11:40	6.39	8.27	1720	168	9.56	55	24	3.7	941		0.8	**0.2**	256	120	15.5	12	9000	7.1	11	7.74	0.9	2.5	0.41	89	0.15	0.864	**0.0314**	0.282
DARS1	11/12/10 11:40	14.40	7.88	9187	149	0.47	305	97	150	5729		39.7	**0.2**	356	1860	250	23.6	500	17	202	7.79	715.4	110	0.36	570	0.52	24.9	1.12	12.5
DARS2	11/12/10 11:40	16.06	7.71	15377	124	0.8	335	175	449	9865		33.2	**0.2**	356	3650	320	33.6	140000	41	430	7.76	442	400	0.37	560	0.59	22.7	0.565	11.5
DR	11/8/10 11:24	9.77	8.71	114	193	7.82	47	2.8	**0.5**	4.1		**0.2**	**0.2**	14.1	2.4	4.1	1.5	9000	12.4	**1**	8.48	**1**	0.058	0.34	**3.1**	1.4	**0.21**	**-0.0512**	**0.131**
DRDS	11/8/10 11:44	14.58	7.97	793	145	5.55	101	1.1	8.2	312		3.2	**0.2**	146	9.3	9	1.2	9000	2.9	**1**	7.76	311.2	0.41	1.3	24	0.66	1.31	**0.0306**	1.07
DRS1	11/8/10 14:01	10.37	7.16	27250	174	1.75	925	1270	534	18497		116.1	**1**	377	7600	600	26.8	540000	16	170	7.25	233.3	950	0.2	550	0.35	108	1.9	41.5
DRS3	11/8/10 15:02	15.18	7.25	22840	198	3.58	1045	798	76	15087		137.2	**1**	410	5900	600	34.6	35000	44	350	7.48	352.9	100	3	690	0.84	98.6	3.74	47.9
DTS1	12/7/10 10:26	1.86	7.11	13503	227	1.82	407	338	413	7698		100.7	**0.2**	330	3000	440	19.5	2300	20.1	143	7.38	792	990	0.26	380	0.56	69.7	1.47	30.5
DTS2	12/7/10 14:11	11.59	7.25	8724	166	5.24	492	387	389	4905		58.4	**0.2**	424	1500	440	32	2300	23	184	7.44	208	600	0.43	760	1.2	44.9	1.26	19.1
DTS3	12/7/10 12:57	8.02	6.99	6576	172	0.4	338	146	6.1	4273		36.5	**0.2**	390	820	420	17.8	9000	13.3	95	7.24	1049	12	0.24	550	0.34	29.5	0.693	13.9
DWS	11/16/10 12:05	3.57	8.45	48519	108	8.1	882	1032	2.9	49063		329.1	**2**	426	15200	2150	71.5	150	81	380	8.21	**1**	10	1.2	430	1.4	253	5.74	101
EF-22	12/2/10 17:02	8.15	7.45	37064	230	0.57	662	1925	3189	22552		173.6	**0.4**	360	9200	1300	34	150	59	211	7.5	407	2300	0.91	510	3.3	139	2.87	57
ETFW	11/11/10 14:00	10.05	7.87	21315	139	2.25						38.1																	
ETFWD	11/11/10 14:00			6300																									
GRCRS	11/12/10 8:32	6.92	7.24	3847	191	5.6	370	45	1.9	2209		21.1	0.24	530	395	100	7.2	2300	28	136	7.5		3.6	0.69	310	0.64	13	**0.0813**	7.38
GS	12/2/10 12:15											34.2																	
HGRP	11/3/10 12:25	8.21	7.82	45645	166	**5.1**																							
HGS	11/3/10 12:10	19.45	7.36	22790	136	2.35	690	102	1371	22540	1	353.9	**8**	450	2550	3300	47	9000	67	575	7.78	119.4	890	1.8	940	1.4	201	8.97	135
HGSE	11/3/10 0:00	9.08	6.88	21658	169	3.4																							
KCFS	11/2/10 12:00	10.90	7.22	26250	221	**3.32**	417	927	2216	16012	1	26.6	**0.2**	404	7200	520	36.4	2300	24	142	7.6	544.3	1400	0.15	500	0.2	37.1	0.744	9.09
LGW	11/12/10 14:15	2.60	8	1326	107	7.18																							
LGWS	11/12/10 14:15	3.87	7.25	1637	10	0.98	75	20	9	616		1.5	**0.2**	161	96	6.2	14	9000	12.3	49	7.59	**1**	16	0.39	41	0.62	2.02	**0.167**	0.895
LOUT11	11/3/10 16:00			11600																									
LOUT11W	11/3/10 16:05			315																									
LOUT12L	11/3/10 15:20	11.20	7.04	6220	252	7.04																							
LOUT12U	11/3/10 15:00	13.36	6.13	5190	281	6.7	310	176	151	3014		89.1	**0.4**	410	640	230	9.9	9000	15.6	79	7.27	452.2	1300	0.24	810	0.65	48.3	1.48	27.2
LOUT13	11/3/10 16:15			5880																									
LOUT14	11/3/10 17:20			17700																									
LOUT3	11/3/10 17:30	11.97	7.03	15330	228	2.65		818	459	8820		102.6	**2**	480	3700	420	28.8	9000	53	309	7.62	107.4	2000	0.66	1100	3.1	59.8	1.97	35
LOUT3	11/4/10 8:05						384															**1**							
LOUT8	11/4/10 10:15	11.74	7.91	22130	250		428	928	3361	14942	1	135.2	**2**	448	6700	720	37	35000	112	605	7.8	433	4700	0.6	990	1.1	68.5	2.08	36.6
LOUT9	11/4/10 11:15	15.65	7.54	8844	197		633	79	342	5696		101.6	**0.4**	430	1220	680	28.8	9000	21	172	7.23	455.3	730	0.22	1200	0.36	58.1	2.01	34
MS	11/16/10 14:50	10.51	7.41	1650	66	3.72	351	53	3.9	553		9.7	**0.2**	72	166	110	1.8	9000	5.8	71	7.52	947	17	0.35	230	2.3	5.65	**0.0582**	4.06
MWS	11/16/10 13:35	7.69	7.77	70002	255	3	1295	3382	33.5	76922		480.5	0.53	600	22750	7000	14.4		265	1962	7.88								
PCS	11/8/10 8:46	9.82	7.56	10739	277	2.62	610	250	**0.5**	7282		217.6	**1**	436	1720	640	29	35000	15	60	7.47	216.9	1.5	0.75	1400	0.24	114	2.88	72.4
S36	11/11/10 14:00	12.41	7.67	24522	164	2.62	479	436	841	17695		122.9	**1**	396	6500	840	23.6	2300	24	84	7.92	256.2	4100	0.36	260	0.47	79.2	1.13	35.9
SCWS	12/7/10 11:33	1.97	7.39	48639	238	1.62	1090	7098	3614	23800		160.3	**0.4**	448	15000	1400	62	140000	183	462	7.53	258	2100	0.65	800	1.1	150	2.58	53.3
SL	11/4/10 15:45	12.94	8.63	1728	-62		124	15.4	2.3	892		11.3	**0.2**	142.5	172	50	5.6	500	8.5	**1**	8.26	8.1	8.9	0.88	170	1.4	6.54	**0.196**	4.36
SNGC	11/4/10 14:43	9.95	8.12	6529	108		334	79	92	4134		32.8	**0.2**	346	1160	200	12.6	35000	31	65	8.1	49.8	110	0.56	530	1.1	21.4	0.424	10
SNS	11/4/10 14:35	8.09	8.45	68114	126			1982	18	78003	3	694.8	**2**	520	25000	1950	45		280	2560	8.46		3500	12	2000	19	468	15	243
SNS	11/30/10 11:39	2.25	8.13	36546	187	6.29						800.4																	
SNS1	11/30/10 11:25	3.44	7.56	53320	239	1.15						984.5																	
SNS2	11/30/10 12:18	4.23	8.3	33489	197	4.41						1921.7																	
SNS3	11/30/10 11:54	2.11	7.44	55959	190	0.61	1726	1589	4.1	47251		821.6	**2**	484	19000	2700	20.5	500	134	520	7.44	193	13	5.3	3200	3.7	489	14.4	280
SRP	11/4/10 15:15	16.35	7.61	39380	-255																								
SRP	11/30/10 15:06	8.02	7.47	35984	**69**	0.54						113.1																	
TWS	11/17/10 11:25	3.36	7.34	10018	-19	1.36	293	171	2.4	6524		13.2	0.31	374	1300	700	6.2	500	6.6	76	7.56	221	1.7	0.62	89	0.28	7.34	0.354	2.61
TWSP	11/17/10 10:50	7.77	6.99	5630	**-40**	1.3																							
UENAS	12/2/10 10:00	8.42	7.3	26607	224	2.66	368	4172	1074	12839		53	0.3	474	5900	1050	21.5	150	161	24	7.37	403	540	0.23	700	0.3	31.3	0.794	14.7
UFWS	11/11/10 0:00	9.46	7.64	6514	100	3.14						9.5																	
UFWS1	11/11/10 0:00	10.57	7.75	2236	-75	0.07																							
UFWS2	11/11/10 0:00	8.92	7.47	2236	-119	0.72																							
US1	11/30/10 15:23	2.85	8.35	41615	127	6.42						361.9																	
WCTS	12/7/10 16:22											700							261	1504	7.74								
WCTS	12/7/10 16:26											487.7							126	570	7.87	76							
WCTSP1	12/7/10 16:26	3.85	8.49	47655	205																								
WCTSP2	12/7/10 16:26			67475																									
WD2	11/2/10 14:10	8.13	6.57	2185	234		221	18	2.5	1085		24.3	**0.2**	266	138	92	4.5	2300	7.8	24	6.03	12.6	15	0.69	310	0.63	10.2	0.526	6.39
WD2S	11/2/10 13:20	11.33	4.15	14285	258	4.06	**0**	171	**0.5**	10820		**1**	16.7	380	2950	720	20.2	**25**	36	272	4.48	316.8	5.6	2.0	1500	0.19	**0.249**	**-0.0638**	**0.19**
WFFW	11/11/10 16:30			**21000**								57.4																	
YHS	12/1/10 13:30	9.92	7	1442	130	1.9	317	29	**2**	463		9.4	**0.2**	164	92	56	0.9	140000	8.9	**1**	7.18	811	5.9	0.2	150	1	7.21	**0.106**	2.93

* Alkalinity in mg/L as CaCO3.

Bold = detection limit

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Kyle F. Gross
Laboratory Director

Jose Rocha
QA Officer

INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant
Contact: Brad Giles
Project: Huntington Sitewide
Lab Sample ID: 1605144-004
Client Sample ID: UPL-13
Collection Date: 5/3/2016 1300h
Received Date: 5/5/2016 1615h

Analytical Results DISSOLVED METALS

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
Arsenic	mg/L	5/10/2016 1314h	5/11/2016 1444h	SW6020A	0.00200	**0.0116**	
Boron	mg/L	5/10/2016 1314h	5/17/2016 1422h	SW6010C	5.00	**12.1**	
Cadmium	mg/L	5/10/2016 1314h	5/11/2016 1444h	SW6020A	0.000500	< 0.000500	
Calcium	mg/L	5/10/2016 1314h	5/17/2016 1320h	SW6010C	100	**549**	
Chromium	mg/L	5/10/2016 1314h	5/11/2016 1444h	SW6020A	0.00200	**0.0133**	
Iron	mg/L	5/10/2016 1314h	5/17/2016 1558h	SW6010C	0.100	< 0.100	
Magnesium	mg/L	5/10/2016 1314h	5/17/2016 1320h	SW6010C	100	**448**	
Manganese	mg/L	5/10/2016 1314h	5/11/2016 1444h	SW6020A	0.00200	**0.0284**	
Mercury	mg/L	5/10/2016 1720h	5/11/2016 925h	SW7470A	0.000150	< 0.000150	
Nickel	mg/L	5/10/2016 1314h	5/11/2016 1444h	SW6020A	0.00200	**0.0206**	
Potassium	mg/L	5/10/2016 1314h	5/17/2016 1422h	SW6010C	10.0	**37.8**	
Selenium	mg/L	5/10/2016 1314h	5/11/2016 1444h	SW6020A	0.00200	**0.0306**	
Sodium	mg/L	5/10/2016 1314h	5/17/2016 1320h	SW6010C	100	**369**	

Analysis performed on a portion of the sample filtered at the laboratory upon receipt. The sample was received after the filtration holding time had expired for dissolved analysis.

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INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Brad Giles
Project: Huntington Sitewide
Lab Sample ID: 1605144-004
Client Sample ID: UPL-13
Collection Date: 5/3/2016 1300h
Received Date: 5/5/2016 1615h

Analytical Results TOTAL METALS

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
Arsenic	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.0121**	^
Barium	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.287**	
Beryllium	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	< 0.00200	
Cadmium	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.000500	< 0.000500	
Calcium	mg/L	5/10/2016 1314h	5/27/2016 1036h	SW6010C	100	**528**	^
Chromium	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.0138**	
Copper	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.0395**	
Lead	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	< 0.00200	
Magnesium	mg/L	5/10/2016 1314h	5/27/2016 1036h	SW6010C	100	**434**	^
Mercury	mg/L	5/27/2016 1307h	5/31/2016 922h	SW7470A	0.000150	< 0.000150	^
Molybdenum	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.0284**	
Nickel	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.0197**	^
Potassium	mg/L	5/10/2016 1314h	5/27/2016 1046h	SW6010C	10.0	**39.9**	^
Selenium	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.0301**	^
Sodium	mg/L	5/10/2016 1314h	5/27/2016 1036h	SW6010C	100	**344**	^
Uranium	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00200	**0.00597**	
Vanadium	mg/L	5/10/2016 1314h	5/17/2016 1515h	SW6010C	0.00500	**0.0197**	
Zinc	mg/L	5/10/2016 1314h	5/11/2016 1631h	SW6020A	0.00500	**0.0240**	

^ - Reissue of a previously generated report. Information has been added, updated, or revised. Information herein supersedes that of the previously issued reports.

INORGANIC ANALYTICAL REPORT

Client: PacifiCorp - Huntington Plant **Contact:** Brad Giles
Project: Huntington Sitewide
Lab Sample ID: 1605144-004
Client Sample ID: UPL-13
Collection Date: 5/3/2016 1300h
Received Date: 5/5/2016 1615h

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Kyle F. Gross
Laboratory Director

Jose Rocha
QA Officer

Analytical Results

Compound	Units	Date Prepared	Date Analyzed	Method Used	Reporting Limit	Analytical Result	Qual
Alkalinity (as CaCO3)	mg/L		5/6/2016 707h	SM2320B	10.0	**141**	
Bicarbonate (as CaCO3)	mg/L		5/6/2016 707h	SM2320B	10.0	**34.4**	
Carbonate (as CaCO3)	mg/L		5/6/2016 707h	SM2320B	10.0	**107**	
Chloride	mg/L		5/12/2016 2232h	E300.0	10.0	**619**	
Conductivity	µmhos/cm		5/6/2016 600h	SM2510B	2.00	**6,420**	
Fluoride	mg/L		5/13/2016 751h	E300.0	0.100	**5.91**	
Hardness (as CaCO3)	mg/L		5/17/2016	SM2340B	10.0	**3,220**	
Nitrate/Nitrite (as N)	mg/L		5/18/2016 1344h	E353.2	0.100	**12.1**	
pH @ 25° C	pH Units		5/5/2016 1829h	SM4500-H+B	1.00	**7.41**	H
Sulfate	mg/L		5/12/2016 1728h	E300.0	750	**2,980**	
Total Dissolved Solids	mg/L		5/6/2016 1346h	SM2540C	20.0	**5,020**	

H - Sample was received outside of the holding time.

RadioChemistry Analytical Results

American West Analytical Labs
Project ID: 1605144
Sample ID: UP&L 13
Locator:

ACZ Sample ID: ***L30344-01***
Date Sampled: *05/03/16 13:00*
Date Received: *05/10/16*
Sample Matrix: *Ground Water*

Radium 226
M903.1

Prep Method:

Parameter	Measure Date	Prep Date	Result	Error(+/-)	LLD	Units	XQ	Analyst
Radium 226	05/23/16 0:15		0.38	0.17	0.36	pCi/L	*	mns

Radium 228
M904.0

Prep Method:

Parameter	Measure Date	Prep Date	Result	Error(+/-)	LLD	Units	XQ	Analyst
Radium 228	05/25/16 10:14		1.8	0.84	0.79	pCi/L		djc

Arizona license number: AZ0102

Inorganic Analytical Results

American West Analytical Labs
Project ID: 1605144
Sample ID: UP&L 13

ACZ Sample ID: ***L30344-01***
Date Sampled: *05/03/16 13:00*
Date Received: *05/10/16*
Sample Matrix: *Ground Water*

Inorganic Prep

Parameter	EPA Method	Dilution	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Total Hot Plate Digestion	M200.2 ICP-MS				*				05/12/16 13:14	scp

Metals Analysis

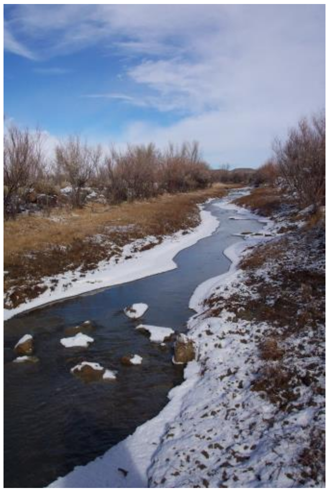
Parameter	EPA Method	Dilution	Result	Qual	XQ	Units	MDL	PQL	Date	Analyst
Tellurium, total	M200.8 ICP-MS	1		U	*	mg/L	0.001	0.005	05/13/16 15:01	enb
Thorium, total	M200.8 ICP-MS	1		U	*	mg/L	0.001	0.005	05/13/16 15:01	enb

Arizona license number: AZ0102

** Please refer to Qualifier Reports for details.*

PRICE RIVER, SAN RAFAEL RIVER, AND MUDDY CREEK TMDLS FOR TOTAL DISSOLVED SOLIDS WEST COLORADO WATERSHED MANAGEMENT UNIT, UTAH

EPA APPROVAL DATE: AUGUST 4, 2004



Prepared for:

UTAH DIVISION OF WATER QUALITY

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MFG Project No. 180976

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APPENDICES

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LIST OF ACRONYMS

BLM	Bureau of Land Management
BMP	Best Management Practice
BOR	Bureau of Reclamation
CBM	coal-bed methane
cfs	cubic feet per second
DEQ	Utah Department of Environmental Quality
DO	Dissolved Oxygen
EWCD	Emery Water Conservancy District
Fe	Iron
gpm	gallons per minute
L	liter
LA	load allocation
M&I	municipal and industrial
mg	milligrams
MOS	margin of safety
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRCS	Natural Resources Conservation Service
PIP	Project Implementation Plan
POC	Parameter of Concern
SCS	Soil Conservation Service
SLA	sum of individual load allocations
SWLA	sum of individual wasteload allocations
TDS	total dissolved solids
TMDL	total maximum daily load
UAC	Utah Administrative Code
USFS	United States Forest Service
USGS	United States Geological Survey
WCRW	West Colorado River Watershed
WLA	wasteload allocation

1.0 INTRODUCTION

This TMDL study has been prepared for the Price River, San Rafael River, and Muddy Creek watersheds. These three watersheds encompass a large portion of the West Colorado Watershed Management Unit located in east-central Utah. Water quality assessments completed by the Utah Department of Environmental Quality, Division of Water Quality (DEQ) in 1997 resulted in several stream segments in these watersheds being listed on the Utah's 303 (d) list for impaired waters in 2000. The DEQ determined that primarily due to high concentrations of total dissolved solids (TDS) several portions and/or tributaries of the Price River its headwaters and the Green River are non-supporting or partially supporting of their agricultural use classifications. Additionally, for certain smaller river sections, pH, dissolved oxygen (DO), and dissolved iron (Fe) are also cited as causing impairment. The water quality assessment performed by the DEQ, which was also supported by water quality sampling performed by the Emery County Water Conservancy District (EWCD), also revealed that agricultural use classifications are not being supported in several stream segments in the San Rafael and Muddy Creek watersheds as a result of high concentrations of TDS in these waters. The impaired stream segments in the watershed are listed in Table 1-1.

Section 303 (d) of the Clean Water Act requires states to identify waterbodies not currently meeting water quality standards after technology-based controls are in place. Consequently, states are required to have TMDLs established in order to attain water quality standards for impaired waters. The TMDL establishes allowable loadings for pollutants for a given waterbody. Although pH, dissolved oxygen (DO), and iron (Fe) have also been cited as causing water quality impairments in the Price River and one tributary (see Table 1-1), the focus of this TMDL study is TDS. As described in Section 3.1 of this report, analyses of available data indicate that there are no impairments attributable to DO and pH (Toole 2003).

This section of the report describes the purposes of this TMDL study, the watersheds studied, and the associated water quality impairments. Section 2 of this report describes the applicable water quality standards and the establishment of target sites and a TMDL endpoint. Section 3 discusses the assessment of the current water quality in the watersheds and impairment analysis. Section 4 addresses the sources of TDS loading in the watersheds. Section 5 describes the methods that were used to establish TDS loading capacity, and Section 6 describes the TMDL allocations required to meet established TMDL endpoints.

Table 1-1 Impaired Stream Segments in the Price River, San Rafael, and Muddy Creek Watersheds due to TDS loadings[1]

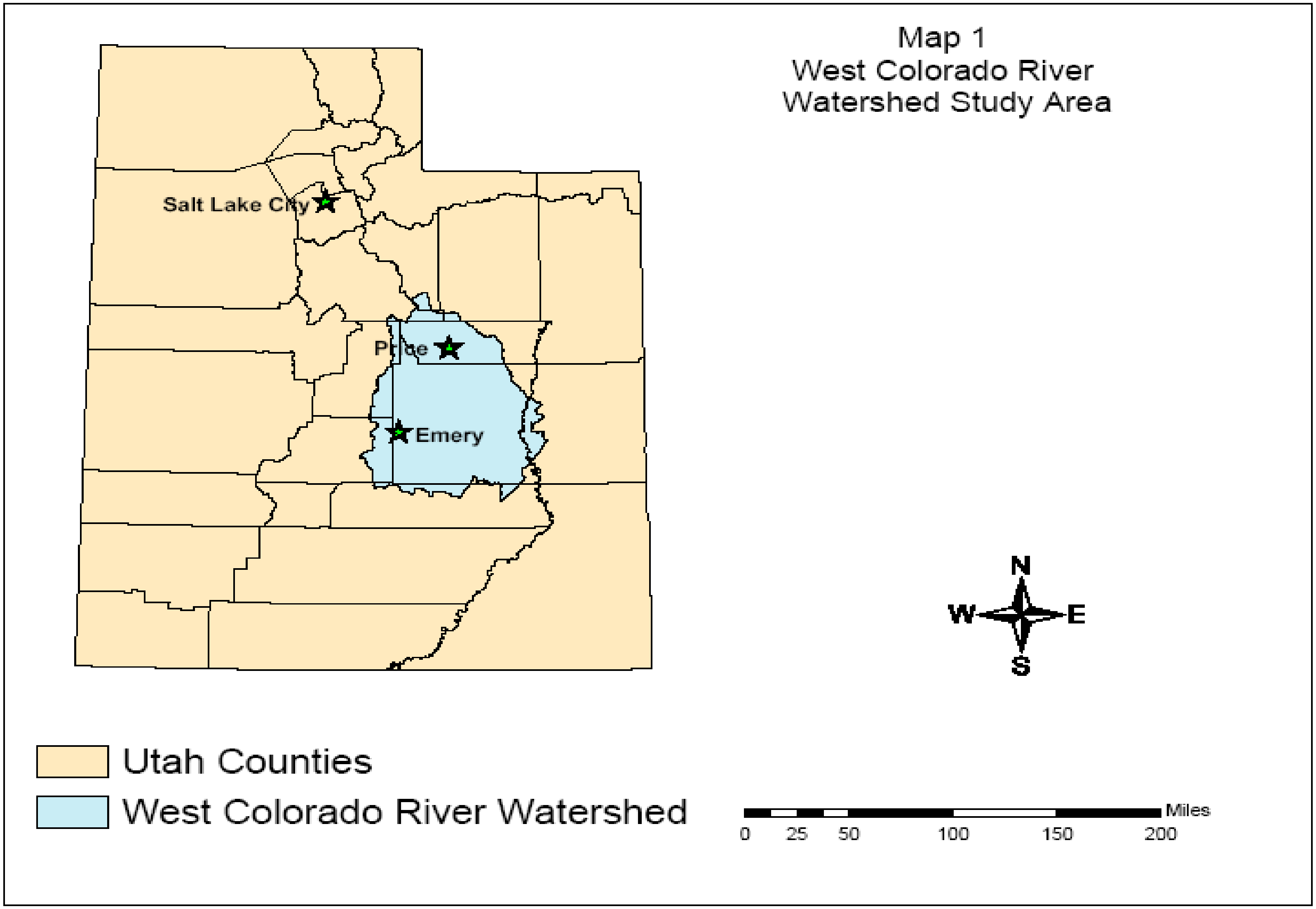
Price River Watershed	San Rafael River Watershed	Muddy Creek Watershed
Non-supporting segments[2]:	***Non-supporting segments:***	***Non-supporting segments:***
Gordon Creek and tributaries from confluence with Price River to headwaters[6]	Huntington Creek tributaries from the confluence with Cottonwood Creek to Utah highway 10	Muddy Creek and its tributaries from Quitchupah Creek confluence to the Utah Highway 10 bridge
Pinnacle Creek from confluence with Price River to headwaters[8]	Huntington Creek and tributaries from Highway 10 crossing to USFS boundary[7]	Quitchupah Creek from confluence with Ivie Creek to the Utah Highway 10 bridge
Price River and tributaries from confluence with Green River to near Woodside[3]	Cottonwood Creek from the confluence with Huntington Creek to Highway 57	Ivie Creek and its tributaries from the confluence with Muddy Creek to Utah Highway 10
Price River and tributaries from near Woodside to Soldier Creek confluence	Rock Canyon Creek from confluence with Cottonwood Creek to headwaters[5]	Muddy Creek from the confluence with Fremont River to Quitchupah Creek confluence
Upper Grassy Trail Creek from Grassy Trail Creek Reservoir to headwaters [4]	San Rafael River from Buckhorn Crossing to the confluence with Huntington Creek and Cottonwood Creek	
Partially-supporting segments[2]:	San Rafael River from the confluence with the Green River to Buckhorn Crossing	
Price River and its tributaries from Coal Creek to Carbon Canal Diversion		

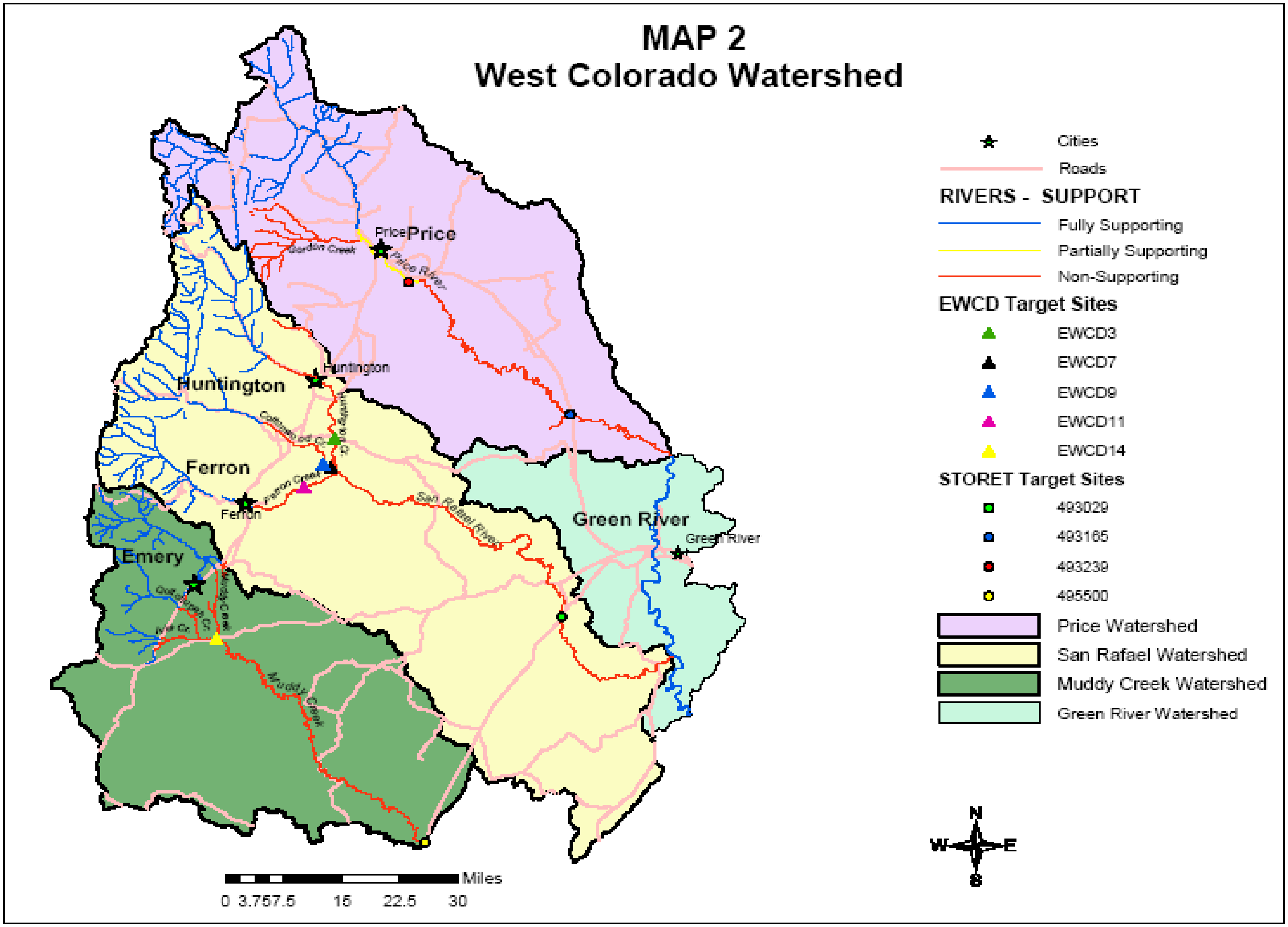
Source: DEQ (2000)

1. All impairments are due to measured TDS concentrations and also dissolved oxygen and iron concentrations as noted.
2. Non-support is defined as TDS criteria that were exceeded at least two times and the criterion was exceeded in more than 25% of the samples. Partial support for TDS is defined as criterion that was exceeded at least two times and the criterion was exceeded in more than 10% but less than 25% of the samples.
3. Includes impairment for DO and Fe
4. This reach is listed in DEQ (2000) as impaired due to pH. More recent information indicates that it is not impaired and DEQ has petitioned for delisting in the draft Utah 2004 303 (d) list of waters.
5. Rock Canyon Creek is not listed as impaired in DEQ (2000) but the available data indicate that there is impairment from TDS.
6. Gordon Creek is not listed in DEQ (2000) but recent information indicates that there is impairment from TDS.
7. This reach is not listed in DEQ (2000), but is included in the draft Utah 2004 303(d) list of waters.
8. Pinnacle Creek was originally listed as Gordon Creek

1.1 Watershed Characterization

The Price River, San Rafael River, and Muddy Creek watersheds, which collectively make up the West Colorado River Watershed (WCRW) TMDL, are located in east-central Utah, approximately 100 miles southeast of Salt Lake City (Map 1). The WCRW is generally encompassed within Carbon and Emery counties and is approximately 100 miles in length north to south and 65 miles in length east to west (Map 2). Elevations within the WCRW range from approximately 3,700 feet to 11,000 feet.


Map 1
West Colorado River
Watershed Study Area



MAP 2
West Colorado Watershed

The Price River is the northernmost river in the WCRW. It is approximately 50 miles long and discharges into the Green River above Green River, Utah. The San Rafael River, located further south, is approximately 55 miles long and empties into the Green River below Green River, Utah. Muddy Creek, the southernmost river in the WCRW, is approximately 40 miles long and empties into the Dirty Devil River. The Green and Dirty Devil Rivers ultimately empty into the Colorado River. Smaller hierarchy streams in the WCRW include Gordon Creek in the Price River watershed; Huntington Creek, Cottonwood Creek, Rock Canyon Creek, and Ferron Creek in the San Rafael River watershed; and Quitchupah Creek and Ivie Creek in the Muddy Creek watershed. The WCRW contains approximately 2,550 perennial stream miles. Of this total, approximately 1,986 stream miles were assessed for beneficial use by the DEQ (DEQ 2000).

1.1.1 Land Use and Administration

Current land uses in the WCRW are agriculture (crop production and rangeland), mixed use public lands, and gas and coal production. There is a small amount of forest production in the higher elevations of the WCRW.

Based on data from the USGS (2000), existing land uses in the WCRW were grouped into seven general land use categories. Current land use distributions for the three watersheds in the WCRW are given in Table 1-2.

Table 1-2 Land Use Distributions in the WCRW

Land Use	Price River watershed		San Rafael River watershed		Muddy Creek watershed	
	Area (acres)	% of total area	Area (acres)	% of total area	Area (acres)	% of total area
Barren	91,737	7.0%	328,767	12%	225,932	13%
Residential	3,812	<1%	2,877	<1%	1,105	<1%
Agriculture	16,341	<1%	20,202	1%	4,618	<1%
Rangeland	792,271	66%	1,022,531	73%	662,453	75%
Forest	300,125	24%	179,300	13%	97,309	11%
Water	1,954	<1%	1,982	<1%	173	<1%
Wetland	228	<1%	304	<1%	192	<1%
TOTAL	1,206,468	100.0%	1,555,963	100%	991,782	100%

Source: USGS 2000

Approximately 73 percent of the land in the WCRW is administered by three federal agencies: the U.S. Forest Service (USFS), the Bureau of Land Management (BLM), and the National Park Service (NPS). The State of Utah administers about 11 percent of the WCRW, while 16 percent is privately owned land. Land administration types and acreages for the three watersheds are listed in Table 1-3. Maps 3, 4, and 5 show the land administrative ownership for the three sub-watersheds in the WCRW.

Table 1-3 WCRW Land Ownership/Administration

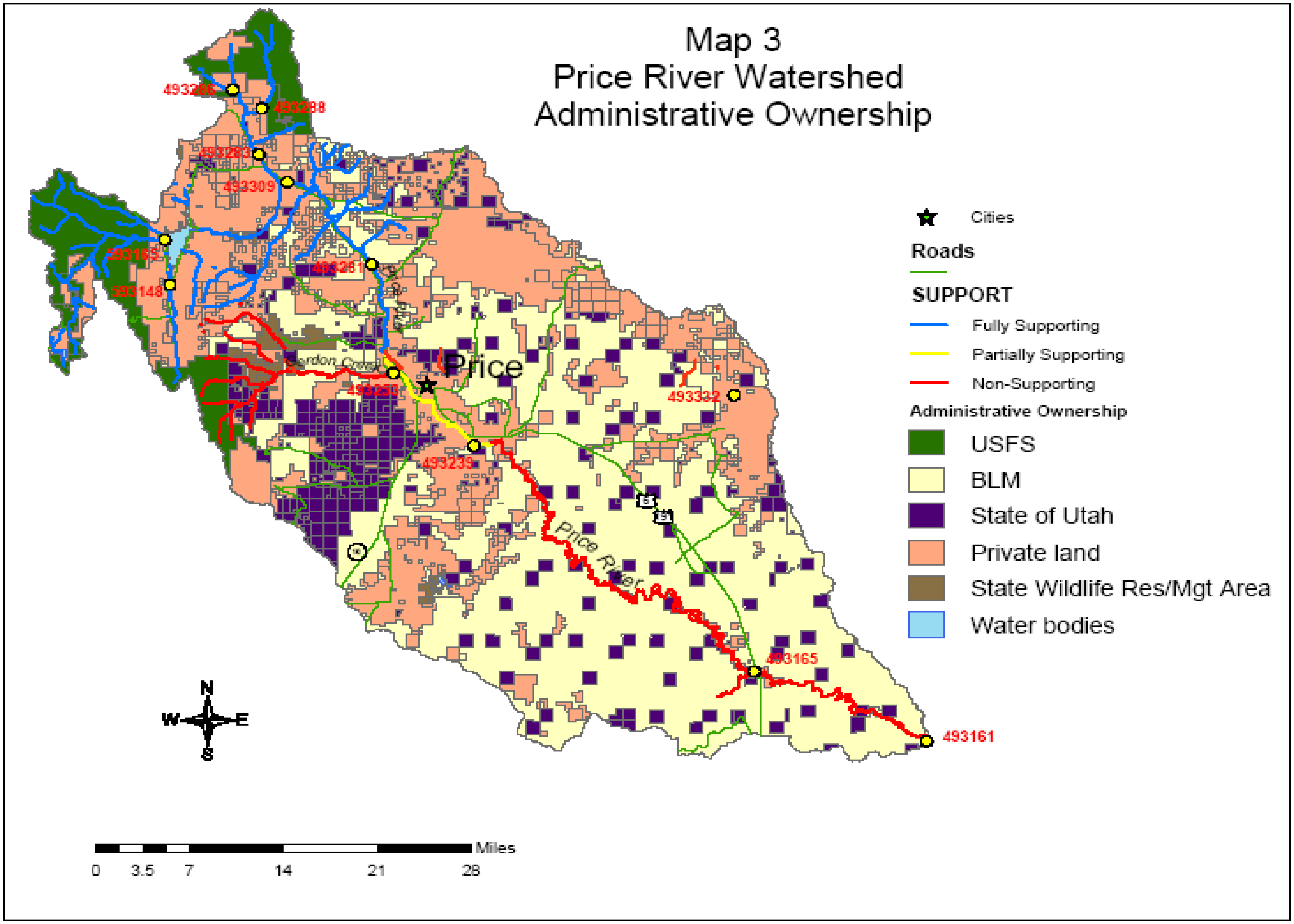
Land Ownership/ Administrator	Price watershed		San Rafael watershed		Muddy Creek watershed	
	Area (acres)	% of area	Area (acres)	% of area	Area (acres)	% of area
USFS	86,656	7%	335,920	21%	196,980	20%
BLM	532,559	44%	915,885	59%	644,929	65%
State of Utah	143,131	12%	160,256	10%	85,399	8%
Private	424,861	35%	138,847	9%	46,313	5%
Nat Parks/Mon.	0	0%	45	<1%	17,571	2%
State Parks/Rec. Areas	0	0%	393	<1%	0	0%
State Wildlife Areas	15,604	1%	1,171	<1%	0	0%
Water	3,133	<1%	2,778	<1%	91	<1%
TOTAL	1,205,944	100%	1,555,295	100%	991,283	100%

Source: DEQ 2000

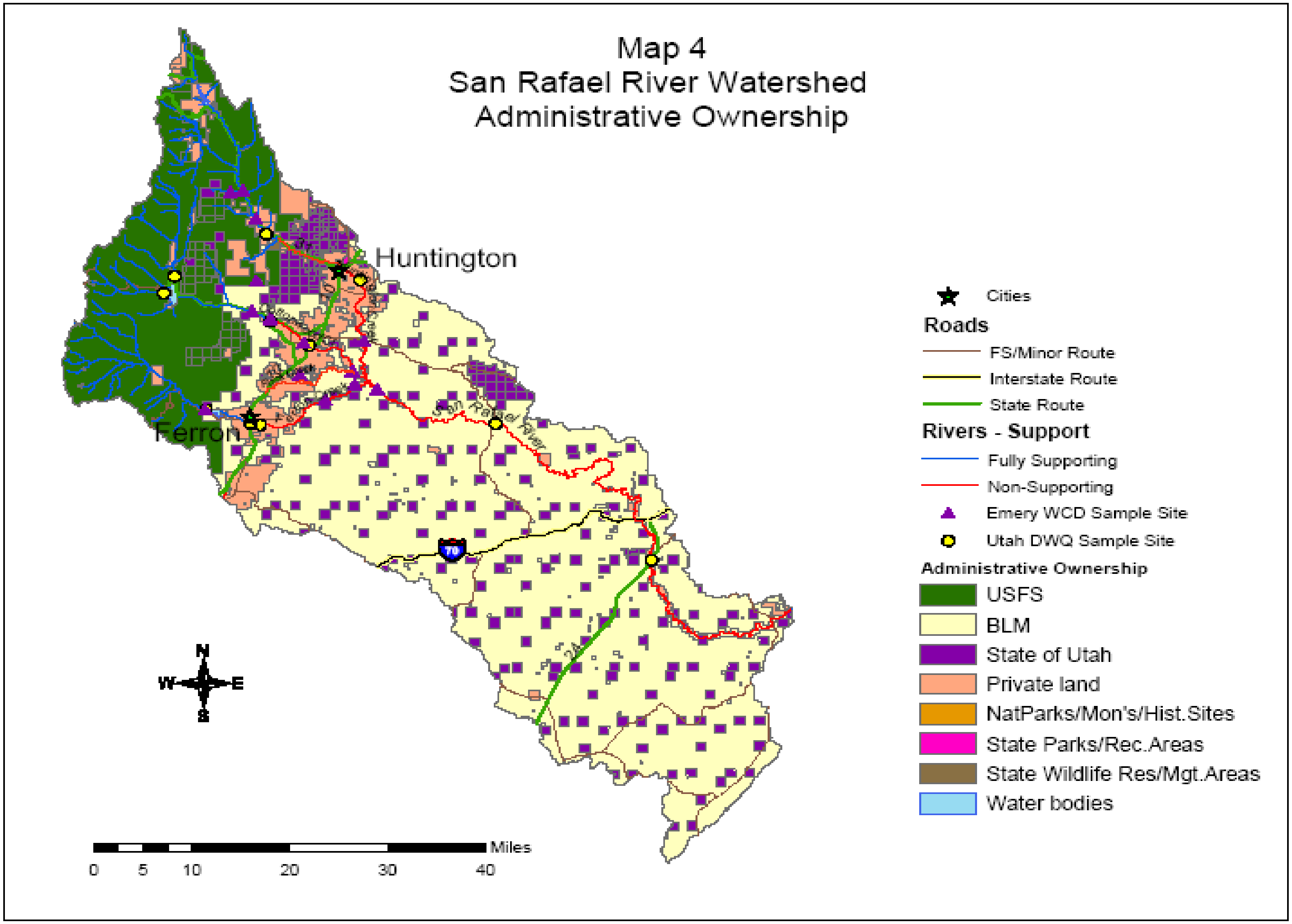
1.1.2 Geology

1.1.2.1 Physiography and Topography

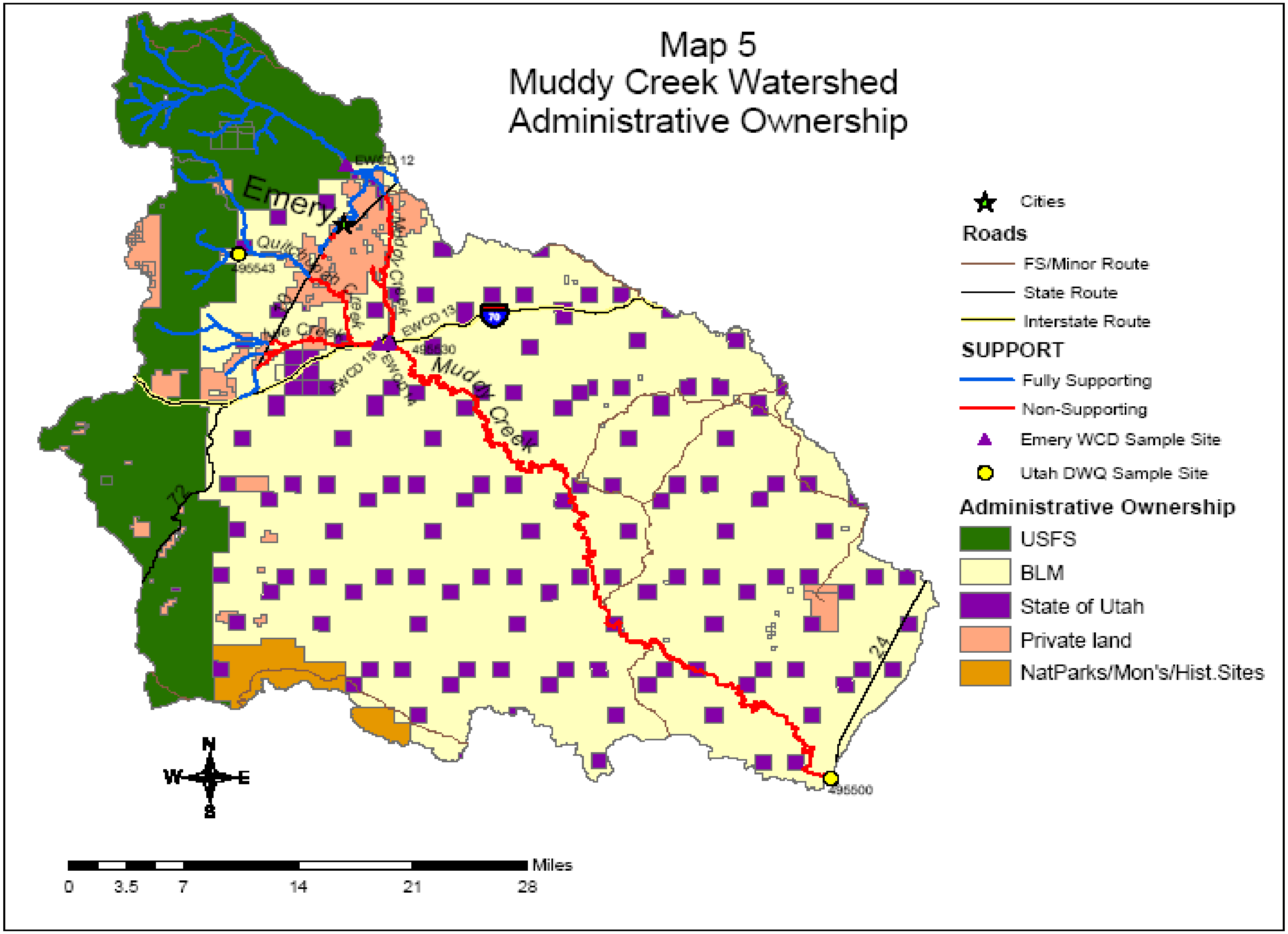
The WCRW is located in the northwestern portion of the Colorado Plateau physiographic province, within the Mancos Shale Lowlands (Stokes 1986). The Mancos Shale Lowlands is characterized by sloping, gravel-covered pediments, rugged badlands and narrow, flat-bottomed alluvial valleys (Stokes 1986). The Mancos Shale Lowlands is bounded by the Book Cliffs-Roan Plateau to the north, the San Rafael Swell to the southeast, and the Wasatch Plateau to the west. The Book Cliffs-Roan Plateau is a series of erosional cliffs, including the Book Cliffs, Roan Cliffs and Badland Cliffs that separate the Mancos Shale Lowlands from the Uinta Basin to the northeast. The San Rafael Swell, an anticline structure of uplifted and exposed Paleozoic and Cretaceous rocks (Stokes 1986), is approximately 80 miles long and 30 miles wide. The Wasatch Plateau is primarily sedimentary rock that contains zones of normal faulting, which forms long, narrow horst and graben structures. The Joes Valley Fault system is found along the eastern edge of the Wasatch Plateau and separates it from the Mancos Shale Lowlands.



