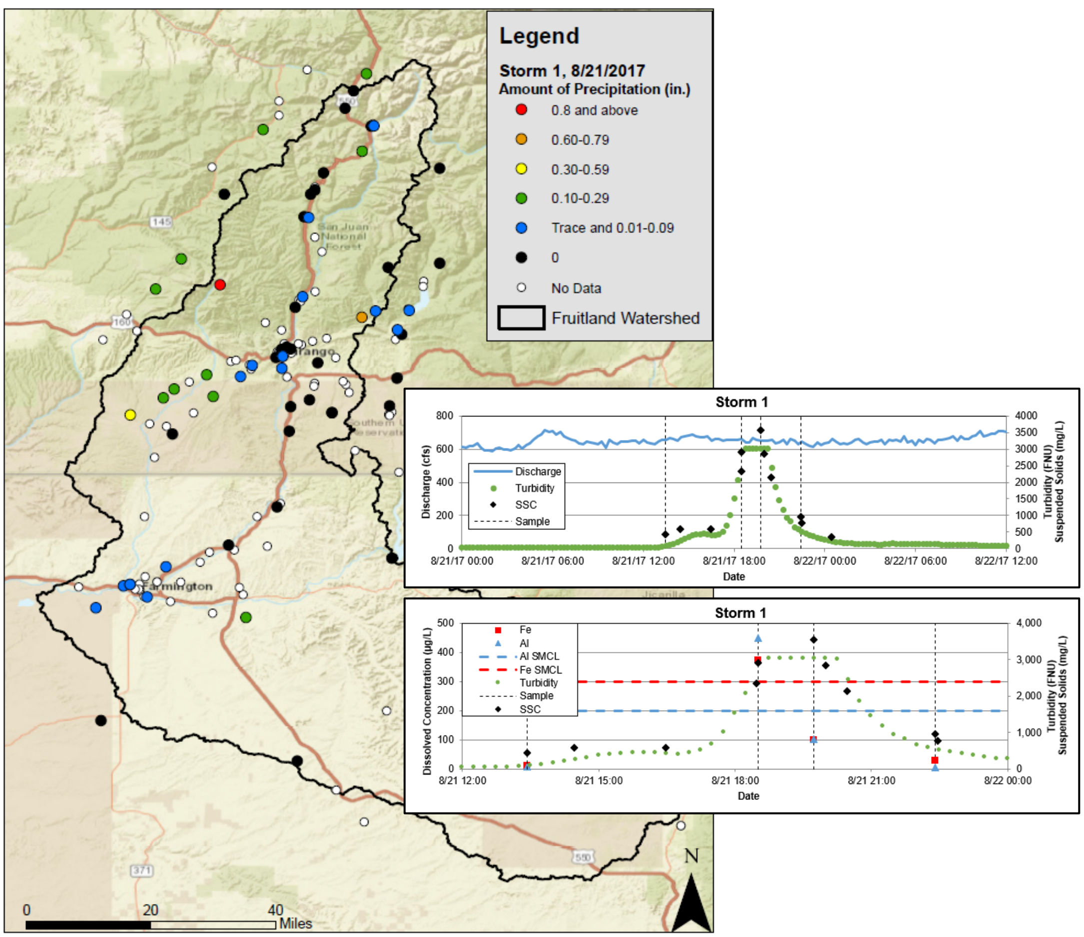
Water Quality Impacts in the Animas and San Juan River Basins

Science and Technology Program
Research and Development Office
Final Report ST-2020-1790-01



U.S. Department of the Interior

September 2020

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
09-15-2020	Research	01-10-2016 – 09-15-2020