Map 3
Price River Watershed
Administrative Ownership
493286
493288
493283
493309
593165
593148
493281
Price River
Gordon Creek
493253
Price
493239
493332
Price River
493165
493161
Cities
Roads
SUPPORT
Fully Supporting
Partially Supporting
Non-Supporting
Administrative Ownership
USFS
BLM
State of Utah
Private land
State Wildlife Res/Mgt Area
Water bodies
N
W
E
S
Miles
0
3.5
7
14
21
28

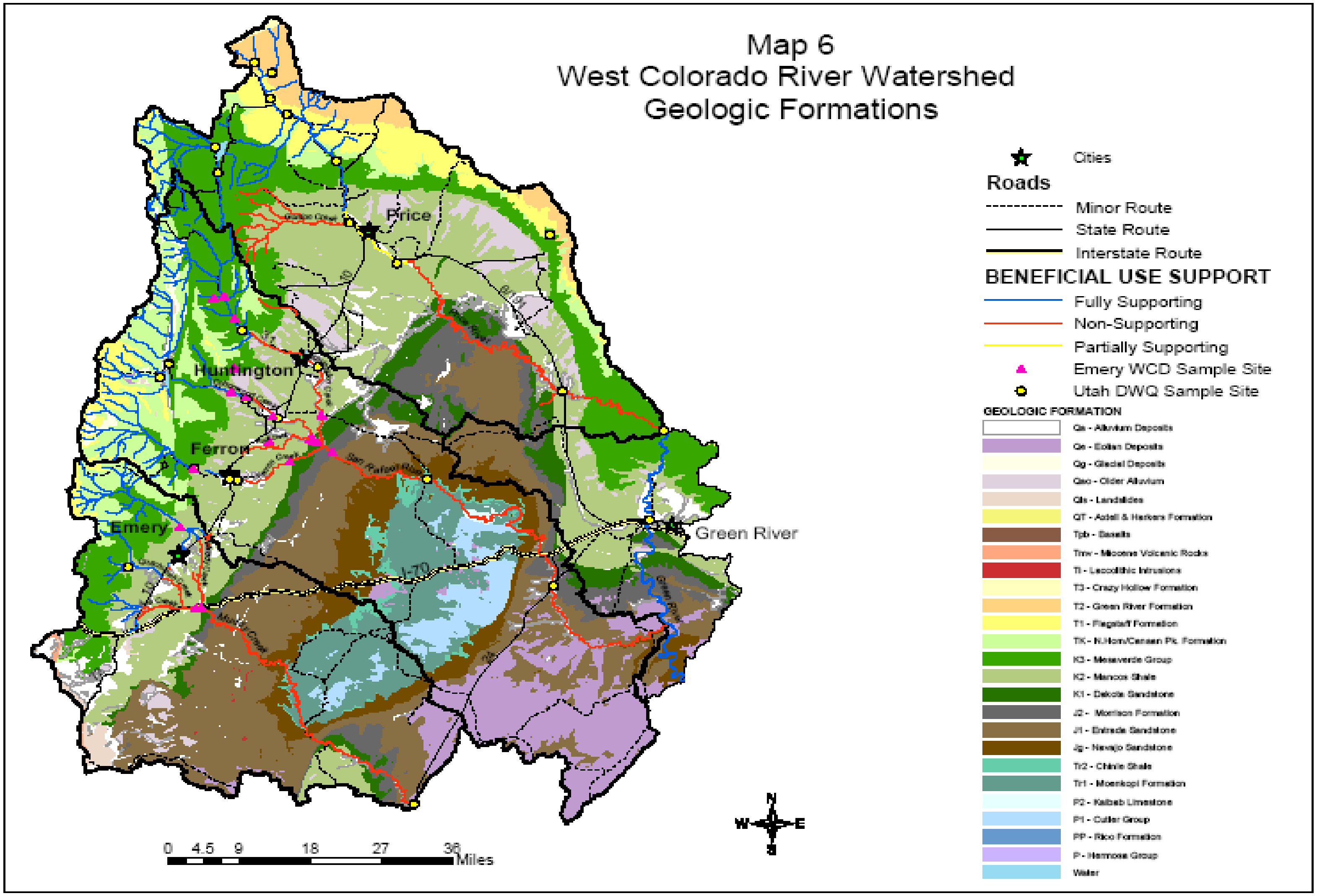


Map 4
San Rafael River Watershed
Administrative Ownership


Map 5
Muddy Creek Watershed
Administrative Ownership
Cities
Roads
FS/Minor Route
State Route
Interstate Route
SUPPORT
Fully Supporting
Non-Supporting
Emery WCD Sample Site
Utah DWQ Sample Site
Administrative Ownership
USFS
BLM
State of Utah
Private land
NatParks/Mon's/Hist.Sites
Emery
EWCD 12
EWCD 13
EWCD 15
495543
495530
495500
Quitchupah Creek
Ivie Creek
Muddy Creek
70
72
24
N
W
E
S
Miles
0
3.5
7
14
21
28

1.1.2.1 Stratigraphy and Structure

Stratigraphic units in the WCRW include exposed igneous and sedimentary units that range from Triassic to Tertiary in age (Map 6). The exposed rocks include limestone, sandstone, shale, conglomerate, coal, and various types of igneous rocks. Units of the Mesaverde Group form the distinct cliffs along the northern and western edge of the WCRW. Within the Mesaverde Group is the coal-bearing Blackhawk Formation. The Mancos Shale Formation is exposed in the middle reaches of the WCRW. Within the Mancos Shale, the Ferron Sandstone Member is a source of coal and groundwater. Surrounding the San Rafael Swell are the Dakota Sandstone, Morrison Formation, Entrada Sandstone, Navajo Sandstone, and Chinle Shale units.

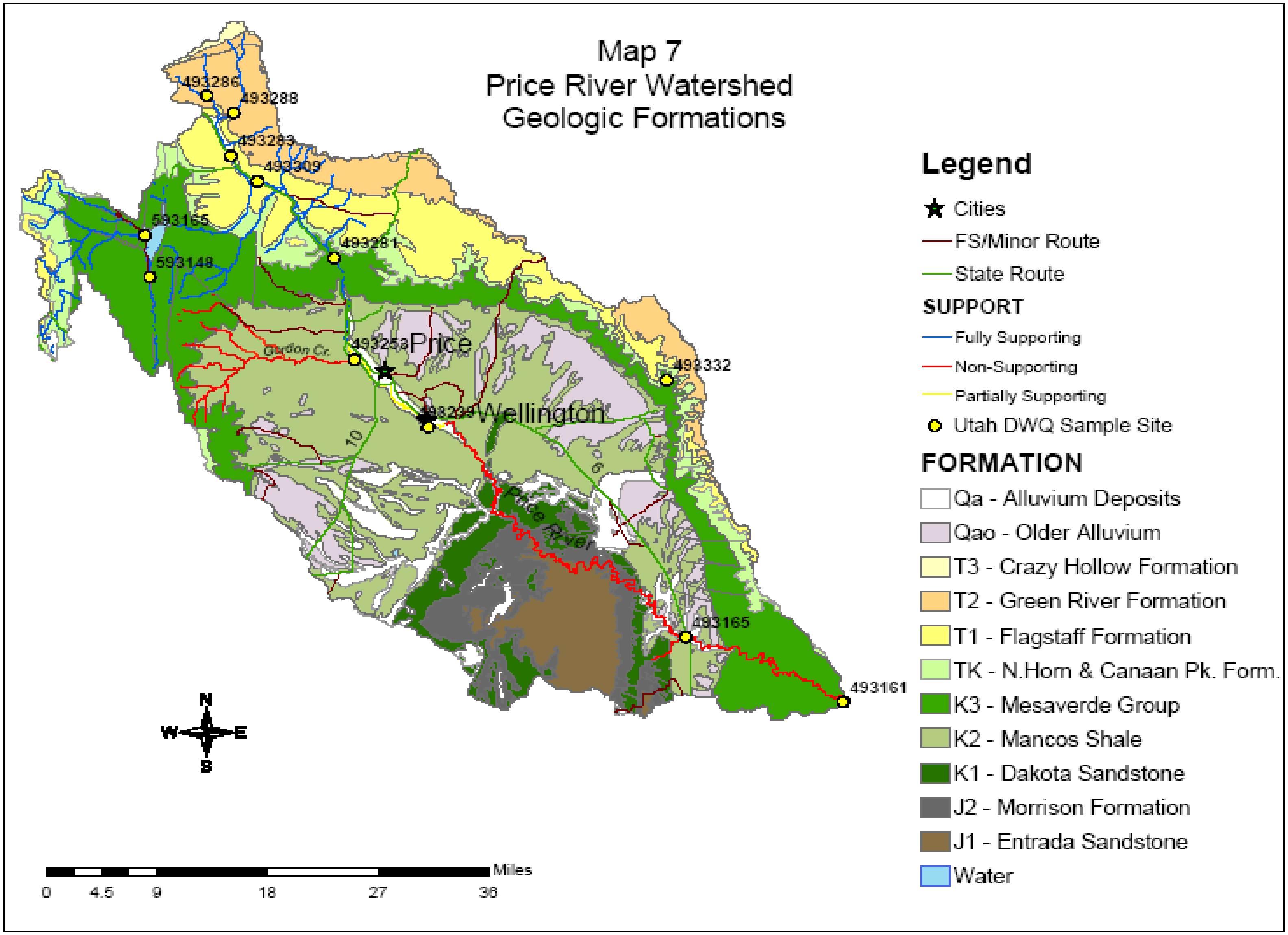

Map 6
West Colorado River Watershed
Geologic Formations
Cities
Roads
Minor Route
State Route
Interstate Route
BENEFICIAL USE SUPPORT
Fully Supporting
Non-Supporting
Partially Supporting
Emery WCD Sample Site
Utah DWQ Sample Site
GEOLOGIC FORMATION
Qa - Alluvium Deposits
Qe - Eolian Deposits
Qg - Glacial Deposits
Qao - Older Alluvium
Qls - Landslides
QT - Adell & Harkers Formation
Tpb - Basalts
Tmv - Miocene Volcanic Rocks
Tl - Laccolithic Intrusions
T3 - Crazy Hollow Formation
T2 - Green River Formation
T1 - Flagstaff Formation
TK - N.Horn/Canaan Pk. Formation
K3 - Mesaverde Group
K2 - Mancos Shale
K1 - Dakota Sandstone
J2 - Morrison Formation
J1 - Entrada Sandstone
Jg - Navajo Sandstone
Tr2 - Chinle Shale
Tr1 - Moenkopi Formation
P2 - Kaibab Limestone
P1 - Cutler Group
PP - Rico Formation
P - Hermosa Group
Water
Price
Huntington
Ferron
Emery
Green River
I-70
0
4.5
9
18
27
36
Miles
N
W
E
S

1.1.2.2 Mancos Shale and Blackhawk Formation

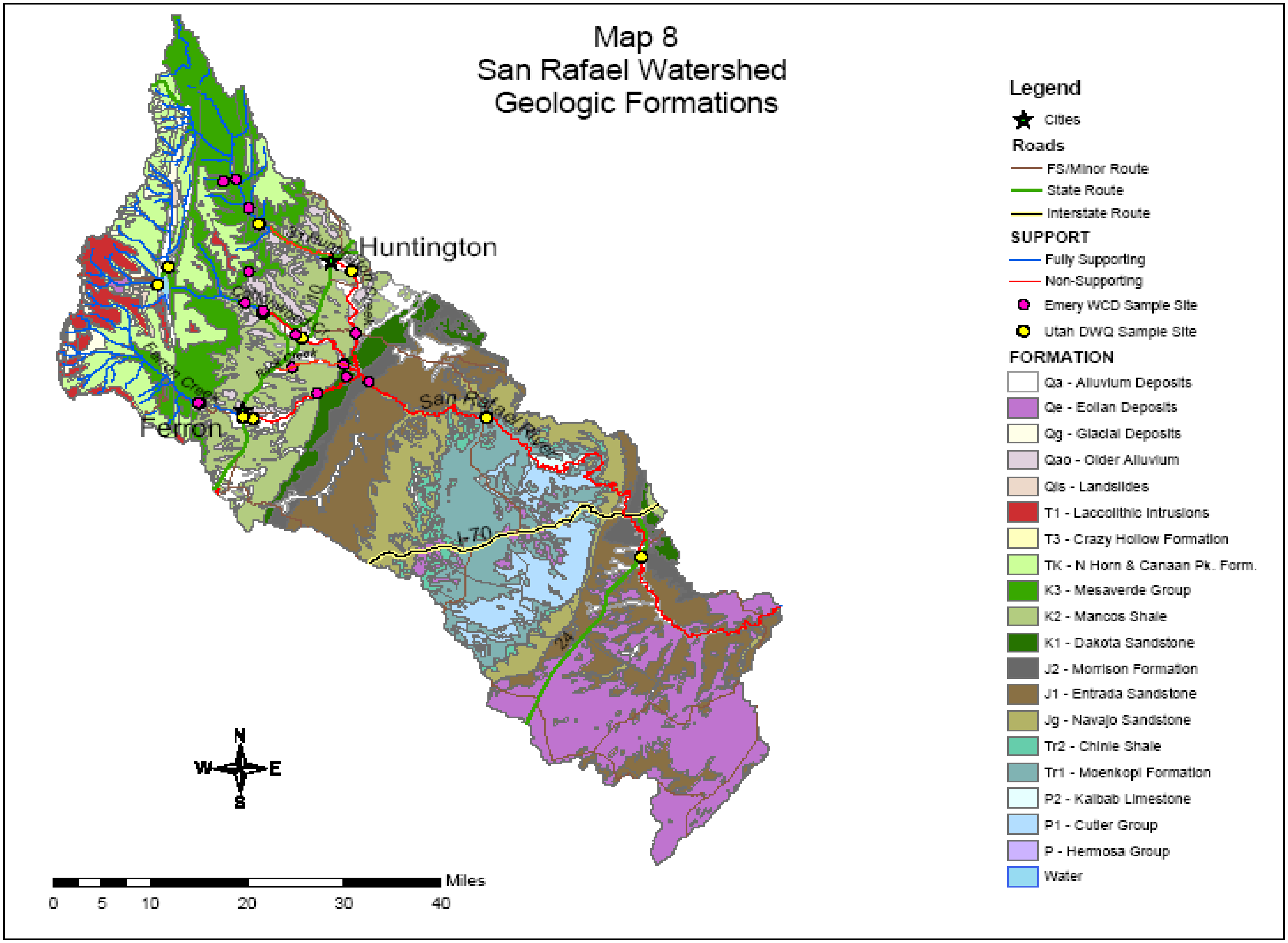
Due to their geochemical composition, range of exposure in the WCRW, and erodability from physical contact with water, the Mancos Shale and Blackhawk Formations present natural sources of soluble salts. Both are similar in composition in that they contain coal-bearing beds, formed in coastal-marine environments, and are predominately shale units. Through mineral dissolution and cation/anion exchange, shale and coal beds are a known contributor of increased TDS in surface water and groundwater (Freeze and Cherry 1979).

The Mancos Shale Formation is a known source of soluble sodium-sulfate minerals such as mirabilite ($Na_2SO_4 * 10H_2O$) and thenardite (Na_2SO_4) (Waddell et al. 1979). Thickness of the Mancos Shale ranges from 2,300 to 6,100 feet. It consists of six members, the Upper Blue Gate, Emery Sandstone, Blue Gate, Garley Canyon Sandstone, Ferron Sandstone, and Tununk Shale, that were deposited from the transgression and regression of coastal marine environments (BLM 2000, Frazier and Schwimmer 1987). The Upper Blue Gate Member is a light to dark-gray shale and shaley siltstone with minor thin sandstone beds. The Emery Sandstone consists of two fine-grained, light brown quartzose sandstones with an average thickness of 285 feet. A gray, thin-bedded shale averaging 35 to 50 feet thick separates the two sandstones units. The Blue Gate Member consists of light bluish gray thin-bedded shale and shaley siltstones that range in thickness from 1,600 to more than 3,500 feet (BLM 1999). The Garley Canyon Sandstone consists of two thin, cliff forming sandstone beds, separated by shale, which ranges in thickness from 70 to 220 feet (BLM 1999). The Ferron Sandstone consists of alternating fluvial-deltaic sandstones and thick coals, which range in thickness from 250 to 490 feet (BLM 2000). Deposition of the Ferron Sandstone occurred by a repeating series of wave and river dominated shorelines, delta plains, and bog swamp facies (BLM 1994). The Tununk Shale consists of light- to dark-gray, thin-bedded shale and shaley siltstones that range in thickness from 400 to 650 feet (BLM 2000).

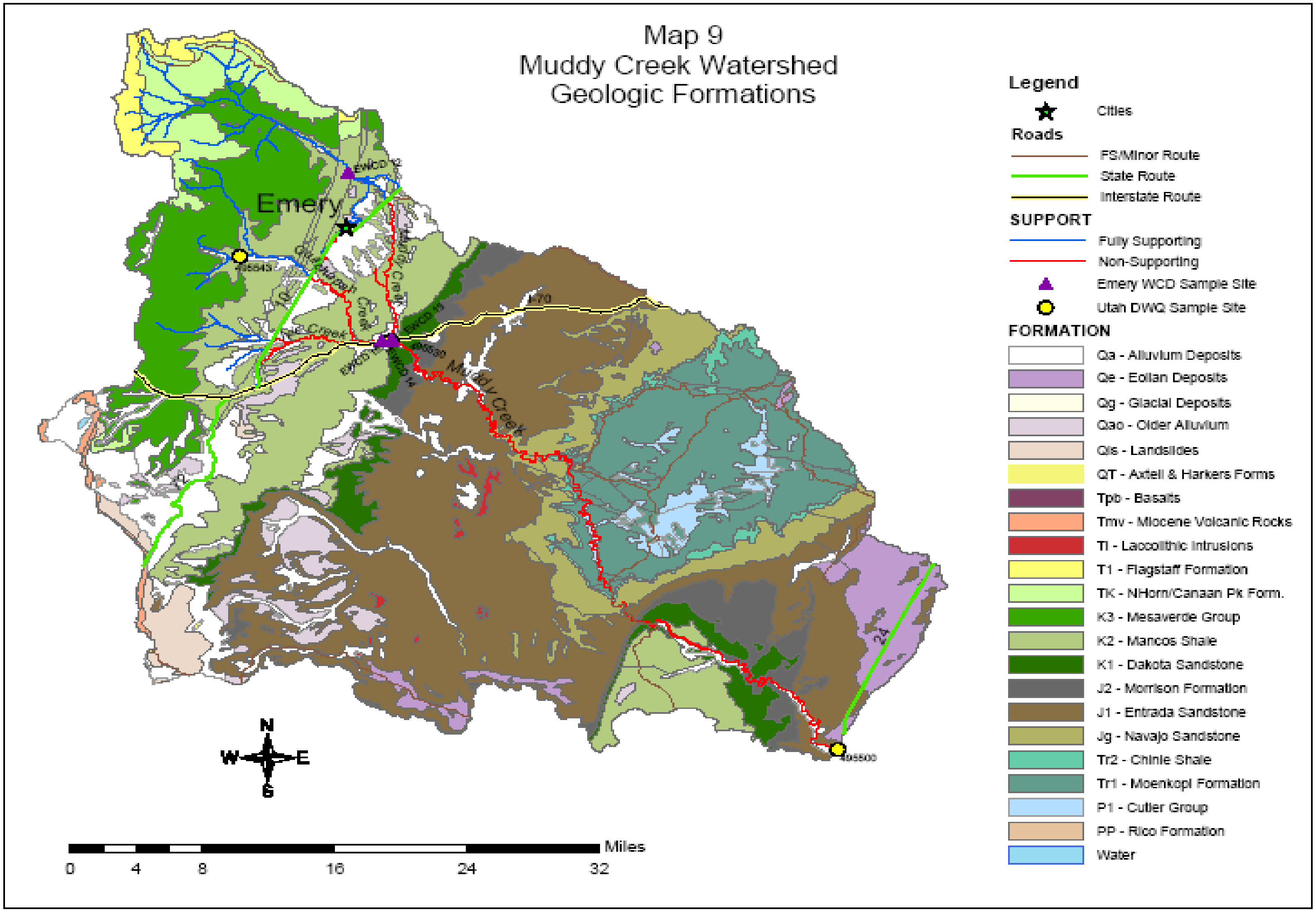
The Blackhawk Formation of the Mesaverde Group is an important large coal-bearing formation. It consists of bedded quartzose sandstones with shaley siltstone, shale, carbonaceous shale, and coal beds that intertongue with and pinch-out into the Mancos Shale (BLM 1997, Hettinger and Kirschbaum 2002). Thickness of the Blackhawk Formation ranges from 700 feet to approximately 1,250 feet (BLM 1999, Hettinger and Kirschbaum 2002). Maps 7, 8, and 9 show the geologic formations for the three watersheds in the WCRW.



Map 7
Price River Watershed
Geologic Formations



Map 8
San Rafael Watershed
Geologic Formations



Map 9
Muddy Creek Watershed
Geologic Formations

Soils

Information regarding soils data was taken from the Natural Resource Conservation Service (NRCS 2003). Soil series that dominate the WCRW are Casmos, Hanksville, Moenkopie, Nakai, Sheppard, and Strych. These soils can be characterized by the parent material and the climatic zones in which they were formed.

Higher elevations in the WCRW (8,000 to 11,000 feet), where the average annual precipitation ranges from 22-40 inches per year, have developed deeper soil profiles than lower elevation areas, where the average annual precipitation ranges from 6-8 inches per year. The loamy soils in the higher elevations are generally well drained, exhibit moderately rapid permeability, and relatively high organic matter content. Although slopes range from 20 to 70 percent in the upper regions of the WCRW, the high percentage of vegetative cover in these areas holds the soil in place. High elevation soils were derived mainly from igneous material and are thus low in soluble salts. Therefore, these soils provide little TDS loading into stream segments in the WCRW. Land use in the higher elevations of the WCRW is centered on forestry and livestock grazing. These soils are predominantly represented by Bundo, Castino, Midfork, Skylick, and Trag soil series.

The middle portions of the WCRW are dominated by soils that were derived predominately from marine shale deposits. Slopes in the area range from 0 to 10 percent, and the mean annual precipitation is approximately 7 inches. The shale derived soils, along with the underlying shale deposits in these areas, are a significant source of TDS loading in WCRW streams. Water moving within the soil profile can dissolve salts and convey them to the streams in surface runoff and via groundwater. Groundwater in contact with the underlying shale formations provides an additional source of TDS loading in WCRW streams.

Soils in the middle portion of the WCRW, where most of the irrigated agricultural land is located, are dominated by two distinctly different soil textural types: silty clay loams and sandy clay loams. The silty clay loam soils are represented by the Billings, Chipeta, Penoyer, Ravola, Saltair and Killpack soil series. These soils are fine textured, exhibit slow permeability and moderate to rapid runoff, and are thus susceptible to erosion caused by irrigation and intense thunderstorms. The soluble salt content of these soils ranges from 0.08 to 2.1 percent and is due to the shaly parent material from which they were derived. The sandy clay loams are represented by the Sanpete and Sanpete-Minchey soil series. These soils contain a significant amount of sand, exhibit moderate to rapid permeability and slow runoff, and have soluble salt contents ranging from 0.02 to 0.7 percent.

Lower portions of the WCRW are dominated by soils that are derived primarily from sedimentary and igneous rocks. The soils derived from sedimentary material are generally calcareous in nature and are therefore also a potential source of TDS loading in the lower portions of the WCRW. Slopes in the lower region range from 0 to 60 percent. Permeability and runoff from these soils is moderate. Land use in this portion of the WCRW is associated with livestock grazing.

1.1.3 Vegetation

The amount of precipitation, along with slope aspect, generally determines the type of vegetation found in the WCRW. Vegetation cover ranges from spruce, fir, and aspen at higher elevations, where precipitation averages nearly 30 inches per year, to cheatgrass, ricegrass, blackbrush, greasewood, and atriplex at lower elevations, where the average annual precipitation is about 7 inches per year. Mid-elevation areas, where the annual precipitation averages from 10-15 inches per year, are dominated by juniper, sagebrush, rabbitbrush, and ricegrass.

The distribution and occurrence of some of the lower elevation species, notably greasewood and atriplex, is somewhat controlled by the concentration of salt in the soil. These species can withstand salt concentrations in excess of 10,000 parts per million (Skougard and Brotherson 1979), well above the threshold for non-salt tolerant species.

1.1.4 Climate

The average annual precipitation at lower elevations in the WCRW ranges from over 9 inches at Price to less than 8 inches at Emery. Lower elevations of the WCRW receive most of the yearly total precipitation in the spring and summer months. Summer precipitation is generally from localized, intense thunderstorms that may cause erosion due to increased runoff. Higher elevations in the Wasatch Plateau receive in excess of 30 inches per year, 70 percent of which falls in the October-April time period (USGS 1986a). Winter precipitation in the WCRW usually is in the form of snow. The accumulation of snow, especially in the higher elevations, provides support for plant communities at the base of the mountains as well as along river courses. Runoff from snowmelt is used for irrigation purposes, municipal use, and by industry.

Average daily temperatures in the WCRW range from approximately 8 to 90 degrees Fahrenheit (Western Regional Climate Center 2003). Temperature and precipitation data for Price, Ferron, and Emery are summarized in Tables 1-4, 1-5, and 1-6 and Figures 1-1, 1-2, and 1-2, respectively.

Table 1-4 Price Temperature and Precipitation Data (1968-2000)

Month	Maximum ^{0}F	Minimum ^{0}F	Mean ^{0}F	Maximum (in./month)	Minimum (in./month)	Mean (in./month)
January	36.9	13.4	25.1	2.57	0	0.8
February	42.8	19.7	31.2	3.81	0	0.76
March	52.5	27.6	40.1	2.38	0	0.74
April	63.2	34.6	48.9	2.01	0	0.53
May	72.5	42.9	57.7	2.34	0	0.73
June	83.8	52.1	68.1	2.41	0	0.61
July	90	58.3	74.2	3.14	0.01	0.9
August	88.4	57	72.7	4.21	0.02	1.07
September	79.5	48.1	63.9	3.12	0	1.1
October	64.8	37.5	51	4.34	0	1.32
November	49.5	25.7	37.3	3.47	0	0.6
December	40.1	16.7	28.4	1.51	0	0.48
ANNUAL	63.7	36.1	49.9	17.46	5.83	9.65

(Data source: Western Regional Climate Center` 2003.)

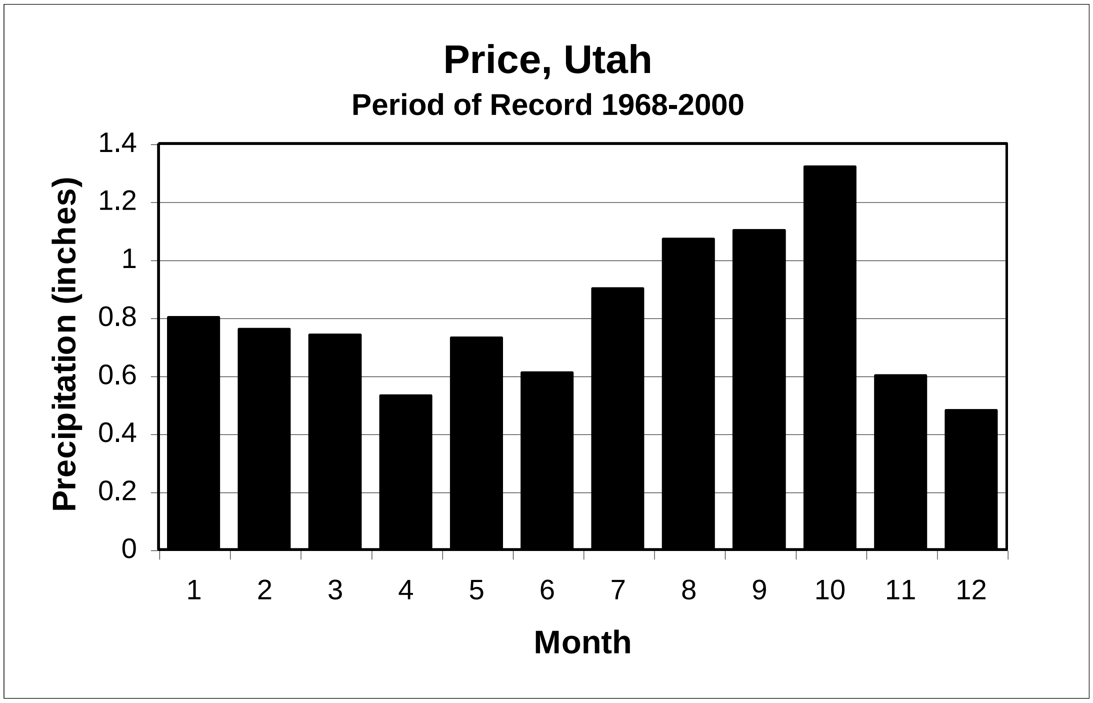


Figure 1-1 Mean monthly precipitation at Price, Utah, 1968-2000

Table 1-5 Ferron Temperature and Precipitation Data (1948-2000)

Month	Maximum ^{0}F	Minimum ^{0}F	Mean ^{0}F	Maximum (in./mo)	Minimum (in./mo)	Mean (in./mo)
January	35.8	11.1	23.5	2.65	0	0.67
February	41.7	17.2	29.4	2.41	0	0.59
March	51	25.3	38.2	1.88	0	0.61
April	60.7	33.3	47	2.3	0	0.5
May	70.6	42.4	56.5	2.24	0.03	0.74
June	80.7	51.1	65.9	1.95	0	0.5
July	87.3	57.8	72.5	3.47	0.01	0.89
August	84.9	55.4	70.2	3.14	0.01	1.12
September	77.3	46.7	62	4.36	0	0.96
October	65.6	35.3	50.4	2.64	0	0.84
November	49.6	22.9	36.3	2.73	0	0.55
December	38.4	14	26.2	1.71	0	0.5
ANNUAL	62	34.4	48.2	13.82	5.03	8.47

(Data source: Western Regional Climate Center 2003.)

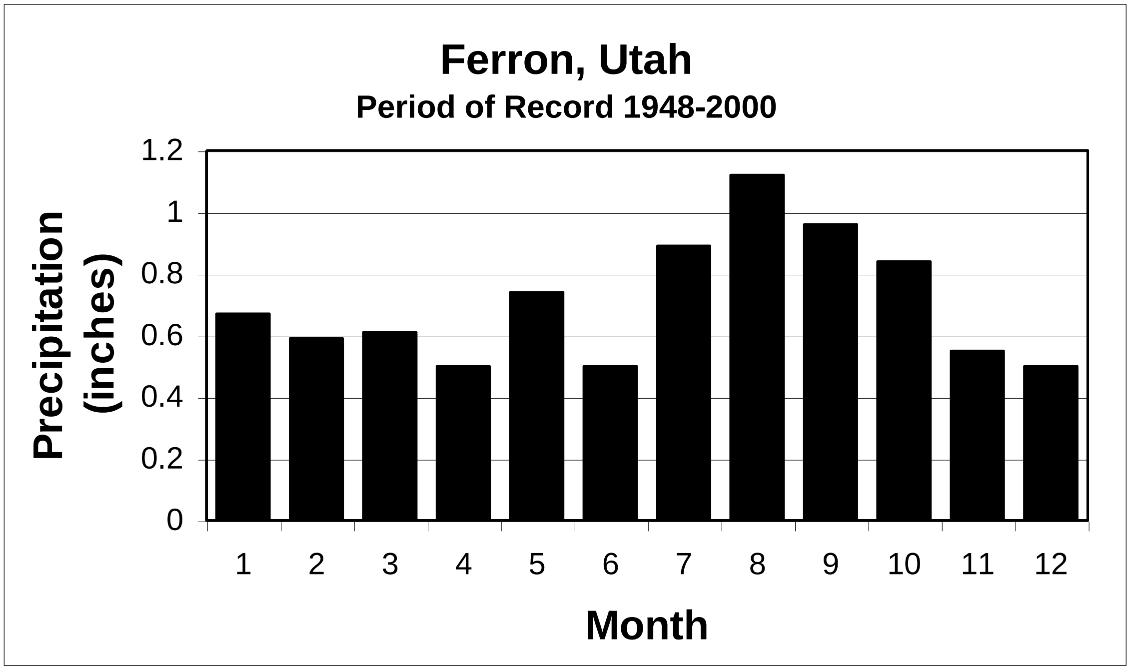


Figure 1-2 Mean Monthly Precipitation at Ferron, Utah, 1948-2000

Table 1-6 Emery Temperature and Precipitation Data (1901-1978)

Month	Maximum ^{0}F	Minimum ^{0}F	Mean ^{0}F	Maximum (in./month)	Minimum (in./month)	Mean (in./month)
January	36.7	10.9	23.9	2.5	0	0.47
February	42	16.1	29.1	3.01	0	0.5
March	49.7	22.8	36.2	1.97	0	0.43
April	59.3	30	44.6	2.6	0	0.39
May	68.8	37.8	53.3	4	0	0.6
June	77.6	45.4	61.5	3.34	0	0.51
July	83.2	52.2	67.7	4.26	0	0.83
August	81.3	50.7	66	5.47	0	1.12
September	74.4	42	58.2	3.48	0	0.9
October	63.3	32.3	47.8	3.87	0	0.81
November	49.7	21.6	35.7	2	0	0.33
December	39.3	13.5	26.4	1.7	0	0.44
ANNUAL	60.4	31.3	45.9	16.84	0.94	7.33

(Data source: Western Regional Climate Center 2003.)

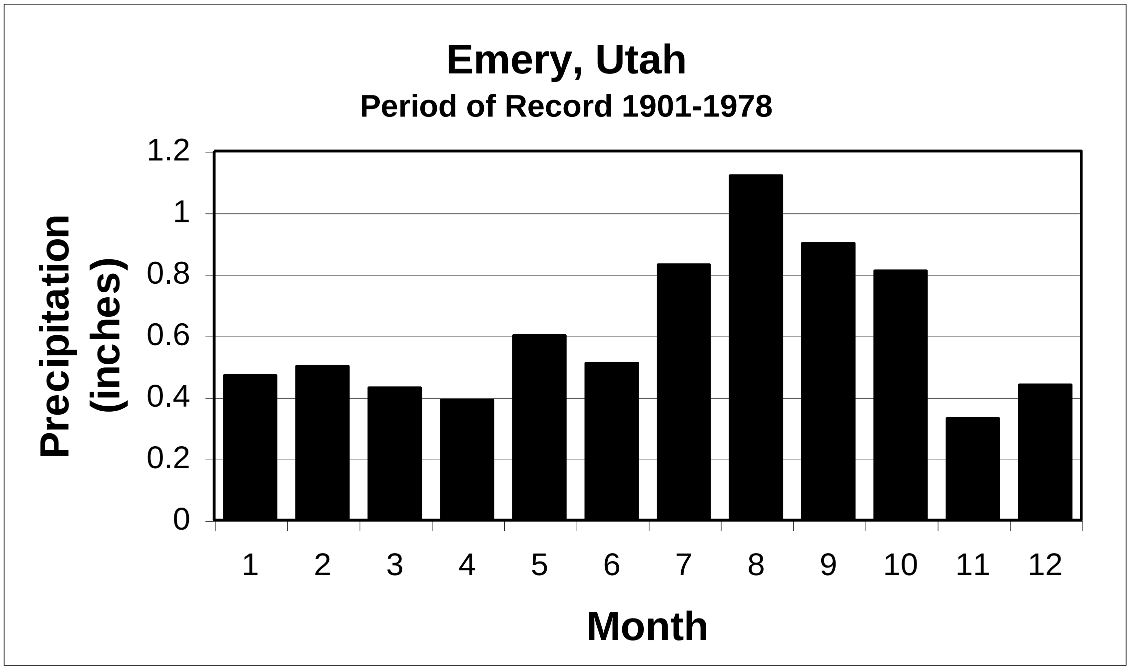


Figure 1-3 Mean monthly precipitation at Emery, Utah, 1901-1978

2.0 UTAH WATER QUALITY STANDARDS AND TMDL TARGET SITES/ENDPOINTS

The purpose of a TMDL is to attain and maintain applicable water quality standards. The TMDL specifies the maximum amount of a pollutant that a body of water can receive in order to meet these goals.

In order to evaluate the attainment of acceptable water quality, measurable in-stream endpoints must be established. These endpoints may be narrative or numeric criteria, and represent the water quality goals that are to be met by load reductions specified in the TMDL. The criteria for this TMDL are based on Utah state water quality standards (UAC 2003). Target sites represent those locations along the streams in the WCRW where constituent loads are calculated and allocated to upgradient sources contributing load to the target site. In this TMDL, target sites were selected downgradient of the three distinguishable land uses in each of the watersheds: 1) upper forest lands, 2) middle agricultural and urban uses, and 3) BLM rangeland. The target sites were selected at locations where there was sufficient chemical and flow data to allow for the calculation of constituent loads.

2.1 Water Quality Standards

Water quality standards applicable to streams within the WCRW are comprised of designated uses and numerical criteria. Narrative standards, as well as the State of Utah's antidegradation policy, also apply. Additionally, streams in the WCRW are protected by requirements of *Proposed Water Quality Standards for Salinity including Numeric Criteria and Plan of Implementation for Salinity Control, Colorado River System* (June 1975) and subsequent supplements and revisions.

2.1.1 Use Designations

The DEQ has classified the waters in the State of Utah so as to protect the beneficial uses designated within each stream reach. These classifications and associated beneficial uses are presented in Table 2.1. The beneficial use classification assigned to the Price River, San Rafael River, Muddy Creek, and their tributaries are presented in Table 2-2.

Table 2-1 Utah Water Quality Classifications/Beneficial Uses

Class 1	Protected for uses as a raw water source for domestic water systems Class 1A: Reserved Class 1B: Reserved Class 1C: Protected for domestic purposes with prior treatment by treatment processes as required by the Utah Division of Drinking Water
Class 2	Recreational and aesthetic use Class 2A: Protected for primary contact recreation such as swimming Class 2B: Protected for secondary contact recreation such as boating, wading or similar uses
Class 3	Protected for use by aquatic wildlife Class 3A: Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain Class 3B: Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain Class 3C: Protected for non-game fish and other aquatic life, including necessary aquatic organisms in their food chain Class 3D: Protected for waterfowl, shore birds, and other water-oriented wildlife not included in Classes 3A, 3B or 3C, including the necessary aquatic organisms in their food chain Class 3E: Severely habitat-limited waters
Class 4	Protected for agricultural uses including irrigation of crops and stock watering
Class 5	The Great Salt Lake. Protected for primary and secondary contact recreation, aquatic wildlife, and mineral extraction

Source: Utah Administrative Code (UAC) R317-2-6

Table 2-2 Use Classifications Assigned to Stream Segments in the WCRW

Stream Segment	Use Classifications
Gordon Creek and tributaries from confluence with Price River to headwaters	1C, 2B, 3A, 4
Pinnacle Creek from confluence with Price River to headwaters	1C, 2B, 3A, 4
Grassy Trail Creek and tributaries from Grassy Trail Creek reservoir to headwaters	1C, 2B, 3A, 4
Price River and tributaries from confluence with Green River to near Woodside	2B, 3C, 4
Price River and tributaries from near Woodside to Soldier Creek confluence	1C, 2B, 3A, 4
Price River and tributaries from Coal Creek to Carbon Canal Diversion	1C, 2B, 3A, 4
Portion of Lower Grassy Trail Creek	2B, 3C, 4
Huntington Creek and tributaries from Utah Highway 10 to headwaters	1C, 2B, 3A, 4
Huntington Creek and tributaries from the confluence with Cottonwood Creek to Utah highway 10	2B, 3C, 4
Cottonwood Creek from the confluence with Huntington Creek to highway 57	2B, 3C, 4
San Rafael River from Buckhorn Crossing to the confluence with Huntington Creek and Cottonwood Creek	2B, 3C, 4
San Rafael River from the confluence with the Green River to Buckhorn Crossing	2B, 3C, 4
Muddy Creek and its tributaries from Quitchupah Creek confluence to the Utah highway 10 bridge	2B, 3C, 4
Muddy Creek from the confluence with Fremont River to Quitchupah Creek confluence	2B, 3C, 4
Quitchupah Creek from confluence with Ivie Creek to the Utah highway 10 bridge	2B, 3C, 4
Ivie Creek and its tributaries from the confluence with Muddy Creek to Utah highway 10	2B, 3C, 4

Source: Utah Administrative Code (UAC) R317-2-13.1

2.1.2 Numeric Criteria

Numeric criteria, set forth in Utah Administrative Code (UAC) R317-2-14, have been promulgated for each of the beneficial use classes assigned to waters in the State. Of the use classifications assigned to the streams in the WCRW, numeric criteria for TDS only apply for agricultural use (beneficial use class 4). The numeric criterion for TDS in the WCRW streams is 1,200 mg/L. Although this numeric criterion has been established, Section R317-2-14 of the UAC provides that TDS limits may be adjusted if the adjustment does not impair the beneficial use of the receiving water.

2.1.3 Narrative Standards

In addition to numeric criteria, narrative standards set forth at UAC R317-2-7.2 also apply to the WCRW streams. These narrative standards generally address the discharge or placement of wastes or other substances in a waterbody that are offensive, that will cause conditions that produce undesirable aquatic life or tastes in edible aquatic organisms, that result in undesirable physiological responses in aquatic life, or that produce undesirable human health effects.

2.1.4 Antidegradation Policy

The State’s antidegradation policy is set forth at UAC R317-2-3. If a water body has a better water quality than necessary to support its designated uses, the antidegradation policy requirements dictate that the existing water quality shall be maintained and protected, unless the State finds that a lowering of water quality is necessary to accommodate important economic or social development in the area in which the water is located. The antidegradation policy applies to three categories of high quality waters designated by the State.

Waters in the State designated as High Quality Waters – Category 1 are listed at UAC R317-2-12.1. As set forth in UAC R317-2-12.1.1, these include all surface waters geographically located within the outer boundaries of the U.S. National Forests, whether on public or private lands, with limited exceptions. Portions of Gordon Creek, Huntington Creek, Cottonwood Creek, Muddy Creek, and Quitchupah Creek are located within the outer boundary of the Manti-La Sal National Forest and are, therefore, designated Category 1, High Quality Waters.

2.1.5 Colorado River Salinity Standards

Due to the concern of the adverse impacts of high salinity concentrations on water use, the Colorado River Basin states established the Colorado River Basin Salinity Control Forum in 1973 to address the issue of salinity in the Colorado River System. The Forum submitted to the EPA in June 1975 a report entitled *Proposed Water Quality Standards for Salinity Including Numeric Criteria and Plan of Implementation for Salinity Control-Colorado River System*. A supplement was issued on August 26, 1975, entitled *Supplement, Including Modifications to Proposed Water Quality Standards for Salinity Including Numeric Criteria and Plan of Implementation for Salinity Control, Colorado River System, June 1975*. These standards require the development of a plan that would maintain the flow-weighted average annual salinity at or below 1972 levels. As set forth at UAC R317-2-4, waters of the Colorado River and its tributaries shall also be protected by these requirements.