4. TITLE AND SUBTITLE Water Quality Impacts in the Animas and San Juan River Basins	5a. CONTRACT NUMBER FA910
	5b. GRANT NUMBER -
	5c. PROGRAM ELEMENT NUMBER 1541 (S&T)
6. AUTHOR(S) Alyssa Aligata, aaligata@usbr.gov, 303-445-2264	5d. PROJECT NUMBER Final Report ST-2020-1790-01
	5e. TASK NUMBER -
	5f. WORK UNIT NUMBER 86-68190
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation, Technical Service Center, Water Treatment 6th & Kipling Street Denver, CO 80225	8. PERFORMING ORGANIZATION REPORT NUMBER -
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Science and Technology Program Research and Development Office Bureau of Reclamation U.S. Department of the Interior Denver Federal Center PO Box 25007, Denver, CO 80225-0007	10. SPONSOR/MONITOR'S ACRONYM(S) Reclamation 11. SPONSOR/MONITOR'S REPORT NUMBER(S) Final Report ST-2020-1790-01

12. DISTRIBUTION/AVAILABILITY STATEMENT
Final Report may be downloaded from https://www.usbr.gov/research/projects/index.html

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Navajo-Gallup Water Supply Project will convey water from the San Juan River to the Navajo Nation, the Jicarilla Apache Nation, and the City of Gallup, New Mexico. One aspect of the NGWSP is the design and construction of the San Juan Lateral (SJL) water treatment plant (WTP). The SJL WTP will treat water from the San Juan River to meet Safe Drinking Water Act (SDWA) requirements. This project is intended to provide information to determine how monsoon events affect the influent water quality to the SJL WTP. Parameters that exceeded SDWA limitations during storm events include several total metals and total dissolved solids. No correlation was observed between discharge flow rate and turbidity or suspended sediment concentration (SSC) in the San Juan River near the proposed intake. Turbidity correlated to several total metals. Evidence suggests that when SSC was high during Storm Event 3, the turbidimeter incorrectly recorded decreasing turbidity. Without Storm Event 3 data, turbidity correlates to SSC. When the turbidimeter is recording values lower than its maximum recording limit, it may be used to predict SSC and some total metals. Dissolved metals did not correlate to turbidity, SSC, discharge, or total metals.

15. SUBJECT TERMS
San Juan River, Animas River, Monsoons, Metals Concentrations, Suspended Sediment Concentration

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Alyssa Aligata
a. REPORT U	b. ABSTRACT U	THIS PAGE U		108	19b. TELEPHONE NUMBER *(Include area code)* 303-445-2264

Water Quality Impacts in the Animas and San Juan River Basins

Final Report ST-2020-1790-01

prepared by

Technical Service Center
Water Treatment Group
Alyssa Aligata, Civil Engineer, Project Manager

Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer

Information in this report may not be used for advertising or promotional purposes. The data and findings should not be construed as an endorsement of any product or firm by the Bureau of Reclamation, Department of Interior, or Federal Government. The products evaluated in the report were evaluated for purposes specific to the Bureau of Reclamation mission. Reclamation gives no warranties or guarantees, expressed or implied, for the products evaluated in this report, including merchantability or fitness for a particular purpose.

Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research. I would like to acknowledge Catherine Hoffman, Julie Korak, Jeb Brown, Dave Varyu, Jose Feliciano Cestero, and Jack Truax for their contributions to this project.

Peer Review

Bureau of Reclamation
Research and Development Office
Science and Technology Program

Final Report ST-2020-1790-01

Water Quality Impacts in the Animas and San Juan River Basins

ALYSSA ALIGATA Digitally signed by ALYSSA ALIGATA Date: 2020.09.24 15:33:11 -06'00'

Prepared by: Alyssa Aligata
Civil Engineer, Bureau of Reclamation, Water Treatment Group

KATHERINE GUERRA Digitally signed by KATHERINE GUERRA Date: 2020.09.24 15:54:32 -06'00'

Peer Review by: Katie Guerra, P.E.
Civil Engineer, Bureau of Reclamation, Water Treatment Group