2.2 TMDL Endpoint and Target Sites

This TMDL establishes an endpoint and target sites where loading capacities for TDS are calculated and allocated to upgradient sources contributing TDS load to a target site. The initial endpoint selected for this TMDL for TDS is the water quality criterion of 1,200 mg/L. This endpoint may be modified at selected target sites to reflect an adjustment in the TDS criterion based on specific site conditions as allowed for under the Utah water quality standards. The basis for selection of site-specific criteria for TDS is discussed in the Project Implementation Plan, which is Appendix A of this report.

The Price River, San Rafael River, and Muddy Creek watersheds can be divided into upper, middle, and lower reaches, based generally on land uses within the watersheds. As discussed in Section 3 of this report, water quality in the upper reaches of the watersheds meets TDS water quality standards. Land in this portion of the watershed is primarily forest lands managed by the BLM or USFS. TDS loading sources (e.g., Mancos Shale) and activities contributing TDS loading to streams in the watersheds (e.g., irrigation) predominantly occur in the middle sections of the watersheds, and it is within and below these areas where impairment in water quality is first noted. Much of the land in this section of the watershed is privately owned, and is where the majority of the irrigated land and urban areas are located. Impairment of water quality is also present in the lower reaches of the watershed. This portion of the watershed is primarily BLM administered land. Target sites in each watershed were located based on these watershed characteristics, as well as other considerations. These other considerations included bracketing sources within defined sub-watersheds and the amount and availability of water quality and flow data taken at and around the target site locations that allowed for the adequate assessment of water quality in the stream reaches above the target sites.

Two target sites were selected for establishing a TMDL in the Price River watershed, five target sites were selected in the San Rafael River watershed, and two target sites were selected for the Muddy Creek watershed. The selected target sites are shown on Map 2.

3.0 WATER QUALITY ASSESSMENTS AND IMPAIRMENT ANALYSIS

Surface water quality and flow data for all three watersheds within the WCRW were available from a number of sources, including the U.S. Environmental Protection Agency (USEPA) STORET data retrieval system (including data collected by the DEQ), the U.S. Geological Survey (USGS), and the Emery Water Conservancy District (EWCD). Together with other available information, such as watershed characteristics, and permitted discharge monitoring reports, these available data were compiled and reviewed to evaluate water quality impairment and to identify and characterize the significant causes and sources of TDS loading to surface waters in the WCRW.

3.1 Non-TDS Impairments

While the majority of impaired sections within the WCRW are listed due to TDS, there are also reported impairments due to pH, iron, and dissolved oxygen (DEQ 2000). Only one stream segment, Lower Grassy Creek Trail (Table 1-1) is listed as impaired due to pH. This segment is only 1.74 miles in length (DEQ 2000). The review of the STORET data for this segment over the period of 1997 to 2002 indicated that there are no exceedances (N=11) of the pH criterion (range of 6.5-9.0) for lab-analyzed pH samples. There is a single exceedance (pH=10; June 1998) for a field-measured pH value, although the corresponding lab analyzed pH for that date of 8.53 is within the standard range. Based on the data evaluation, this segment of Grassy Creek should not be listed as pH impaired. DEQ is petitioning for delisting in the draft Utah 2004 303 (d) list of waters.

The segment of the Price River between Utah DEQ STORET Stations 493165 (Price River at Woodside) and 493161 (Price River confluence with Green River) is listed as non-supporting for Class 3C waters in the West Colorado Watershed Unit, Water Quality Assessment Report (DEQ 2000). As noted in the Utah DEQ assessment report, this segment of the Price River is listed as non-supporting due to low dissolved oxygen (DO) and excess dissolved iron. The chronic criterion of Class 3C surface waters for dissolved oxygen is a minimum of 5.0 mg/L (30 day average) and a dissolved iron concentration of 1.0 mg/L.

This segment of the Price River is located between the San Rafael Swell to the south and the Uinta Uplift province to the north. Bedrock in this area includes those of the Mancos Shale and Mesa Verde Group. The Mancos Shale is mainly comprised of marine mudstones and siltstones with interbedded sandstone members that have been found to contain high amounts of soluble salts (Halite, Gypsum) in the shale and sandstones. The Mesa Verde Group includes sandstones with interbedded shale and coal seams. Sandstone formations within the study area have been found to contain iron-containing minerals as part of their mineralogy.

DO and iron measurements from Utah DWQ STORET Stations 493165 and 493161 were used for the assessment report (DEQ 2000) and for this study. In order to account for natural sources of dissolved iron, stations 493281, 493239, and 493253 that are located upstream of 493165 and 493161, and within the Mancos Shale and Mesa Verde Group formations, were also examined. A summary of the data is provided below in Table 3-1.

Table 3-1 Segments Listed for Iron and Dissolved Oxygen

STORET Station	**Name**	**Period of Record**	**Number of Samples**		**Range**		**Mean**		**Number of Exceedances**		**Percent Exceedance**	
			Fe (mg/L)	**DO (mg/L)**	**Fe (mg/L)**	**DO (mg/L)**	**Fe (mg/L)**	**DO (mg/L)**	**Fe (mg/L)**	**DO (mg/L)**	**Fe (mg/L)[1]**	**DO (mg/L)[2]**
493165	Price River at Woodside	1976 - 2002	47	258	0.01-1.48	3.86-14.45	0.13	8.91	3[3]	1[4]	6%	0.4%
493161	Price River at mouth	1980 - 2002	19	12	0.01-4.49	4.3-10.6	0.56	7.43	3[5]	2[6]	16%	17%

Notes:
1. Utah DEQ Dissolved Iron Water Quality Criterion of 1.0 mg/L (Class 3C).
2. Utah DEQ Minimum Acute Dissolved Oxygen Water Quality Criterion of 5.0 mg/L (Class 3C)
3. 2/16/1995 (1.2 mg/L),8/8/1995 (1.2 mg/L), 2/3/2000 (1.48 mg/L).
4. 7/30/1998 (3.86 mg/L).
5. 10/21/1997 (4.49 mg./L), 5/25/1998 (1.65 mg/L), 8/19/2001 (2.87mg/L).
6. 6/23/1998 (4.3 mg/L), 10/21/1997 (4.7 mg/L).

Dissolved oxygen measurements from the Lower Price River are summarized in Table 3-1 for the range and mean of measurements for the period of record shown. As shown in Table 3-1, there are some limited exceedances of the 5.0 mg/L DO minimum set by the Utah DEQ (Table 3-1). However, there have not been any exceedances of the DO standard at these locations within the last three years, which indicates that there are no current impairments based on DO. Based on discussions with Tom Toole of the Utah Department of Water Quality, these segments will be removed as impaired in the next 305(b) listing, and have been petitioned for delisting in the draft Utah 2004 303 (d) list of waters.

Dissolved iron measurements from the Lower Price River are summarized in Table 3-1 for the minimum, maximum, and the mean for the period of record shown. For stations 493165 and 493161, the iron water quality standard was exceeded three times during the noted period of sampling. This is equivalent to exceeding the standard 6 percent and 16 percent of the time. In general, dissolved iron concentrations increase from station 493165 downstream to station 493161 at the Price River confluence with the Green River. Seasonal variations in dissolved iron concentration and natural sources could not be examined in this study due to the sporadic and limited data available.

Sources of natural dissolved iron include transport by surface run-off and physical contact of the Price River with the Mancos Shale and formations within the Mesa Verde Group. Precipitation data is reported as monthly totals; therefore daily run-off associated with daily measurements of iron exceedances could not be determined. The Mancos Shale and Mesa Verde Group is encountered in the upper and lower reaches of the Price River. Dissolution of iron-bearing minerals from these formations where the Price River is in contact with the Mancos Shale and Mesa Verde Group is a possible contributor to elevated dissolved iron in the Price River. Since stations 493281, 493253, and 493239 are also located within the Mancos Shale and Mesa Verde Group, they were analyzed for exceedances of the iron water quality criteria. As shown in Table 3-1, iron exceeds the water quality standard once at stations 493281 (6.1 mg/L) and 493253 (6.81 mg/L). Based on the low occurrence of exceedances and lack of identified sources of iron, all of the reaches listed for dissolved iron have been delisted in the draft Utah 2004 303 (d) list of waters.

3.2 TDS Impairments- DEQ and EWCD Water Quality and Flow Data

TDS concentrations and flow data were collected by the DEQ at several monitoring sites within each of the three watersheds in the WCRW. These data were queried through the USEPA's STORET data retrieval system. The data collected at the 26 stations located within the WCRW were not consistent over the period of record. At times water chemistry and flow data were collected; other times only water chemistry or only flow data was collected. The EWCD has collected water chemistry and flow data for the San Rafael River and Muddy Creek watersheds from 1987 to the present. The EWCD consistently collected data at each of eleven monitoring stations during either the second or third week of each month. Data was also collected at eight additional monitoring stations, but only during 2001. Data from the DEQ and EWCD monitoring locations in the Price River, San Rafael River, and Muddy Creek watersheds are shown in Figures 3-1, 3-2, and 3-3, respectively. Monitoring station descriptions and period of record for data at each location are shown in Table 3-2.

In addition to the available data, there are several other studies that are planned or currently being conducted that may result in data that can be utilized to update the TMDL in the future. These studies include intensive sampling being conducted by the Utah DEQ in 2003, a three-year study on transit sources of TDS loading in the San Rafael River that is being lead by the BLM, and a water balance salinity study being conducted by Utah State University.

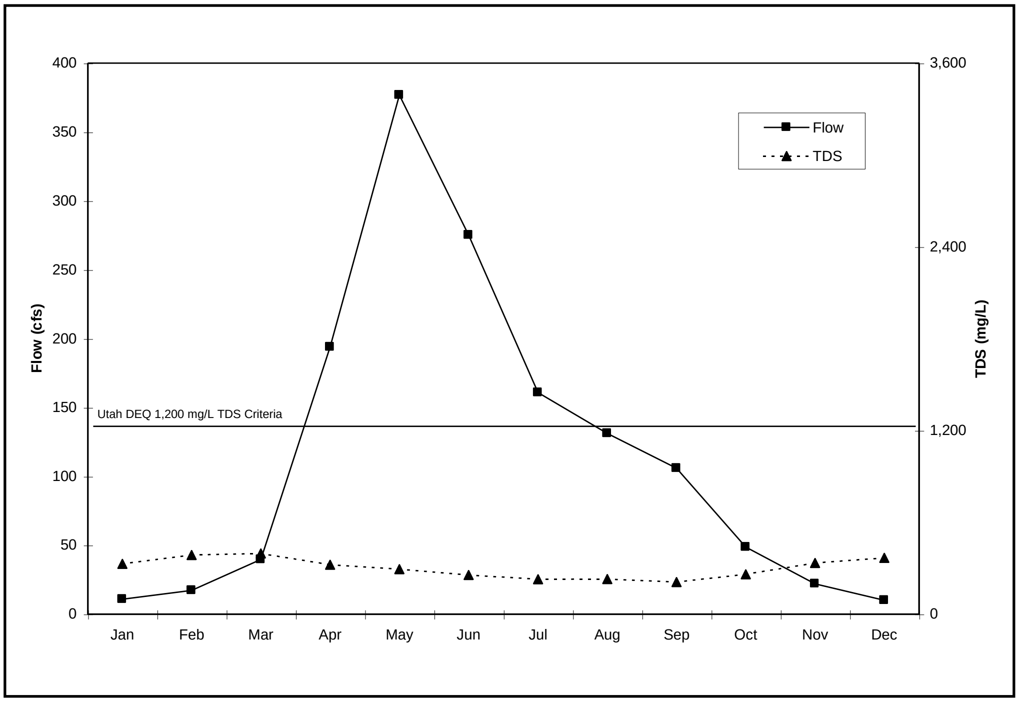


Figure 3-1 Average Monthly Flow and TDS at STORET 493281 (Price River above Price River Coal)

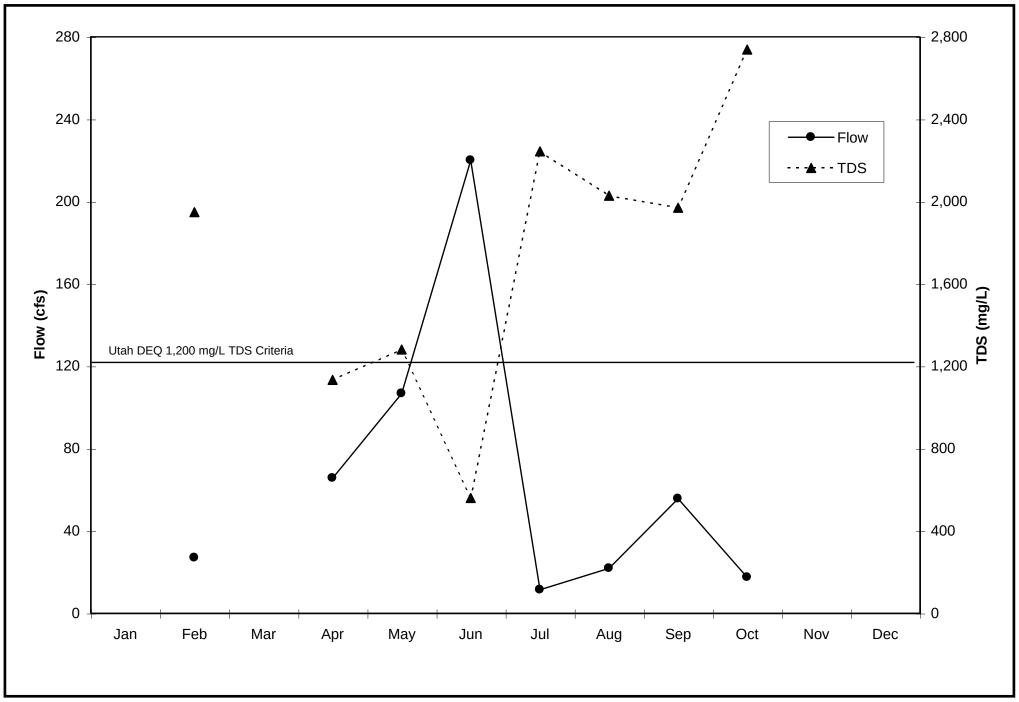


Figure 3-2 Average Monthly Flow and TDS at STORET 493239 (Price River above Price WWTP at Wellington Bridge)

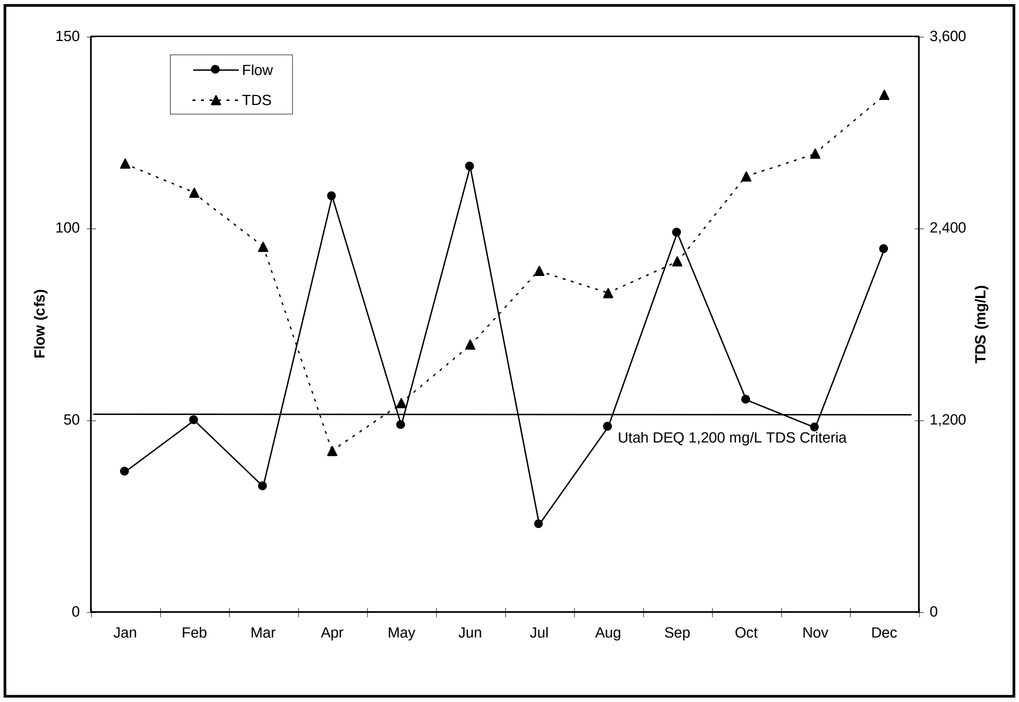


Figure 3-3 **Average Monthly Flow and TDS at STORET 493165 (Price River near Woodside at US 6 crossing)**

Table 3-2 DEQ and EWCD Monitoring Station Descriptions (shown on Maps 10, 11, and 12)

Station ID	Station Name	Start	End	SamplingEvents
STORET #[1]				
493029	San Rafael R. at US 24 crossing	2/22/90	12/12/01	60
493034	San Rafael R. at Buckhorn Rd. crossing	6/12/92	6/10/98	11
493052	Huntington Cr. above Huntington lagoons outfall	4/17/90	6/10/98	30
493053	Huntington Cr. above Utah Power and Light	7/29/97	11/20/02	15
493080	Ferron Cr. below Ferron lagoons	8/03/90	10/17/02	37
493082	Ferron Cr. above Ferron lagoons at US 10 crossing	1/23/90	11/21/02	72
493093	Cottonwood Cr. at US 10 crossing in Castle Dale	2/20/90	6/10/98	32
493095	Cottonwood Cr. above Grimes wash	8/25/97	11/20/02	14
493161	Price R. at mouth	6/14/93	7/29/02	22
493165	Price R. near Woodside at US 6 crossing	3/21/90	8/30/01	55
493239	Price R. above Price WWTP at Wellington bridge	5/10/90	8/20/02	25
493253	Gordon Cr. above confluence with Price R.	4/4/90	8/20/02	16
493281	Price R. above Price River coal	2/11/92	8/21/01	70
493283	White R. at US 6 crossing	1/23/90	7/16/02	20
493286	Left fork White R. above USFS boundary	7/24/91	11/7/02	30
493288	Right fork White R. at USFS boundary	7/30/93	1/15/02	19
493309	Price R. below confluence with White R.	8/25/97	10/17/02	14
493332	Grassy Cr. trail above Sunnyside Coal 002	8/1/97	9/19/02	11
495500	Muddy Cr. at old US 24 crossing	4/18/90	9/17/02	70
495530	Muddy Cr. at I 70 crossing	1/23/90	8/21/02	88
495543	Quitchupah Cr. above USFS boundary	8/26/97	8/21/02	10
593148	Mud Cr. Above Scofield	8/25/97	11/21/02	16
593165	Fish Cr. Above Scofield Reservoir	6/10/92	8/21/01	21
593176	Ferron Cr. above Millsite Reservoir	6/4/91	11/21/02	29
EWCD #[2,3]				
1	San Rafael River	1/87	12/01	180
2	Huntington Creek upper	1/87	12/01	180
3	Huntington Creek lower	1/87	12/01	180
4	Cottonwood Creek upper	1/87	12/01	180
5	Cottonwood Creek Bott Lane	1/01	12/01	12
6	Cottonwood Creek above Rock Canyon	1/01	12/01	12
7	Cottonwood Creek lower	1/87	12/01	180
8	Rock Canyon Creek upper	10/90	12/01	138
9	Rock Canyon Creek lower	10/90	12/01	138
10	Ferron Creek upper	1/87	12/01	180
11	Ferron Creek lower	1/87	12/01	180
12	Muddy Creek upper	1/87	12/01	180
13	Muddy Creek above Ivie Creek	1/01	12/01	12
14	Muddy Creek lower	1/87	12/01	180
15	Ivie Creek lower	1/01	12/01	180
16	Grimes Wash upper	1/01	12/01	109
17	Grimes Wash lower	1/01	12/01	12
18	Crandal Canyon Creek upper	1/01	12/01	12
19	Crandal Canyon Creek lower	1/01	12/01	12

1. Only data collected after 1990 is presented.
2. EWCD monitoring is continuing to the present. Only data through December 2001 was used in the assessment of water quality in the WCRW.
3. Flow measurements are also taken at the EWCD locations, and are used in the TMDL.

3.3 Flow Data

The two primary sources of flow data for the watershed are the USGS and the EWCD. As noted in Table 3-2, the EWCD database includes both flow and chemistry data. Additionally, the USGS has been measuring flows throughout the WCRW since the early 1900s. Stream flow monitoring station descriptions and period of record for each USGS location, in each of the three watersheds in the WCRW that has been recently (e.g., 1990-2000) sampled are provided in Tables 3-3, 3-4, and 3-5.

Table 3-3 USGS Flow Gages in the Price River Watershed

Station ID	Station Name	Date		No. of flow readings	Drainage Area (mi^2)
		Start	End		
9310500	Fish Creek above reservoir, near Scofield	6/1/1931	9/30/2001	23317	60.1
9310700	Mud Creek below Winter Quarters Canyon at Scofield	8/22/1978	9/30/2001	6991	29.1
9313000	Price River near Heiner	6/1/1934	9/30/2001	17689	455
9314500	Price River at Woodside	12/1/1945	9/30/2001	17566	1540

Table 3-4 USGS Flow Gages in the San Rafael Watershed

Site No.	Site Name	Date		No. of flow readings	Drainage Area (mi^2)
		Start	End		
9326500	Ferron Creek (upper station) near Ferron	10/1/1911	9/30/2001	24107	138
9328500	San Rafael River near Green River	10/1/1909	9/30/2001	23741	1628

Table 3-5 USGS Flow Gages in the Muddy Creek Watershed

Site No.	Site Name	Date		No. of flow readings	Drainage Area (mi^2)
		Start	End		
9330500	Muddy Creek near Emery	10/1/1910	9/30/2001	20382	105

3.4 Data Use and Limitations

In order to perform a representative assessment of water quality in each watershed in the WCRW, the available water chemistry and flow data were evaluated for limitations, so that the best available data could be used in the TMDL. The following limitations were encountered:

- Limited water chemistry data
- Limited flow data

- Inconsistencies and gaps between measurement dates

These limitations were taken into consideration when characterizing current water quality within each watershed. As described below, these limitations primarily affected the evaluation of water quality in the Price River watershed, as the data collected by the EWCD in the San Rafael River and Muddy Creek watersheds allowed for a more comprehensive evaluation of water quality in these watersheds.

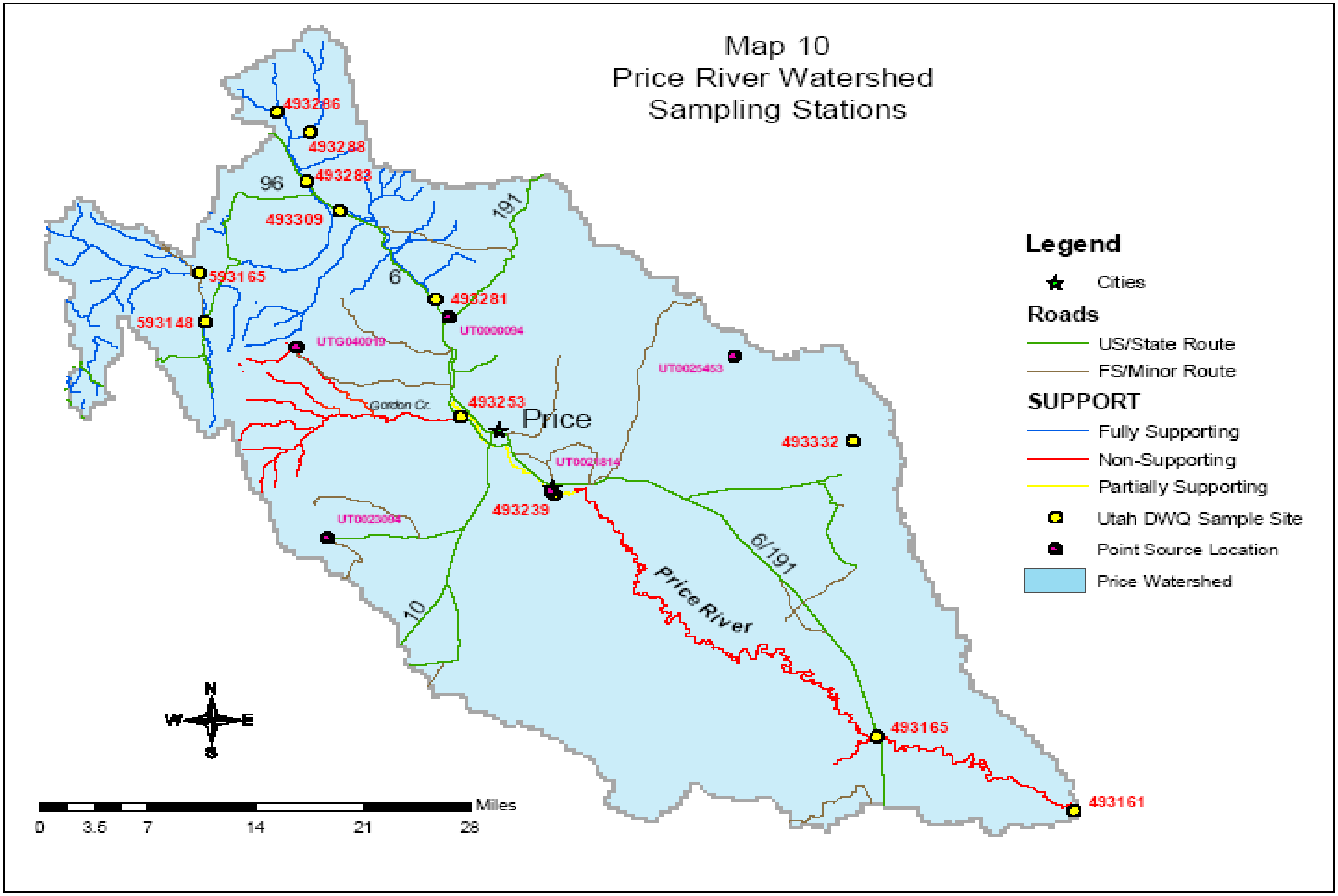
Although data obtained prior to 1990 exists, only data collected from 1990 forward were used in this study. Data was generally not consistently collected prior to 1990, and although these data were considered, it was determined that omission of these data would not result in mischaracterization of water chemistry and hydrology in the WCRW.

3.5 Water Quality Assessment

Water quality in each of the three watersheds in the WCRW was assessed based on the available TDS and flow data previously described. This assessment included an evaluation of the general spatial and temporal patterns in TDS concentrations in surface waters in the watersheds and confirmation of the existing impairment of streams within the watersheds. As discussed in the following sections, water quality assessment was sometimes restricted because of data limitations. The collection of data within the watersheds is an ongoing effort. Any additional data collected will be evaluated for its effect on the TMDLs established in the watersheds. If warranted, the TMDLs may be revised based on new data.

3.5.1 Price River Watershed

Table 3-6 provides a summary of the known water quality data available in the Price River watershed. The locations of the water quality monitoring stations listed in Table 3-6 are shown in Map 10. As shown in Table 3-6, historic TDS concentrations measured in the upper reaches of the watershed were below the criterion of 1,200 mg/L, and the monitored surface waters in the upper reaches are considered to be fully supporting of the agricultural beneficial use classification. Exceedances of the TDS criteria were measured in the middle and lower reaches of the watershed, where surface waters are considered to be only partially supporting or not supporting the agricultural beneficial use classification.



Map 10
Price River Watershed
Sampling Stations

The upper portion of the Price River watershed is primarily forest lands, with the typical land uses being livestock grazing and recreation. The middle portion of the Price River watershed is dominated by agriculture with significant irrigation and urban activities. Additionally, there are significant coal bed methane (CBM) reserves in this portion of the Price River watershed which are currently being exploited, as well as coal mines. Mancos Shale, a natural source of salts in the watershed is also prevalent in the middle portion of the watershed. These land uses and geologic characteristics of the middle portion of the watershed account for the noted variation in water quality in the watershed.

Table 3-6 Water Quality Data for the Price River Watershed

Site ID	Description	TDS (mg/L)				No. of samples	Number of Violations	Support[1]
		Min	Max	Mean	Upper 95% Confidence Interval			
493161	Price River at mouth	652	3,442	1,618	1,781	20	14	NS
493165	Price River at Woodside	548	4,866	2,164	2,166	71	57	NS
493239	Price River above Price WWTP in Wellington	408	2,918	1,511	1,933	21	11	PS
493253	Pinnacle Creek above Confluence with Price River[2]	888	4,038	2,470	2,634	12	10	NS
493137	Gordon Creek above Price River confluence	1112	2254	1,765	2183	6	5	NS
493281	Price River above Price River Coal	172	518	297	300	72	0	FS
493283	White River at US 50 crossing	320	420	371	367	20	0	FS
493286	Left fork White River above Right fork White River	182	340	310	319	19	0	FS
493288	Right fork White River above Left fork White River	286	368	326	342	15	0	FS
493309	Price River below confluence with White River	206	374	293	312	10	0	FS
493332	Grassy Trail Creek above Sunnyside Mine[3]	316	538	381	442	10	0	PS
593148	Mud Creek above Scofield	236	906	413	458	11	0	FS
593165	Fish Creek above Scofield Reservoir	168	220	190	193	21	0	FS

[1] NS = Not Supporting; PS = Partially Supporting; FS = Fully Supporting (as listed in the RFP for the TMDL)

[2] While Gordon Creek is listed as the impaired segment, the impairment listing was based on sampling of Pinnacle Creek. However, subsequent sampling of Gordon Creek demonstrates that it is also impaired due to TDS concentrations and Gordon Creek is listed in the draft Utah 2004 303 (d) list of impaired waters.

[3] This segment is listed due to pH (DEQ 2000)

3.5.1.1 Critical Seasonal Variations in TDS Concentrations

Average monthly TDS concentrations and flows measured at STORET monitoring stations Nos. 493281, 493239 and 493165, located in the upper, middle, and lower reaches of the Price River, are shown in

Figures 3-1, 3-2, and 3-3, respectively. Monitoring stations Nos. 49239 and 493165 were chosen as target sites in the Price River watershed.

As shown in Figure 3-1, seasonal variations in flow in the upper reach of the Price River are apparent, but little change in average TDS concentrations occur. The relative consistency in TDS concentrations in the upper reaches of the Price River points to the lack of TDS sources in the upper reaches of the watershed. Figures 3-2 and 3-3 show that TDS concentrations in the middle and lower reaches of the Price River, on average, exceed the water quality criterion throughout most of the year. The exception is average measured TDS concentrations in the spring/early summer when seasonal increases in flow appear to provide a dilution effect on TDS concentrations in the river. These patterns suggest that TDS loading to the Price River occurs throughout the year, influenced seasonally by irrigation diversions and return flows (increasing TDS concentrations) and spring run-off (decreasing TDS concentrations due to dilution).

3.5.1.2 Critical Flow verses TDS Concentrations

The data presented in Figure 3-1 shows that there are no significant seasonal or flow effects on TDS concentrations within the upper reaches of the Price River, confirming the absence of any significant TDS sources in the area. A comparison of Figures 3-1, 3-2 and 3-3 shows that while flow in the Price River decrease in the downstream reaches of the river (below STORET monitoring station 493281), TDS concentrations increase. This pattern points to the effect of irrigation diversions and natural stream losses from the Price River that occurs in the middle and lower reaches of the watershed and the sources (e.g., Mancos Shale) of TDS existing in the area. It also reflects the complex interaction between stream diversions, losses, irrigation return flows, and other inflows, and the resulting effect on water quality in the lower reaches of the Price River. While overall flow in the river is decreasing, it is apparent that surface water and/or groundwater inflows with very high TDS concentrations are entering the river, resulting in the higher TDS concentrations measured at the downstream monitoring stations. Given the complex hydrology within the watershed, the available data does not allow for a meaningful comparison of flow versus TDS concentrations in the lower reaches of the Price River.

3.5.2 San Rafael River Watershed

For purposes of this TMDL study, the San Rafael River watershed was divided into five sub-watersheds. These sub-watersheds are Huntington Creek, Cottonwood Creek, Rock Canyon Creek, Ferron Creek, and the lower San Rafael River. The five target sites established in the San Rafael watershed (see Section 2.2) were located in the downstream reaches of the major drainages in each of these five sub-watersheds. The analysis of sub-watersheds within the San Rafael River watershed was possible due to the amount of data available. By establishing the five target sites in the San Rafael watershed, a more discrete assessment of water quality in the watershed could be performed.

3.5.2.1 Water Chemistry

Tables 3-7 through 3-11 provide a summary of measured water chemistry in the Huntington Creek, Cottonwood Creek, Rock Canyon Creek, Ferron Creek, and the lower San Rafael River sub-watersheds, respectively. The water chemistry data summarized in these tables was collected by both the DEQ and EWCD. The locations of the water quality monitoring stations listed in the tables are shown in Map 11.

As shown in Tables 3-7, 3-8, and 3-10, measured TDS concentrations in the upper reaches of the Huntington Creek, Cottonwood Creek, and Ferron Creek sub-watersheds were below the criterion of 1,200 mg/L, and the monitored surface waters in the upper reaches of these sub-watersheds are considered to be fully supporting of the agricultural beneficial use classification. Exceedances of the TDS criteria were noted in the middle to lower reaches of these sub-watersheds, where Huntington Creek, Cottonwood Creek, and Ferron Creek are considered to be non-supporting of the agricultural beneficial use classification. Similar to the Price River Watershed, the noted variations in water quality in these three sub-watersheds are attributed to land use and geologic characteristics of the sub-watersheds. Land use in the upper reaches of these sub-watersheds is primarily forest, along with some power generation and coal mining in the Huntington Creek sub-watershed, coal mining in the Cottonwood Creek sub-watershed, and CBM activities in the Ferron Creek sub-watershed. The middle and lower reaches of all three sub-watersheds are dominated by agriculture use, with significant irrigation and urban activities. Mancos Shale is also prevalent in the middle and lower reaches of the sub-watersheds.

As shown in Tables 3-9 and 3-11, measured TDS concentrations in Rock Canyon Creek and the San Rafael River have exceeded the TDS criterion throughout the monitored reaches of these waters, and Rock Canyon Creek and the San Rafael River are considered to be non-supporting of the agricultural beneficial use classification. The elevated TDS concentrations in Rock Canyon Creek are attributed to land use activity in the watershed (i.e., agriculture use, with irrigation and urban activities) and the presence of Mancos Shale. Additionally, the Hunter Power Plant is located in the Rock Canyon Creek subwatershed. While there are no existing UPDES permits for the plant, discharge of water to Rock Canyon Creek occurs from plant operations. Recognizing that this discharge needs to be permitted, the Department of Environmental Quality has initiated the permit process. It is expected that the issued permit will include a discharge limit for concentrations of TDS.

Table 3-7 Water Quality Data for the Huntington Creek Sub-watershed

Site ID	Description	TDS (mg/L)				# Samples	Number of Violations	Support [1]
		Min	Max	Mean	Upper 95% Confidence Interval			
493052	Huntington Creek above Lagoons	426	4,768	2,559	3,105	21	15	NS
493053	Huntington Creek above UP&L diversion	172	284	216	222	11	0	FS
EWCD-2	Huntington Creek upper	10	460	220	225	175	0	FS
EWCD-3	Huntington Creek lower	464	6,242	3,241	3,324	174	165	NS
EWCD-18	Crandal Canyon Creek upper	216	536	341	345	47	0	FS
EWCD-19	Crandal Canyon Creek lower	260	664	417	423	51	0	FS

[1] NS = Not Supporting; PS = Partially Supporting; FS = Fully Supporting (as listed in the RFP for the TMDL)

Table 3-8 Water Quality Data for the Cottonwood Creek Sub-watershed

Site ID	Description	TDS (mg/L)				# Samples	Number of Violations	Support[1]
		Min	Max	Mean	Upper 95% Confidence Interval			
493093	Cottonwood Creek above Castle Dale Lagoons	324	2,202	1,033	1,238	22	7	NS
493095	Cottonwood Creek above Grimes Wash	196	298	238	246	10	0	FS
EWCD-4	Cottonwood Creek upper	108	460	249	255	175	0	FS
EWCD-5	Cottonwood Creek at Bott Lane	690	1,800	1,113	1,208	12	5	NS
EWCD-6	Cottonwood Creek above Rock Canyon Creek	1,600	3,200	1,992	2,162	12	12	NS
EWCD-7	Cottonwood Creek lower	348	4,750	2,325	2,355	175	163	NS
EWCD-16	Grimes Wash upper	440	5,010	1,252	1,280	109	37	NS
EWCD-17	Grimes Wash lower	602	2,800	1,549	1,570	96	71	NS

[1] NS = Not Supporting; PS = Partially Supporting; FS = Fully Supporting (as listed in the RFP for the TMDL)

Table 3-9 Water Quality Data for the Rock Canyon Creek Sub-watershed

Site ID	Description	TDS (mg/L)				# Samples	Number of Violations	Support[1]
		Min	Max	Mean	Upper 95% Confidence Interval			
EWCD-8	Rock Canyon Creek upper	892	5,660	3,411	3,475	91	86	NS
EWCD-9	Rock Canyon Creek lower	696	7,750	3,583	3,624	135	134	NS

[1] NS = Not Supporting; PS = Partially Supporting; FS = Fully Supporting (as listed in the RFP for the TMDL)

Table 3-10 Water Quality Data for the Ferron Creek Sub-watershed

Site ID	Description	TDS (mg/L)				# Samples	Number of Violations	Support[1]
		Min	Max	Mean	Upper 95% Confidence Interval			
493080	Ferron Creek below Ferron Lagoons	958	1,678	1,318	2,316	2	1	FS
493082	Ferron Creek above Ferron Lagoons	308	958	758	832	21	0	FS
593176	Ferron Creek above Millsite Reservoir	214	366	286	291	23	0	FS
EWCD-10	Ferron Creek upper	48	756	350	360	175	0	FS
EWCD-11	Ferron Creek lower	448	7,260	2,692	2,734	174	164	FS

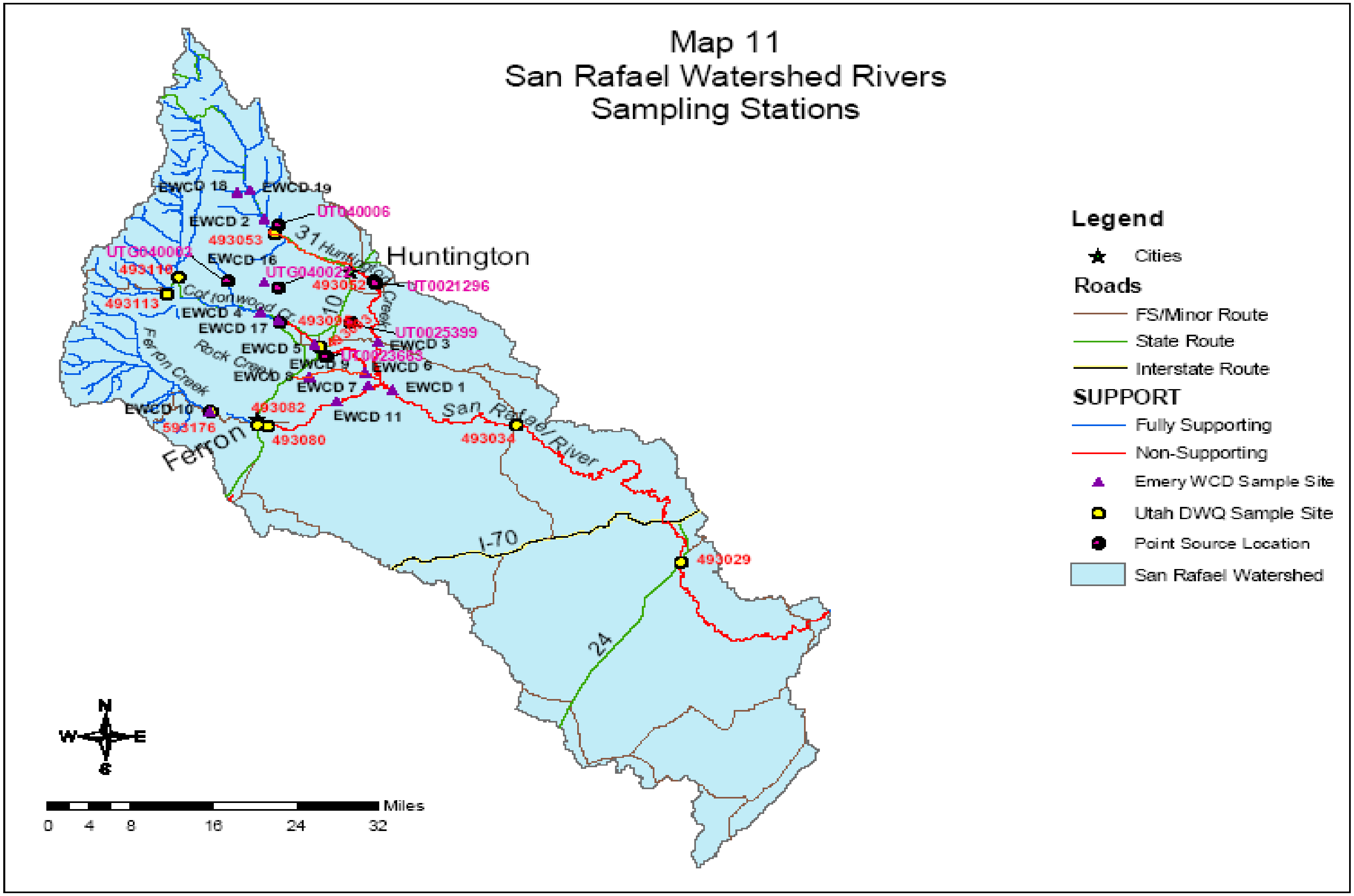
[1] NS = Not Supporting; PS = Partially Supporting; FS = Fully Supporting (as listed in the RFP for the TMDL)

Table 3-11 Water Quality Data for the Lower San Rafael River Sub-watershed

Site ID	Description	TDS (mg/L)				# Samples	Number of Violations	Support[1]
		Min	Max	Mean	Upper 95% Confidence Interval			
493029	San Rafael at U24 crossing	492	3,924	2,170	2,868	29	26	NS
493034	San Rafael at Buckhorn road	780	3,030	1,803	2,003	11	8	NS
EWCD-1	San Rafael River lower	480	5,070	2,549	2,580	175	164	NS

[1] NS = Not Supporting; PS = Partially Supporting; FS = Fully Supporting (as listed in the RFP for the TMDL)

Given the measured concentrations of TDS in Huntington Creek, Cottonwood Creek, Rock Canyon Creek, and Ferron Creek, all which drain to the San Rafael River, the measured concentrations of TDS in the San Rafael River were not unexpected. As shown in Table 3-11, the mean concentration of TDS in the San Rafael River decreases in the lower reach of the river. This may be attributable to water inflows of lower TDS concentrations, consistent with the lack of any significant TDS sources in the lower San Rafael River watershed.



Map 11
San Rafael Watershed Rivers
Sampling Stations

3.5.2.2 Critical Seasonal Variations in TDS Concentrations

Monitoring stations EWCD-03 (Lower Huntington Creek), EWCD-07 (Lower Cottonwood Creek), EWCD-09 (Lower Rock Canyon Creek), EWCD-11 (Lower Ferron Creek) and Storet Monitoring Station 493029 (San Rafael at U24 crossing) were chosen as target sites for TMDL analysis in the San Rafael River watershed. Monitoring stations EWCD-03, EWCD-07, EWCD-09, and EWCD-11 were chosen as target sites because the measured water chemistry and flows at these locations reflect the effects of all TDS sources and hydrological processes (i.e., irrigation diversions, return flows, groundwater and surface water inflows) in their respective sub-watersheds. STORET monitoring station 493029 was chosen as a target site because the measured water chemistry and flows at this location reflect the effects of all significant TDS sources and hydrological processes within substantially the entire San Rafael River watershed.

The average monthly TDS concentrations and flows measured at monitoring stations EWCD-03, EWCD-07, EWCD-09, EWCD-011 are shown in Figures 3.4 through 3.7, respectively. Each of these figures shows similar relationships between flow and TDS concentrations attributed to irrigation activities and spring runoff occurring in the sub-watersheds. First, a decrease in average measured flow associated with an increase in average TDS concentration is noted in the month of April. This is followed by a significant increase in flows associated with a significant decrease in TDS concentrations; the highest average flows and, except for Huntington Creek, the lowest average TDS concentrations occurring in June. Average monthly flows then generally decrease, with some variation, associated with generally increasing TDS concentrations, with some variation over the months of July through October. Flows in the streams appear to be generally consistent over the months of November through February, rising or falling again in March.

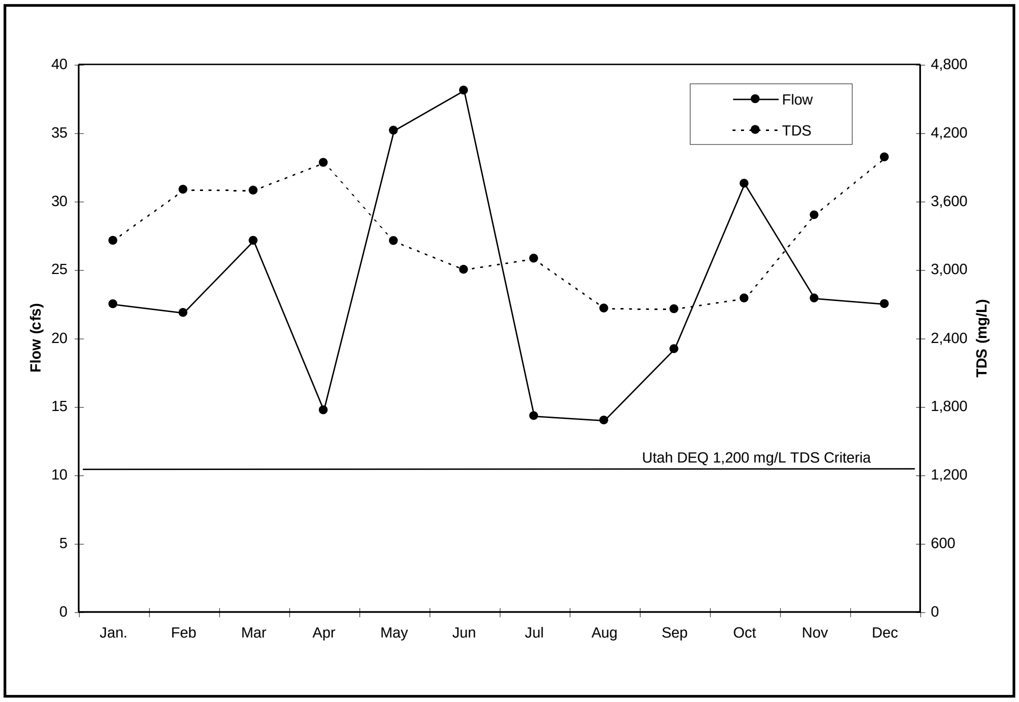


Figure 3-4 Average Monthly Flow and TDS for EWCD-03 (Lower Huntington Creek)

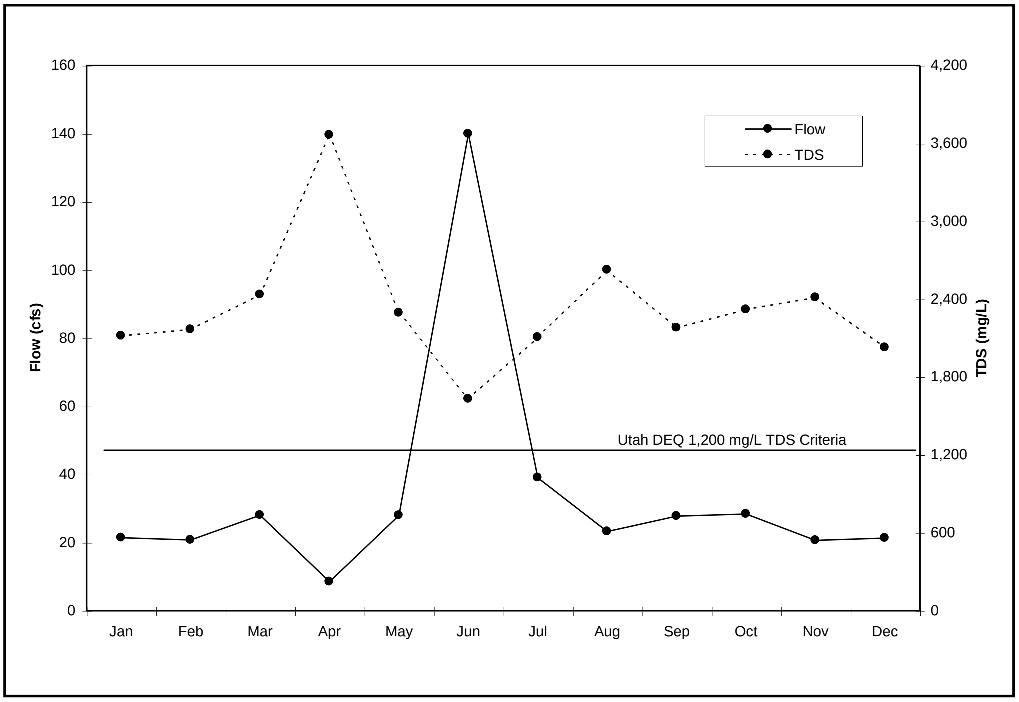


Figure 3-5 Average Monthly Flow and TDS for EWCD-07 (Lower Cottonwood Creek)

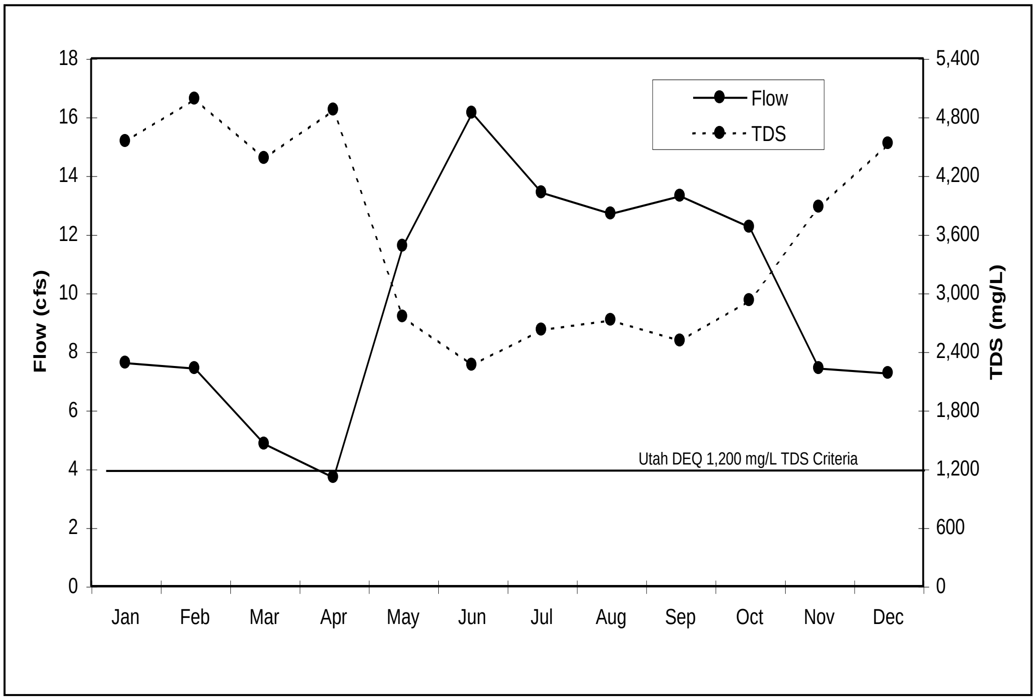


Figure 3-6 Average Monthly Flow and TDS for EWCD-09 (Lower Rock Canyon Creek)

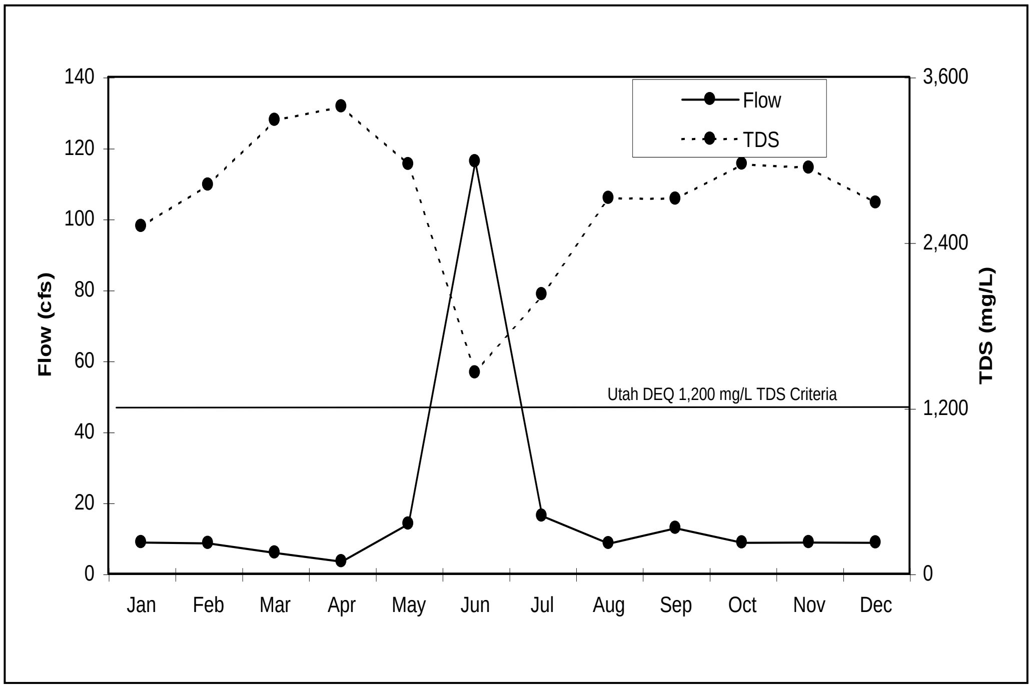


Figure 3-7 Average Monthly Flow and TDS for EWCD-11 (Lower Ferron Creek)

The decrease in average flow and increase in average TDS concentrations occurring in April may be due to the first significant diversions of surface water for irrigation during the year and associated high TDS concentration return flows. The decreased TDS concentration measurements in June are indicative of the seasonal dilution effect of increased flows occurring in this month. Between July and October, stream flow and measured TDS concentrations are subject to complex interactions between stream diversions, losses, irrigation return flows and other inflows to the streams. The more consistent flow patterns and associated TDS concentrations over the months of November through February are consistent with the decrease in runoff and irrigation activity over these months. Although seasonal variations in TDS concentrations are shown, it is noted that there is no one critical season for high TDS concentrations in Huntington, Cottonwood, Rock Canyon, and Ferron Creeks, as the average measured TDS concentrations in these creeks consistently exceed the TDS criterion of 1,200 mg/L over the entire year.

The average monthly TDS concentrations and flows measured at the STORET monitoring station 493029 are shown in Figure 3-8. The variations in average flow and TDS concentrations measured in the San Rafael River at this location reflect the collective contribution of inflows to the San Rafael River from Huntington, Cottonwood, Rock Canyon, and Ferron Creeks. As with these tributaries, it is noted that there is no one critical season for high TDS concentrations in the San Rafael River, as measured TDS concentrations in the lower San Rafael River consistently exceed the TDS criterion of 1,200 mg/L over the entire year.

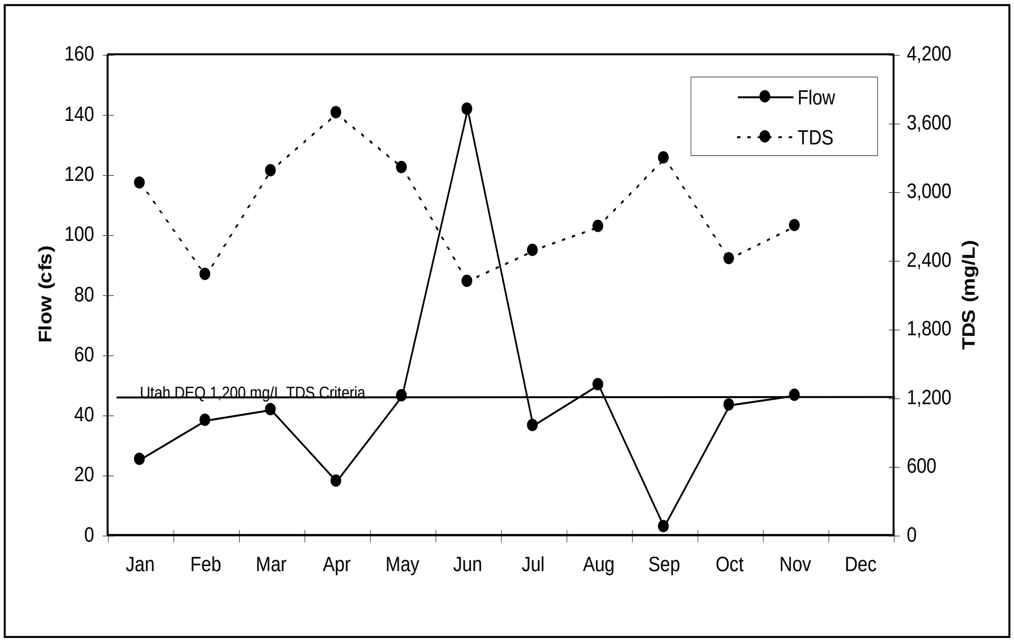


Figure 3-8 **Average Monthly Flow and TDS for 493029 (San Rafael River at US 24 Crossing)**

3.5.2.3 Critical Flow versus TDS Concentration

Figures 3-9 through 3-13 are plots of TDS concentrations verses flow at monitoring stations EWCD-03 through EWCD-11 and STORET monitoring station 493029, respectively. These plots show the trend of increasing TDS concentration with decreasing flow and the dilution effect of decreasing TDS concentration at high flows in each of the measured streams. The TDS concentrations are the highest during low flow conditions when it may be expected that groundwater inflows (including long-term irrigation return flow) with elevated TDS concentrations provide the majority of streamflow. The elevated TDS concentrations in groundwater are attributed to contact with the Mancos Shale (Laronne 1977), which is prevalent in the middle and lower portions of the Huntington Creek, Cottonwood Creek, Rock Canyon Creek, and Ferron Creek sub-watersheds. Although TDS concentrations decrease with increasing flows, TDS concentrations occur above the TDS water quality criterion throughout most of the range of flows. The consistently high TDS concentrations throughout the range of normal flows are attributed to continual loading from natural sources, irrigation return flows, and other inflows occurring over the range of these flows. As a practical matter, there is no critical flow, within the range of normally expected flows, above which the TDS criterion is attained in these stream reaches.

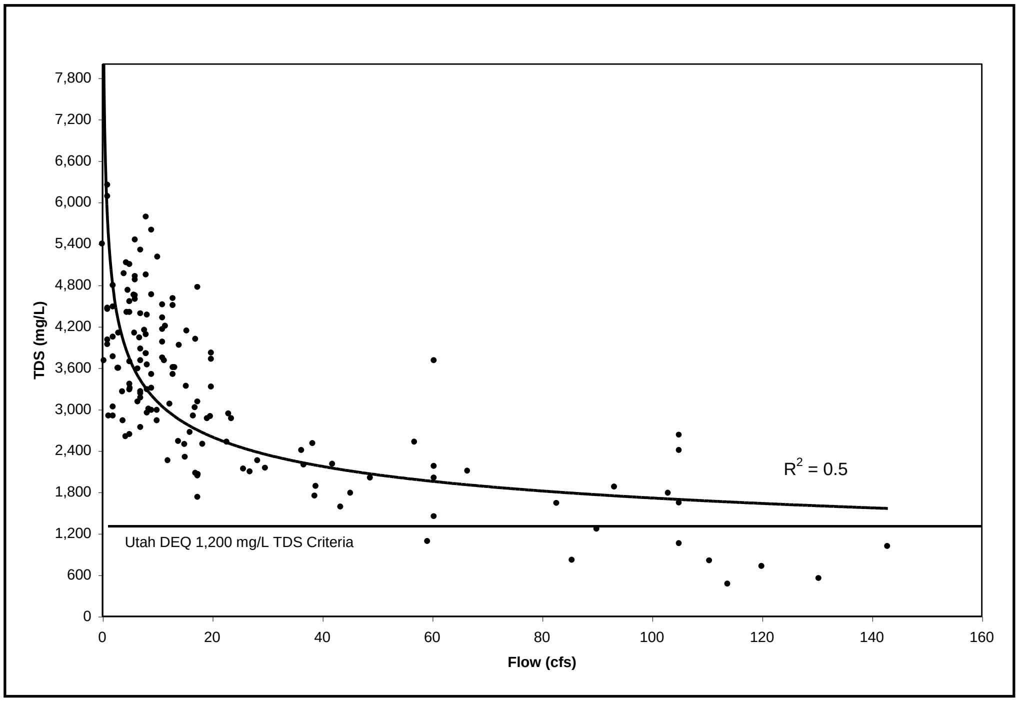


Figure 3.9 Flow verses TDS Regression Plot for EWCD-03 (Lower Huntington Creek)

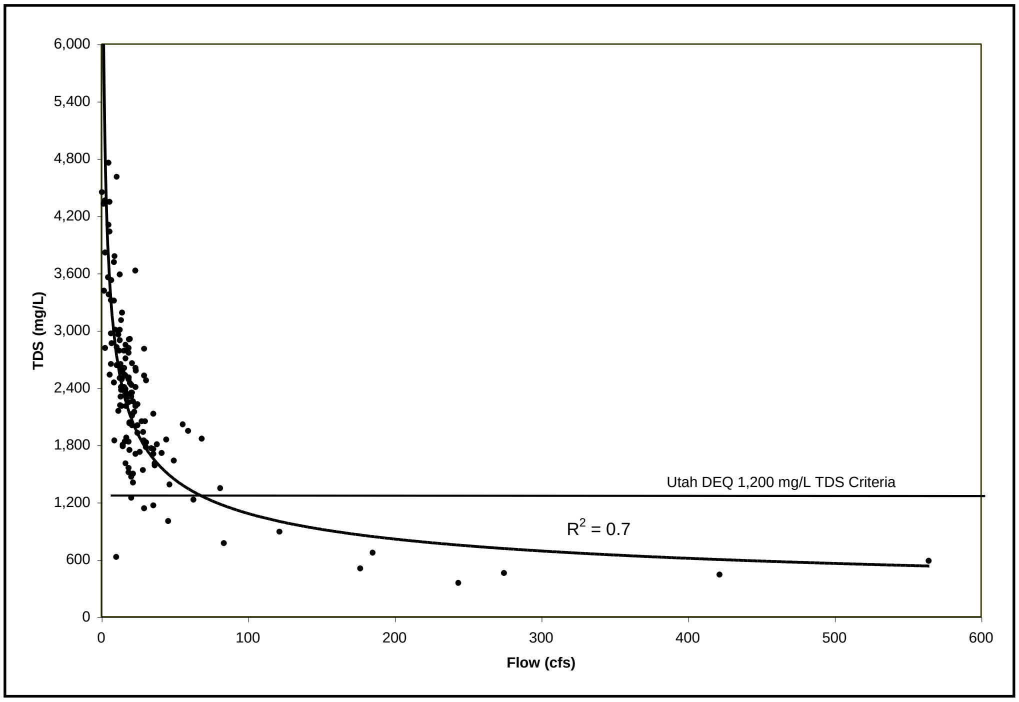


Figure 3-10 Flow verses TDS Regression Plot for EWCD-07 (Lower Cottonwood Creek)

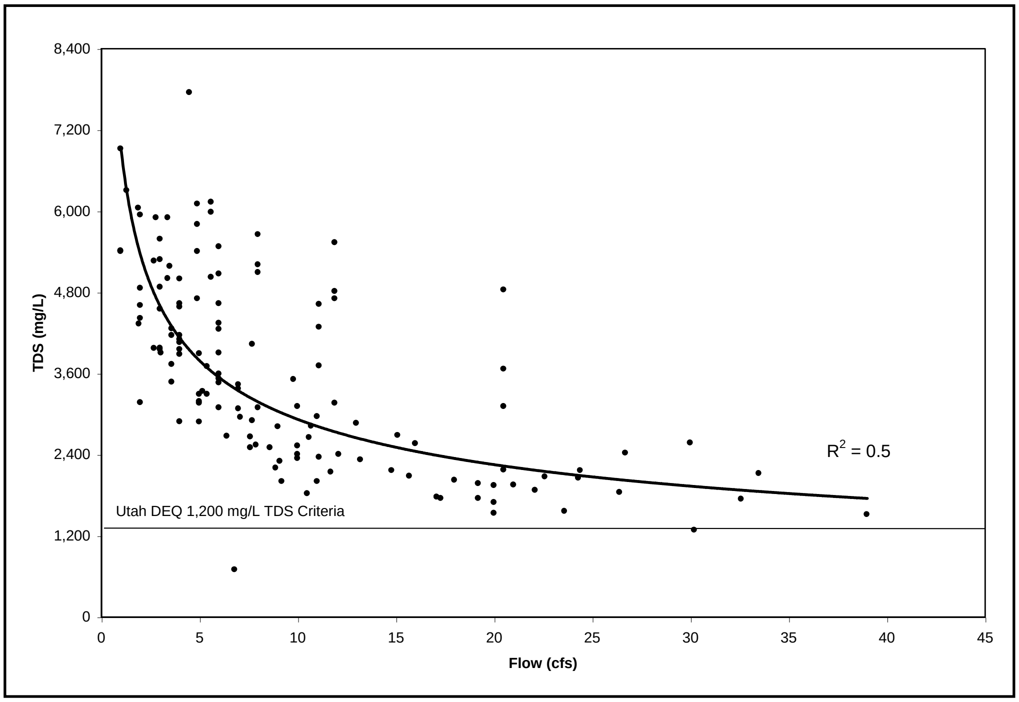


Figure 3-11 Flow verses TDS Regression Plot for EWCD-09 (Lower Rock Canyon Creek)

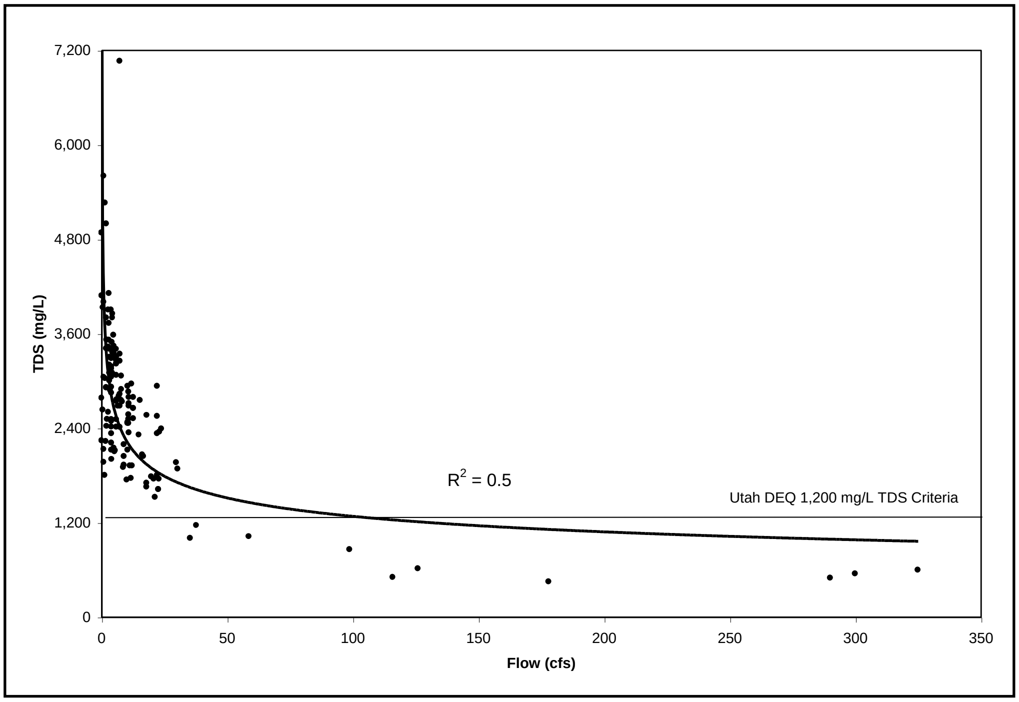


Figure 3-12 Flow verses TDS Regression Plot for EWCD-11 (Lower Ferron Creek)

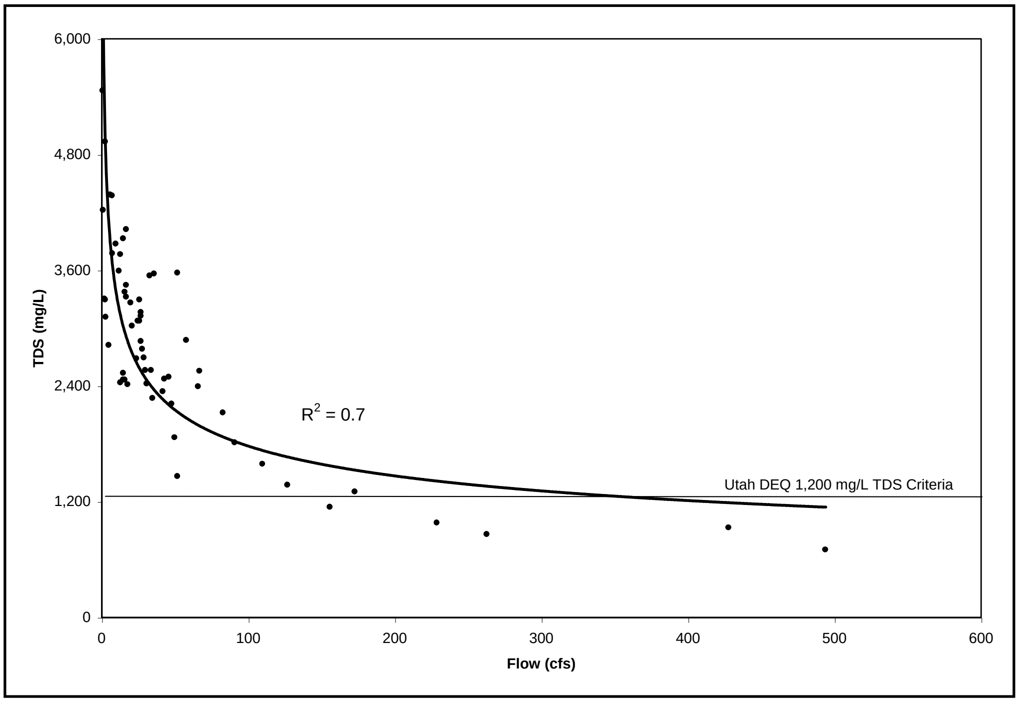


Figure 3-13 Flow verses TDS Regression Plot for 493029 (San Rafael River at US 24 Crossing)

3.5.3 Muddy Creek Watershed

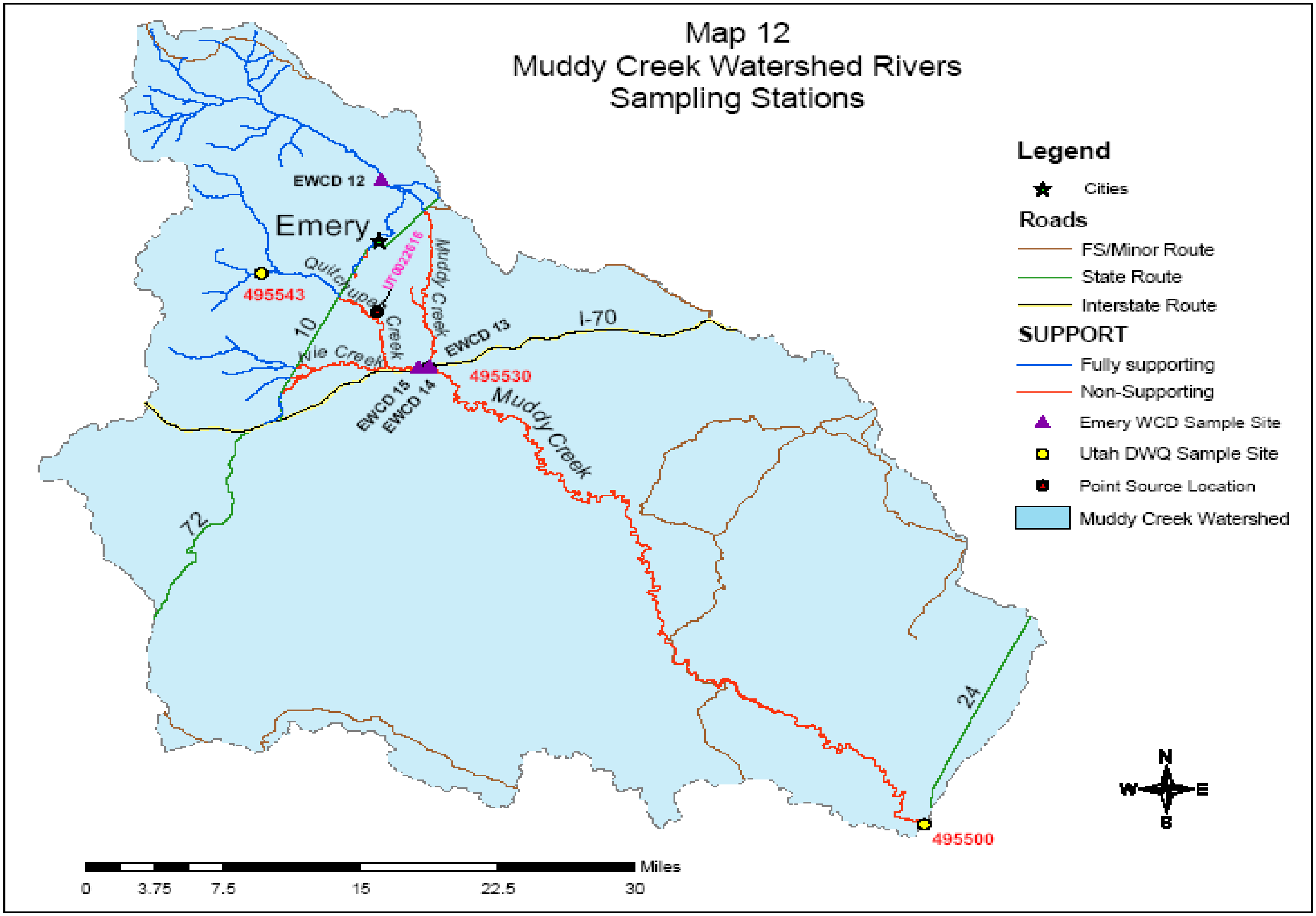
Table 3-12 provides a summary of the measured water chemistry in the Muddy Creek watershed. The locations of the water quality monitoring stations listed in Table 3-12 are shown in Map 12. As shown in Table 3-12, historic TDS concentrations measured in the upper reaches of the watershed were below the criterion of 1,200 mg/L, and the monitored surface waters in the upper reaches are considered to be fully supporting of the agricultural beneficial use classification. Exceedances of the TDS criteria were measured in the middle and lower reaches of the watershed, where surface waters are considered to be only partially supporting or non- supporting of the agricultural beneficial use classification.

The noted variations in water quality in the Muddy Creek watershed are attributed to land use and geologic characteristics of this watershed. The upper portion of the Muddy Creek watershed is primarily BLM and USFS administered lands. There is also some coal mining that occurs in this portion of the watershed. The middle portion of the Muddy Creek watershed is dominated by irrigated agriculture and urban (inhabited) areas. Mancos Shale is also prevalent in the middle portion of the watershed. These land use and geologic characteristics of the watershed account for the noted variation in water quality throughout the watershed.

Table 3-12 Water Quality Data for the Muddy Creek Watershed

Site ID	Description	TDS (mg/L)				Count	Number of Violations	Support[1]
		Min	Max	Mean	Upper 95% Confidence Interval			
495500	Muddy Creek at Old U24 crossing	806	6,080	3,276	3,736	63	57	NS
495530	Muddy Creek at I70 crossing	386	5,332	1,702	1,835	74	53	NS
495543	Quitchupah Creek above USFS boundary	466	852	675	724	10	0	FS
EWCD-12	Muddy Creek upper	60	648	274	282	175	0	FS
EWCD-13	Muddy Creek above Ivie Creek	620	4,900	2,284	3,531	12	4	NS
EWCD-14	Muddy Creek lower	416	4,580	1,829	1,735	173	141	NS
EWCD-15	Ivie Creek	740	3,100	1,711	1,925	12	10	NS

[1] NS = Not Supporting; PS = Partially Supporting; FS = Fully Supporting (as listed in the RFP for the TMDL)



Map 12
Muddy Creek Watershed Rivers
Sampling Stations

3.5.3.1 Critical Seasonal Variations in TDS Concentrations

Average monthly TDS concentrations and flows measured at STORET monitoring station 495500 (Muddy Creek at Old U24 Crossing) and monitoring station EWCD-14 (Lower Muddy Creek) are shown in Figures 3-14 and 3-15, respectively. Figures 3-14 and 3-15 show a generally similar seasonal pattern of average monthly flows and associated TDS concentrations attributed to similar irrigation activities and runoff patterns as described for the sub-watersheds in the San Rafael watershed. As with the sub-watersheds in the San Rafael watershed, although seasonal variations in TDS concentrations are shown, it is noted that there is no one critical season for high TDS concentrations in these reaches of Muddy Creek, as the average measured TDS concentrations consistently exceed the TDS criterion of 1,200 mg/L over the entire year.

3.5.3.2 Critical Flow verses TDS Concentrations

Figures 3-16 and 3-17 are plots of measured TDS concentrations verses flow at STORET monitoring station 495500 and monitoring station EWCD-14, respectively. These plots show a trend of increasing TDS concentration with decreasing flow and a dilution effect of decreasing TDS concentrations at high flows at each station. TDS concentrations are the highest during low flow conditions when it may be expected that groundwater inflows (including long-term irrigation return flow) with elevated TDS concentrations provide the majority of streamflow. The elevated TDS concentrations in groundwater are attributed to contact with the Mancos Shale (Laronne 1977), which is prevalent in the middle portion of the watershed. Although TDS concentrations decrease with increasing flows, TDS concentrations occur above the TDS water quality criterion throughout most of the range of flows. The consistently high TDS concentrations throughout the range of normal flows are attributed to the continual inflow of groundwater, irrigation return flows, and other inflows to the stream occurring over the range of these flows. As a practical matter, there is no critical flow, within the range of normally expected flows, above which the TDS criterion is attained in these stream reaches.

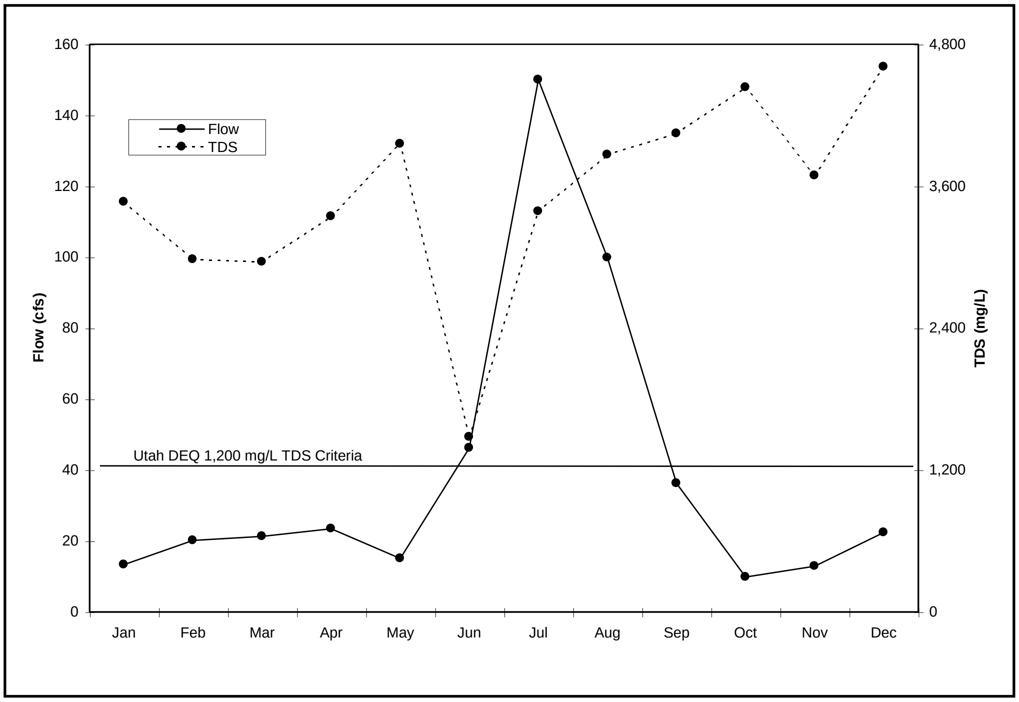


Figure 3-14 Average Monthly Flow and TDS for 495500 (Muddy Creek at Old US 24 Crossing)

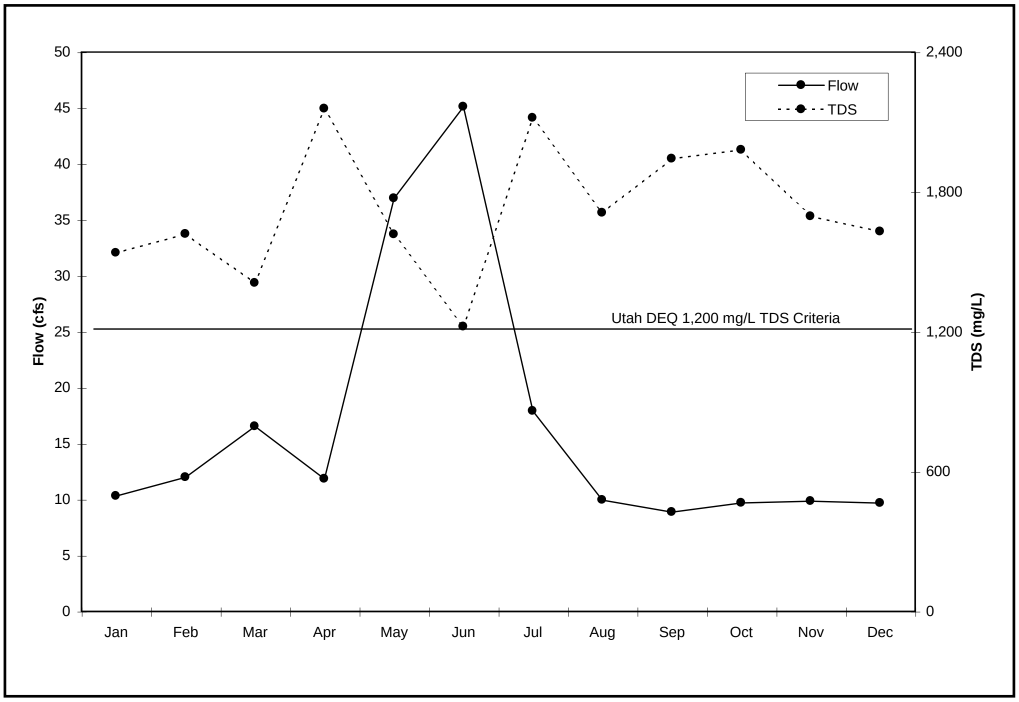


Figure 3-15 Average Monthly Flow and TDS for EWCD-14 (Lower Muddy Creek)

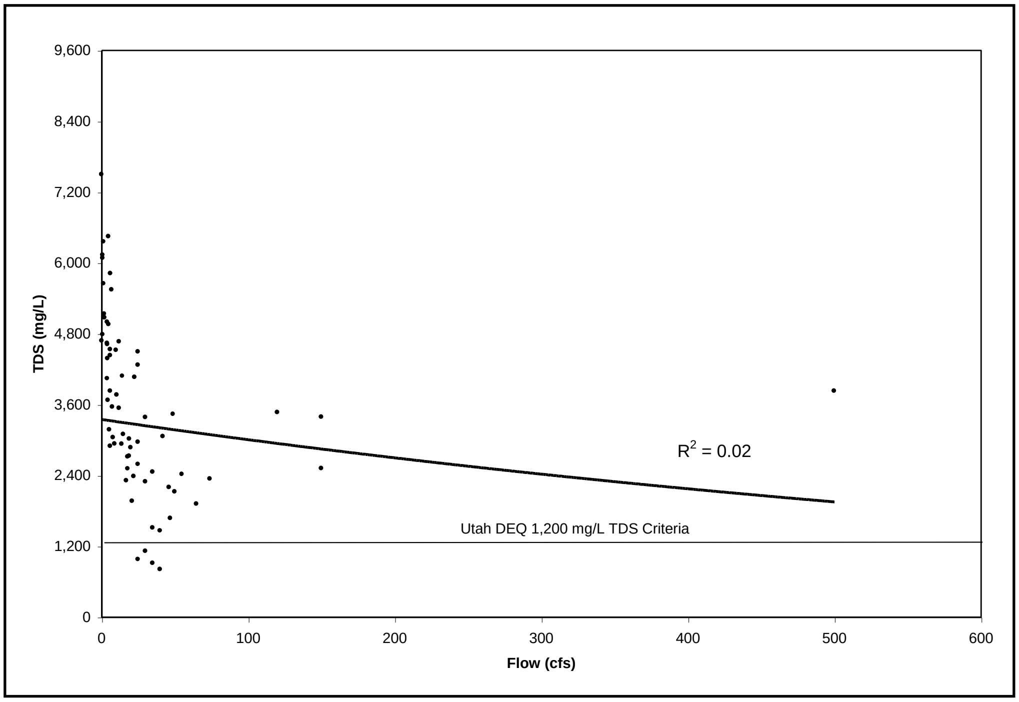


Figure 3-16 Flow verses TDS Regression Plot for 495500 (Muddy Creek at Old US 24 Crossing)

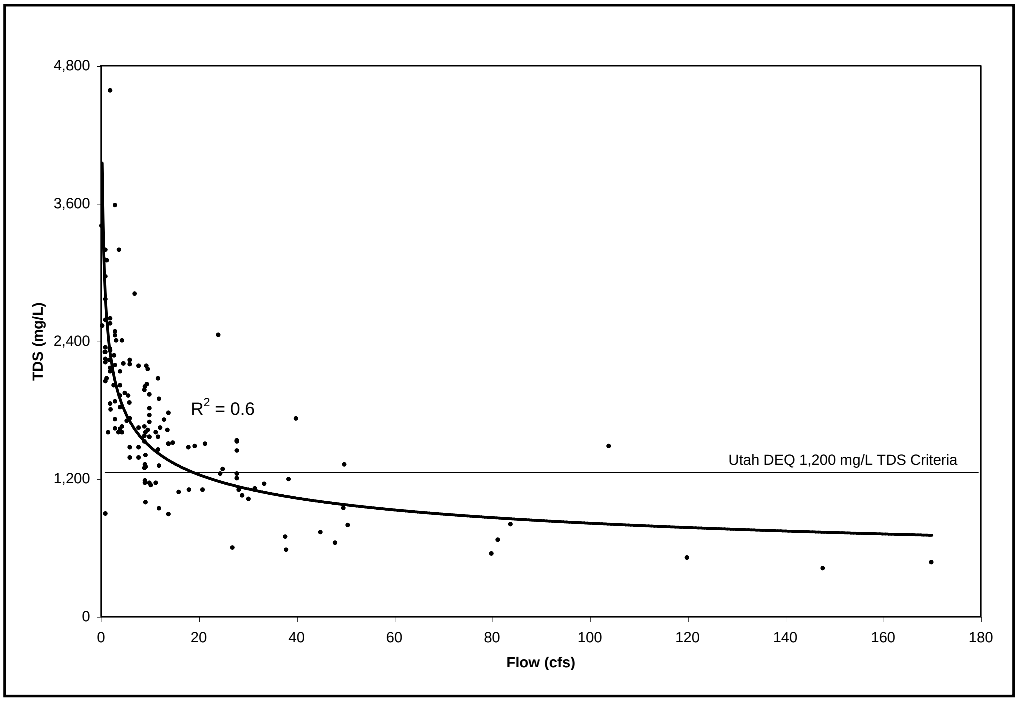


Figure 3-17 Flow verses TDS Regression Plot for EWCD-14 (Lower Muddy Creek)

3.5.4 Summary

The majority of the water quality standards violations occur in the middle and lower portions of the Study Area watersheds where agriculture and rangeland are the predominant land use. As discussed in Section 3.1, with only limited exceptions, TDS is the constituent of concern for the WCRW. The available data indicates that Grassy Creek, the sole segment listed for impairment from pH, should not be listed as impaired. Furthermore, there have not been any exceedances of the DO standard in any stream segment in the WCRW in the last three years. Segments listed as impaired due to DO will be removed in the next 305(b) listing. Based on the limited exceedances of the dissolved iron concentrations and the lack of any identified sources, all stream segments listed as impaired from iron have been delisted in the draft Utah 2004 303 (d) list of waters.

The primary factors in increased TDS loads in the middle and lower reaches of the Price, San Rafael, and Muddy Creek watersheds are from agricultural irrigation practices, surface runoff, and natural geological loadings. Increased surface run-off, and loading of TDS, is also associated with current irrigation practices. Irrigation water percolating through the soil and shale dissolves salts, principally carbonates and sulfates, and transports them to the natural drainages (Laronne 1977). Groundwater moving through the Mancos Shale formation, already affected by soils containing elevated salt levels, picks up additional salts from the shale and discharges the high TDS concentration into streams. Due to different geology and landuses, the upper portions of each of the watersheds generally have insignificant salt loadings relative to the downstream reaches. Specific non-point and point sources for each of the target locations are discussed in greater detail in Sections 4 and 6.