Acronyms and Abbreviations

μg/L	micrograms per liter
AMD	acid mine drainage
ARD	acid rock drainage
CWA	Clean Water Act
DLBLK	detection limit by blank data
DLDQC	detection limit by DQCALC (USGS software to determine detection and reporting levels). Lowest concentration that with 90% confidence will be exceeded no more than 1% of the time when a blank sample is measured (<1% false positive risk). It is also the critical level by ASTM D6091 approximately equals the method detection limit.
EPA	U.S. Environmental Protection Agency
FNU	Formazin Nephelometric Unit
ft^3/s	cubic feet per second
GIS	geographic information system
HUC	USGS Hydrologic Unit Code
LOWESS	Locally Weighted Scatterplot Smoothing
MCL	maximum contaminant level
mg/L	milligrams per liter
MRL	minimum reporting level
mS/cm	milli Siemens per centimeter
NGWSP	Navajo-Gallup Water Supply Project
NOAA	National Oceanic and Atmospheric Administration
NTU	nephelometric turbidity unit
NWIS	National Weather Information System
Reclamation	Bureau of Reclamation
S&T	Science and Technology
SCADA	supervisory control and data acquisition
SJL	San Juan Lateral
SMCL	secondary maximum contaminant level
SSC	suspended sediment concentration
SU	standard units
TDS	total dissolved solids
TSS	total suspended solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WTP	water treatment plant

Contents

Page

Appendices

Tables

Page

Tables (continued)

Page

Figures

Page

Executive Summary

The Navajo-Gallup Water Supply Project (NGWSP) will convey municipal and industrial water from the San Juan River to the eastern section of the Navajo Nation, the southwestern portion of the Jicarilla Apache Nation, and the City of Gallup, New Mexico. One aspect of the NGWSP is the design and construction of the San Juan Lateral (SJL) water treatment plant (WTP). The SJL WTP will treat water from the San Juan River to meet Safe Drinking Water Act (SDWA) requirements. While historical water quality data for this watershed is available, more information is needed to determine how monsoon events affect the influent water quality to the SJL WTP. Chemical dosing and filter run times are examples of water treatment operational parameters that are dependent on the influent water quality.

The specific objectives of this study are to:

1. Identify the duration and magnitude of water quality fluctuations in the San Juan River based on the data collected and analyzed.

2. Determine if there is a relationship between flow, turbidity, and suspended sediment concentrations in the San Juan River near the proposed WTP intake location (Hogback Diversion).

3. Assess if/how online turbidity or suspended sediment measurements can be used to inform WTP intake operations.

4. Determine whether suspended sediment or metals concentration is the primary water quality parameter that would dictate temporarily suspending river water intake to the WTP.

This project measured water quality from four storm events: three in 2017 and one in 2018. Turbidity, discharge flow rate, and SSC were measured throughout the storms. Other water quality parameters, including total and dissolved metals, were measured several times during each storm. The parameters that exceeded SDWA limitations during the storm events were dissolved aluminum, dissolved iron, total aluminum, total antimony, total arsenic, total barium, total beryllium, total cadmium, total chromium, total iron, total lead, total manganese, total thallium, total uranium, total dissolved solids, and sulfate.

The duration of the water quality impacts to the river from the storms ranged from approximately 12 hours (Storm Event 1) to 4 days (Storm Event 3); however, based on the level of suspended sediment and metals, water intake may not need to be suspended for the entire storm event.

No correlation was observed between discharge flow rate and turbidity or suspended sediment concentration (SSC) in the San Juan River near the Hogback Diversion, based on data from the four storms studied. This may be a characteristic of the San Juan River because there are many ephemeral streams in its watershed that could increase solids without increasing riverflow. We believe that the turbidimeter falsely recorded low values during Storm Event 3 because the high suspended sediment concentration interfering with its measurement process. When Storm Event 3 data were excluded, the relationship between turbidity and suspended sediment concentration was strong. Strong correlations also occurred with turbidity and many total metals; therefore, there is

potential to use turbidity to predict SSC and several total metals if the turbidity is not near the maximum recording limit of the turbidimeter.