4.0 SOURCE ASSESSMENT

Data evaluation shows that both point and non-point sources are contributing TDS load to streams within the WCRW. The evaluation also shows non-point source pollution is the leading cause of excessive TDS concentrations within the watershed. Past work in the area (BOR and SCS 1993) estimates that irrigation, waste discharge, and natural geologic loadings results in an increase in TDS from approximately 300 mg/L above areas of agricultural irrigation use to greater than 2,000 mg/L below these areas.

4.1 Municipal and Industrial Sources

There are both municipal and industrial sources of TDS loading in the WCRW Study Area. Past work in the Colorado River Basin has estimated that municipal and industrial sources can increase salt loading by approximately 100 tons per 1,000 people per year (BOR 2001). Permitted municipal source discharges in the Study Area are associated with wastewater treatment facilities. Permitted industrial source discharges are associated with coal mine operations and power plants. These permitted point source discharges and discharge data are shown in Tables 4-1 and 4-2.

Wastewater treatment facilities located in Price, Huntington, Castle Dale, and Ferron contribute TDS load to the Price River, Huntington and Cottonwood Creeks, and Ferron Creek, respectively. However, the flow from these treatment plants is relatively small and the loads are limited (see Tables 4-1 and 4-2, permit numbers UT0021814, UT0021296, and UT0023663). General surface disturbance and run-off from urban areas, as well as leakage from municipal water supply lines also contributes non-point source loadings of TDS. Runoff rates and flows from urban areas can be 20 percent more than the runoff generated from grassland areas due to the many impervious surfaces in urban areas such as roads, buildings, and parking lots. Along with the possibility for additional erosion of high salt content soils, urban runoff can also contain road salts and other soluble materials that may contribute loading to the WCRW streams (Texas Non-Point Source Book 2003).

Coal mining activities can increase salts through the leaching of spoil materials, groundwater discharge, or erosion of disturbed surface material. Point source discharges are possible from the discharge of dewatering effluents, and from other controlled sources. Non-point discharges can also occur from uncontrolled sources and from increased surface disturbances. A study completed by USGS (1986b) observed that water from mines in the Book Cliffs area of the Price River watershed area contain TDS ranging from 800-1,600 mg/L, while water from mines in the coal resource areas of the San Rafael River watershed contain TDS concentrations of 50-750 mg/L. Most mining operations discharge relatively low annual loads of TDS into streams (see Tables 4-1 and 4-2).

Table 4-1 NPDES Permit Holders, Permit Numbers, and Locations in the WCRW[1]

PERMITEE[2]	PERMIT #	ISSUED	EXPIRES	FACILITY LOCATION
Andalex-West Ridge	UTG040023*	N/A	N/A	PO Box 902, Price
Andalex-Centennial	UTG040008*	9/01/98	4/30/03	PO Box 902, Huntington
Andalex-Wildcat	UTG040007*	6/01/98	4/30/03	PO Box 902, Price
Ark Land Company	UT0025453	7/31/02	7/31/07	18 miles east of Helper
Canyon Fuel-Banning	UTG040011*	5/29/98	4/30/03	PO Box 1029, Wellington
Castlegate Central Processing	UT0025437*	1/14/02	1/31/07	11 miles north of Helper
Castle Valley Special SSD	UT0023663	7/11/00	7/31/05	86 South First East, Castle Dale
Castle Valley SSD- Huntington	UT0021296	11/18/99	11/30/04	PO Box 877, Castle Dale
Consolidation Coal Company Emery Mine	UT0022616	6/17/99	6/30/04	PO Box 527, Emery
Co-Op Mining Company	UT040006	5/01/98	4/30/03	Bear/Trail Canyon Mines, Huntington
Cyprus Plateau Mining-Willow Creek	UTG040012*	1/12/00	4/30/03	847 Northwest Highway 191, Helper
East Carbon Water Treatment Plant	UTG640012*	5/08/98	4/31/03	Whimore Canyon above East Carbon
Emery Water Treatment	UTG640030*	5/08/98	5/31/03	Castle Dale
Ferron Sewerage System	UT0020052**	5/27/99	5/31/04	PO Box 820, Ferron
Genwal Resources	UT0024368**	8/07/95	8/31/05	PO box 1077, Price
Hiawatha Coal Company	UT0023094	9/09/99	9/30/04	PO Box 1201, Huntington
Horse Canyon Mine	UTG040013*	5/20/98	4/30/03	31 North Main St., Helper
Interwest Mining Co Des Be Dov	UTG040022	6/16/98	4/30/03	7 Miles NE of Castle Dale, Huntington
JW Operating Corp.	UT0025488*	N/A	N/A	Soldier Creek Canyon
Lodestar Energy - Horizon	UTG040019	5/04/99	4/30/03	H.C. Box 370, Helper
Lodestar Energy-Scofield	UTG040021*	8/07/98	4/30/03	Scofield Route, Helper
Mountain Coal Co.	UTG040004*	5/29/98	4/30/03	C/O Blackhawk Engineering, Wellington
Orangeville Water Treatment Plant	UTG640031*	5/08/98	5/31/03	NW of Orangeville, Castle Dale
Pacificorp-Carbon Plant	UT0000094	11/30/01	11/30/06	Hwy. 67191, 3 Miles North of Helper
Pacificorp-Deer Creek Coal	UT0023604**	11/18/02	12/31/07	Hwy. 31, 7 miles S. of Huntington
Pacificorp-Trail Mountain	UTG040003*	6/25/93	4/30/03	Sec 25 T17S R6E Alb&M, Orangeville
Pacificorp-West Mine	UT0023728*	1/22/03	12/31/07	PO Box 310, Huntington
Plateau Mining	UT0023736*	12/21/01	12/31/06	Star Point, Price
Price City Water Treatment Plant	UTG640035*	N/A	N/A	Price Canyon Highway 6, Price
Price River Water Improvement District	UT0021814	12/31/01	12/31/06	265 North Fairgrounds Road, Price
Price River Water Treatment Plant	UTG640034*	N/A	N/A	432 West 600 South, Price
Savage Industries	UTG040005**	5/29/98	4/30/03	Route 1 Box 146-H5, Wellington
Star Point Refuse Pile	UTG040025*	8/06/02	4/30/03	Sec. 10&15,T15S, R8E, Wattis
Sunnyside Cogeneration	UT0024759*	8/01/02	7/31/07	1 Power Plant Road, Sunnyside
Talon Resources Inc.	UT0025399	8/24/01	8/31/06	375 South Carbon Ave., A-10, Price
Utahamerican Energy	UTG040024*	N/A	N/A	Lila Canyon, Price
Wal-Mart Supercenter	UTR100812*	N/A	N/A	255 South Highway 55, Price

[1] CBM belowground discharge is not regulated under the UPDES program.

[2] There are two additional power plants (Hunter and Huntington) that are in the process of being permitted for discharge.

* No data available for this location from USEPA's PCS Environmental Warehouse Internet Database

** Three or less data observations available for this location from USEPA's PCS Environmental Warehouse Internet Database

Table 4-2 NPDES Permit Numbers, Flow, and TDS Data in the WCRW

	Flow (cfs)			TDS (mg/L)		Load	
Permittee[1] Name/Permit Number	Design Flow Rate	Existing Flow Mean	Existing Flow Range	Existing TDS Mean	Existing TDS Range	Existing Annual Load[2] (tons/year)	Waste Load[3] (tons/year)
Ark Land Company (UT0025453)	0.046	0.020	$7.74\text{x}10^{-9}$ - 0.03	567	531-625	8	30
Canyon Fuel - SUFCO (UT0022918)	8.3	4.07	0.03-8.67	794	221-1,449	2,500	10,044
Castle Valley Special SSD (UT0023663)	1.09	0.6	0.31- 1.04	1,513	1,410-1,610	730	1278
Castle Valley SSD – Huntington (UT0021296)	0.619	$3.56\text{x}10^{-7}$	$2.63\text{x}10^{-7}$ – $4.33\text{x}10^{-7}$	2,738	2,400-3,205	0.001	730
Ferron Lagoons- Ferron (UT0020052)	0.84	0.81	0.57-0.96	1195	1070-1320	95	986
Consolidation Coal – Emery (UT0022616)	0.879	0.31	0.11-0.57	4,177	2,460-5,048	1,095	1,104
Co-Op Mining Company (UT040006)	0.78	0.06	$1.42\text{x}10^{-4}$ – 0.21	594	296-998	35	670
Hiawatha Coal Company (UT0023094)	0.981	0.23	$4.23\text{x}10^{-4}$ – 1.55	705	677-740	146	941
Interwest Mining Co Des Be Dov (UTG040022)	371.4	$1.75\text{x}10^{-8}$	$9.28\text{x}10^{-9}$ – $3.09\text{x}10^{-8}$	10,347	9,533-11,885	0.0002	NA[4]
Lodestar Energy – Horizon (UTG040019)	2.05	$4.77\text{x}10^{-4}$	$7.74\text{x}10^{-6}$ – 0.89	382	317-482	258	1035
Pacific – Carbon Plant (UT0000094)	0.433	0.50	$3.25\text{x}10^{-7}$ – $8.05\text{x}10^{-7}$	298	190-510	146	552
Pacificorp – Trail Mountain (UTG040003)	36.46	0.08	0.01 – 0.13	3,035	1,452-7,070	233	138
Price River Water Imp. Dist (UT0021814)	6.2	2.17	$1.70\text{x}10^{-6}$ – $2.48\text{x}10^{-6}$	1,061	899-1,190	2,190	7,304
Talon Resources Inc. (UT0025399)	0.75	$9.76\text{x}10^{-3}$	$2.77\text{x}10^{-3}$ – 0.02	327	157-628	3	889

[1] Although there are additional permitted discharges in the WCRW, flow and TDS data for at least four sampling periods is available from USEPA's PCS Environmental Warehouse Internet Database only for the locations listed

[2] Existing annual load from Section 6.3.1

[3] Waste load is calculated based on proposed permit limits as listed in Table 6-1 (permits may be concentration or load-based)

[4] Design flow is based on the 25 year 6-hour storm event only

An additional industrial activity in the Study Area is development of coal bed methane (CBM). The source coals for CBM are generally located in marine-derived formations such as the Mancos Shale, and development and production of CBM wells results in production of high saline waters, which are typically disposed of through evaporation and deep-well injection. Coal bed methane development and production activities first began in the Study Area in 1990, with more significant activity beginning in 1993-1994 in the Ferron Coals located in the Price River watershed. Water production from development of CBM wells and deep well injection of produced water (produced water was injected into the Navajo and Wingate formations) peaked in the Study Area in 2001 and is now declining. (Hunt 2003)

The effects of CBM development were evaluated on an annual and monthly basis in the San Rafael and Price River watersheds. Any effects were assumed to occur by movement of high saline water into the surface streams as a result of development and production of the CBM wells. The evaluation was accomplished by comparing available measured surface water chemistry over time (pre-CBM to current), looking for any increasing trend in measured TDS concentrations in surface streams that might be attributable to CBM activity. While the analysis of surface water chemistry did not indicate that CBM development has resulted in increased TDS loading in the Study Area, the results of continued monitoring should be assessed for any future effects. The USGS is also currently working on a regional model to assess potential future water quality impacts, if any, of CBM development in Utah (Hunt 2003). Details of this study were not available at the time of this report.

Overall, the analysis of point source data revealed that the current impact of point source TDS on the WCRW streams is relatively minor (see additional discussion in Section 6.0).

4.2 Non-point Sources

While there are potential non-point source loadings of TDS from industrial and municipal sources, as discussed above, they are generally insignificant relative to the other non-point sources of TDS concentrations in the watershed. The most significant TDS loading are due to surface and sub-surface movement of water over the Mancos Shale geologic feature present in the area. Mancos Shale formations, which are known to be highly saline and soluble, dominate the middle portion of the WCRW, where irrigation is also ubiquitous. Ground water flows through the Mancos Shale and surface runoff over soils derived from Mancos Shale have been reported as resulting in substantial dissolution of salts (Apodaca 1998, Evangelou et al. 1984, Laronne 1977) and are the primary avenues by which TDS loadings are increased in the WCRW. Water quality data are shown in Appendix B. Specific types of non-point sources fore each of the listed impaired stream segments are summarized in Appendix A.

A previous water quality monitoring project (DEQ 2000) has determined that irrigation return flows, canal seepage, and stock pond seepage constitute a significant source of TDS in the WCRW. Nearly 400 miles of stream segments in the WCRW have been designated as non-supporting or partially supporting their beneficial use due to high TDS caused by agricultural activities. The BOR (2001) estimates that irrigation and other agricultural activities in the Price and San Rafael river sub-watersheds alone results in a salt loading of approximately 258,000 tons per year

Irrigation and associated canal seepage are the largest contributors of TDS in the WCRW. TDS loading associated with irrigation can occur from surface flow and from subsurface movement of return flows. Overland flow caused by over-irrigation can transport salts, as well as sediment, from the soil surface directly to streams. Salt has accumulated on the soil surface in many areas in the WCRW due to the dissolution of salts from the soil and subsurface materials. Below-ground irrigation return flows may eventually enter the groundwater and return to the stream. Data from stream gauges below irrigation areas in all sub-watersheds show significant increases in TDS loadings compared to data from gauges above irrigation areas. Increased TDS concentrations caused by irrigation return flows continue to degrade water quality as the water moves downstream and picks up increasing amounts of salts.

Seepage of water from unlined canals and stock ponds is also a significant contributor to the loading of streams in the WCRW. The BOR and SCS (1993) estimates that canal seepage increases the TDS load by 67.16 tons per mile of canal.

Runoff events are also a significant source of the total salt load in the WCRW. Previous studies have estimated that 21 percent of the salt load in the Price River and 14 percent of the salt load in the San Rafael River are related to runoff events caused by intense precipitation during thunderstorms (BOR 2001). Similar loading has been also been estimated for Muddy Creek (BOR 1987). Additionally, overland flow of snowmelt on lower elevation sites located on saline formations can significantly increase salinity.

Surface runoff over soil derived from Mancos Shale can potentially increase TDS by transporting salt laden soil particles into nearby streams. The aridity of the WCRW results in a net upward movement of water, which deposits salts on the soil surface. These salts are susceptible to movement by surface runoff from natural precipitation events, snowmelt, and over-irrigation (Laronne 1977). Runoff can be exacerbated by disturbances to the soil surface, such as forestry activities, overgrazing and recreational activities.

Improper forestry related activities can increase TDS loading by removing vegetative cover and other protective surfaces, such as pebbles and gravel, as well as loosening the soil surface, all of which increase the erosion potential caused by overland flow. Additionally, roads built for timber extraction are susceptible to erosion, as are all unpaved roads in the watershed. Both the road surface and the steep embankments can be severely eroded by relatively minor storms. However, due to the forested portions of the watershed occurring outside of the Mancos Shale, these practices generally contribute relatively insignificant salt loads.

Livestock and wildlife grazing can result in surface disturbance or compaction, which can alter infiltration, surface cover, and streambank stability. These changes can increase TDS loading in adjacent streams. Infiltration rates decrease, and runoff increases, as livestock or wildlife ground trampling increases. Dadkuh and Gifford (1980) found that untrampled soils exhibit more than two times the infiltration rate as trampled soils. They also reported that by increasing the cover of grasses from 30 percent to 50 percent, sediment production was decreased by more than 50 percent. Streambank degradation caused by watering animals in readily accessible streamside areas can also result in increased sediment production, and accompanying TDS loadings, in the WCRW.

Recreational activities are another potential source of TDS in the WCRW. The loss of vegetative cover and the loosening of soil particles associated with the use of recreational vehicles results in increased erosion potential and possible TDS loading into nearby streams. Recreational activities can also damage or remove the protective cryptogamic crust, which then results in increased sedimentation and associated TDS loading (Belnap et al. 2001).

5.0 LOADING CALCULATIONS

The ultimate goal of a TMDL is the attainment of water quality standards for impaired waters, were feasible and achievable. In order to meet the goal of the TMDL, the relationship between source loading and the loading capacity of the receiving water must be established. The loading capacity is the amount of a given pollutant that can be assimilated by a water body while still meeting the water quality standard for the water body. For this TMDL, the water quality criterion is 1,200 mg/L TDS.

This section describes the procedures used for determining the loading capacity and current TDS loading in the Price River, San Rafael River, and Muddy Creek watersheds. In conjunction with historical flow records, loading capacities were established for flows expected to occur in an average year in the Price River, San Rafael River, and Muddy Creek, as well as selected tributaries in these watersheds, for which target points were established. Existing loads, which were calculated from available monitoring data, were compared to loading capacities in order to evaluate critical conditions and calculate the necessary load reductions.

Each of the established target sites in the WCRW has a TMDL of TDS that can be carried before the TDS criterion is exceeded. This TMDL is equivalent to the loading capacity at each of the target sites, which is calculated by the following formula:

$$\text{Flow (cfs)} \times \text{TDS WQ Criterion (1,200 mg/L)} \times 2.71\times10^{-3}\ \text{(Conversion Factor}^{1}\text{)} = \text{Load Capacity (tons/day)}$$

This same formula is used to calculate existing loads by substituting measured TDS concentrations at respective flows for the TDS water quality criterion.

Critical conditions represent the condition or conditions under which the loading capacity of a target site is exceeded and violation of TDS criterion occurs. These critical conditions can be dependent on environmental and other watershed factors, such as rainfall events when TDS loading to surface waters occurs in surface runoff to the Study Area streams, as well as watershed activities, such as irrigation that can result in TDS loading through surface and ground water return flows. Critical conditions in the Study Area are difficult to identify because of the dynamic combination of hydrology and loading conditions. Loading times that have the greatest impact on water quality conditions are difficult to distinguish, because of lags created by ground water flows, surface water diversions and other factors such as irrigation rates.

[1] Conversion listed is used to convert flows and TDS concentrations to arrive at the units of tons/day.

As discussed in Section 3.5, violations of the TDS water quality criterion occur during all months of the year at target sites in all three Study Area watersheds. As described in the following sections, based on the available water quality data, the TMDL water quality criterion is violated throughout the entire year and at all expected normal flow conditions throughout the watersheds. Therefore, critical conditions in each of the three watersheds exist at all flow conditions, and the TMDLs will be based on flow conditions and not specific seasonal periods. Establishing a TMDL for TDS under all critical flow conditions ensures that the TDS water quality criterion is met under all conditions.

5.1 Price River Watershed

As previously discussed, STORET monitoring stations 493239 (Price River above WWTP in Wellington) and 493165 (Price River at Woodside) were designated as target sites in the Price River watershed and assessed for temporal and spatial variations in flow. The daily stream flows measured at these monitoring stations were arranged in order of magnitude and divided into flow tiers. Each flow tier represents a range of measured flows, the highest measured flow within the range assigned a percentage (e.g., 10 percent, 20 percent) that reflects the chance of any measured stream flow being less than or equal to it. For example, higher measured flow (e.g., 90 cfs) would have a lower (e.g. 10 percent) chance of criterion exceedance while a lower flow (e.g., 10 cfs) would have a greater chance of exceedance. To evaluate the critical flow conditions at each target site, the maximum load capacity for each flow tier was calculated based on the highest measured flow within the tier range of flows and this load capacity compared with existing loads (minimum, maximum, average) calculated from the data. These results are shown in Tables 5-1 (monitoring station 493239) and 5-2 (monitoring station 493165). Plots of calculated loading capacity at each flow tier versus *average* existing load calculated from the data are shown for each monitoring station in Figures 5-1 and 5-2, respectively.

As shown in Table 5-1, maximum TDS loads for all but the 10 percent and 20 percent percentile groups exceeded the allowable load capacities for each percentile group. The plot of average existing load versus calculated loading capacity (Figure 5-1) is consistent with the water quality assessment results presented in Section 3.4.1, which show that, on average, the TDS water quality standard at this monitoring station is exceeded throughout the entire year, except during higher flow periods in the summer (see Figure 3-2). The results for monitoring station 493165 show that loading capacities are exceeded and critical conditions exist throughout the entire range of flow tiers (Table 5-2), although average existing loads do not exceed loading capacities at higher flow tiers (Figure 5-2).

Table 5-1 Loading Statistics for Station 493239, Price River Watershed (Map 10, Price River above Price WWTP at Wellington bridge)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	360	2	0	332	767	550	1,163
10% - 20%	100	3	0	114	299	178	323
20% - 30%	70	2	1	93	295	194	227
30% - 40%	45	3	1	72	242	144	146
40% - 50%	27	2	2	138	177	152	87
50% - 60%	19	3	3	121	141	131	61
60% - 70%	17	3	3	74	109	90	55
70% - 80%	14	2	2	96	116	106	47
80% - 90%	9	3	3	43	67	58	29
90% - 100%	5	2	2	25	41	33	15

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

Table 5-2 Loading Statistics for Station 493165, Price River Watershed (Map 10, Price River near Woodside at US 6 crossing)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	236	5	2	471	1,612	826	763
10% - 20%	132	6	4	211	2,784	574	425
20% - 30%	72	6	6	255	513	361	232
30% - 40%	55	5	4	187	480	290	177
40% - 50%	50	6	5	74	358	262	161
50% - 60%	43	5	5	251	420	329	138
60% - 70%	36	6	6	187	279	220	117
70% - 80%	26	6	5	45	221	150	84
80% - 90%	20	5	5	115	188	145	63
90% - 100%	11	5	4	20	122	70	35

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

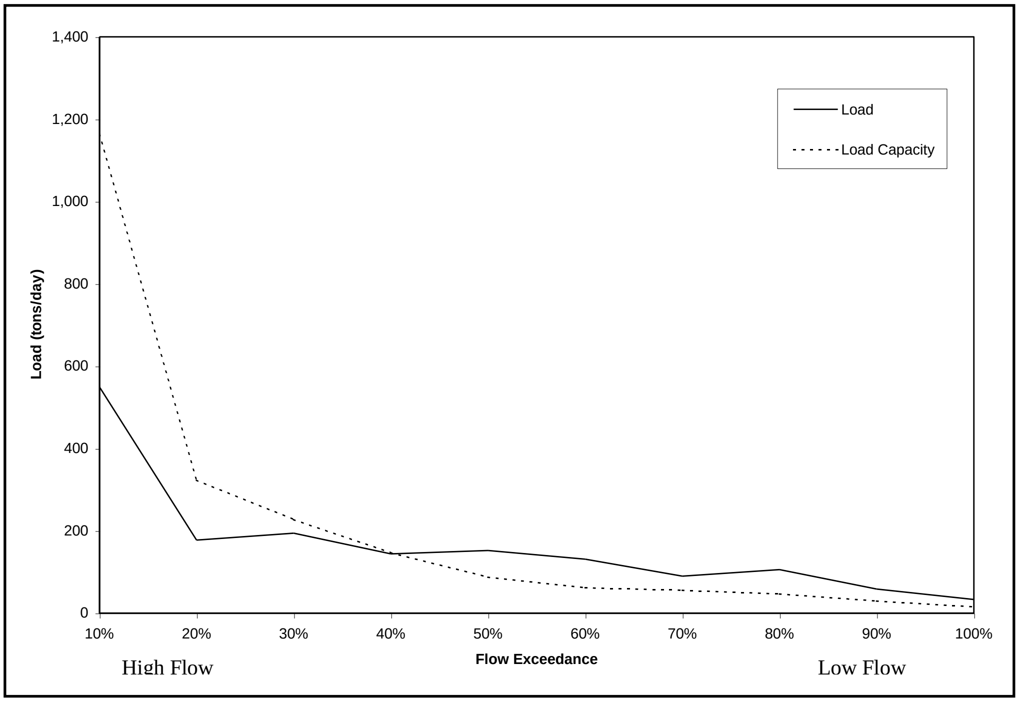


Figure 5-1 Existing TDS Loading by Flow for Station 493239 (Map 10, Price River above Price WWTP at Wellington Bridge)

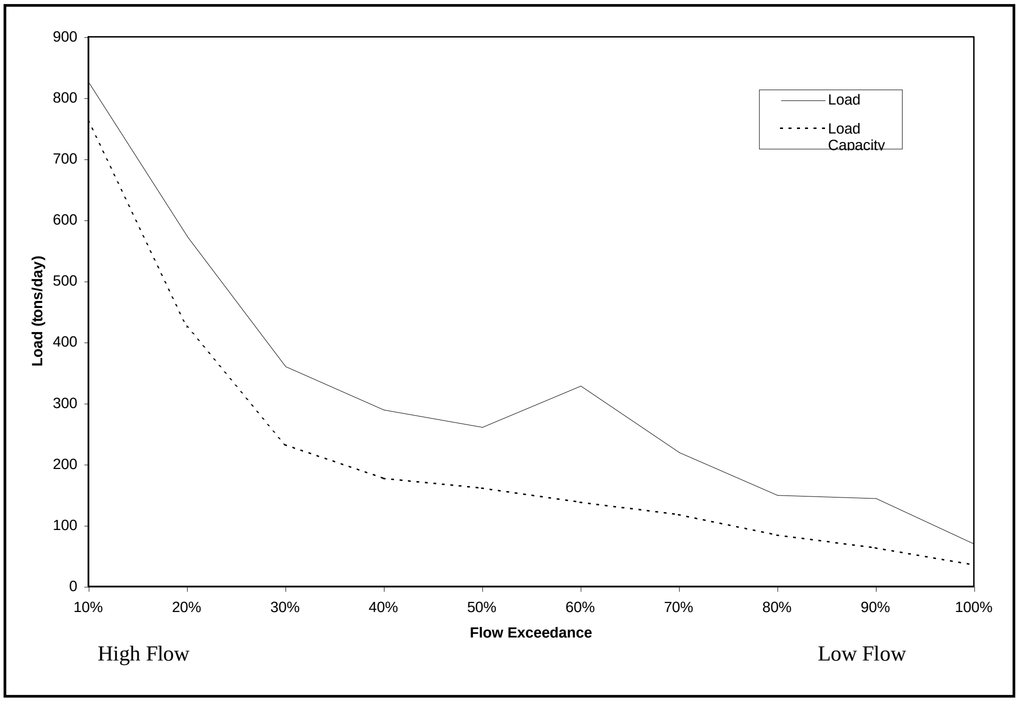


Figure 5-2 Existing TDS Loading by Flow for Station 493165 (Map 10, Price River near Woodside at US 6 Crossing)

5.2 San Rafael Watershed

Results of the analyses of loading capacities, existing loads, and critical conditions for target sites/monitoring stations EWCD-03 (Huntington Creek lower), EWCD-07 (Cottonwood Creek lower), EWCD-09 (Rock Canyon Creek lower), EWCD-11 (Ferron Creek lower), and STORET monitoring station 493029 (San Rafael at U24 crossing) in the San Rafael watershed are shown in Tables 5-3 through 5-7, and Figures 5-3 through 5-7, respectively. The results show that loading capacities are exceeded and critical conditions exist throughout the entire range of flow tiers at each of these monitoring stations (Tables 5-3 through 5-7), although average existing loads do not exceed loading capacities at higher flow tiers at monitoring stations EWCD-07, EWCD-11, and STORET monitoring station 493029 (Figures 5-4, 5-6, and 5-7, respectively).

Table 5-3 Loading Statistics for Station EWCD-03, Huntington Creek Watershed (Map 11, lower Huntington Creek)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	107	14	7	142	741	371	344
10% - 20%	50	15	14	181	602	281	163
20% - 30%	24	14	14	123	235	171	77
30% - 40%	17	14	14	81	223	129	53
40% - 50%	12	15	15	73	160	122	40
50% - 60%	9	14	14	65	141	93	29
60% - 70%	7	15	15	51	125	80	24
70% - 80%	6	14	14	45	88	65	18
80% - 90%	4	14	14	24	61	42	13
90% - 100%	1	14	14	1	26	13	4

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.

[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).

[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.

[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.

[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

Table 5-4 Loading Statistics for Station EWCD-07, Cottonwood Creek Watershed (Map 11, lower Cottonwood Creek)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	175	14	6	173	882	332	566
10% - 20%	37	15	13	112	223	169	121
20% - 30%	27	14	13	90	223	149	89
30% - 40%	22	15	15	83	230	135	72
40% - 50%	20	14	14	79	156	117	64
50% - 60%	18	15	15	73	130	109	58
60% - 70%	15	14	14	73	125	100	50
70% - 80%	13	15	15	69	125	94	42
80% - 90%	9	14	13	18	136	70	29
90% - 100%	4	14	14	11	70	41	13

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

Table 5-5 Loading Statistics for Station EWCD-09, Rock Canyon Creek Watershed (Map 11, lower Rock Canyon Creek)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	27	13	13	99	208	142	89
10% - 20%	19	14	14	82	267	120	61
20% - 30%	13	14	14	67	177	107	41
30% - 40%	10	13	13	51	138	75	33
40% - 50%	8	14	14	51	122	72	26
50% - 60%	6	13	12	13	88	61	20
60% - 70%	5	14	14	39	92	59	17
70% - 80%	4	14	14	31	94	51	13
80% - 90%	3	13	13	32	54	41	10
90% - 100%	2	13	13	15	38	24	6

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

Table 5-6 Loading Statistics for Station EWCD-11, Ferron Creek Watershed (Map 11, lower Ferron Creek)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	120	14	4	95	522	225	386
10% - 20%	20	15	15	80	175	109	66
20% - 30%	12	14	14	56	114	83	40
30% - 40%	10	14	14	45	83	63	32
40% - 50%	7	15	15	40	139	60	23
50% - 60%	5	14	14	28	54	42	18
60% - 70%	4	15	15	22	47	33	14
70% - 80%	4	14	14	26	41	30	11
80% - 90%	2	14	14	11	30	20	7
90% - 100%	1	14	14	1	20	7	2

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

Table 5-7 Loading Statistics for Station 493029, Lower San Rafael River Watershed (Map 11, San Rafael River at US 24 crossing)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	291	6	1	479	1,067	715	939
10% - 20%	91	6	6	425	474	457	293
20% - 30%	51	6	6	204	500	333	165
30% - 40%	37	6	6	214	345	276	120
40% - 50%	29	6	6	202	230	211	93
50% - 60%	25	6	6	171	230	204	80
60% - 70%	17	6	6	106	184	148	56
70% - 80%	14	7	7	85	145	115	46
80% - 90%	6	6	6	25	103	67	21
90% - 100%	2	5	5	14	36	21	6

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

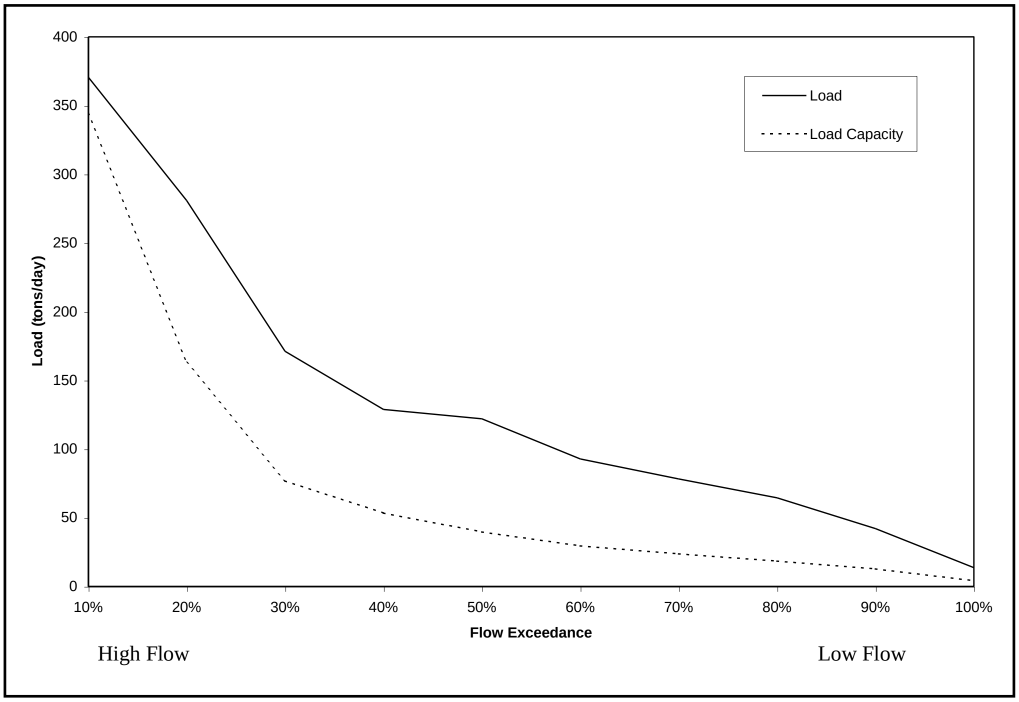


Figure 5-3 Existing TDS Loading by Flow for Station EWCD-03 (Map 11, Lower Huntington Creek)

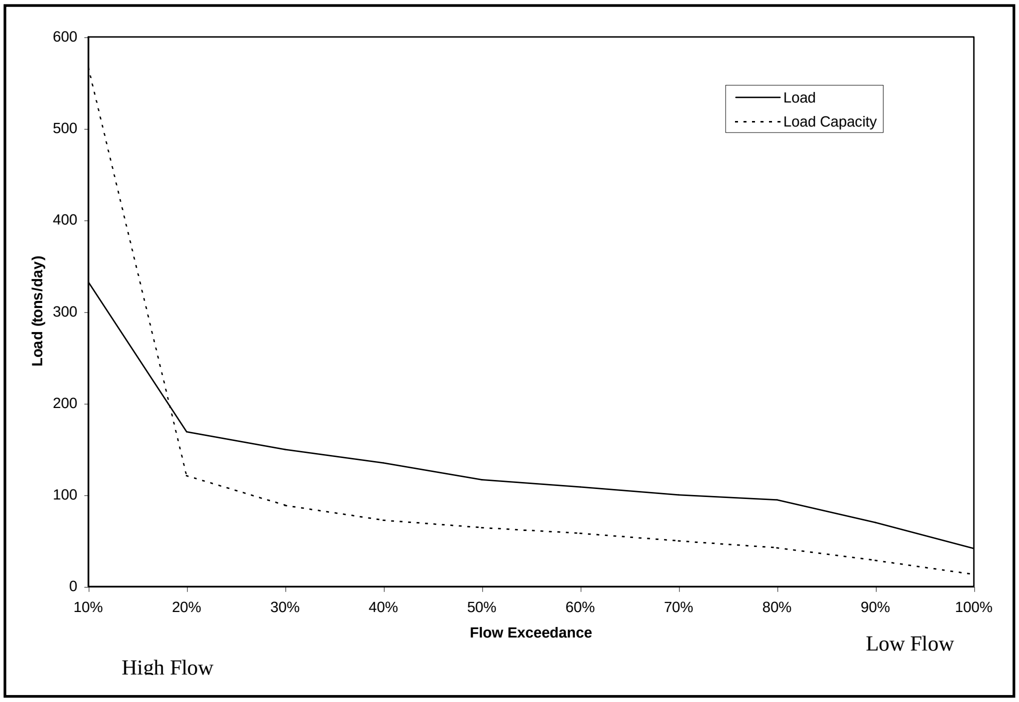


Figure 5-4 Existing TDS Loading by Flow for Station EWCD-07 (Map 11, Lower Cottonwood Creek)

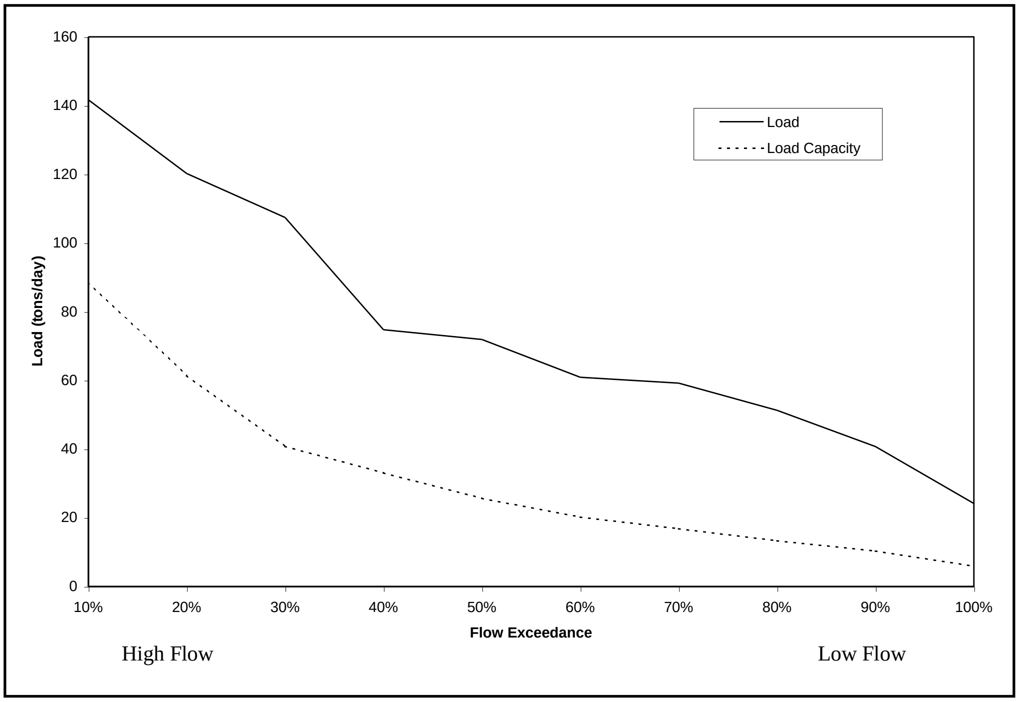


Figure 5-5 Existing TDS Loading by Flow for Station EWCD-09 (Map 11, Lower Rock Canyon Creek)

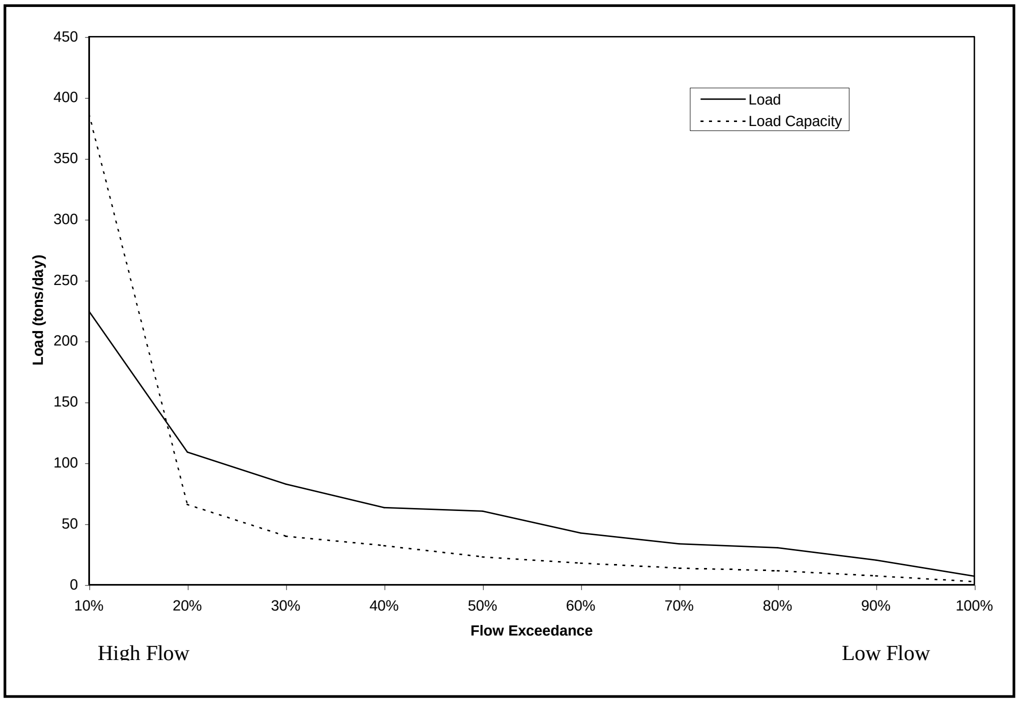


Figure 5-6 Existing TDS Loading by Flow for Station EWCD-11 (Map 11, Lower Ferron Creek)

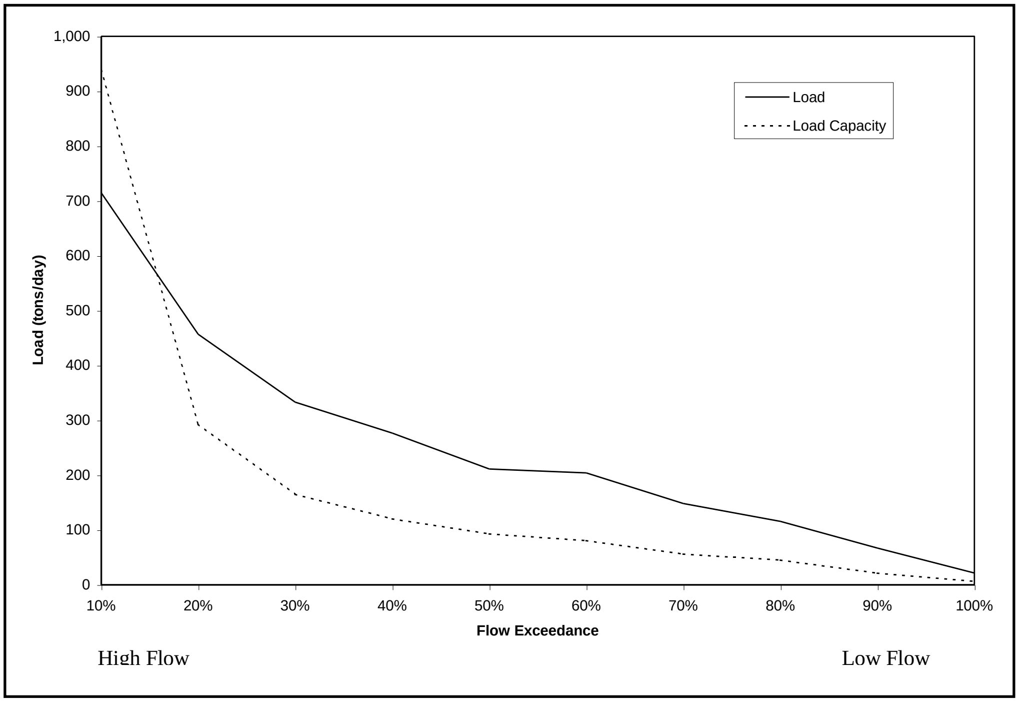


Figure 5-7 **Existing TDS Loading by Flow for Station 493029 (Map 11, San Rafael River at US 24 crossing)**

5.3 Muddy Creek

Results of the analyses of loading capacities, existing loads, and critical conditions for target sites/monitoring station EWCD-14 (Muddy Creek lower) and STORET monitoring station 495500 (Muddy Creek at old U24 crossing) in the Muddy Creek watershed are shown in Tables 5-8 and 5-9, and Figures 5-8 and 5-9, respectively. The results show that loading capacities are exceeded and critical conditions exist throughout the entire range of flow tiers at each of these monitoring stations (Tables 5-8 and 5-9), although average existing loads do not exceed loading capacities at higher flow tiers at monitoring station EWCD-14 (Figure 5-8).

Table 5-8 Loading Statistics for Station EWCD-14 Muddy Creek Watershed (Map 12, lower Muddy Creek)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	79	14	3	82	414	164	256
10% - 20%	30	14	6	43	115	88	97
20% - 30%	17	15	11	33	159	69	56
30% - 40%	11	14	11	30	66	46	36
40% - 50%	9	14	11	25	56	40	31
50% - 60%	8	15	14	28	53	37	26
60% - 70%	5	14	14	18	36	25	16
70% - 80%	3	14	14	13	33	20	11
80% - 90%	2	14	14	7	25	12	6
90% - 100%	1	14	13	2	9	6	3

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

Table 5-9 Loading Statistics for Station 495500, Muddy Creek Watershed (Map 12, Muddy Creek at old US 24 crossing)

Flow Exceedances	Average Flow (cfs)[1]	Number of Loads[2]	Water Quality Violations[3]	Existing Load (tons/day)[4]			Load Capacity (tons/day)[5]
				Minimum	Maximum	Average	
0% - 10%	159	7	7	334	5,151	1,402	514
10% - 20%	45	7	6	87	452	259	145
20% - 30%	31	7	5	86	287	185	102
30% - 40%	24	7	6	65	302	177	76
40% - 50%	18	7	7	106	155	133	58
50% - 60%	12	7	7	71	158	119	38
60% - 70%	7	8	8	47	105	74	21
70% - 80%	5	7	7	44	83	55	15
80% - 90%	2	7	7	23	54	34	8
90% - 100%	1	6	6	0	15	7	2

[1] Flow values shown represent the average measured flow within the respective flow tier over the period of 1/1990-12/2001.
[2] Equals the total number of available measurements (flow and TDS) within each flow tier from which loads were calculated (Appendix B).
[3] Number of times that the measured TDS concentrations exceeded 1,200 mg/L.
[4] Load (tons/day)= measured flow (cfs) x measured TDS concentration x Conversion Factor. Data is shown in Appendix B.
[5] Load capacity calculated as highest measured flow in each flow tier x TDS criterion of 1,200 mg/L x Conversion Factor.