The suspended sediment from all four storms had similar metals content. SSC displayed linear relationships with many of the total metals, even when Storm Event 3 data was included. This information could be useful for plant operators, who could use these linear relationships to calculate total metals exceedances based on the influent SSC. However, complete further testing is recommended to ensure that all total metals can be quantified by the laboratory. During Storm Event 3, the samples were diluted too much to obtain an accurate reading for some of the total metals. Because Storm Event 3 produced the most extreme metals results, it is recommended that further work be completed to ensure these relationships.

The SJL WTP intake will first feed into presedimentation basins designed to settle much of the suspended sediment in the influent water before the water enters the rest of the WTP processes. The tentative target intake shutdown SSC is 12,000 milligrams per liter (mg/L) based on the preliminary Reclamation SJL WTP 30% design assumptions. Only three samples taken during this study were above this limit, and they were all during Storm Event 3. These samples included the highest concentrations of total aluminum, arsenic, barium, beryllium, cadmium, chromium, iron, lead, manganese, and uranium. One of these samples had very high levels of dissolved aluminum and dissolved iron, but the other two samples had relatively low concentrations. Conversely, there were four samples with much lower SSC values that also had high dissolved metals concentrations. Intake design engineers should consider the implications of potential metals concentrations when they finalize target intake shutdown limit based on SSC. At 12,000 mg/L, water will be allowed into the intake that may have elevated total/dissolved metals concentrations. Dissolved metals would likely pass through the pretreatment sedimentation basins; therefore, it may be necessary to conduct further research to discover why dissolved metals did not correlate to total metals and to determine if there is a way to predict high dissolved metals concentrations.

1. Introduction

The Navajo-Gallup Water Supply Project (NGWSP) will convey municipal and industrial water from the San Juan River to the eastern section of the Navajo Nation, the southwestern portion of the Jicarilla Apache Nation, and the City of Gallup, New Mexico (NM). One aspect of the NGWSP is the design and construction of the San Juan Lateral (SJL) water treatment plant (WTP). The SJL WTP will treat water from the San Juan River. One of the proposed intakes for this WTP is at the Hogback Diversion, located on the San Juan River about 12 miles above Shiprock, New Mexico, and about 22 river miles downstream of Farmington, New Mexico (Bureau of Reclamation, 2016a) (Figure 1).

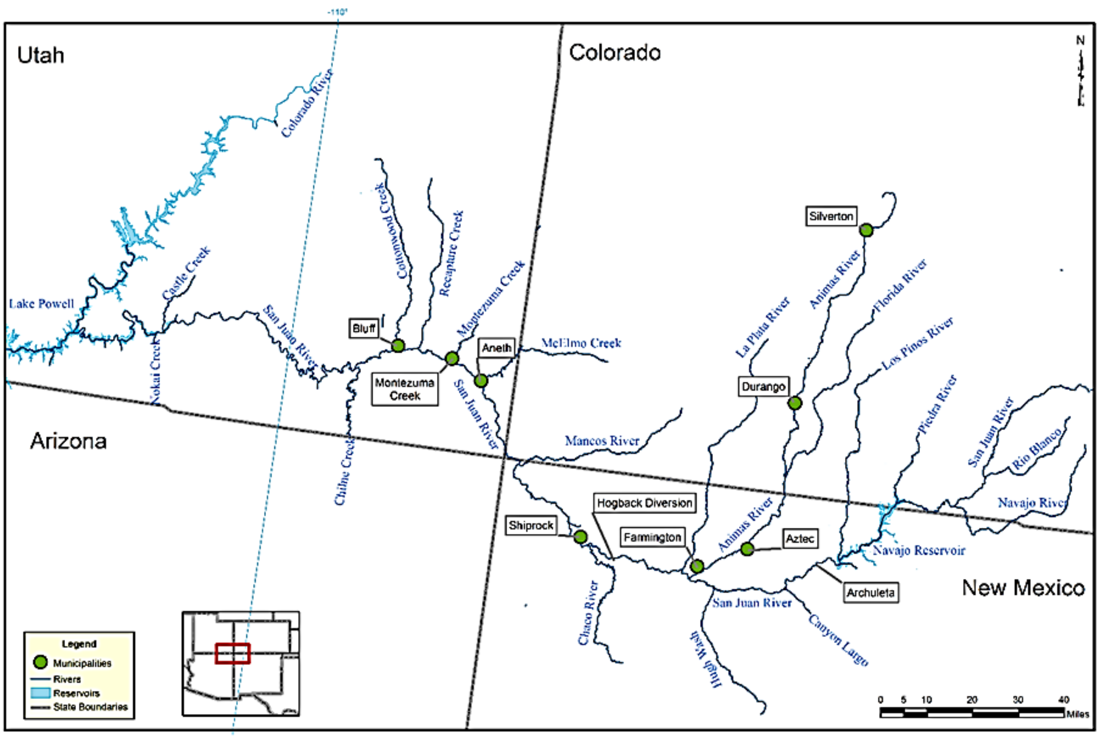


Figure 1. Map of the San Juan River showing the Hogback Diversion location and nearby towns (Bureau of Reclamation, 2016a).

The Bureau of Reclamation (Reclamation) has collected water quality samples from the San Juan River and Hogback Diversion, performed settling tests, and completed water treatment pilot tests at this proposed intake location. The Gold King Mine spill in August 2015 caused water quality fluctuations during monsoon events, particularly related to metals concentrations, that need to be better understood (Bureau of Reclamation, 2016b). Past sampling efforts have shown that flow variations due to snowmelt and precipitation caused abrupt changes in sediment transport and water quality. During these peak events, increases in total and dissolved metals concentrations of one to two orders of magnitude were observed. The dissolved metals concentrations were even measured at levels above the Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs). High metals concentrations in the influent water could impact finished water quality and solids disposal. Monsoon events could also transport high amounts of total suspended solids (TSS). This concept is well

documented in the Hogback Diversion through previous sampling, but the fluctuations in dissolved metals concentrations are not well documented yet (Bureau of Reclamation, 2016a).
Because monsoon events can drastically change the influent water quality to the SJL WTP, these weather events could cause problems for water treatment operations. Operational water treatment parameters, such as chemical dosing and filter run times, are dependent on the influent water quality. Additional data analyses are necessary to better understand the influent water conditions during monsoons, especially the duration and magnitude of the water quality fluctuations. The objectives of this project are to:

1. Identify the duration and magnitude of water quality fluctuations in the San Juan River based on the data collected and analyzed

2. Determine if there is a relationship between flow, turbidity, and suspended sediment concentrations in the San Juan River near the proposed WTP intake location

3. Assess if/how online turbidity or suspended sediment measurements can be used to inform WTP intake operations

4. Determine whether suspended sediment or metals concentration is the primary water quality parameter that would dictate temporarily suspending river water intake to the WTP

1.1 Historical Water Quality Evaluation

One of the proposed locations for the NGWSP SJL WTP intake is the Hogback Diversion, which is located in northwest New Mexico along the San Juan River. As part of a previous Science & Technology (S&T) scoping project (Final Report-2016-SJR16-01) (Reclamation, 2016a), a literature review was conducted of previous water quality sampling in the San Juan River and the surrounding watershed. The San Juan River is a tributary of the Colorado River, and the watershed for it overlaps the Four Corners Area (Colorado, Utah, Arizona, and New Mexico) as shown in Figure 2. The entire drainage area of this watershed (hydrologic unit 1408) covers 64,577 square kilometers (km^2) and includes both perennial tributaries that flow year round (e.g., Animas River) and ephemeral streams that flow intermittently after precipitation events (e.g., Cañon Largo) (Bureau of Reclamation, 2016a).