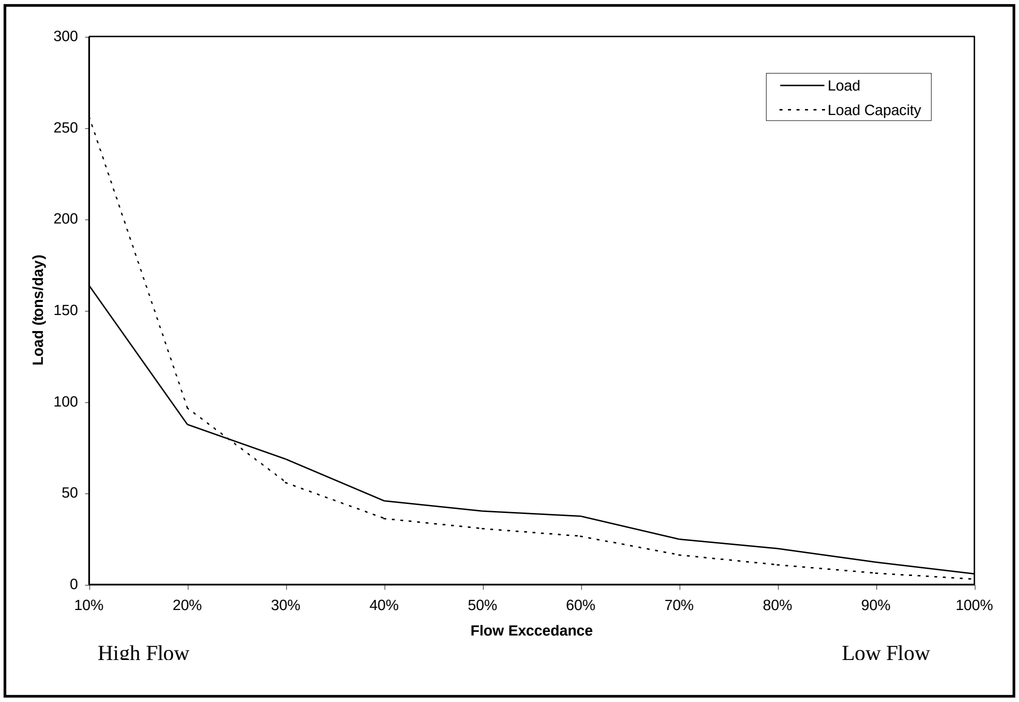


Figure 5-8 Existing TDS Loading by Flow for Station EWCD-14 (Map 12, Lower Muddy Creek)

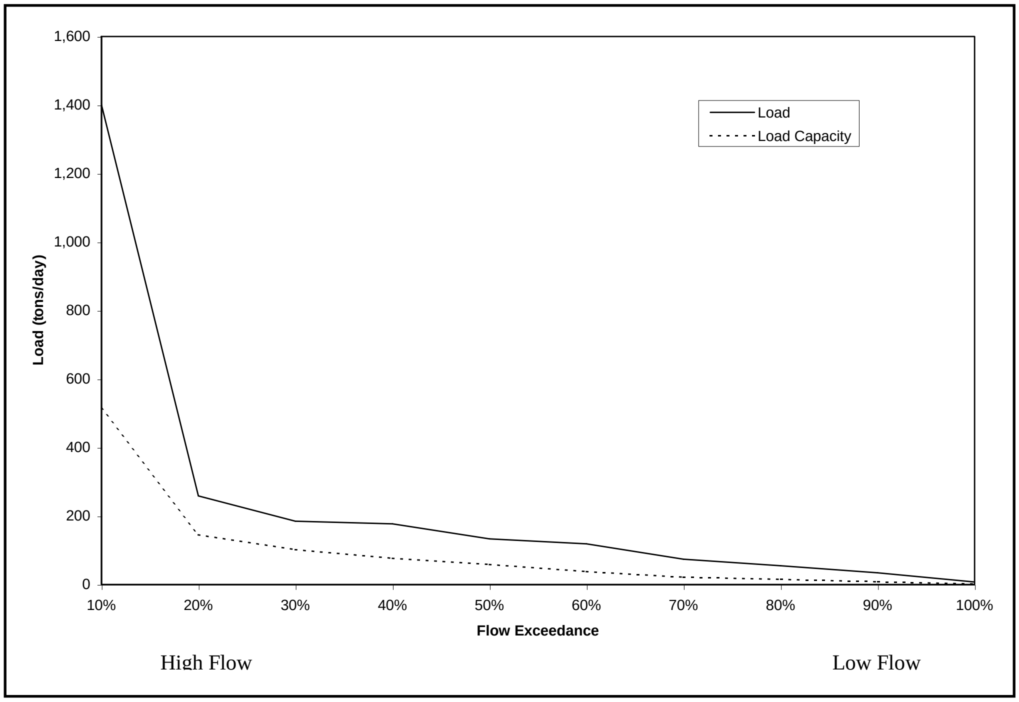


Figure 5-9 Existing TDS Loading by Flow for Station 495500 (Map 12, Muddy Creek at old US 24 crossing)

6.0 TMDL AND LOAD ALLOCATION

6.1 Description of TMDL Allocation

A TMDL is composed of the sum of individual waste load allocations (WLAs) for point sources, load allocations (LAs) for non-point sources and natural background loading (which is naturally occurring and cannot be controlled), and a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving streams. A TMDL is denoted by the equation:

$$\text{TMDL} = \Sigma\ \text{WLAs} + \Sigma\ \text{LAs} + \text{MOS}.$$

The TMDL is the total amount of pollutant that can be assimilated by the receiving stream while still achieving water quality standards. For some pollutants, TMDLs are expressed as a mass-loading basis (e.g., pounds or kilograms per day). In some cases, a TMDL is expressed as another appropriate measure that is the relevant expression for the reduction of loadings of the specific pollutant needed to meet water quality standards or goals. The TMDLs for TDS for the Price River, San Rafael River, and Muddy Creek watershed are expressed on a mass-loading basis (tons/day) and represent the loading capacity of the watershed streams to assimilate TDS load and achieve the TDS water quality standard.

6.2 Margin of Safety

The MOS is a required part of the TMDL development process. There are two basic methods for incorporating the MOS:

- Implicitly incorporate the MOS using conservative model assumptions to develop allocations
- Explicitly specify a portion of the total TMDL (stream loading capacity) as the MOS.

For the Price River, San Rafael River, and Muddy Creek TMDLs, the MOS was calculated as 5 percent of stream loading capacity.

6.3 TMDL Allocations

The TMDLs and load allocations for the Price River, San Rafael River, and Muddy Creek watersheds were developed based on flow and water quality data over an 11-year period of record from 1990 to 2001. The average annual loading capacity/TMDL at each target site was calculated as the product of the average annual flow at the target site, the TDS standard criterion of 1,200 mg/L, and a conversion factor to express the average annual loading capacity/TMDL in tons/year TDS. The difference between the

TMDL and the existing average annual TDS load at each target (calculated using water quality and flow data at each target site over the 11-year period of record) plus the MOS represents the reduction in TDS loading required to meet the TMDL at that site. This reduction in TDS loading was, in turn, used to determine the allocation in TDS loading from non-point sources under the TMDLs.

The existing average annual TDS load at each target site is comprised of TDS loads from both point and non-point sources. The average annual point-source TDS load at each target site was calculated from discharge monitoring report data from permitted point-source dischargers located above the site (see Section 4, Tables 4-1 and 4-2). The average annual non-point source TDS load at each target site was calculated as the difference between the existing average annual TDS load and average annual point-source load. As shown in Tables 6-2 through 6-10, existing TDS load from point sources is generally much less than the non-point source load. At the lowest target site in each watershed, the point source load is less than 5% of the total existing load (Tables 6-3, 6-8, and 6-10). The existing point source load at all target sites is less than 10% of the existing load. This TMDL proposes to establish point source permits as the permits come open for review. The proposed limits listed in Table 6-1 will come into effect at that time. The resulting WLAs based on the limits listed in Table 6-1 are also listed in Tables 6-2 through 6-10. The reduction in TDS load required to meet the average annual loading capacity/TMDL at each target site was applied to non-point source loading to arrive at load allocations under the TMDLs, as based on the proposed new WLAs.

Tables 6-2 through 6-10 summarize the existing average annual point- and non-point source loads, loading capacity, reduction in TDS load to meet the loading capacity, and the waste load, load allocations, and MOS under the TMDL for each target site in the Price River, San Rafael River, and Muddy Creek watersheds.

Table 6-1 Proposed New Permit Limits for TDS for the Existing Point Sources in WCRW.

Permittee Name/Permit Number	Permit Limit (mg/L)	Loading (tons/year)	Annual Loading (tons/year)	Footnote(s)
Ark Land Company (UT0025453)	656		30	3
Canyon Fuel - SUFCO (UT0022918)		10,044	10,044	4
Castle Valley SSD – Castle Dale (UT0023663)		1,278	1,278	1,4
Castle Valley SSD – Huntington (UT0021296)		730	730	1,4
Ferron Lagoons- Ferron (UT0020052)		986	986	1,4
Consolidation Coal –Emery (UT0022616)		1,041	1,041	4
Co-Op Mining Company (UT040006)	880		670	3
Hiawatha Coal Company (UT0023094)	981		941	3
Interwest Mining Co- Des Be Dov (UTG040022)				2
Lodestar Energy – Horizon (UTG040019)	519		1,042	3
Pacific – Carbon Plant (UT0000094)				5
Pacificorp – Trail Mountain (UTG040003)	1136		14	3
Price River Water Imp. Dist (UT0021814)		7,304	7,304	1,4
Talon Resources Inc. (UT0025399)		889	889	4
Hunter Power Plant				5
Huntington Power Plant				5

1. It is recommended that Facilities conduct an (I&I) Inflow/Infiltration study to determine the extent of I&I from ground water into their collection systems, followed by a project to repair or replace defective sewer piping.
2. This mining facility does not have a mine water discharge (dry mine) thus is would not be required to have a UPDES Discharge Permit. The facility has constructed holding ponds designed to receive and hold a 10 year 24 hour storm event. The facility discharges from the storm water containment about once every three years. This is generally done to for preventative maintenance measures.
3. For concentration based discharge permit limit calculation purposes, if there were more that 20 TDS data points available, the 95th percentile of that data set was used; otherwise the average of data points, less than 20 were taken, plus two standard deviations.
4. Those facilities with outfall concentrations near or exceeding 1200 mg/L, permit limits are based on the design flow of the facility and the water quality standard of 1200 mg/L to determine an annual loading permit limit in tons per year.
5. When UPDES permits are renewed for Pacific Carbon Plant or written for the Hunter and Huntington Power plants, waste load allocations will be developed to insure the discharges from these facilities will not violate the instream water quality standard for TDS of 1200 mg/L.

6.3.1 Existing Conditions

The existing condition represents TDS loadings in the Price River, San Rafael River, and Muddy Creek watersheds calculated using existing monitoring data. As discussed in Section 5, existing loads were calculated for days that had recorded flow and TDS concentrations. The average annual TDS loadings are summarized in Tables 6-2 through 6-10. These tables also list the estimated existing TDS loads from specific point sources and the proposed waste load allocations for these existing point sources. The derivation of these values is summarized in Table 6-1. Permit limits were set using three methods: 1) for current discharges that are less than the 1,200 mg/L, the 95th percentile TDS concentrations was set as the permit limit; 2) for discharges that are at or slightly above the 1,200 mg/l criteria, a total annual load of the design flow x 1,200 mg/L is used, and 3) for discharges that occur where there is sufficient mixing capacity, the permit limit is established to prevent exceedance of the 1,200 mg/L criteria..

The estimated allocation of the non-point load to different sources (e.g., canal seepage, irrigation return flows, erosion) for each watershed is provided in the Project Implementation Plan (Appendix A). For the Price River-Wellington (Storet 493239), the table is shown for the average annual period (Table 6-2a) and for the defined critical condition (Table 6-2b), which is for the 40-100 percent flow exceedance (Table 5-1).

Table 6-2a Summary of Average Annual TDS Load and TMDL Load Allocation for the Price River Watershed from Coal Creek to Carbon Canal Diversion (based on UTDEQ STORET Station 493239- Price River above Price WWTP at Wellington Bridge)

Source	Existing TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UTG040019[a]	*258*	*1,042*
NPDES UT0023094[b]	*146*	*941*
NPDES UT0000094[c]	*146*	
NPDES UT0025453[d]	*8*	*30*
NPDES UT0021814[e]	*2,190*	*7,304*
Total Point Source Load	2,748	9,317
Non-Point Source Load[2]	62,874	
Total Existing Load[3]	65,622	
Loading Capacity[4]	79,847	
Margin of Safety[5]	3,992	
Load Reduction Required to Meet Loading Capacity[6]	0	

Source	TMDL TDS Load Allocation[7] (tons/year)	% of Reduction in Existing Load to Achieve Allocation
Point Source	9,317	0%
Non-Point Source	66,538	0%
Margin of Safety	3,992	Not Applicable

Notes:
a. Lodestar Energy Inc. – Horizon, H.C. Box 370, Helper, UT. Data collected from 3/31/2000 – 12/31/2002.
b. Mine discharge. Hiawatha Coal Company, P.O. Box 1201, Huntington UT. Data collected from 8/31/2000 – 12/31/2002.
c. Pacific- Carbon Plant. Data collected from 12/31/2001 – 12/31/2002.
d. Ark Land Company. Data collected from 8/31/2002 – 11/30/2002. Due to high flow during the 8/31/2002 – 10/31/2002 period only the data from 11/30/2002 is used.
e. Price Waste Water Treatment Plant. Data collected from 1/31/2002 – 12/31/2002.
1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (67.7 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-2b Summary of Average TDS Load and TMDL Load Allocation for critical conditions in the Price River Watershed from Coal Creek to Carbon Canal Diversion (based on UTDEQ STORET Station 493239- Price River above Price WWTP at Wellington Bridge)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UTG040019[a]	*258*	*1,042*
NPDES UT0023094[b]	*146*	*941*
NPDES UT0000094[c]	*146*	
NPDES UT0025453[d]	*8*	*30*
NPDES UT0021814[e]	*2,190*	*7,304*
Total Point Source Load	2,748	9,317
Non-Point Source Load[2]	52,732	
Total Existing Load[3]	55,480	
Loading Capacity[4]	31,755	
Margin of Safety[5]	1,588	
Load Reduction Required to Meet Loading Capacity[6]	25,313	

Source	TMDL TDS Load Allocation[7] (tons/year)	% of Reduction in Existing Load to Achieve Allocation
Point Source	9,317	0%
Non-Point Source	20,850	60%
Margin of Safety	1,588	Not Applicable

Notes:
a. Lodestar Energy Inc. – Horizon, H.C. Box 370, Helper, UT. Data collected from 3/31/2000 – 12/31/2002.
b. Mine discharge. Hiawatha Coal Company, P.O. Box 1201, Huntington UT. Data collected from 8/31/2000 – 12/31/2002.
c. Pacific- Carbon Plant. Data collected from 12/31/2001 – 12/31/2002.
d. Ark Land Company. Data collected from 8/31/2002 – 11/30/2002. Due to high flow during the 8/31/2002 – 10/31/2002 period only the data from 11/30/2002 is used.
e. Price Waste Water Treatment Plant. Data collected from 1/31/2002 – 12/31/2002.
1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (67.7 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-3 Summary of Average Annual TDS Load and TMDL Load Allocation for the Price River Watershed from Confluence of Green River to Soldier Creek Confluence (based on UTDEQ STORET Station 493165- Price River near Woodside at US 6 Crossing)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UTG040019[a]	*258*	*1,042*
NPDES UT0023094[b]	*146*	*941*
NPDES UT0000094[c]	*146*	
NPDES UT0025453[d]	*8*	*30*
NPDES UT0021814[e]	*2,190*	*7,304*
Total Point Source Load	2,748	9,317
Non-Point Source Load[2]	126,849	
Total Existing Load[3]	129,597	
Loading Capacity[4]	74,200	
Margin of Safety[5]	3,710	
Load Reduction Required to Meet Loading Capacity[6]	59,107	

Source	TMDL TDS Load Allocation[7] (tons/year)	% of Reduction in Existing Load to Achieve Allocation
Point Source	9,317	0%
Non-Point Source	61,173	52%
Margin of Safety	3,710	Not Applicable

Notes:
a. Lodestar Energy Inc. – Horizon, H.C. Box 370, Helper, UT. Data collected from 3/31/2000 – 12/31/2002.
b. Mine discharge. Hiawatha Coal Company, P.O. Box 1201, Huntington UT. Data collected from 8/31/2000 – 12/31/2002.
c. Pacific- Carbon Plant. Data collected from 12/31/2001 – 12/31/2002.
d. Ark Land Company. Data collected from 8/31/2002 – 11/30/2002. Due to high flow during the 8/31/2002 – 10/31/2002 period only the data from 11/30/2002 is used.
e. Price Waste Water Treatment Plant. Data collected from 1/31/2002 – 12/31/2002.
1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (62.9 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-4 Summary of Average Annual TDS Load and TMDL Load Allocation for the Huntington Creek Watershed from Confluence with Cottonwood Creek Upstream to USFS Boundary (based on EWCD-03- Lower Huntington Creek)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UTG040006[a]	*35*	*670*
NPDES UT0021296[b]	*0.001*	*730*
Total Point Source Load	35	1,400
Non-Point Source Load[2]	58,504	
Total Existing Load[3]	58,539	
Loading Capacity[4]	27,776	
Margin of Safety[5]	1,389	
Load Reduction Required to Meet Loading Capacity[6]	32,152	

Source	TMDL TDS Load Allocation[7] (tons/year)	% of Reduction in Existing Load to Achieve Allocation
Point Source	1,400	0%
Non-Point Source	24,987	57%
Margin of Safety	1,389	Not Applicable

Notes: a. Co-Op Mining – Bear/Trail Mines. Data collected from 5/30/1998 – 12/31/2002.
b. Castle Valley SSD (Huntington). Data collected from 10/31/2002 – 12/31/2002.
1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (23.5 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-5 Summary of Average Annual TDS Load and TMDL Load Allocation for the Cottonwood Creek Watershed from the Confluence of Huntington Creek to Highway 57 (based on EWCD-07- Lower Cottonwood Creek)

Source	**TDS Load (tons/year)**	**WLA[1] (tons/year)**
Point Source		
NPDES UTG040003[a]	*233*	*14*
NPDES UTG040022[b]	*0.0002*	*0*
NPDES UT0025399[c]	*3*	*889*
NPDES UT0023663[d]	*730*	*1,278*
Total Point Source Load	966	2,181
Non-Point Source Load[2]	67,041	
Total Existing Load[3]	68,007	
Loading Capacity[4]	39,940	
Margin of Safety[5]	1,997	
Load Reduction Required to Meet Loading Capacity[6]	30,064	

Source	**TMDL TDS Load Allocation[7] (tons/year)**	**% of Reduction in Existing Load to Achieve Allocation**
Point Source	2,181	0%
Non-Point Source	35,762	47%
Margin of Safety	1,997	Not Applicable

Notes:
a. Pacificorp – Trail Mtn. Mine. Data collected from 1/31/1998 – 5/30/1998.
b. Interwest Mining Co.- Des Be Dov. Data collected from 10/31/2001 – 12/31/2001.
c. Talon Resources Inc. Data collected from 6/30/2002 – 12/31/2002.
d. Castle Valley Special Service. Sewer system. Data collected from 9/30/2002 – 11/30/2002.
1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (33.8 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-6 Summary of Average Annual TDS Load and TMDL Load Allocation for the Rock Canyon Creek Watershed from Confluence with Cottonwood Creek to Headwaters (based on EWCD-09- Lower Rock Canyon Creek)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
*None**		
Total Point Source Load	0	
Non-Point Source Load[2]	31,905	
Total Existing Load[3]	31,905	
Loading Capacity[4]	11,500	
Margin of Safety[5]	575	
Load Reduction Required to Meet Loading Capacity[6]	20,980	
Source	**TMDL TDS Load Allocation[7] (tons/year)**	**% of Reduction in Existing Load to Achieve Allocation**
Point Source	0	0%
Non-Point Source	10,925	66%
Margin of Safety	575	Not Applicable

Notes: * While there is no existing UPDES permit, the Hunter Power Plant (PacifiCorp) operations results in discharge to Rock Creek, permitting is underway

1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (9.7 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-7 Summary of Average Annual TDS Load and TMDL Load Allocation for the Ferron Creek Watershed from Confluence with the San Rafael River to Headwaters (based on EWCD-11- Lower Ferron Creek)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UT0020052[a]	*95*	*986*
Total Point Source Load	95	986
Non-Point Source Load[2]	44,788	
Total Existing Load[3]	44,883	
Loading Capacity[4]	21,558	
Margin of Safety[5]	1,078	
Load Reduction Required to Meet Loading Capacity[6]	24,403	
Source	**TMDL TDS Load Allocation[7] (tons/year)**	**% of Reduction in Existing Load to Achieve Allocation**
Point Source	986	0%
Non-Point Source	19,494	57%
Margin of Safety	1,078	Not Applicable

Notes: a. Ferron Lagoon

1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (18.3 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-8 Summary of Average Annual TDS Load and TMDL Load Allocation for the Lower San Rafael River Watershed from Confluence with the Green River to Confluence with Huntington Creek (based on UTDEQ STORET 493029- San Rafael River at US 24 Crossing)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UTG040006[a]	*35*	*670*
NPDES UT0021296[b]	*0.001*	*730*
NPDES UTG040003[c]	*233*	*14*
NPDES UTG040022[d]	*0.0002*	
NPDES UT0025399[e]	*3*	*889*
NPDES UT0023663[f]	*730*	*1,278*
NPDES UT0020052[g]	*95*	*986*
Total Point Source Load	1,096	4,567
Non-Point Source Load[2]	136,425	
Total Existing Load[3]	137,521	
Loading Capacity[4]	101,524	
Margin of Safety[5]	5,076	
Load Reduction Required to Meet Loading Capacity[6]	41,073	

Source	TMDL TDS Load Allocation[7] (tons/year)	% of Reduction in Existing Load to Achieve Allocation
Point Source	4,567	0%
Non-Point Source	91,881	33%
Margin of Safety	5,076	Not Applicable

Notes:
a. Co-Op Mining Company. Data collected from 5/30/1998-12/31/2002.
b. Castle Valley SSD-Huntington, Data collected from 10/31/2002-12/31/2002.
c. Pacificorp – Trail Mtn. Mine. Data collected from 1/31/1998 – 5/30/1998.
d. Interwest Mining CO-DES-BEE. Data collected from 10/31/2001 – 12/31/2001.
e. Talon Resources Inc. Data collected from 6/30/2002 – 12/31/2002.
f. Castle Valley Special Service. Sewer system. Data collected from 9/30/2002 – 11/30/2002.
g. Ferron Lagoons
1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (86.0 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-9 Summary of Average Annual TDS Load and TMDL Load Allocation for the Upper Muddy Creek Watershed from Confluence with Ivie Creek to Highway 10 (based on EWCD-14- Lower Muddy Creek)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UT0022616[a]	*1,095*	*1,041*
NPDES UT0022918[b]	*2,500*	*10,044*
Total Point Source Load	3,595	11,085
Non-Point Source Load[2]	50,767	
Total Existing Load[3]	54,362	
Loading Capacity[4]	19,916	
Margin of Safety[5]	996	
Load Reduction Required to Meet Loading Capacity[6]	35,442	

Source	TMDL TDS Load Allocation[7] (tons/year)	% of Reduction in Existing Load to Achieve Allocation
Point Source	11,085	0%
Non-Point Source	7,835	85%
Margin of Safety	996	Not Applicable

Notes: a. Consolidation Coal CO-Underground Mine. Data collected from 9/30/1999 – 9/30/2002. Due to high flow from 9/30/1999 – 3/31/2000, only data from 4/30/2000 – 9/30/2002 was used for existing load calculations.

b. Canyon Fuel-SUFCO. Data collected from 5/2001-6/2003

1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (16.9 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

Table 6-10 Summary of Average Annual TDS Load and TMDL Load Allocation for the Lower Muddy Creek Watershed from Confluence with the Fremont River to Ivie Creek Confluence (based on UTDEQ STORET 495500- Muddy Creek at Old US 24 Crossing)

Source	TDS Load (tons/year)	WLA[1] (tons/year)
Point Source		
NPDES UT0022616[a]	*1,095*	*1,041*
NPDES UT0022918[b]	*2,500*	*10,044*
Total Point Source Load	3,595	11,085
Non-Point Source Load[2]	85,155	
Total Existing Load[3]	88,750	
Loading Capacity[4]	34,590	
Margin of Safety[5]	1,729	
Load Reduction Required to Meet Loading Capacity[6]	55,889	

Source	TMDL TDS Load Allocation[7] (tons/year)	% of Reduction in Existing Load to Achieve Allocation
Point Source	11,085	0%
Non-Point Source	21,776	76%
Margin of Safety	1,729	Not Applicable

Notes:
a. Consolidation Coal CO-Underground Mine. Data collected from 9/30/1999 – 9/30/2002. Due to high flow from 9/30/1999 – 3/31/2000, only data from 4/30/2000 – 9/30/2002 was used for existing load calculations.
b. Canyon Fuel-SUFCO. Data collected from 5/2001-6/2003
1. Waste load allocations (WLA) are discussed in Table 6-1 (permit limits may be concentration or load-based)
2. Non-point source load = total existing load – point source load
3. Total existing load calculated based on available flow and water chemistry data over 11-year period (1990 – 2001)
4. Loading capacity = average annual flow (29.3 cfs) for period of 1/1990-12/2001 x 1,200 mg/L x conversion factor
5. Margin of safety = 5% of loading capacity
6. Load reduction = total existing load – (loading capacity - margin of safety)
7. Point source is listed from WLA. Non-point= loading capacity- WLA- margin of safety

6.3.2 Summary of TDS Load Allocation

As discussed in Section 5-1, observed flow and TDS measurements were used to calculate the loading capacity for each watershed based on the existing criteria of 1,200 mg/L. The TDS load at each of the target sites within each watershed includes contributions from point and non-point sources, which also includes background sources. The point and non-point allocations for each location, along with a margin of safety, are summarized in Tables 6-2 through 6-10. As discussed in the Project Implementation Plan (PIP; Appendix A), attainment of the 1,200 mg/L may not be feasible at all locations in the WCRW due to natural loading of TDS. While the recommendations contained in the PIP will reduce in-stream load of TDS, there is uncertainty in what TDS concentrations will result. For these locations, site specific criteria are recommended. The recommended values and the basis for theses values is provided in Appendix A.

7.0 PUBLIC PARTICIPATION

Two meetings were held in Price, UT with the Price-San Rafael Rivers Watershed Committee. The initial meeting was held in November 2002, with a subsequent meeting in May of 2003. Participants in the watershed committee, which was organized to provide local input into watershed issues in the West Colorado Watershed, include:

- San Rafael Soil Conservation District
- Price River Soil Conservation District
- Green River Soil Conservation District
- Muddy Creek Irrigation Company
- Ferron Canal and Reservoir Company
- Cottonwood Creek Irrigation Company
- Huntington/Cleveland Irrigation Company
- Price River Irrigation Company
- Carbon Canal Irrigation Company
- North Carbon Irrigation Company
- Emery County Commissioners
- Emery County Public Lands Council
- Emery County Water Conservancy District
- Price River Water Conservancy District
- Carbon County Commissioners
- Carbon County Planning and Zoning
- Utah Association of Conservation Districts (Zone 7)
- Utah Division of Water Quality
- Utah Division of Water Rights
- Utah Division of Wildlife Resources
- Bureau of Land Management
- US Forest Service
- Natural Resources Conservation Service
- Castleland RC&D Council
- US Fish and Wildlife Service
- Bureau of Reclamation
- Local cities and communities
- Other interested parties

The Price-San Rafael Rivers Watershed Committee is committed to the maintaining or improving the quality of water within its jurisdiction. There is a desire to work with all interests to keep the river systems as clean as possible, given the geologic constraints of the area, and still maintain economically viable communities.

It is important to have local input in order to affect water quality improvements and practices. Local irrigation companies and shareholders involved in agricultural production are already actively participating in the Colorado River Salinity Control Program to reduce salt (TDS) loading into the river systems through improved irrigation practices. This proven program will help reduce salt loading into the Price/San Rafael/Green/Colorado River systems. With local support, this and other water quality improvement practices can be implemented as may be recommended in the TMDL.

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APPENDIX A

PROJECT IMPLEMENTATION PLAN

1.0 INTRODUCTION

The load reduction of TDS into WCRW streams is primarily associated with nonpoint sources. The implementation of best management practices (BMPs) aimed at controlling these sources is voluntary. The implementation plan was developed utilizing USEPA guidance for 319 projects while also considering the ongoing irrigation conversion program. At a minimum, the implementation plan will address the implementation options listed below. Additional management or treatment options may also be considered as the implementation is developed and refined during implementation of management activities.

1.1 TDS Sources

The majority of TDS loading in the WCRW streams is associated with nonpoint sources. Therefore, best management practices aimed at reducing TDS loading will focus on nonpoint sources. However, in order to limit TDS loadings from all sources, the inclusion of a concentration or loading limit in future UPDES permits is also recommended. Permit limits will generally be based on the 1,200 mg/L criteria, unless site specific considerations (i.e., site specific standards) support a different value. The derivation of each proposed permit limit is provided in Section 6.4.1 of the main report.

While there are several stream segments within the three subwatersheds- Price River, San Rafael River, and Muddy Creek- that are listed as impaired, the BMPs discussed are directed at decreasing load within the entire watershed and associated subwatersheds. Table A-1 lists each of the listed segments and the identified non-point sources of TDS load in each stream segment and the BMPs recommended for each type of source. The term Urban is meant to reflect areas of human inhabitation with concurrent occurrence of roads and other impervious services. This includes smaller rural towns such as Ferron and Emery.

Table A-1. Non-point sources and recommended BMPs for each impaired stream reach

PRICE RIVER		
Non-supporting segment[1]	**Identified nonpoint source**	**Recommended BMPs**
Pinnacle Creek and Gordon Creek from confluence with Price River to headwaters	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler type irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
	Forest	Minimize access roads and stream crossings, install culverts, revegetate slopes
Price River and tributaries from Coal Creek confluence to Carbon Canal diversion	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler type irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas

Table A-1. Non-point sources and recommended BMPs for each impaired stream (continued)

PRICE RIVER (continued)		
Non-supporting segment[1]	**Identified non-point source**	**Recommended BMP's**
Price River and tributaries from near Woodside to Soldier Creek confluence	Surface runoff	Plant vegetation buffer strips
	Livestock grazing	Move cattle out of pastures before overgrazing
	Recreational activities	Fence around sensitive areas, revegetate bare areas, close trails /roads that are eroded, implement education programs that focus on responsible use
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abut-ments, cribs, rock diversion structures Restore/revegetate failing streambanks
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds
Price River and tributaries from confluence with Green River to near Woodside	Surface runoff	Plant vegetation buffer strips
	Livestock grazing	Move cattle out of pastures before overgrazing
	Recreational activities	Fence around sensitive areas, revegetate bare areas, close trails /roads that are eroded, implement BMPs for roads and trails and enhance education programs that focus on responsible use
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambanks
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds

Table A-1. Non-point sources and recommended BMPs for each impaired stream (continued)

SAN RAFAEL RIVER		
Non-supporting segment[1]	**Identified non-point source**	**Recommended BMP's**
Cottonwood Creek from the confluence with Huntington Creek to Highway 57	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambanks
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds
	Forest	Minimize access roads and stream crossings, install culverts, revegetate slopes
Huntington Creek and tributaries from confluence with Cottonwood Creek upstream to USFS boundary	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler type irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds
	Forest	Minimize access roads and stream crossings, install culverts, revegetate slopes

Table A-1. Non-point sources and recommended BMPs for each impaired stream (continued)

SAN RAFAEL RIVER(continued)		
Non-supporting segment[1]	**Identified non-point source**	**Recommended BMP's**
Rock Canyon Creek from confluence with Cottonwood Creek to headwaters	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler type irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds
San Rafael River from Buckhorn Crossing to the confluence with Huntington Creek and Cottonwood Creek	Surface runoff	Plant vegetation buffer strips, monitor cattle grazing pressure, limit recreation near streams
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
San Rafael River from the confluence with the Green River to Buckhorn Crossing	Surface runoff	Plant vegetation buffer strips
	Livestock grazing	Move cattle out of pastures before overgrazing
	Recreational activities	Fence around sensitive areas, revegetate bare areas, close trails /roads that are eroded, implement education programs that focus on responsible use
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambanks

Table A-1. Non-point sources and recommended BMPs for each impaired stream (continued)

MUDDY CREEK WATERSHED		
Non-supporting segment[1]	**Identified non-point source**	**Recommended BMP's**
Muddy Creek and tributaries from Quitchipah Creek confluence to the Utah Highway 10 bridge	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler type irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds
	Forest	Minimize access roads and stream crossings, install culverts, revegetate slopes
Quitchupah Creek from the confluence with Ivie Creek to the Utah Highway 10 bridge	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler type irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds
	Forest	Minimize access roads and stream crossings, install culverts, revegetate slopes

Table A-1. Non-point sources and recommended BMPs for each impaired stream (continued)

MUDDY CREEK WATERSHED (continued)		
Non-supporting segment[1]	**Identified non-point source**	**Recommended BMP's**
Ivie Creek and tributaries from the confluence with Muddy Creek to Utah Highway 10	Irrigation return flows	Increase irrigation efficiency through the use of sprinkler type irrigation systems Improved surface irrigation techniques such as automated water control valves, water measuring devices, gated pipe, borders, water control structures, and tailwater recovery systems
	Canal seepage	Line canals with concrete
	Stockwater pond seepage	Install membrane liners
	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
	Urban runoff	Install vegetation filter strips along roadsides, construct detention ponds
	Forest	Minimize access roads and stream crossings, install culverts, revegetate slopes
Muddy Creek from the confluence with Fremont River to Quitchupah Creek confluence	Surface runoff	Plant vegetation buffer strips
	Streambank erosion	Construct fences and in-stream livestock watering stations to prevent streambank damage Stabilize streambanks with log abutments, cribs, rock diversion structures Restore/revegetate failing streambank areas
	Recreation	Minimize access roads and stream crossings, install culverts, revegetate slopes

[1] Listed segments are consistent with the draft Utah 2004 303 (d) list of waters. The target sites discussed in the main report cover these segments (though not at each listed segment). Target sites were selected based on the availability of sufficient data to allow for loading calculations.

Estimated TDS loading from different non-point sources are listed for each of the target sites in the Price River, San Rafael River, and Muddy Creek watersheds in Tables A-2 through A-10. These locations are shown on Map 2 in the main report. Loadings for each target site were estimated using percentage of total area or by percentage of stream length for each target site. While we believe these estimates are a fair representative of actual conditions in the watershed, they are only estimates. While the sum of loadings from the different segments equals the values calculated in the Main Report for each of the three watersheds (i.e., total load at location 493165 in the Price, 493029 in the San Rafael, and 495500 in Muddy Creek), the loadings in each segment do not necessarily equal the values listed in Tables 6-2 through 6-10. This difference results from the approach used to estimate the source of loadings in each of the segments. Therefore, caution is advised in interpreting these data. The methods used to derive the allocation are discussed in Appendix Section 2.0.

Table A-2. Price River watershed (UTDEQ STORET Station 493239- Price River near Wellington) non-point TDS sources, loadings, and reductions

Source	**Loading (tons/year)**	**Reduction (tons/year)**
Irrigation return flows	66,470	55,980
Canal seepage	4,677	3,692
Winter water replacement	18,806	14,685
Surface erosion	3,555	1,997
Streambank erosion	112	84
Urban areas	90	28
Forest	204	64
Totals	**93,914**	**76,530**
Ambient loading	**2,030**	**0**
TOTAL LOADING	**95,944**	**18,314 (post BMP)**

Table A-3. Price River watershed (between UTDEQ STORET Station 493239 and UTDEQ STORET Station 493165- Price River near Woodside at US 6 Crossing) non-point TDS sources, loadings, and reductions

Source	**Loading (tons/year)**	**Reduction (tons/year)**
Irrigation return flows	17,368	13,995
Canal seepage	1,569	923
Winter water replacement	4,676	3,671
Surface erosion	6,601	3,709
Streambank erosion	167	125
Urban areas	5	1
Forest	11	3
Totals	**30,397**	**22,427**
Ambient loading	**508**	**0**
TOTAL LOADING	**30,905**	**7,078 (post BMP)**

Table A-4. San Rafael watershed (EWCD 3- lower Huntington Creek) non-point TDS sources, loadings, and reductions

Source	**Loading (tons/year)**	**Reduction (tons/year)**
Irrigation return flows	27,809	17,586
Canal seepage	1,994	1,163
Winter water replacement	7,974	5,085
Surface erosion	3,218	1,869
Streambank erosion	51	38
Urban areas	13	4
Forest	80	24
Totals	**41,139**	**25,769**
Ambient loading	**2,214**	**0**
TOTAL LOADING	**43,353**	**17,584 (post BMP)**

Table A-5. San Rafael watershed (EWCD 9- lower Rock Canyon Creek) non-point TDS sources, loadings, and reductions

Source	**Loading (tons/year)**	**Reduction (tons/year)**
Irrigation return flows	11,961	7,537
Canal seepage	854	498
Winter water replacement	3,417	2,179
Surface erosion	2,146	1,246
Streambank erosion	25	19
Urban areas	4	1
Forest	34	7
Totals	**18,441**	**11,487**
Ambient loading	**949**	**0**
TOTAL LOADING	**19,390**	**7,903 (post BMP)**

Table A-6. San Rafael watershed (EWCD 7- lower Cottonwood Creek) non-point TDS sources, loadings, and reductions

Source	**Loading (tons/year)**	**Reduction (tons/year)**
Irrigation return flows	23,827	15,074
Canal seepage	1,709	997
Winter water replacement	3,417	2,179
Surface erosion	3,218	1,869
Streambank erosion	51	38
Urban areas	12	4
Forest	69	21
Totals	**32,303**	**20,182**
Ambient loading	**1,898**	**0**
TOTAL LOADING	**34,201**	**14,114 (post BMP)**

Table A-7. San Rafael watershed (EWCD 11- lower Ferron Creek) non-point TDS sources, loadings, and reductions

Source	Loading (tons/year)	Reduction (tons/year)
Irrigation return flows	15,948	10,049
Canal seepage	1,139	664
Winter water replacement	4,557	2,906
Surface erosion	3,218	1,869
Streambank erosion	51	38
Urban areas	8	2
Forest	46	14
Totals	**24,967**	**15,542**
Ambient loading	**1,265**	**0**
TOTAL LOADING	**26,232**	**10,690 (post BMP)**

Table A-8. San Rafael watershed (river segment from confluence with Huntington Creek, Cottonwood Creek and Ferron Creek to UTDEQ STORET 493029 - San Rafael River at US 24 Crossing) non-point TDS sources, loadings, and reductions

Source	Loading (tons/year)	Reduction (tons/year)
Irrigation return flows	0	0
Canal seepage	0	0
Winter water replacement	3,417	2,187
Surface erosion	9,756	5,607
Streambank erosion	76	57
Urban areas	0	0
Forest	0	0
Totals	**13,249**	**7,851**
Ambient loading	**0**[1]	**0**
TOTAL LOADING	**13,249**	**5,398 (post BMP)**

1. While the methodology used to estimate the loading for each source indicates that all of the load can be accounted for and that there is no residual ambient loading in this segment, there is likely some natural (ambient) loading that does occur.

Table A-9. Muddy Creek watershed (headwaters to EWCD-14) nonpoint TDS sources, loadings, and reductions

Source	Loading (tons/year)	Reduction (tons/year)
Irrigation return flows	24,600	18,950
Canal seepage	360	247
Winter water replacement	1,240	1,030
Surface erosion	5,251	3,344
Streambank erosion	60	45
Urban areas	6	2
Forest	148	45
Totals	**31,665**	**23,663**
Ambient loading	**30,570**	**0**
TOTAL LOADING	**62,235**	**40,672 (post BMP)**

Table A-10. Muddy Creek watershed (stream segment from EWCD-14 to UTDEQ STORET 495500) nonpoint TDS sources, loadings, and reductions

Source	Loading (tons/year)	Reduction (tons/year)
Irrigation return flows	6,210	4,737
Canal seepage	90	62
Winter water replacement	360	256
Surface erosion	8,426	5,015
Streambank erosion	91	68
Urban areas	0	0
Forest	0	0
Totals	**15,177**	**10,138**
Ambient loading	**7,743**	**0**
TOTAL LOADING	**22,920**	**13,182 (post BMP)**

As indicated in Tables A-2 through A-8, the annual ambient TDS loadings to the Price and San Rafael River watersheds is approximately 2 to 5% of the existing annual load. This loading is attributed to natural ‘background’ loading that results primarily from groundwater discharge to the system. It is important to note that some degree of surface erosion and stream bank erosion is also natural to the system, and should be considered as background loading as well. The allocation of non-point source TDS loading in the Muddy Creek watershed is unique from the Price and San Rafael. In Muddy Creek, between 34 and 49% of the annual load is from ambient loading (Tables A-9 and A-10). This finding is in agreement with other studies in the Muddy Creek watershed which have reported that much of the annual load results from inputs from salt washes that occur within the watershed (BOR 1987, Miller 2003). Additionally, the Muddy Creek portion of the WCRW has less irrigated acreage than does the Price and San Rafael watersheds, which results in less return flow loadings of TDS.

1.2 Potential Best Management Practices (BMPs)

As listed in Tables A-2 through A-10, the majority of nonpoint source TDS loads in the WCRW watersheds, especially in the upper Price and to a lesser extent in the upper portions of the San Rafael watersheds, are associated with irrigation practices. Other nonpoint TDS sources include animal grazing, forestry related activities, urban runoff, erosion, stock pond seepage, and recreational activities. BMP’s have been identified for each of these TDS sources.

The implementation of BMPs will aid in the preservation of current water uses by reducing the TDS loadings throughout the watershed. The following list of BMP options provides some potential management activities that can reduce TDS loadings to streams in the Study Area:

- Increase irrigation efficiency thereby reducing deep percolation of surface water
- Control canal and ditch seepage by limiting infiltration losses

- Install membrane liners on stockwater ponds to prevent seepage
- Create vegetated buffer strips along streams and ditches to reduce erosion
- Revegetate stream banks with soil holding species, use rock barbs to divert flow from banks, and re-slope steep streambanks to allow for vegetation establishment
- Maintain plant cover with proper grazing strategies
- Identify areas where due to erodible soils, grazing may not be sustainable due to wind erodible soils
- Improve riparian condition by excluding grazing and through planting wetland species
- Limit recreational vehicle usage to non-sensitive areas away from streams
- Identify and improved roads and trails that don’t meet best practices
- Revegetate coal mine spoil to prevent erosion and deep percolation
- Plug abandoned wells to prevent saline discharge into streams
- Construct stormwater retention ponds in urban areas

2.0 RECOMMENDATIONS

The BMPs recommended for application within the WCRW are described below.

2.1 Irrigation

Mitigation of irrigation associated TDS would be accomplished by installing gravity pressure sprinkler systems, pump pressurized sprinkler systems, or through surface irrigation improvements. Sprinkler systems improvements would include mains and laterals, pipelines with risers, sprinkler hardware, pumps and motors, and water measuring devices. Surface irrigation improvements would include water measuring devices, water control structures, land leveling, pipelines, gated pipe, borders, automated water control valves, and tail water recovery systems (BOR and SCS 1993). Soil moisture meters should be used by all irrigators to ensure that excessive amounts of water are not applied to fields. Additionally, technical assistance provided to irrigation companies and landowners alike would result in improved management of water delivery and application.

Under the RP (Resource Protection) plan, there are approximately 17,000 acres under consideration for irrigation improvements for the Price River watershed and 19,000 acres under consideration for irrigation improvements in the San Rafael River watershed. Current furrow irrigation practices in the WCRW have a water use efficiency of 35% or less (BOR and SCS 1993). The projected on-farm irrigation efficiency for the RP plan using a combination of improved surface irrigation, pressure sprinkler irrigation, and gravity sprinkler systems is 60%. The RP plan is projected to decrease the salt load in the Price River watershed by 69,975 tons per year and by 50,245 tons per year in the San Rafael River watershed (BOR and SCS 1993). Application of the same irrigation improvements to the 5,500 irrigated acres in the Muddy Creek watershed could potentially reduce the annual salt load in the WCRW by an additional 23,687 tons, or by 143,907 tons per year in the entire Study Area. Uses of newer center pivot irrigation systems, which have an average efficiency of 77.5% (Texas A&M 2001), could reduce the annual salt load in the WCRW by 169,080 tons per year. Center pivot irrigation systems that employ the use of 16 inch drop heads would increase efficiency to 85-90% (Texas A&M 2001), resulting in a potential reduction of 183,469 tons of salt entering the WCRW streams. The efficiency of furrow irrigation could be increased to 75% (NCSU 2003) with the installation of surge flow irrigation valves. If this technology was employed on all of the Study Area’s irrigated acreage, the annual salt load reduction in the WCRW watersheds could total 179,884 tons.

2.2 Open Lateral Replacement

Seepage from open laterals that supply water for irrigation purposes could be reduced by replacing open laterals and canals with pipe. Replacing 100% of the 69 miles of open laterals and canals in the Price River watershed and 87 miles of open laterals in the San Rafael watershed could potentially reduce the salt load by nearly 8,000 tons per year (BOR and SCS 1993). Replacing all 9 miles of open laterals and canals in the Muddy Creek watershed could potentially reduce the salt load into the WCRW streams by an additional 460 tons per year.