The four subbasins of this drainage area are shown in Figure 3. The Upper San Juan and Piedra subbasins (depicted together in Figure 3) make up the largest area within the watershed (8,887 km^2 and 1,752 km^2, respectively) and include Navajo Reservoir. The Blanco Canyon subbasin has an area of 4,439 km^2. The primary tributary of the San Juan River is Cañon Largo, which is in this subbasin and is an ephemeral stream that only flows during summer precipitation events (USDA Natural Resources Conservation Service, 2007). The next largest subbasin is the Animas subbasin, which covers 3,350 km^2 and includes the Animas River. The headwaters of the Animas River are north of Silverton, Colorado. The Animas subbasin does not have any reservoirs along the main reach of the Animas River to manage flow; therefore, temporal variations in water quality and flow are not reduced before the water enters the San Juan River (Bureau of Reclamation, 2016a). The last subbasin in the Hogback watershed is the Middle San Juan subbasin, which includes La Plata River. A portion of this subbasin lies west of the Hogback Diversion, so runoff would enter the San Juan River downstream of this proposed intake.

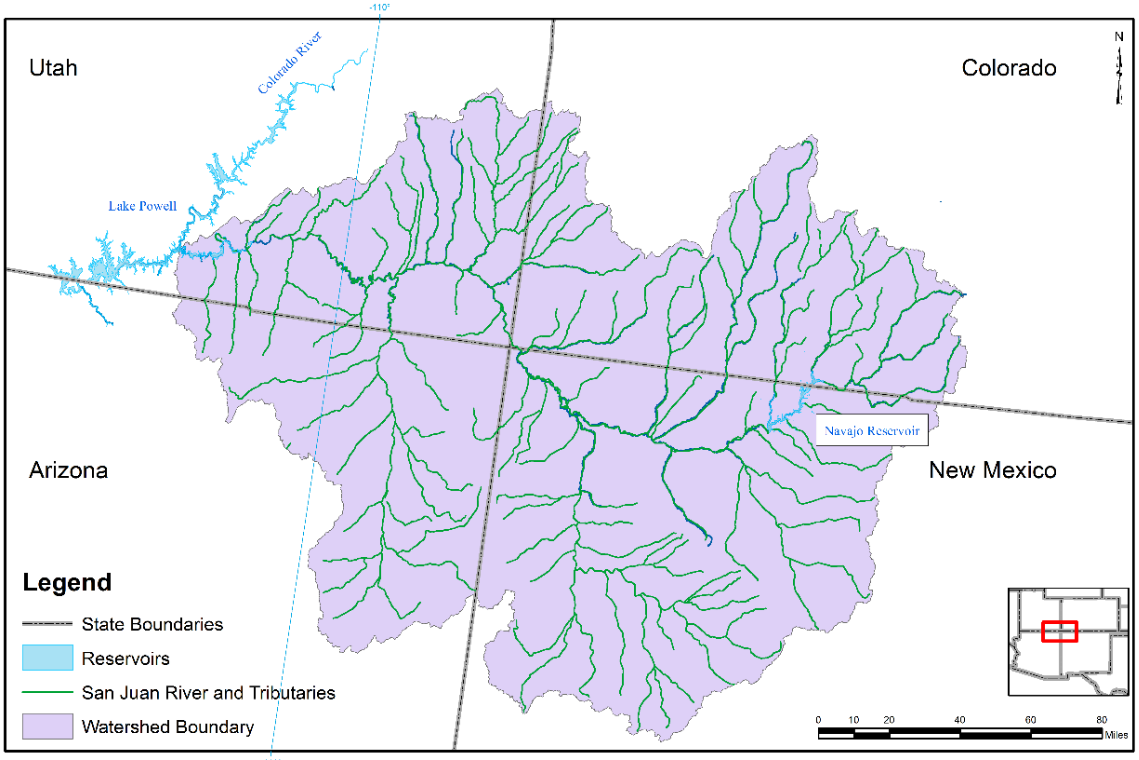


Figure 2. San Juan River watershed boundary and primary tributaries. Data source: USGS Watershed Boundary Dataset Hydrologic Unit (HUC) 1408 (Bureau of Reclamation, 2016a).

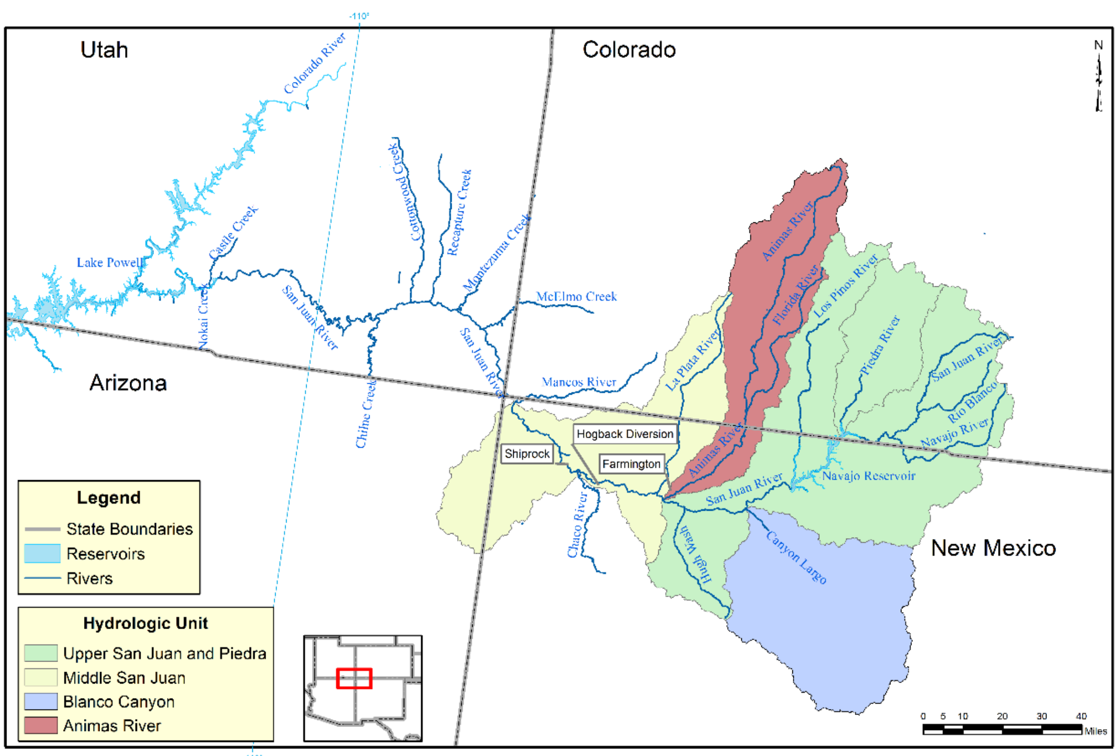


Figure 3. San Juan River watershed boundaries (8-digit) upstream of the Hogback Diversion. Data source: USGS Watershed Boundary Dataset (Bureau of Reclamation, 2016a).