2.3 Winter Water Replacement

Water delivery canals for livestock and municipal use that are operated in the winter cause additional TDS loading due to seepage. Winter water could be supplied from other sources and the canals could be dewatered during the winter months. Additionally, stock ponds could be lined with impervious materials to prevent seepage. According to BOR and SCS (1993), dewatering of the Price River and San Rafael area canal systems in winter and lining stock ponds could result in a load reduction of 18,356 and 14,529 tons of salt per year, respectively. While the number of stock ponds in the Muddy Creek watershed is unknown, the application of similar BMPs in this watershed would be expected to produce a proportional load reduction on a per pond basis.

2.4 Surface Erosion

The main factor controlling sediment production due to surface erosion is the percentage of grass cover (Dadkuh and Gifford 1980). The presence of grass aids in binding soil particles together as well as slowing overland flow and allowing sediment to settle out of suspension. Grass cover percentages of 50% or more minimize the amount of sediment production on rangelands. While rangelands in the WCRW would benefit from improved range condition through seeding efforts, the cost would be prohibitively high for the amount of salt removed. The most effective means for improving grass cover on rangelands is through proper grazing management. Livestock producers should be educated about range management practices that maintain or enhance vegetation cover in the Study Area, especially as it relates to soil type and erodibility. Through the employment of strategies such as controlling overall livestock density and distribution, and season of use, livestock can be used successfully for vegetation management.

Roads in the lower portion Study Area can significantly increase the loading into nearby streams. The lack of vegetative cover on road surfaces and ditch slopes can allow sediment to flow unimpeded into streams and other water bodies. As mentioned previously, grass cover can significantly reduce the amount of sediment production. Vegetation buffers strips that are 50 feet wide along both sides of roads could be expected to reduce sediment production by at least 50%. Additional measures for improvements include identification of roads and trails that are not built to best standards and implementing improvements to limit erosion.

Recreational activities result in a reduction in vegetative ground cover and increased soil compaction which can eventually lead to higher rates of runoff and erosion. The impacts of recreation on stream loading can be reduced by maintaining sufficient ground cover in areas susceptible to erosion, such as campsites, trails, and vehicle usage areas. BMPs would include fencing to eliminate usage in sensitive areas, revegetation of bare areas, and select road/trail closures. Education programs that focus on responsible use of resources are perhaps the most effective means for reducing the impact from recreational activities.

Vegetation filter strips along streams can measurably reduce sediment inflow to the streams. The recommended width for buffer strips along streams and other water bodies is 50 feet. If both sides of a stream are buffered, the resulting filter strips would occupy approximately 12 acres over the course of one mile of stream length. It is estimated that 50 foot wide buffer strips on both sides of a stream could reduce sedimentation from 56 to 95% (Leeds et al. 2003, Parsons et al. 1994, Snyder et al. 1998). The current estimates of surface erosion induced TDS loading are 10,156 tons per year in the Price River watershed, 21,455 tons per year in the San Rafael River watershed, and 14,377 tons per year in the Muddy Creek watershed. After the implementation of filter strips to control erosion and assuming a 60% sediment reduction estimate, a potential TDS reduction of 6,094, 12,873, and 8,626 tons per year from barren land, roads, rangeland, and agricultural land in the Price River, San Rafael River, and Muddy Creek watersheds, respectively, may be realized.

2.5 Streambank Erosion

Based on published literature (Rosgen 2000, Bouquetriver 2003), it is estimated that unstable stream banks in the WCRW add approximately 684 tons of salt per year to streams. Of this total, the Price River watershed contributes 279 tons, the San Rafael River watershed contributes 254 tons, and the Muddy Creek watershed contributes 151 tons per year. Areas where livestock and wildlife cross streams or where they frequently water can cause vegetation loss, and ultimately, bank failure. Salt loading due to erosion can be reduced by installing fencing to concentrate livestock in engineered in-stream watering stations. Fencing will keep livestock out of sensitive areas and allow for restoration of the site. Erosion can also be lessened by restoring/stabilizing stream banks with log abutments, cribs, rock diversion structures, and revegetation of streambank areas that are in imminent danger of failing, or have already failed. Restoration/revegetation efforts on streambank areas can reduce salt loading from unstable stream banks in the WCRW by 75%. It is estimated that approximately 5%, or 100 miles, of stream banks in the WCRW are contributing to the salt load through bank failure.

2.6 Gully Erosion

Gully erosion can also be a significant source of TDS loading in the WCRW. Utilized BMPs and hydromodification practices should focus on prevention rather than restoration. The primary cause of gully erosion in related to transportation routes, which berm sheet flow, convert to channel flow, and discharge with accelerated velocity to create gullies. Headcutting from improperly installed culverts at drains and crossings can also contribute to erosion. Gullies can also abe created when soil is compacted and vegetation removed. Earlier discussed BMPs for surface erosion are applicable for limiting gully erosion as well.

2.7 Urban Runoff

Urban areas increase the total amount of runoff because of the many impervious surfaces, such as roads, roofs, and parking lots. New development in urban areas (any inhabited areas) can also potentially increase sediment yields due to disturbed soil conditions commonly found near construction sites. Urban runoff may contain salt-laden sediment and dissolved road salts that potentially add up to 138 tons of salt annually in the WCRW. Urban areas in the Price River watershed contribute 95 tons of salt annually, while urban areas in the San Rafael and Muddy Creek watersheds adds an additional annual load of 37 tons and 6 tons, respectively. Vegetation filter strips located along roadsides can help prevent erosion and thus salt laden soil from reaching streams in the Study Area. Detention ponds can control runoff rates and allow sediment to settle (USEPA 2003a, Law et al. 1998). An estimated 29 tons of salt can be removed each year from WCRW streams by the application of vegetative filter strips and detention ponds in urban areas in the Price River watershed. Applying these same BMPs to urban areas in the San Rafael and Muddy Creek watersheds can result in a load reduction of 11 tons and 2 tons annually, respectively.

2.8 Forest Runoff

Most forested areas have low sediment yields because soils are generally stable and vegetative cover is high. Erosion problems are usually associated with surface disturbance through logging, grazing, or recreational activities. Forests in the WCRW are not intensively used for logging, though grazing and recreational activities do occur. The main source of sediment in forests of the WCRW is vehicle use of forest access roads. The Muddy Creek watershed also contains steep canyons that increase loadings at certain times of the year. Sediment loss associated with forest roads can range from 6.8 tons per acre at a slope of 1%, to 32.3 tons per acre at a 6% slope (SFRA 2002). Even though forested areas are not underlain by Mancos shale formations, it is estimated that approximately 215 tons of salt from the Price River, 229 tons of salt from the San Rafael River, and 45 tons of salt from the Muddy Creek watersheds are added to the loading of WCRW streams due to forest roads. It is estimated that the existing salt load could be reduced by 30% through the adoption of forest road BMPs such as revegetation of cut and fill slopes, installing culverts, avoiding development of forest roads when possible, minimizing stream crossings, and other similar measures. This would equate to an annual salt load reduction of 67 tons in the Price River watershed, 66 tons in the San Rafael watershed, and 45 tons in the Muddy Creek watershed.

3.0 COSTS

Cost effectiveness is a primary criterion for BMP selection. Some of the BMPs described in Section 2 are relatively inexpensive to implement, while others are probably cost prohibitive. A summary of estimated costs for these BMPs is presented below. These costs, which are in 2003 dollars, are a general estimate only. Actual costs may vary depending on local economies, transportation costs, inflation, etc.

3.1 Irrigation Improvement

Irrigation improvement was originally presented by the BOR and SCS (1993) and included pressurized sprinkler systems, gravity sprinkler systems, and improved surface irrigation. The following irrigation improvement increment is essentially the same as that of the BOR, but with improved irrigation efficiencies due to ongoing irrigation R&D and the resulting improved technologies.

A good portion of the agricultural land in the WCRW is well adapted to center pivot sprinkler or other wheel type irrigation practices, such as hand lines. The total initial cost of a new 80 acre center pivot irrigation system is approximately $947 per acre and the total annual operating costs, including labor, fuel and oil, repairs and maintenance, depreciation, and interest are approximately $58 per acre (Tyson and Curtis 1997). Total annual cost for the useful life of this system (20 years) is approximately $230 per irrigated acre and the cost of salt removed is $58 per ton (Table A-11). When full length drop-down tubes (low heads) are used with this system, the percent efficiency increases to an average of 87.5% (NMOSE 2001) and the cost of salt removed drops to $54 per ton (Table A-11).

Surge flow surface irrigation systems are a cost effective means of reducing irrigation return flows and thus salt loading. The total annual cost of a surge flow system is approximately $75 per acre, which includes all PVC piping, valves, and operating expenses (Texas A&M 2001). The cost for removing one ton of salt per year from WCRW streams with surge flow irrigation is approximately $20. Installation costs, and thus the costs of removing salts, would be less on existing PVC irrigation piping.

3.2 Canal Seepage/Winter Water

In 1993 the BOR and SCS estimated that canals delivering water for livestock and municipal use during the winter months cause additional salt loading to WCRW streams due to seepage from canals and stock ponds. Dewatering WCRW canals in winter and by excavating stock ponds, lining stock ponds with PVC or clay liners, installing waterers, and fencing out livestock, would reduce the salt load by an estimated 32,880 tons per year. The BOR and SCS estimated that the cost for this project would be $499,400, or

$15 per ton of salt removed in 1989 dollars. Based on 2003 prices this project would cost approximately $23 per ton of salt removed from the system (Table A-11).

3.3 Surface Erosion Reduction

As previously stated, filter strips would reduce surface erosion and the resulting salt loading in the WCRW streams. Initial costs for the installation of filter strips would be confined to tillage and seeding operations. Tillage operations would consist of disking the area prior to seeding. Seeding operations would be performed with a rangeland drill. The total cost of tilling, seed, and seeding operations of filter strips would cost approximately $400 per acre, or $4800 per mile (USEPA 2003b). Assuming that approximately 10% of the streambank areas are in need of filter strips, the total mileage of streambank filter strips would be approximately 200 miles. The annual cost to remove salts from the WCRW streams due to surface erosion is approximately $32 per ton (Table A-11).

3.4 Streambank Restoration/Stabilization

Streambank restoration and stabilization would include activities such as grading damaged streambank areas, seeding/transplanting where vegetation is sparse or non-existent, and fencing to exclude livestock. The costs associated with streambank restoration/revegetation and fencing is estimated at approximately $5000 per mile, resulting in a cost of $974 per ton of salt removed (Purdue University 2003, USEPA 2003b) (Table A-11).

3.5 Forest Related Activities

Cost analysis was not performed for this salt loading source because of the relatively minor effects on salt loading into the WCRW streams. Additionally, the costs associated with BMPs for this source are highly variable and are likely not competitive with the other treatment options presented.

Table A-11. Salt loading sources, BMPs, costs, efficiencies, and salt removed per year in the WCRW

BMP Assessment Table				
Source	**Alternative BMP**	**Annual Cost /ton (2003)**	**Efficiency**	**Tons of salt removed/year**
Current on-farm systems (BOR and SCS 1993)	Pressure and gravity irrigation, improved surface irrigation (SCS on-farm improvements)	$58	50 - 65%	143,907
Current off-farm delivery systems (BOR and SCS 1993)	Replacement of open laterals (RP)	$181	100%	8,246
Furrow irrigation	Center Pivot Irrigation gravity/pump	$58	75-80%	169,080
Furrow irrigation	Center Pivot Irrigation with low heads (16”)	$54	85-90%	183,469
Furrow irrigation	Furrow Irrigation with Surge Valves	$20	80-90%	179,884
Unlined stockwater ponds, canal seepage	Excavation, PVC liner and waterers	$22	100%	N/A
Denuded land	Vegetation Buffer Strips	$32	60%	27,409
Damaged streambanks	Stabilization with grading, seeding, transplanting	$974	75%	513

4.0 MONITORING PROGRAM

In developing this TMDL, it has been noted that there is an inadequate amount of data to completely characterize all of the components of the TMDL. Given these data limitations, it is suggested that further data be collected and the TMDL be refined, as appropriate, based on the results of additional analysis (a more complete data set would include monthly data over the entire year to better evaluate both high-flow and low-flow periods). Nonetheless, the results of this TMDL can provide a basis for future data collection and implementation of some of the actions and management measures required to implement the allocations provided in this report. As new data becomes available through monitoring efforts, elements of the TMDL may be changed to reflect this new information.

Several implementation components directed towards reduction of TDS loading can be established while new data is being developed. It is noted, however, that uncertainties exist regarding the potential effectiveness of some of these recommended practices, and that implementation of the recommended practices may be constrained by other factors. Issues such as water rights, in-stream flows, and restrictions on land application will also need to be considered during the development of specific control programs. Alternative options to treat discharge waters may also be required if TMDL endpoints cannot be achieved through the current implementation strategy. These options will be evaluated at the appropriate time, after implementation of the current recommendations and collection of additional data.

Salt loading in the Muddy Creek watershed differs from that of the Price River and San Rafael river watersheds due to the abundance of springs and salt washes in the area. Although implementation of BMPs may reduce salt loading in the Price River and San Rafael River watersheds to acceptable levels, BMP implementation in the Muddy Creek watershed will not reduce salt loading to the extent necessary to meet current water quality criteria. Natural springs and salt washes in the Muddy Creek watershed are a significant source of salts, and BMPs will have little effect, if any, on reducing the salt load from these sources.

4.1 Future Water Quality Monitoring

A water-monitoring program needs to be conducted to further validate or define loading sources, and to monitor stream responses to implementation actions. Continued water quality monitoring is essential for evaluating the effects of BMPs and the progress of meeting water quality standards. The program should be designed to measure stream flows conditions over an entire year, encompassing both the spring-runoff period and the low flow period. At a minimum, TDS and flow should be monitored at the target points.

4.2 Summary

As shown in Table A-5, the cost and effectiveness of the listed BMPs is quite variable. BMP selection criteria should include not only cost and effectiveness of the BMP, but also the ease of putting the particular BMP in place. Once a particular BMP has been shown to reduce salt loading, other BMPs will likely be adopted.

In the final analysis, no matter which BMPs are put into place in the WCRW, salt loading will be reduced. However, it must be noted that while BMPs will decrease the salt *load* into WCRW streams, the concentration of TDS in certain stream segments may still not meet the numeric criteria for these waters. Because the ability to meet the water quality criteria is not solely dependent on the TDS load, a monitoring program is critical to understanding the ultimate impact of BMP implementation on TDS concentrations in the WCRW.

5.0 SITE-SPECIFIC CRITERIA

As discussed in Appendix Section 4.0, salt loading in the Muddy Creek watershed differs from that of the Price River and San Rafael river watersheds due to the abundance of springs and salt washes in the area. While implementation of BMPs will reduce salt loading in the Price River and San Rafael River watersheds, BMP implementation in the Muddy Creek watershed will not reduce salt loading to the extent necessary to meet current water quality criteria. While implementation of the BMPs, will reduce salt loadings in each of the watersheds, it *may not* reduce the concentration of TDS in the watersheds, due to potential concurrent reductions in flow. While the stream reaches are identified as impaired due to exceedance of numeric criteria, the purpose of the TMDL process is to reduce load and to lower TDS concentrations in each reach.

Due to the uncertainty in what are achievable TDS concentrations in each watershed, it is recommended that the selection of site-specific TDS criteria be established at this time. The site-specific criteria should be revisited after implementation of BMPs and subsequent monitoring of the resulting changes in the TDS concentrations in each of the stream reaches. In order to establish site-specific criteria, the dataset from 1990 to 2001 was reviewed for the lower stations in each watershed, and the 90th percentile TDS concentration determined. This 90th percentile was selected as the criteria for many of the segments. This recognizes that much of the WCRW is a groundwater-dominated system, and that due to the presence of Mancos Shale, will have elevated TDS concentrations. While the State would like to achieve the current 1,200 mg/L criterion, it is unlikely that it can be achieved, except in the highest portions of the watersheds. This designation also recognizes that, with only minor exceptions, water used for irrigation in the WCRW is sourced from the upper portion of the watersheds, where TDS levels are typically less then 500 mg/L and therefore meet the agricultural criteria of 1,200 mg/L. The calculated 90th percentile values for each of the target sites evaluated in the main report are listed in Table A-12. While the Muddy Creek value of 5,800 mg/L seems quite high, the BOR (1987) states that surface flows from salt washes in the watershed "exhibit average flow-weighted concentrations of about 5,600 mg/L TDS" and that concentrations of TDS in groundwater that discharges to Muddy Creek average about 6,700 mg/L TDS. The calculated value of 5,800 mg/L falls within these reported concentrations.

While the 90th percentile TDS value may be an appropriate site-specific criteria for some of the target sites, it is anticipated that due to significant reductions in TDS loadings through BMP implementation, concentrations less than the 90th percentile can be achieved at some locations. An example is the Wellington Bridge target site in the Price watershed, where agricultural BMPs will reduce salt loads and should reduce the concentration of TDS. It is the recommendation of this TMDL to establish a site-specific criteria of 1,700 mg/L. This concentration is based on realizing 50% of the potential BMP load reduction shown in Table A-2. It is expected that reductions in the middle portion of the Price watershed will be reflected by some decrease in TDS concentrations in the bottom portion of the watershed. Similar reductions may be realized in the middle portion of the San Rafael watershed, as shown in Table A-12. Because of the high natural loadings in the Muddy Creek watershed, the 90th percentile is recommended as the site-specific criteria in the portion of the WCRW.

Table A-12. 90th Percentile Values of TDS at each Target Site and Site Specific Criteria

Target Site	90th Percentile TDS (mg/L)	Listed Stream Reaches Above or Near Target Site	Recommended Criteria (mg/L)
Price River			
493239- Above WWTP at Wellington Bridge	3,800	Pinnacle[1] and Gordon Creeks and their tributaries from confluence with Price River to headwaters	3,800
	2,800	Price River and tributaries from Coal Creek to Carbon Canal diversion	1,700[3]
493165- Lower Price River near Woodside	3,200	Price River and tributaries from confluence with Green River to near Woodside	3,000
	3,200	Price River and tributaries from near Woodside to Soldier Creek confluence	3,000
San Rafael River			
EWCD-03- Lower Huntington Creek	4,800	Huntington Creek tributaries from the confluence with Cottonwood Creek to Utah Highway 10	4,800
	Insufficient data	Huntington Creek and tributaries from Highway 10 crossing to USFS boundary	1,200[2]
EWCD-07- Lower Cottonwood Creek	3,500	Cottonwood Creek from the confluence with Huntington Creek to Highway 57	3,500[4]
EWCD-09- Lower Rock Canyon Creek	5,400	Rock Canyon Creek from confluence with Cottonwood Creek to headwaters[1]	3,500[4]
EWCD-11- Lower Ferron Creek	4,000	Ferron Creek from confluence with San Rafael River to Highway 10[1]	3,500[4]
493029- San Rafael at US 24 Crossing	4,100	San Rafael River from the confluence with the Green River to Buckhorn Crossing	4,100
	4,100	San Rafael River from Buckhorn Crossing to the confluence with Huntington Creek and Cottonwood Creek	3,500[4]
Muddy Creek			
EWCD-14- Lower Muddy Creek	2,600	Muddy Creek and its tributaries from Quitchupah Creek confluence to the Highway 10	2,600
	2,600	Quitchupah Creek from confluence with Ivie Creek to Highway 10	2,600
	2,600	Ivie Creek and its tributaries from the confluence with Muddy Creek to Highway 10	2,600
495500- Muddy Creek at Old US24 Crossing	5,800	Muddy Creek from the confluence with Fremont River to Quitchupah Creek confluence	5,800

1. Though not listed in the draft Utah 2004 303(d) list, data indicates that these reaches are impaired by TDS. The more extensive data for Pinnacle was used to establish criteria for both Pinnacle and Gordon Creeks.
2. The existing criterion of 1,200 mg/L may be achievable after implementation of BMPs, if not a site-specific criterion will be recommended
3. Based on achievement of 50% of the potential load reduction listed in Table A-2 multiplied by the 90th percentile.
4. Based on the analysis of the most current data, a value of 3,500 mg/L may be attainable.

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APPENDIX B

WATER QUALITY DATA USED FOR LOAD CALCULATIONS

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
STORET 493239	5/10/90	18	2,318	109	57
	6/21/90	20	2,244	121	65
	8/30/90	9	2,746	67	29
	10/11/90	12	2,956	96	39
	5/21/91	12	2,016	65	39
	7/18/91	17	1,890	86	54
	9/12/91	56	1,970	295	180
	10/24/91	17	2,568	116	54
	4/2/92	24	2,128	138	78
	5/14/92	30	2,194	177	97
	7/6/92	6	2,664	43	19
	7/9/92	6	2,532	41	19
	8/20/92	3	2,918	25	10
	10/8/92	18	2,908	141	58
	4/1/93	100	1,112	299	323
	4/29/93	46	582	72	148
	5/16/96	85	408	93	275
	8/1/97	50	882	119	162
	8/28/97	40	2,244	242	129
	2/19/98	27	1,948	142	87
	4/2/98	100	424	114	323
	5/7/98	100	442	119	323
	5/21/98	500	570	767	1,616
	6/25/98	220	560	332	711
	8/20/02	17	1,604	74	55
STORET 493165	3/21/90	40	2,334	251	129
	5/2/90	35	2,440	230	113
	7/4/90	13	2,386	84	42
	8/9/90	25	2,086	140	81
	9/19/90	250	2,394	1,612	808
	10/31/90	18	3,722	180	58
	12/12/90	19	3,684	188	61
	2/15/91	18	2,508	122	58
	3/27/91	23	1,550	96	74
	5/10/91	8	938	20	26
	6/28/91	230	820	508	743
	8/7/91	75	1,308	264	242
	9/18/91	38	1,964	201	123
	11/13/91	47	2,626	332	152
	1/15/92	28	2,936	221	90
	2/26/92	73	1,908	375	236
	4/8/92	175	624	294	565
	5/13/92	24	694	45	78
	7/23/92	20	2,214	119	65
	9/2/92	40	2,734	294	129
	10/14/92	3	3,336	27	10
	6/23/93	60	1,156	187	194
	7/31/93	40	1,732	187	129
	8/27/93	45	2,934	356	145
	9/17/93	200	1,380	743	646
	10/29/93	75	2,492	503	242
	11/19/93	43	3,630	420	139
	1/14/94	45	2,672	324	145
	2/18/94	30	2,922	236	97
	4/1/94	120	654	211	388
	5/6/94	50	548	74	162
	5/20/94	200	874	471	646

	6/24/94	300	986	797	969
	9/14/94	50	1,564	211	162
	10/27/94	125	1,342	452	404
	12/16/94	170	2,784	1,274	549
	2/10/95	70	2,722	513	226
	6/23/95	50	1,770	238	162
	8/4/95	40	1,746	188	129
	9/29/95	100	1,502	404	323

Station	**Date**	**Flow (cfs)**	**TDS (mg/L)**	**Existing Load (tons/day)**	**Load Capacity (tons/day)**
STORET 493165 (cont)	2/2/96	59	3,046	480	189
	3/22/96	35	2,964	279	113
	5/24/96	51	1,748	241	165
	7/26/96	20	2,166	115	64
	9/20/96	12	3,002	99	40
	11/8/96	51	2,604	358	165
	4/25/97	69	1,374	255	223
	6/27/97	28	2,648	200	90
	8/22/97	52	1,942	272	168
	7/27/00	21	2,166	122	68
	9/21/00	100	3,002	808	323
	11/9/00	51	2,604	358	165
	4/26/01	69	1,374	255	223
	6/28/01	28	2,648	200	90
	8/23/01	52	1,942	272	168
EWCD-03	Jan-90	7.0	3,224	61	23
	Feb-90	7.0	3,870	73	23
	Mar-90	6.0	4,590	74	19
	Apr-90	4.0	4,960	53	13
	May-90	2.0	4,480	24	6
	Jun-90	1.0	4,460	12	3
	Jul-90	0.3	3,700	3	1
	Sep-90	2.9	3,590	28	9
	Oct-90	5.0	3,360	45	16
	Nov-90	5.9	4,100	65	19
	Dec-90	9.0	2,980	72	29
	Jan-91	9.0	3,500	85	29
	Feb-91	9.0	3,300	80	29
	Mar-91	17.0	4,010	184	55
	Apr-91	3.0	3,590	29	10
	May-91	5.0	5,094	69	16
	Jun-91	7.0	2,732	51	23
	Jul-91	1.0	3,932	11	3
	Aug-91	7.0	3,252	61	23
	Sep-91	10.0	2,980	80	32
	Oct-91	15.0	2,486	100	48
	Nov-91	14.0	3,922	148	45
	Dec-91	5.0	3,686	50	16
	Jan-92	5.0	3,278	44	16
	Feb-92	5.0	4,556	61	16
	Mar-92	9.0	4,656	113	29
	Apr-92	8.0	4,942	106	26
	May-92	8.0	4,076	88	26
	Jun-92	1.0	6,242	17	3
	Jul-92	2.0	4,042	22	6
	Aug-92	2.0	3,756	20	6
	Sep-92	3.0	4,100	33	10
	Oct-92	2.0	4,790	26	6
	Nov-92	5.0	4,400	59	16
	Dec-92	6.0	4,870	79	19
	Jan-93	6.0	4,642	75	19
	Feb-93	6.0	4,920	79	19
	Mar-93	9.0	5,590	135	29
	Apr-93	8.0	3,800	82	26
	May-93	1.0	4,440	12	3
	Jun-93	10.0	2,830	76	32
	Jul-93	7.0	3,160	60	23
	Aug-93	5.0	2,630	35	16
	Sep-93	12.0	2,250	73	39
	Oct-93	23.0	2,930	181	74
	Nov-93	11.0	4,320	128	36
	Dec-93	11.0	3,740	111	36
	Jan-94	11.0	4,150	123	36

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-03 (cont)	Feb-94	11.0	3,970	118	36
	Mar-94	11.0	4,510	134	36
	Apr-94	1.0	6,080	16	3
	May-94	7.0	4,380	83	23
	Jun-94	0.0	5,390	1	0
	Jul-94	2.0	3,030	16	6
	Aug-94	2.0	2,900	16	6
	Sep-94	3.8	2,830	29	12
	Oct-94	6.8	4,030	74	22
	Nov-94	8.0	3,800	82	26
	Dec-94	8.0	5,780	125	26
	Jan-95	7.7	4,140	86	25
	Feb-95	4.7	4,720	59	15
	Mar-95	6.0	5,450	88	19
	Apr-95	4.4	5,120	61	14
	May-95	5.8	4,650	73	19
	Jun-95	48.8	2,000	263	158
	Jul-95	66.5	2,100	376	215
	Aug-95	25.7	2,130	147	83
	Sep-95	18.3	2,490	123	59
	Oct-95	36.3	2,400	235	117
	Nov-95	8.2	3,640	80	26
	Dec-95	8.2	4,360	96	26
	Jan-96	8.2	2,940	65	26
	Feb-96	8.2	3,280	72	26
	Mar-96	16.9	3,020	137	55
	Apr-96	5.1	3,300	45	16
	May-96	113.8	464	142	368
	Jun-96	59.2	1,080	172	191
	Jul-96	19.1	2,860	147	62
	Aug-96	17.4	2,050	96	56
	Sep-96	56.9	2,520	386	184
	Oct-96	23.5	2,860	181	76
	Nov-96	17.4	3,100	145	56
	Dec-96	17.4	4,760	223	56
	Jan-97	17.4	2,030	95	56
	Feb-97	17.4	1,720	81	56
	Mar-97	142.9	1,010	389	462
	Apr-97	85.5	808	186	276
	May-97	130.4	544	191	421
	Jun-97	90.0	1,260	305	291
	Jul-97	38.9	1,880	197	126
	Aug-97	38.3	2,500	258	124
	Sep-97	36.7	2,190	216	119
	Oct-97	110.5	800	238	357
	Nov-97	60.4	1,440	234	195
	Dec-97	60.4	2,000	325	195
	Jan-98	60.4	2,170	353	195
	Feb-98	60.4	3,700	602	195
	Mar-98	38.7	1,740	181	125
	Apr-98	29.7	2,140	171	96
	May-98	93.2	1,870	469	301
	Jun-98	103.0	1,780	494	333
	Jul-98	16.0	2,660	115	52
	Aug-98	17.0	2,070	95	55
	Sep-98	43.4	1,580	185	140
	Oct-98	82.7	1,630	363	267
	Nov-98	105.0	1,050	297	339
	Dec-98	105.0	2,400	679	339
	Jan-99	105.0	1,640	464	339
	Feb-99	105.0	2,620	741	339
	Mar-99	15.3	3,330	137	49
	Apr-99	10.1	5,200	141	33

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-03 (cont)	May-99	22.7	2,520	154	73
	Jun-99	120.0	720	233	388
	Jul-99	13.9	2,530	95	45
	Aug-99	28.3	2,250	171	91
	Sep-99	26.9	2,090	151	87
	Oct-99	45.2	1,780	217	146
	Nov-99	19.9	3,720	199	64
	Dec-99	19.9	3,320	177	64
	Jan-00	19.9	3,810	204	64
	Feb-00	15.4	4,130	171	50
	Mar-00	41.9	2,200	248	135
	Apr-00	6.5	3,580	63	21
	May-00	19.7	2,890	153	64
	Jun-00	12.3	3,070	102	40
	Jul-00	3.7	3,250	32	12
	Aug-00	4.3	2,600	30	14
	Sep-00	15.1	2,300	94	49
	Oct-00	16.6	2,900	130	54
	Nov-00	12.9	4,500	156	42
	Dec-00	12.9	4,600	160	42
	Jan-01	12.9	3,500	122	42
	Feb-01	12.9	3,600	125	42
	Mar-01	11.5	4,200	130	37
	Apr-01	11.3	3,700	113	37
	May-01	13.2	3,600	128	43
	Jun-01	4.5	4,400	53	15
	Jul-01	1.0	4,000	11	3
	Aug-01	6.5	3,100	54	21
	Sep-01	1.2	2,900	9	4
	Oct-01	8.5	3,000	69	27
	Nov-01	7.0	3,700	70	23
	Dec-01	7.0	5,300	100	23
EWCD-07	Jan-90	15.0	1,796	145,088	96,941
	Feb-90	15.0	1,780	143,796	96,941
	Mar-90	14.0	2,370	178,694	90,478
	Apr-90	6.0	4,030	130,224	38,776
	May-90	12.0	2,150	138,948	77,553
	Jun-90	12.0	2,950	190,650	77,553
	Jul-90	3.0	2,810	45,401	19,388
	Aug-90	2.3	3,410	42,607	14,994
	Sep-90	9.4	1,840	92,654	60,426
	Oct-90	28.0	2,040	307,625	180,956
	Nov-90	14.4	2,480	191,796	92,805
	Dec-90	17.0	1,600	146,488	109,866
	Jan-91	17.0	2,380	217,901	109,866
	Feb-91	17.0	2,350	215,155	109,866
	Mar-91	13.0	2,890	202,337	84,015
	Apr-91	3.0	4,356	70,379	19,388
	May-91	9.0	3,306	160,243	58,164
	Jun-91	13.0	2,494	174,612	84,015
	Jul-91	9.0	2,448	118,656	58,164
	Aug-91	17.0	2,842	260,200	109,866
	Sep-91	21.0	2,422	273,922	135,717
	Oct-91	16.0	2,516	216,803	103,404
	Nov-91	20.0	2,442	263,033	129,254
	Dec-91	19.0	1,552	158,811	122,792
	Jan-92	19.0	1,506	154,104	122,792
	Feb-92	19.0	1,828	187,053	122,792
	Mar-92	16.0	2,400	206,807	103,404
	Apr-92	3.0	4,330	69,959	19,388
	May-92	20.0	2,904	312,796	129,254
	Jun-92	11.0	2,818	166,943	71,090
	Jul-92	7.0	2,962	111,665	45,239

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-07 (cont)	Aug-92	11.0	4,602	272,630	71,090
	Sep-92	5.0	3,550	95,594	32,314
	Oct-92	9.5	3,770	193,088	61,460
	Nov-92	16.0	2,600	224,041	103,404
	Dec-92	22.0	2,250	266,587	142,180
	Jan-93	22.0	1,492	176,777	142,180
	Feb-93	22.0	1,400	165,876	142,180
	Mar-93	14.0	3,100	233,735	90,478
	Apr-93	9.0	3,710	179,825	58,164
	May-93	10.0	3,000	161,568	64,627
	Jun-93	29.0	1,930	301,432	187,419
	Jul-93	25.0	2,220	298,901	161,568
	Aug-93	14.0	2,400	180,956	90,478
	Sep-93	17.0	2,520	230,719	109,866
	Oct-93	31.0	2,470	412,375	200,344
	Nov-93	19.0	2,760	282,421	122,792
	Dec-93	19.0	2,480	253,769	122,792
	Jan-94	19.0	2,490	254,793	122,792
	Feb-94	19.0	2,240	229,211	122,792
	Mar-94	17.0	2,700	247,199	109,866
	Apr-94	6.0	4,340	140,241	38,776
	May-94	24.0	2,570	332,184	155,105
	Jun-94	7.0	2,640	99,526	45,239
	Jul-94	2.0	4,320	46,532	12,925
	Aug-94	0.9	4,440	21,043	5,687
	Sep-94	7.0	3,310	124,784	45,239
	Oct-94	19.1	2,810	288,294	123,115
	Nov-94	12.7	2,780	190,294	82,141
	Dec-94	13.0	3,000	210,038	84,015
	Jan-95	13.0	3,580	250,646	84,015
	Feb-95	11.0	2,630	155,805	71,090
	Mar-95	6.2	2,530	84,206	39,940
	Apr-95	3.0	3,810	61,557	19,388
	May-95	23.0	2,140	265,079	148,643
	Jun-95	47.0	1,380	349,310	303,748
	Jul-95	185.6	664	663,713	1,199,481
	Aug-95	68.9	1,860	690,186	445,281
	Sep-95	21.7	2,120	247,759	140,241
	Oct-95	16.3	2,530	222,097	105,342
	Nov-95	19.6	2,320	244,894	126,669
	Dec-95	19.6	2,030	214,282	126,669
	Jan-96	19.6	2,020	213,227	126,669
	Feb-96	19.6	1,740	183,671	126,669
	Mar-96	16.5	1,830	162,618	106,635
	Apr-96	7.2	3,520	136,493	46,532
	May-96	29.4	1,840	291,339	190,004
	Jun-96	564.7	580	1,763,924	3,649,498
	Jul-96	44.7	1,850	445,263	288,819
	Aug-96	10.6	620	35,261	68,246
	Sep-96	81.6	1,340	588,955	527,423
	Oct-96	38.3	1,800	370,992	247,328
	Nov-96	35.9	1,750	338,350	232,012
	Dec-96	35.9	2,120	409,887	232,012
	Jan-97	35.9	1,700	328,683	232,012
	Feb-97	35.9	1,160	224,278	232,012
	Mar-97	177.0	500	476,626	1,143,901
	Apr-97	17.5	1,870	176,244	113,098
	May-97	25.0	1,920	258,509	161,568
	Jun-97	244.0	348	457,302	1,576,904
	Jul-97	31.0	1,820	303,856	200,344
	Aug-97	59.6	1,940	622,705	385,178
	Sep-97	63.2	1,220	415,251	408,444
	Oct-97	49.9	1,630	438,049	322,490

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-07 (cont)	Nov-97	20.9	2,340	263,388	135,071
	Dec-97	20.9	1,460	164,336	135,071
	Jan-98	20.9	1,240	139,573	135,071
	Feb-98	20.9	2,300	258,886	135,071
	Mar-98	14.6	3,180	250,043	94,356
	Apr-98	30.9	1,770	294,555	199,698
	May-98	121.9	884	580,350	787,806
	Jun-98	275.0	452	669,430	1,777,248
	Jul-98	84.0	764	345,626	542,868
	Aug-98	30.3	2,040	332,895	195,820
	Sep-98	41.6	1,710	383,110	268,849
	Oct-98	56.0	2,010	606,203	361,912
	Nov-98	21.5	2,650	306,845	138,948
	Dec-98	21.5	2,100	243,160	138,948
	Jan-99	21.5	2,000	231,581	138,948
	Feb-99	21.5	2,340	270,950	138,948
	Mar-99	14.8	2,560	204,050	95,648
	Apr-99	5.3	4,750	135,582	34,252
	May-99	15.9	2,780	238,054	102,757
	Jun-99	422.1	436	991,142	2,727,914
	Jul-99	46.0	996	246,747	297,285
	Aug-99	36.9	1,580	313,991	238,474
	Sep-99	36.9	1,600	317,966	238,474
	Oct-99	34.5	1,760	327,014	222,964
	Nov-99	29.6	2,520	401,723	191,297
	Dec-99	29.6	1,130	180,138	191,297
	Jan-00	29.6	2,800	446,359	191,297
	Feb-00	23.6	3,620	460,103	152,520
	Mar-00	13.5	2,640	191,943	87,247
	Apr-00	5.5	3,370	99,822	35,545
	May-00	26.6	1,720	246,402	171,908
	Jun-00	28.8	1,530	237,311	186,126
	Jul-00	13.3	2,210	158,299	85,954
	Aug-00	7.5	2,860	115,521	48,470
	Sep-00	14.2	2,200	168,246	91,771
	Oct-00	23.7	2,200	280,805	153,166
	Nov-00	23.7	1,700	216,986	153,166
	Dec-00	23.7	2,200	280,805	153,166
	Jan-01	23.7	2,400	306,333	153,166
	Feb-01	23.7	2,600	331,861	153,166
	Mar-01	19.1	2,500	257,162	123,438
	Apr-01	5.3	4,100	117,029	34,252
	May-01	18.3	2,300	226,680	118,268
	Jun-01	25.1	2,000	270,357	162,214
	Jul-01	17.2	2,200	203,791	111,159
	Aug-01	19.3	2,900	301,432	124,730
	Sep-01	13.6	2,300	168,462	87,893
	Oct-01	17.8	2,300	220,486	115,036
	Nov-01	14.0	2,600	196,036	90,478
	Dec-01	14.0	2,400	180,956	90,478
EWCD-09	Oct-90	20.0	1,940	104	65
	Nov-90	3.0	4,550	37	10
	Dec-90	5.0	2,880	39	16
	Jan-91	6.0	4,250	69	19
	Feb-91	6.0	4,630	75	19
	Mar-91	3.0	5,280	43	10
	Apr-91	1.0	6,916	19	3
	May-91	3.0	4,874	39	10
	Jun-91	5.0	3,160	43	16
	Jul-91	4.0	2,884	31	13
	Aug-91	11.0	2,960	88	36
	Sep-91	7.0	3,074	58	23
	Oct-91	10.0	2,526	68	32

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-09 (cont)	Nov-91	10.0	3,108	84	32
	Dec-91	3.0	3,972	32	10
	Jan-92	2.0	3,166	17	6
	Feb-92	2.0	4,600	25	6
	Mar-92	4.0	4,994	54	13
	Apr-92	2.0	4,856	26	6
	May-92	7.0	3,370	64	23
	Jun-92	5.0	3,182	43	16
	Jul-92	4.0	4,052	44	13
	Aug-92	4.0	4,630	50	13
	Sep-92	3.0	3,950	32	10
	Oct-92	3.0	5,580	45	10
	Nov-92	5.0	3,890	52	16
	Dec-92	8.0	5,650	122	26
	Jan-93	8.0	5,204	112	26
	Feb-93	8.0	5,090	110	26
	Mar-93	6.0	3,460	56	19
	Apr-93	4.0	4,160	45	13
	May-93	6.0	3,590	58	19
	Jun-93	21.0	1,950	110	68
	Jul-93	16.0	2,560	110	52
	Aug-93	10.0	2,340	63	32
	Sep-93	8.0	3,090	67	26
	Oct-93	7.0	3,430	65	23
	Nov-93	6.0	4,340	70	19
	Dec-93	6.0	3,090	50	19
	Jan-94	6.0	5,070	82	19
	Feb-94	6.0	5,470	88	19
	Mar-94	4.0	4,100	44	13
	Apr-94	2.0	5,940	32	6
	May-94	9.0	2,810	68	29
	Jun-94	5.0	3,290	44	16
	Jul-94	2.0	4,410	24	6
	Aug-94	1.0	5,400	15	3
	Sep-94	5.2	3,330	46	17
	Oct-94	6.0	3,520	57	19
	Nov-94	4.0	3,950	43	13
	Dec-94	4.0	3,880	42	13
	Jan-95	4.0	4,580	49	13
	Feb-95	3.1	3,900	32	10
	Mar-95	1.9	4,330	23	6
	Apr-95	1.0	5,410	15	3
	May-95	11.0	2,000	59	36
	Jun-95	20.0	1,690	91	65
	Jul-95	32.6	1,740	153	105
	Aug-95	33.5	2,120	191	108
	Sep-95	15.7	2,080	88	51
	Oct-95	6.4	2,670	46	21
	Nov-95	3.6	4,260	41	12
	Dec-95	3.6	3,470	34	12
	Jan-96	3.6	3,730	36	12
	Feb-96	3.6	4,160	40	12
	Mar-96	5.4	3,290	48	17
	Apr-96	2.7	5,260	38	9
	May-96	9.2	2,000	50	30
	Jun-96	20.0	1,530	82	65
	Jul-96	22.6	2,070	126	73
	Aug-96	6.8	696	13	22
	Sep-96	24.4	2,160	142	79
	Oct-96	13.0	2,860	100	42
	Nov-96	20.5	2,170	120	66
	Dec-96	20.5	4,830	267	66
	Jan-97	20.5	3,110	172	66
	Feb-97	20.5	3,660	202	66
	Mar-97	9.8	3,510	93	32

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-09 (cont)	Apr-97	7.9	2,540	54	26
	May-97	7.6	2,660	54	25
	Jun-97	30.2	1,280	104	98
	Jul-97	11.7	2,140	67	38
	Aug-97	26.4	1,840	131	85
	Sep-97	23.6	1,560	99	76
	Oct-97	19.2	1,970	102	62
	Nov-97	11.1	2,360	71	36
	Dec-97	11.1	3,710	111	36
	Jan-98	11.1	4,280	128	36
	Feb-98	11.1	4,620	138	36
	Mar-98	7.7	4,030	84	25
	Apr-98	13.2	2,320	82	43
	May-98	39.0	1,510	159	126
	Jun-98	30.0	2,570	208	97
	Jul-98	19.2	1,750	90	62
	Aug-98	15.1	2,680	109	49
	Sep-98	24.3	2,050	134	79
	Oct-98	26.7	2,420	174	86
	Nov-98	11.9	3,160	101	38
	Dec-98	11.9	4,810	154	38
	Jan-99	11.9	4,700	151	38
	Feb-99	11.9	5,530	177	38
	Mar-99	3.5	5,180	49	11
	Apr-99	2.8	5,900	44	9
	May-99	10.7	2,820	81	35
	Jun-99	22.1	1,870	111	71
	Jul-99	14.8	2,160	86	48
	Aug-99	17.1	1,770	82	55
	Sep-99	17.1	1,770	82	55
	Oct-99	18.0	2,020	98	58
	Nov-99	5.6	5,020	76	18
	Dec-99	5.6	5,980	90	18
	Jan-00	5.6	6,130	92	18
	Feb-00	4.5	7,750	94	15
	Mar-00	1.9	6,040	31	6
	Apr-00	2.7	3,970	29	9
	May-00	17.3	1,750	82	56
	Jun-00	10.5	1,820	51	34
	Jul-00	10.6	2,650	76	34
	Aug-00	7.1	2,950	56	23
	Sep-00	9.1	2,300	56	29
	Oct-00	12.1	2,400	78	39
	Nov-00	4.9	4,700	62	16
	Dec-00	4.9	6,100	80	16
	Jan-01	4.9	5,800	77	16
	Feb-01	4.9	5,400	71	16
	Mar-01	6.0	3,900	63	19
	Apr-01	1.3	6,300	22	4
	May-01	7.7	2,900	60	25
	Jun-01	8.6	2,500	58	28
	Jul-01	10.0	2,400	65	32
	Aug-01	7.6	2,500	51	25
	Sep-01	8.9	2,200	53	29
	Oct-01	5.4	3,700	54	17
	Nov-01	3.4	5,000	46	11
	Dec-01	3.4	5,900	54	11
EWCD-11	Jan-90	5.0	2,144	29	16
	Feb-90	5.0	2,110	28	16
	Mar-90	4.0	3,048	33	13
	Apr-90	2.0	3,410	18	6
	May-90	0.0	4,880	1	0
	Jun-90	1.0	2,130	6	3
	Jul-90	0.2	2,240	1	1
	Aug-90	1.4	1,800	7	4

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-11 (cont)	Sep-90	1.8	2,230	11	6
	Oct-90	4.0	2,920	31	13
	Nov-90	4.5	3,400	41	15
	Dec-90	4.0	2,120	23	13
	Jan-91	4.0	2,210	24	13
	Feb-91	4.0	2,330	25	13
	Mar-91	5.0	3,440	46	16
	Apr-91	1.0	1,966	5	3
	May-91	2.0	4,994	27	6
	Jun-91	126.0	612	208	407
	Jul-91	4.0	2,486	27	13
	Aug-91	6.0	2,506	40	19
	Sep-91	7.0	2,804	53	23
	Oct-91	4.0	2,844	31	13
	Nov-91	6.0	3,258	53	19
	Dec-91	4.0	2,508	27	13
	Jan-92	4.0	2,414	26	13
	Feb-92	4.0	3,284	35	13
	Mar-92	6.0	3,214	52	19
	Apr-92	3.0	3,516	28	10
	May-92	6.0	3,218	52	19
	Jun-92	1.0	3,046	8	3
	Jul-92	2.0	2,916	16	6
	Aug-92	2.0	2,910	16	6
	Sep-92	0.1	4,080	1	0
	Oct-92	4.0	3,180	34	13
	Nov-92	4.0	3,150	34	13
	Dec-92	6.0	3,300	53	19
	Jan-93	6.0	2,412	39	19
	Feb-93	6.0	2,740	44	19
	Mar-93	6.0	3,070	50	19
	Apr-93	3.0	4,110	33	10
	May-93	23.0	1,750	108	74
	Jun-93	178.0	448	215	575
	Jul-93	18.0	1,700	82	58
	Aug-93	9.0	2,040	49	29
	Sep-93	9.0	1,930	47	29
	Oct-93	12.0	2,960	96	39
	Nov-93	11.0	2,790	83	36
	Dec-93	11.0	2,680	79	36
	Jan-94	11.0	2,340	69	36
	Feb-94	11.0	2,710	80	36
	Mar-94	5.0	3,350	45	16
	Apr-94	3.0	3,730	30	10
	May-94	1.0	4,000	11	3
	Jun-94	0.6	3,930	6	2
	Jul-94	0.1	2,780	1	0
	Aug-94	0.6	2,630	4	2
	Sep-94	1.0	7,260	20	3
	Oct-94	4.8	3,580	46	16
	Nov-94	8.0	3,060	66	26
	Dec-94	8.0	2,750	59	26
	Jan-95	8.0	2,890	62	26
	Feb-95	5.1	3,320	45	16
	Mar-95	4.2	3,490	39	14
	Apr-95	2.0	3,800	20	6
	May-95	9.0	2,190	53	29
	Jun-95	18.0	1,650	80	58
	Jul-95	98.8	856	228	319
	Aug-95	23.1	2,350	146	75
	Sep-95	21.4	1,520	88	69
	Oct-95	11.4	1,920	59	37
	Nov-95	10.8	2,460	72	35

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-11 (cont)	Dec-95	10.8	2,510	73	35
	Jan-96	10.8	2,570	75	35
	Feb-96	10.8	2,860	83	35
	Mar-96	2.8	3,430	26	9
	Apr-96	6.6	2,680	48	21
	May-96	22.7	1,620	99	73
	Jun-96	290.1	495	387	937
	Jul-96	20.9	1,750	98	68
	Aug-96	7.3	7,060	139	24
	Sep-96	15.0	2,310	93	48
	Oct-96	8.3	2,730	61	27
	Nov-96	10.5	2,120	60	34
	Dec-96	10.5	2,470	70	34
	Jan-97	10.5	2,460	70	34
	Feb-97	10.5	2,930	83	34
	Mar-97	15.4	2,750	114	50
	Apr-97	6.1	2,760	45	20
	May-97	37.8	1,160	118	122
	Jun-97	116.0	504	157	375
	Jul-97	11.8	1,760	56	38
	Aug-97	23.9	2,390	154	77
	Sep-97	30.4	1,880	154	98
	Oct-97	16.3	2,060	90	53
	Nov-97	22.2	1,800	108	72
	Dec-97	22.2	2,330	139	72
	Jan-98	22.2	2,550	152	72
	Feb-98	22.2	2,930	175	72
	Mar-98	7.4	3,250	65	24
	Apr-98	4.5	3,360	41	15
	May-98	58.7	1,020	161	190
	Jun-98	300.0	548	443	969
	Jul-98	22.7	1,620	99	73
	Aug-98	12.2	1,920	63	39
	Sep-98	29.8	1,960	157	96
	Oct-98	18.1	2,560	125	58
	Nov-98	12.7	2,790	95	41
	Dec-98	12.7	2,650	91	41
	Jan-99	12.7	2,520	86	41
	Feb-99	12.7	2,650	91	41
	Mar-99	5.9	3,400	54	19
	Apr-99	4.5	3,850	47	15
	May-99	1.5	5,260	21	5
	Jun-99	325.0	596	522	1050
	Jul-99	10.1	1,740	47	33
	Aug-99	5.5	2,110	31	18
	Sep-99	19.9	1,780	95	64
	Oct-99	16.8	2,040	92	54
	Nov-99	7.4	3,340	67	24
	Dec-99	7.4	2,410	48	24
	Jan-00	7.4	2,680	53	24
	Feb-00	7.4	2,830	56	24
	Mar-00	4.5	3,070	37	15
	Apr-00	2.1	3,520	20	7
	May-00	3.6	2,880	28	12
	Jun-00	2.3	2,510	16	7
	Jul-00	2.1	2,420	14	7
	Aug-00	1.5	3,030	12	5
	Oct-00	3.2	3,200	28	10
	Nov-00	3.2	3,300	28	10
	Dec-00	3.2	3,400	29	10
	Jan-01	3.2	3,000	26	10
	Feb-01	3.2	3,100	27	10
	Mar-01	3.9	3,900	41	13

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-11 (cont)	Apr-01	2.8	3,900	29	9
	May-01	2.8	2,600	20	9
	Jun-01	35.4	1,000	95	114
	Jul-01	4.1	2,000	22	13
	Aug-01	8.7	1,900	45	28
	Sep-01	5.3	2,100	30	17
	Oct-01	1.0	5,600	15	3
	Nov-01	4.4	3,800	45	14
	Dec-01	4.4	3,100	37	14
STORET 493029	2/22/90	35	2,270	214	113
	3/27/90	13	3,760	132	42
	4/20/90	6	4,380	71	19
	5/24/90	3	4,930	36	9
	6/20/90	1	5,460	15	3
	8/20/90	17	3,320	152	55
	10/17/90	24	2,680	173	78
	11/26/90	21	3,020	171	68
	3/29/91	20	3,260	176	65
	4/25/91	8	3,770	77	25
	5/23/91	7	4,370	86	24
	6/24/91	52	1,460	204	168
	7/26/91	91	1,810	444	294
	10/2/91	43	2,470	286	139
	11/25/91	26	3,070	215	84
	3/10/92	127	1,370	469	410
	4/22/92	17	4,020	184	55
	5/29/92	46	2,490	308	149
	6/19/92	2	3,300	20	7
	7/20/92	3	3,110	25	10
	8/13/92	5	2,820	39	16
	11/16/92	28	2,780	210	90
	2/25/93	50	1,860	250	162
	3/26/93	36	3,560	345	116
	4/27/93	33	3,540	315	107
	5/21/93	173	1,300	606	559
	6/23/93	263	858	608	850
	7/23/93	15	2,530	102	48
	8/25/93	18	2,410	117	58
	10/4/93	30	2,560	207	97
	11/16/93	58	2,870	448	187
	3/21/94	26	3,290	230	84
	4/19/94	10	3,870	103	32
	5/25/94	12	3,590	116	39
	6/23/94	13	2,430	85	42
	8/31/94	229	978	603	740
	10/5/94	31	2,420	202	100
	11/21/94	27	3,160	230	87
	3/27/95	17	3,440	157	55
	5/31/95	66	2,390	425	213
	10/30/95	83	2,120	474	268
	3/20/96	52	3,570	500	168
	4/24/96	27	2,860	208	87
	6/6/96	428	926	1067	1383
	6/27/96	156	1,140	479	504
	8/1/96	42	2,340	265	136
	8/16/96	16	2,460	106	52
	11/22/96	67	2,550	460	217
	11/19/97	110	1,586	470	355
	6/3/98	494	696	926	1596
	4/13/99	15	3,924	158	48
	10/16/00	48	2,210	286	155
	11/29/00	34	2,560	234	110
	1/9/01	25	3,070	207	81

Station	**Date**	**Flow (cfs)**	**TDS (mg/L)**	**Existing Load (tons/day)**	**Load Capacity (tons/day)**
STORET 493029 (cont)	2/20/01	29	2,690	210	94
	4/3/01	27	3,120	227	87
	5/11/01	16	3,370	145	52
	6/21/01	15	2,460	99	48
	8/1/01	1	4,220	14	4
	9/6/01	3	3,290	23	8
EWCD-14	1/1/90	12.0	1,892	122,275	77,553
	2/1/90	12.0	1,310	84,662	77,553
	3/1/90	6.0	2,194	70,896	38,776
	4/1/90	2.0	4,580	49,332	12,925
	5/1/90	1.0	2,760	14,864	6,463
	6/1/90	1.0	2,300	12,387	6,463
	7/1/90	0.2	3,400	4,212	1,486
	8/1/90	0.4	2,530	4,905	2,327
	9/1/90	1.3	2,070	14,047	8,143
	10/1/90	4.0	1,820	39,207	25,851
	11/1/90	10.0	1,560	84,015	64,627
	12/1/90	10.0	1,560	84,015	64,627
	1/1/91	10.0	1,690	91,017	64,627
	2/1/91	10.0	1,750	94,248	64,627
	3/1/91	10.0	1,810	97,479	64,627
	4/1/91	2.0	2,162	23,287	12,925
	5/1/91	1.0	3,102	16,706	6,463
	6/1/91	9.0	1,290	62,527	58,164
	7/1/91	1.0	2,958	15,931	6,463
	8/1/91	1.0	2,046	11,019	6,463
	9/1/91	3.0	2,446	39,520	19,388
	10/1/91	2.0	2,316	24,946	12,925
	11/1/91	5.0	1,942	52,294	32,314
	12/1/91	3.0	1,714	27,693	19,388
	1/1/92	3.0	1,634	26,400	19,388
	2/1/92	3.0	1,870	30,213	19,388
	3/1/92	6.0	1,722	55,644	38,776
	4/1/92	25.0	1,280	172,339	161,568
	5/1/92	7.0	2,808	105,859	45,239
	6/1/92	3.0	2,186	35,319	19,388
	7/1/92	1.0	3,190	17,180	6,463
	8/1/92	2.0	2,592	27,919	12,925
	9/1/92	2.0	2,550	27,467	12,925
	10/1/92	2.0	2,130	22,943	12,925
	11/1/92	4.0	1,630	35,114	25,851
	12/1/92	4.0	2,130	45,885	25,851
	1/1/93	4.0	1,608	34,640	25,851
	2/1/93	4.0	1,920	41,361	25,851
	3/1/93	29.0	1,050	163,992	187,419
	4/1/93	18.0	1,470	142,503	116,329
	5/1/93	48.0	638	164,929	310,211
	6/1/93	38.0	576	117,880	245,583
	7/1/93	2.0	1,850	19,927	12,925
	8/1/93	1.0	2,340	12,602	6,463
	9/1/93	1.0	2,240	12,064	6,463
	10/1/93	9.0	1,970	95,487	58,164
	11/1/93	9.0	1,520	73,675	58,164
	12/1/93	9.0	1,650	79,976	58,164
	1/1/94	9.0	1,570	76,099	58,164
	2/1/94	13.0	1,710	119,722	84,015
	3/1/94	16.0	1,080	93,063	103,404
	4/1/94	3.0	3,580	57,841	19,388
	5/1/94	4.0	2,010	43,300	25,851
	6/1/94	0.9	2,300	11,024	5,752
	8/1/94	1.0	2,210	11,902	6,463
	9/1/94	1.0	2,580	13,895	6,463
	10/1/94	3.0	2,480	40,069	19,388

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-14 (cont)	11/1/94	6.0	2,230	72,059	38,776
	12/1/94	6.0	1,470	47,501	38,776
	1/1/95	6.0	1,380	44,593	38,776
	2/1/95	10.0	1,160	62,473	64,627
	3/1/95	12.0	938	60,620	77,553
	4/1/95	3.8	3,190	65,284	24,558
	5/1/95	2.8	2,270	34,231	18,096
	6/1/95	170.0	468	428,478	1,098,662
	7/1/95	45.0	728	176,432	290,822
	8/1/95	33.5	1,150	207,480	216,501
	9/1/95	4.4	1,650	39,099	28,436
	10/1/95	5.4	1,700	49,440	34,899
	11/1/95	9.1	1,180	57,831	58,811
	12/1/95	9.1	2,000	98,018	58,811
	1/1/96	9.1	1,160	56,850	58,811
	2/1/96	9.1	1,320	64,692	58,811
	3/1/96	10.3	1,140	63,238	66,566
	4/1/96	4.7	2,200	55,687	30,375
	5/1/96	83.9	800	361,481	542,222
	6/1/96	27.0	595	86,520	174,493
	7/1/96	1.9	2,330	23,842	12,279
	8/1/96	1.0	892	4,804	6,463
	9/1/96	10.0	1,930	103,942	64,627
	10/1/96	5.9	1,860	59,302	38,259
	11/1/96	13.9	887	66,401	89,832
	12/1/96	13.9	1,770	132,502	89,832
	1/1/97	13.9	1,500	112,290	89,832
	2/1/97	13.7	1,620	119,528	88,539
	3/1/97	31.6	1,110	188,905	204,222
	4/1/97	20.9	1,100	123,815	135,071
	5/1/97	147.8	416	331,133	955,190
	6/1/97	120.0	508	328,306	775,526
	7/1/97	2.7	2,010	29,228	17,449
	8/1/97	38.5	1,190	246,741	248,815
	9/1/97	40.0	1,720	370,529	258,509
	10/1/97	14.8	1,510	120,357	95,648
	11/1/97	7.8	2,180	91,577	50,409
	12/1/97	7.8	1,380	57,971	50,409
	1/1/98	7.8	1,640	68,893	50,409
	2/1/98	7.8	1,470	61,751	50,409
	3/1/98	24.5	1,240	163,615	158,337
	4/1/98	27.9	1,200	180,310	180,310
	5/1/98	49.7	940	251,604	321,197
	6/1/98	80.0	544	234,381	517,018
	7/1/98	30.3	1,020	166,447	195,820
	8/1/98	11.3	1,160	70,594	73,029
	9/1/98	28.3	1,100	167,654	182,895
	10/1/98	49.9	1,320	354,739	322,490
	11/1/98	27.9	1,440	216,372	180,310
	12/1/98	27.9	1,530	229,895	180,310
	1/1/99	27.9	1,520	228,393	180,310
	2/1/99	27.9	1,240	186,320	180,310
	3/1/99	19.3	1,480	153,834	124,730
	4/1/99	9.5	2,020	103,350	61,396
	5/1/99	50.6	792	215,829	327,014
	6/1/99	81.3	664	290,732	525,419
	7/1/99	104.0	1,480	828,952	672,123
	8/1/99	18.1	1,100	107,227	116,975
	9/1/99	9.7	1,620	84,629	62,688
	10/1/99	9.7	2,150	112,317	62,688
	11/1/99	11.8	2,070	131,549	76,260
	12/1/99	11.8	1,450	92,148	76,260
	1/1/00	11.8	1,560	99,138	76,260

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
EWCD-14 (cont)	2/1/00	24.1	2,450	317,993	155,752
	3/1/00	12.2	1,640	107,755	78,845
	4/1/00	13.9	1,500	112,290	89,832
	5/1/00	9.4	2,180	110,362	60,750
	6/1/00	1.8	2,230	21,618	11,633
	7/1/00	5.7	1,920	58,940	36,838
	9/1/00	3.7	1,600	31,883	23,912
	10/1/00	9.2	1,400	69,367	59,457
	11/1/00	9.2	1,300	64,412	59,457
	12/1/00	9.2	1,300	64,412	59,457
	1/1/01	9.2	1,300	64,412	59,457
	2/1/01	9.2	1,600	79,276	59,457
	3/1/01	21.4	1,500	172,878	138,302
	4/1/01	11.3	1,600	97,372	73,029
	5/1/01	37.8	690	140,467	244,291
	6/1/01	9.2	990	49,052	59,457
	7/1/01	3.2	2,400	41,361	20,681
	8/1/01	1.6	1,600	13,787	10,340
	9/1/01	2.1	1,800	20,358	13,572
	10/1/01	1.3	3,100	21,704	8,402
	11/1/01	4.4	2,400	56,872	28,436
	12/1/01	4.4	1,600	37,915	28,436
STORET 495500	4/18/90	4.8	6,444	83	16
	5/9/90	0.1	7,494	2	0
	5/22/90	0.0	8,746	0	0
	10/10/90	0.9	6,130	15	3
	2/20/91	14.4	4,078	158	47
	9/11/91	48.9	3,434	452	158
	10/23/91	1.5	6,354	26	5
	12/11/91	10.0	4,520	122	32
	2/12/92	17.0	2,310	106	55
	4/1/92	64.9	1,912	334	210
	8/18/92	0.2	4,678	3	1
	12/1/92	6.2	5,818	97	20
	3/30/93	41.9	3,056	345	135
	4/27/93	46.2	2,196	273	149
	6/22/93	47.0	1,672	212	152
	8/12/93	6.0	4,532	73	19
	10/6/93	0.8	6,080	13	3
	11/30/93	25.0	4,266	287	81
	1/19/94	4.0	4,036	43	13
	3/23/94	6.0	3,828	62	19
	5/4/94	2.3	5,070	31	7
	8/9/94	12.0	4,662	151	39
	9/21/94	7.0	5,544	105	23
	11/1/94	1.5	5,644	23	5
	12/13/94	4.0	4,994	54	13
	2/14/95	7.5	3,556	72	24
	3/28/95	4.5	3,672	44	15
	5/11/95	6.0	4,428	72	19
	9/20/95	2.0	5,132	28	6
	11/14/95	6.0	2,894	47	19
	1/17/96	20.0	2,870	155	65
	2/28/96	18.0	2,508	122	58
	4/10/96	8.0	3,040	65	26
	5/14/96	22.0	2,382	141	71
	10/15/96	0.8	4,782	10	3
	12/18/96	2.0	5,070	27	6
	2/13/97	9.0	2,932	71	29
	4/2/97	21.0	1,962	111	68
	5/14/97	35.0	910	86	113
	6/25/97	30.0	1,114	90	97
	7/30/97	150.0	3,386	1368	485

Station	Date	Flow (cfs)	TDS (mg/L)	Existing Load (tons/day)	Load Capacity (tons/day)
STORET 495500 (cont)	8/26/97	50.0	2,120	285	162
	9/16/97	150.0	2,516	1016	485
	11/18/97	13.9	2,928	110	45
	1/13/98	25.0	2,584	174	81
	2/17/98	25.0	2,960	199	81
	3/30/98	35.0	1,508	142	113
	5/19/98	35.0	2,456	231	113
	6/23/98	40.0	806	87	129
	9/16/98	19.0	3,014	154	61
	10/29/98	30.0	2,290	185	97
	12/16/98	120.0	3,464	1119	388
	2/10/99	55.0	2,416	358	178
	4/14/99	12.0	3,536	114	39
	6/23/99	40.0	1,458	157	129
	8/4/99	30.0	3,380	273	97
	9/29/99	4.1	4,616	51	13
	12/8/99	10.5	3,760	106	34
	2/2/00	15.0	3,092	125	48
	3/22/00	18.9	2,726	139	61
	5/24/00	5.0	4,956	67	16
	11/8/00	17.9	2,712	131	58
	4/25/01	5.4	3,170	46	17
	6/27/01	74.0	2,340	466	239
	8/22/01	500.0	3,826	5151	1616
	10/31/01	25.0	972	65	81
	12/12/01	4.0	4,634	50	13
	1/30/02	4.2	4,378	50	14
	4/24/02	25.0	4,492	302	81
	9/17/02	22.6	4,060	247	73

APPENDIX C

COMMENTS ON DRAFT DOCUMENT AND RESPONSES:

Formal comments were received from five individuals. For each of these individuals, the comments provided are listed followed by a response in bold italicized text.

Comment Letter 1: Mark Page, Utah Division of Water Rights

Just a couple of comments after reviewing the final report. First, I think a really good job was done on the report.

On page 2, Table 1-1 it refers to Lower Grassy Trail Creek being the area from Grassy Trail Reservoir to the headwaters. This area might be more appropriately named the upper Grassy Trail Creek area.

Comment noted and change made.

In appendix A, page A-7, Table A-2, the description of the site refers to the Price River near Wellington at US 6 Crossing. Highway 6 never crosses the Price River at or near Wellington.

Comment noted and change made.

Do we have enough data collected on the Price River to set the proper targets?

As is typical for most TMDLs, more data would refine our understanding of the targets. However, there is sufficient data to determine annual TDS loading and to estimate what effect BMPs may have on loadings in the Price River.

The monitoring system that will need to be established to monitor progress was addressed very briefly. Maybe more detail would be helpful. Who will collect the samples, how often and at what sites? At what point will reconsideration of the targets be reviewed if we are not meeting the established figures?

Details of the State-wide water quality monitoring program are available from the Division of Water Quality.

Thanks for your good work on this project. If you have any questions please feel free to contact me. Thanks again.

Comment Letter 2: Roger Barton, Chairman Price-San Rafael River Watershed Committee

March 2, 2004

Utah Division of Water Quality
Attn: Kent Montague
288 North 1460 West
P O Box 144870
Salt Lake City, Utah 84114-4870

RE: Comment on TMDL

The follow comments and questions are offered to you for the Price River, San Rafael River, and Muddy Creek TMDL for Total Dissolved Solids, West Colorado Watershed Management Unit, Utah (January 2004).

1. Section 3.4, Data Use and Limitations: Reference is made to the lack of available data. Do we have enough data to make the determinations and conclusions in the TMDL? Data, especially on the Price River, is lacking in several areas as mentioned in the TMDL.

As noted in the earlier response, additional data would refine the understanding of TDS loadings in the Price. However, as indicated in the report, there is sufficient flow and chemistry data to calculate TDS loading to the watershed at certain locations.

2. The biggest concern that I have is the TDS calculations for the Muddy River. Natural Resources Conservation Service and the Bureau of Reclamation are writing an Environmental Assessment (EA) for the Muddy Creek drainage and are claiming 15,000 tons of “salts” are coming from agricultural non-point sources. This TMDL is showing 50,767 tons (Table 6-9). Table A-9, page A-9, shows 64,335 tons with 25,600+ tons attributed to agriculture. The concern is if these documents, TMDL and EA, are to be recognized by the Federal Government and the calculations are to be used in watershed improvements a consensus on the salt loading should be reached. Both documents should reflect basically the same figures.

   The community of Emery is willing to make irrigation improvements and the tons of salt attributed to agriculture can make a big difference in whether they can afford to install those systems. If the figure is 15,000 tons, the cost per ton of salt removed is very high. If the figure is 25,000 – 50,000 tons, the cost drops considerably. It is stated (page A-10) that, on the Muddy Creek, 45%-93% of the salt loading comes from ambient sources, yet the TMDL shows a wide range of tons attributed to agricultural practices. Is there some way to come to agreement on these calculations?
   The non-point load listed in Table 6-9 was derived using the available flow and water quality data available. The 50,767 tons/year is for all non-point sources, including natural background and irrigation. The value for irrigation return flow, winter water replacement, and canal seepage of 26,200 tons/year listed in Table A-9 was based on allocating the total non-point load in the Muddy Creek watershed to the different segments in the watershed and estimating what portion of the load is attributable to the different sources, as based on land use and available loading values. The 45%-93% values listed as ambient loadings was incorrect. The report has been modified to reflect that 34-49% of the annual non-point load is estimated to be a result of ambient TDS loading.

Roger Barton, Chairman
Price-San Rafael River Watershed Committee
P O Box 263
Ferron, Utah 84523

Comment Letter 3: Steve Gerner, USGS-Salt Lake City

Mr. Judd,

I was delighted to find the draft TMDL document for TDS in West Colorado River Watershed streams posted on the Utah DEQ web site. My particular interest is in the interpretation of existing data relative to dissolved solids in Muddy Creek. I thought the sections describing data limitations particularly inciteful given the lack of flow data for Muddy Creek. I'm familiar with the samples collected by UTDEQ at the U24 Muddy Creek site and appreciate the value inherent in this data set, however, I'm a little concerned about the number of 'estimated' flow values associated with TDS concentrations. Estimated flow values (which comprise about half the data) are notoriously inaccurate and load calculations or streamflow statistics based on these values have a high degree of uncertainty. I think the sections relative to the need for additional data acquisition and monitoring, followed by re-evaluation of the TMDL document can't be overstated.

The USGS Utah District will be initiating a project in the near future to quantify the dissolved-solids load in Muddy Creek. As I'm sure you're aware, a lack of continuous flow and concentration data has resulted in a high degree of uncertainty associated with estimates of the dissolved-solids load in the middle and lower segments of Muddy Creek. The data that is generated by this project should result in improved estimates of average monthly stream flow, dissolved-solids concentrations, and dissolved-solids loads for Muddy Creek. Continuous monitoring of specific conductance and subsequent dissolved solids concentration calculations should enable you to evaluate the site-specific TDS concentration criteria (5,600 mg/L) proposed for Muddy Creek as well. I've attached a copy of the USGS Muddy Creek project proposal if you're interested in learning more about this project. Thank you for the opportunity to review the draft TMDL for the West Colorado Watershed Management Unit.

Regards,
- Steve Gerner

U.S. Geological Survey
2329 Orton Circle
SLC, Utah 84119

(801) 908-5031

(See attached file: Muddy_Regional_Proposal.pdf)

Comment noted and results from the proposed work will be incorporated into the TMDL as it becomes available.

Comment Letter 4: Kathy Hernandez, USEPA Region 8

EPA REGION VII TMDL REVIEW FORM

Document Name:	**West Colorado Watershed – Water Quality Management Plan**
Submitted by:	**Harry Judd – Kent Montague**
Date Received:	**02/06/2004**
Review Date:	**02/14/2004**
Reviewer:	**K. Hernandez**
Draft or Final Review?	**Draft**

This document provides a standard format for the EPA Region 8 to provide comments to the Utah Department of Environmental Quality on TMDL documents provided to the EPA for either official formal, or informal review. All TMDL documents are measured against the following 12 review criteria:

1. Water Quality Impairment Status
2. Water Quality Standards
3. Water Quality Targets
4. Significant Sources
5. Total Maximum Daily Load
6. Allocation
7. Margin of Safety and Seasonality
8. Monitoring Strategy
9. Restoration Strategy
10. Public Participation
11. Endangered Species Act Compliance
12. Technical Analysis

Each of the 12 review criteria are described below to provide the rational for the review, followed by EPA's comments. This review is intended to ensure compliance with the Clean Water Act and also to ensure that the reviewed documents are technically sound and the conclusions are technically defensible. This document review form incorporates, by reference, the summary of TMDL elements presented in Table 1 (attached).

1. Water Quality Impairment Status

1.1 Criterion Description – Water Quality Impairment Status

*TMDL documents must include a description of the listed water quality impairments***.** *While the 303(d) list identifies probable causes and sources of water quality impairments, the information contained in the 303(d) list is generally not sufficiently detailed to provide the reader with an adequate understanding of the impairments. TMDL documents should include a thorough description/summary of all available water quality data such that the water quality impairments are clearly defined and linked to the impaired beneficial uses and/or appropriate water quality*

☐ Satisfies Criterion
☐ Satisfies Criterion. Questions or comments provided below should be considered.
☑ Partially satisfies criterion. Questions or comments provided below need to be addressed.
☐ Criterion not satisfied. Questions or comments provided below need to be addressed.
☐ Not a required element in this case. Comments or questions provided for informational purposes.

The following segments are addressed in the TMDL Watershed Management Unit Plan for the West Colorado Watershed: Price River Watershed, San Rafael River Watershed and Muddy Creek Watershed. Utah DEQ 2000 and 2002 303(d) List identifies the following streams segments as impaired:

Listed Stream Segment	Pollutant	Related Beneficial Use
Price River Watershed		
Gordon Creek and tribs.*	Total dissolved solids (TDS)	Agriculture, water supply, cold water aquatic species
Pinnacle Creek	TDS	***Agriculture, water supply, cold water aquatic species***
Price River and tribs from Green River to near Woodside*	TDS, DO, Iron	Agriculture, non game fish
Price River and tribs from Woodside to Soldier Creek*	TDS	Agriculture, water supply, cold water aquatic species
Lower Grassy Trail Creek*	pH, TDS	Agriculture
Price River and tribs from Coal Creek to Carbon Canal*	TDS	***Agriculture, water supply, cold water aquatic species***
San Rafael River Watershed		
Huntington Creek tribs from Cottonwood Creek to Hwy 10*	TDS	Agriculture
Huntington Creek and tribs from Hwy 10 to USFS boundary	TDS	Agriculture, water supply, cold water aquatic species
Cottonwood Creek from Huntington Creek to Hwy 57*	TDS	Agriculture
Rock Canyon Creek from Cottonwood Cr. to headwaters	TDS TDS	***Agriculture, non game fish***
San Rafael River from Buckhorn to Huntington Creek	TDS	Agriculture
San Rafael River from Green River to Buckhorn Crossing	TDS	Agriculture
Muddy Creek Watershed		
Muddy Creek and tribs from Quitchupah to Hwy 10*	TDS	Agriculture
Quitchupah Cr. from Muddy Cr. to Hwy 10*	TDS	Agriculture
Ivie Creek and trivs from Muddy Cr. to Hwy 10*	TDS	Agriculture

Muddy Creek from Fremont River to Quitchupah*	TDS	Agriculture

There is a good description of the watersheds including the land use, geology, vegetation and climate. The review of STORET data for Lower Grassy Creek from 1997-2002 found only one exceedance of pH , therefore this segment will be delisted for pH. The Lower Price River has not had any exceedance of DO in the past 3 years, therefore this segment will be delisted. Because of the limited exceedances of the dissolved iron concentrations and the lack of any identified sources, Price River has been delisted for iron from the 2004 303 (d) list.

What is the watersheds priority on the 2002 list? If these segments are not high priority, explain how their development affects the high priority TMDL schedule.

Please identify the applicable beneficial use for Pinnacle Creek, Rock Canyon, Cottonwood Creek and the segment of Price Creek near Coal Creek.

2. Water Quality Standards

1.1.1 Criterion Description – Water Quality Standards

The TMDL document must include a description of all applicable water quality standards for all affected jurisdictions. TMDLs result in maintaining and attaining water quality standards. Water quality standards are the basis from which TMDL's are established and the TMDL targets are derived, including the numeric, narrative, use classification, and antidegradation components of

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The chronic numeric water quality standard for TDS for the West Colorado River Watershed is 1200 mg/l to support the agricultural use. The dissolved oxygen standard to support non game fish is 5.0 mg/l as a daily minimum, and a dissolved iron concentration of 1.0 mg/l. The State's antidegradation policy dictating that "existing water quality shall be maintained and protected" applies to waters designated as 'High Quality – Category 1". Portions of Gordon Creek, Huntington Creek, Cottonwood Creek, Muddy Creek, and Quitchupah Creek are designated as Category 1 – High Quality Waters.

3. Water Quality Targets

Criterion Description – Water Quality Targets

Quantified targets or endpoints must be provided to address each listed pollutant/water body combination. Target values must represent achievement of applicable water quality standards and support of associated beneficial uses. For pollutants with numeric water quality standards, the numeric criteria are generally used as the TMDL target. For pollutants with narrative standards, the narrative standard must be translated into a measurable value. At a minimum, one target is required for each pollutant/water body combination. It is generally desirable, however, to include several targets that represent achievement of the standard and support of

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The water quality targets/ initial endpoint selected for these TMDLs to achieve chronic numeric water quality standard for TDS is 1200 mg/l . Additionally this watershed is addressed under the Colorado River Basin Salinity Control Forum, which addresses salinity in the Colorado River System. The standards required a plan that would maintain the flow-weighted average annual salinity at or below 1972 levels.

There are two target sites in the Price River watershed, five target sites in the San Rafael River watershed, and two target sites in the Muddy River watershed which are shown on Map 2 in the TMDL document. The endpoint was modified at selected target sites to reflect an adjustment to TDS criterion based on site-specific conditions as allowed for under Utah water quality standards.

These segments that have site specific targets cannot be approved as TMDLs until the standard is changed by UTDEQ.

4. Significant Sources

1.1.1.1 Criterion Description – Significant Sources

TMDLs must consider all significant sources of the stressor of concern. All sources or causes of the stressor must be identified or accounted for in some manner. The detail provided in the source assessment step drives the rigor of the allocation step. In other words, it is only possible to specifically allocate quantifiable loads or load reductions to each significant source when the relative load contribution from each source has been estimated. Ideally, therefore, the pollutant load from each significant source should be quantified. This can be accomplished using site-specific monitoring data, modeling, or application of other assessment techniques. If insufficient time or resources are available to accomplish this step, a phased/adaptive management approach

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The primary factors in increased TDS loads in the middle and lower reaches of the Price, San Rafael and Muddy Creek watersheds are from agricultural irrigation practices, surface runoff, grazing, recreational activities and natural geological loadings. Increased surface run-off, and loadings of TDS are associated with current irrigation practices.

Elevated TDS concentrations in Rock Canyon Creek are attributed to agricultural use, with irrigation and urban activities, the Hunter Power Plant and the presence of Mancos Shale. Wastewater Treatment facilities located in Price (UT0021814), Huntington (UT00212960) and Castle Dale (UT0023663), contribute TDS loads to Price River, Huntington Creek and Cottonwood Creeks, respectively. Permitted industrial source discharges are associated with coal mine operations and power plants contribute load, as do runoff rates and flows from urban areas.

5. TMDL

Criterion Description – Total Maximum Daily Load

TMDLs include a quantified pollutant reduction target. According to EPA reg (see 40 C.F.R. 130.2(i)) TMDLs can be expressed as mass per unit of time, toxicity, % load reduction, or other measure. TMDLs must address, either singly or in combination, each listed pollutant/water body combination.

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The TMDL is expressed in average annual loading capacity/TMDL in tons/year TDS and in % reduction in existing load to achieve allocation.

Stream Segment – Price River Watershed	**TMDL tons/yr TDS**	**% Reduction**
Pinnacle Creek and tribs	31,755	**43%**
Gordon Creek and tribs		
Price River and tribs from Coal Creek to Carbon Canal Diversion		

6. Allocation

Criterion Description – Allocation

TMDLs apportion responsibility for taking actions or allocate the available assimilative capacity among the various point, nonpoint, and natural pollutant sources. Allocations may be expressed in a variety of ways such as by individual discharger, by tributary watershed, by source or land use category, by land parcel, or other appropriate scale or dividing of responsibility. A performance based allocation approach, where a detailed strategy is articulated for the application of BMPs, may also be appropriate for non point sources.

In cases where there is substantial uncertainty regarding the linkage between the proposed allocations and achievement of water quality standards, it may be necessary to employ a phased or adaptive

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Summary of Average Annual TDS Load and TMDL Allocation for the Price River Watershed from Coal Creek to Carbon Canal Diversion

Source	Current Load Tons/year	WLA Tons/year	LA Tons/year	% increase/reduction
NPDES UTGO40019	258	1,035		+300%
NPDES UT0023094	146	941		+644%
NPDES UT0000094	146	552		+278%
NPDES UT0025453	8	30		+275%
NPDES UT0021814	2,190	7,304		+234%
Non-Point Source Load	52,732		20,305	61%
Margin of Safety	1,558			
Total Existing Load	55,480			43%

There are 17,000 acres under consideration for irrigation improvements for the Price River watershed. The Resource Protection plan is projected to decrease the salt load in the Price River watershed by 69,975 tons per year. Replacing 100% of the 69 miles of open laterals and canals could potentially reduce nearly 4,000 tons per year. Dewatering of the Price River area canal systems in winter and lining stock ponds could result in a load reduction of 18,356 tons of salt per year. It is estimated that Price River watershed contributes 279 tons of salt per year due to unstable stream banks that are impacted by livestock and wildlife, which could be reduced through fencing and restoration. Urban areas in the Price River watershed contribute 95 tons of salt annually, 29 tons removed application of vegetative filter strips and detention ponds.

Price River Watershed – Price River near Wellington at US 6

Source	Loading (tons/year)	Reduction (tons/year)
Irrigation return flows	65,470	55,980

Canal seepage	4,677	3,692
Winter water replacement	18,706	14,685
Surface erosion	3,555	1,997
Streambank erosion	112	84
Urban areas	90	28
Forest	204	64
Totals	92,814	76,530
Ambient loading	2,030	0
TOTAL LOADING	94,844	18,314 (post BMP)

Is the allocation in Table A-2 applicable to the Target Site #493239?

The allocation in Table A-2 was based on looking at the total non-point source loading in the Price River Watershed (Site 493165) and allocating the load to the different segments based on percent of watershed. From there, information on land use and TDS loading by source were used to estimate the allocations listed.

It appears that the tons/year attributed to the point source is actually increasing, since it is based on design flow rather than actual effluent flow. It is not clear if the effluent limit for all NPDES dischargers will be at or below 1200 mg/l. Additionally, are any of the permittees being allowed to backslide to effluent quality greater that their past performance? If so, that would be considered a violoation of the "anti backsliding". Additionally most of these segments are requesting site specific criteria because of their inability to meet the existing WQS, as in Muddy Creek where 1/3 of the load is attributable to point source discharge, which is 3 time greater that the existing point source load and the site specific standard requested ranges from 2600 to 5800 mg/l.

7. Margin of Safety and Seasonality

1.1.1.1.1.1 Criterion Description – Margin of Safety/Seasonality

1.1.1.1.1.2

A margin of safety (MOS) is a required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving water body (303(d)(1)(c)). The MOS can be implicitly expressed by incorporating a margin of safety into conservative assumptions used to develop the TMDL. In other cases, the MOS can be built in as a separate component of the TMDL (in this case, quantitatively, a TMDL = WLA + LA + MOS). In all cases, specific documentation describing the rational for the MOS is required.

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There is an explicit margin of safety of 5%.

8. Monitoring Strategy

1.1.1.1.1.3 Criterion Description – Monitoring Strategy

Many TMDL's are likely to have significant uncertainty associated with selection of appropriate numeric targets and estimates of source loadings and assimilative capacity. In these cases, a phased TMDL approach may be necessary. For Phased TMDLs, it is EPA's expectation that a monitoring plan will be included as a component of the TMDL documents to articulate the means by which the TMDL will be evaluated in the field, and to provide supplemental data in the future to address any uncertainties that may exist when the document is prepared.

At a minimum, the monitoring strategy should:

- *Articulate the monitoring hypothesis and explain how the monitoring plan will test it.*
- *Address the relationships between the monitoring plan and the various components of the TMDL (targets, sources, allocations, etc.).*
- *Explain any assumptions used.*
- *Describe monitoring methods.*
- *Define monitoring locations and frequencies, and list the responsible parties*

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9. Restoration Strategy

1.1.1.1.1.4 Criterion Description – Restoration Strategy

At a minimum, sufficient information should be provided in the TMDL document to demonstrate that if the TMDL were implemented, water quality standards would be attained or maintained. Adding additional detail regarding the proposed approach for the restoration of water quality <u>is not</u> currently a regulatory requirement, but is considered a value added component of a TMDL document.

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Adequate information is provided to demonstrate the water quality standards will be attained with the suggested BMPs and effluent limits.

10. Public Participation

1.1.1.1.1.5 Criterion Description – Public Participation

The fundamental requirement for public participation is that all stakeholders have an opportunity to be part of the process. Public participation should fit the needs of the particular

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Information regarding the public meeting and notification and publications of the TMDL was identified.

A watershed committee was formed and there was two public meetings. The draft and final TMDL are posted on the UTDEQ website for review.

11. Technical Analysis

1.1.1.1.1.6 Criterion Description – Technical Analysis

*TMDLs must be supported by an appropriate level of technical analysis***.** *It applies to* ***<u>all</u>*** *of the components of a TMDL document. It is vitally important that the technical basis for* ***<u>all</u>*** *conclusions be articulated in a manner that is easily understandable and readily apparent to the reader. Of particular importance, the cause and effect relationship between the pollutant and impairment and between the selected targets, sources, TMDLs, and allocations needs to be supported by an*

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The TMDL and load allocations were developed based on flow and water quality data over an 11 year period of record from 1990 to 2001. The average annual loading capacity/TMDL at each target site were calculated as the product of the average annual flow at the target site, the TDS standard criterion of 1,200 mg/l and a conversion factor to express the average annual loading capacity/TMDL in tons/year TDS.

12. Endangered Species Act Compliance

1.1.1.1.1.7 Criterion Description – Endangered Species Act Compliance

EPA's approval of a TMDL may constitute an action subject to the provisions of Section 7 of the Endangered Species Act ("ESA"). EPA will consult, as appropriate, with the US Fish and Wildlife Service (USFWS) to determine if there is an effect on listed endangered and threatened species pertaining to EPA's approval of the TMDL. The responsibility to consult with the USFWS lies with EPA and is not a requirement under the Clean Water Act for approving TMDLs. States are encouraged, however, to participate with FWS and EPA in the consultation process and, most importantly, to document in its TMDLs the potential effects

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The USFWS has been involved with the development of this TMDL and is currently reviewing the draft document.

13. Miscellaneous Comments/Questions

Comment Letter 5: Kerry Flood, BLM-Price

Comment Narrative for Price River, San Rafael River, and Muddy Creek TMDL
Primary Sources of Sediment Loading from BLM Managed Lands
K. Flood – Hydrologist

There are 3 major sources of sediment from excessive erosion coming from BLM land in PFO. This is the most relevant consideration of impacts because all five major basins are 303(d) listed for non-attainment of water quality standards. The sources are:

A. sheet erosion - major causes in decending order of contribution:

    1) grazing wind erodible soils – any level of surface disturbance on these soils, which are naturally protected from wind erosion by cryptobiotic soil crusts, increases soil movement and loss dramatically over natural levels. This changes site productivity, which is degrading. Eventually the use will not be sustainable. This increases sediment loading to streams, the source of 303(d) target parameters in the PFO area. Grazing is the one uncontrollable activity, it is either graze or no-graze on these soils. There is one alternative which proposes to close an allotment (the Iron Wash Allotment) from grazing due to this impact. Very desirable. The allotment boundary doesn't coincide with the soils types, so some of the closure area is not necessary to close, and some erodible soils will be missed in the closure, but, better than not doing it.

We agree that grazing of erodible soils is a source of TDS loading in the watersheds. Identification of locations, based on soil type, where grazing is problematic and modifying the landuse could be an effective BMP for this source.

2) Roads, trails, and other development on wind erodible soils – where roads aren't built to standards, the surface continually erodes downward, resulting in significant soil loss/sediment loading. Anywhere vegetation is removed and the soil crust destroyed on these soils, sheet erosion accelerates.

As noted in Appendix A, roads and recreational use are identified as sources of TDS. We agree that BMPs that focus on identifying and improving roads that are not built to best standards would help limit loading.

3) Grazing erodible soils – primarily only a problem where overgrazed, and where livestock distribution is poor. Standards and guidelines are going a long way to mitigating this. The critical soil loss threshold plays a role in this also.

We agree that proper grazing techniques are an important BMP for limiting TDS loading to the watersheds. These recommendations are included in Appendix A.

4) Vegetative reduction on erodible soils by surface occupancy increases sheet erosion and reduces infiltration.

We agree that increased vegetative cover on erodible soils can limit TDS loading from sheet erosion.

B. Stream channel erosion (difficult to quantify, but possibly as large a contributer as sheet erosion). Consequences have and can include degradation of stream potential and type (Rosgen class). Results in non-sustainable uses.

Causes:
- Improperly functioning riparian due to channel bank defoliating (grazing)
- Improperly functioning riparian due to changes in flow regime, i.e. 100% diversion practice.
- Hydrologic instability due to changes in flow regime, such as interbasin transfers (even by road drainages) and diversions. Results in degraded stream type (i.e. from perennial flow to intermittent flow, lowering of water table, changes in use imminent.
- Bank trampling, usually grazing related.
- Poorly designed stream channel alterations.

Stream channel erosion is identified in Appendix A as an identified source of TDS loading in the evaluated watersheds. Appropriate BMPs are provided that are in agreement with the identified sources of stream erosion listed above.

C. Gully erosion – Probably equivalent total quantity as stream channel erosion
More easily prevented than restored. Caused primarily by transportation routes, which berm sheet flow, convert to channel flow, and discharge with accelerated velocity to create gullies. Also caused by headcutting from improperly installed culverts at drains and crossings. Prevented and sometimes reversed by PFO hydromods and BMP's. Otherwise, gullying can be a domino problem, which does not stop when cause is removed.
Gullies also are created when soil is compacted and vegetation removed. The effects are severe, both in soil loss and changes in infiltration rate and area. Changes in land use due to

unsustainable yield, and elimination of access to land are potential consequences, as well as the soil loss and sediment loading

Comments noted and text added to Appendix A to incorporate information provided.

General comment summation: Almost all of the above are mitigatable, or manageble within targets. Grazing wind erodible soils is the one impact we can’t mitigate, only no-graze can prevent that. It would be possible to determine whether we could “sacrifice” certain areas and remain within sediment loading limits for a particular watershed, if we had completed soils analysis by watershed.

End.