To provide perspective for the summarized historical data, the reported values were compared to water quality standards in both the Clean Water Act (CWA) and the SDWA. The CWA regulates surface water quality based on criteria developed for designated uses such as domestic water supply, irrigation supply, and recreation. New Mexico criteria for domestic water supply and irrigation for metals are summarized in Table 1 (New Mexico Water Quality Control Commission, n.d.). The SDWA regulates water quality in treated drinking water. Primary (enforceable) maximum contaminant levels (MCL) and secondary (nonenforceable) maximum contaminant levels SMCLs for select inorganic constituents are summarized in Table 2. SDWA standards are based on total concentrations, not dissolved concentrations. Usually, the particulate fraction in treated drinking water is negligible after filtration. By comparing dissolved concentrations to SDWA standards, constituents can be identified that warrant further investigation during the WTP design and operation. Comparing water quality data from the literature review or from this study to CWA or SDWA standards does not imply any regulatory implications or noncompliance. The historical water quality and data collected in this project apply to the raw water and do not take the treatment process into consideration. SDWA regulations are for finished water leaving the WTP. This data may also not be representative of the data that would be collected for CWA compliance with respect to sampling frequency or location. Comparisons are included to provide contextual perspective to the data and identify potential contaminants of interest (Bureau of Reclamation, 2016a).

Table 1. New Mexico State Criteria for Surface Water Protection via the CWA (NMAC 20.6.4.900) (Bureau of Reclamation, 2016a)

Parameter	Designated Use	
	Domestic Water Supply (µg/L)	Irrigation (µg/L)
Aluminum, dissolved		5,000
Antimony, dissolved	6	
Arsenic, dissolved	10	100
Barium, dissolved	2,000	
Beryllium, dissolved	4	
Boron, dissolved		750
Cadmium, dissolved	5	10
Chromium, dissolved	100	100
Cobalt, dissolved		50
Copper, dissolved	1,300	200
Lead, dissolved	15	5,000
Mercury	2	
Molybdenum, dissolved		1,000
Nickel, dissolved	700	
Nitrate as N	10,000	
Selenium, dissolved	50	*
Thallium, dissolved	2	
Uranium, dissolved	30	
Vanadium, dissolved		100
Zinc, dissolved	10,500	2,000

* If SO_4 < 500 mg/L, criterion is 0.13 mg/L. If SO_4 > 500 mg/L, criterion is 0.25 mg/L.
Note: µg/L = micrograms per liter, mg/L = milligrams per liter.

Table 2. Select SDWA MCLs (Bureau of Reclamation, 2016a)

Parameter	MCL	SMCL
Aluminum		50-200 µg/L
Antimony	6 µg/L	
Arsenic	10 µg/L	
Barium	2,000 µg/L	
Beryllium	4 µg/L	
Cadmium	5 µg/L	
Chloride		250 mg/L
Chromium	100 µg/L	
Color		15 color units
Copper	1,300* µg/L	
Fluoride	4.0 mg/L	2.0 mg/L
Iron		300 µg/L
Lead	15* µg/L	
Manganese		50 µg/L
Mercury	2 µg/L	
Nitrate	10 mg/L as N	
Nitrite	1 mg/L as N	
pH		6.5-8.5
Selenium	50 µg/L	
Silver		100 µg/L
Sulfate		250 mg/L
Thallium	2 µg/L	
TDS		500 mg/L
Uranium	30 µg/L	
Zinc		5,000 µg/L

* Action level

Note: TDS = total dissolved solids

The subbasins surrounding Navajo Reservoir and its tributaries are the Upper San Juan and Piedra Subbasins. For purposes of this report, both subbasins will be referred to as the Upper San Juan Subbasin. Water quality and hydrology in this subbasin are strongly influenced by the Navajo Reservoir, which extends about 35 miles upstream from Navajo Dam. Irregularities in flow and water quality from upstream tributaries are dampened by a long residence time in the reservoir. The San Juan River flows out of Navajo Dam and heads West. Historical data in this subbasin was measured at Navajo Reservoir by Reclamation and the San Juan River near Archuleta, New Mexico (downstream of Navajo Dam) by the U.S. Geological Survey (USGS) National Water Information System (NWIS). The only observed SDWA exceedances were for total iron and total manganese in the San Juan River (Table 3) (Bureau of Reclamation, 2016a).

Table 3. Historical SDWA Exceedances in the Upper San Juan Subbasin

Parameter	Units	Upper San Juan Subbasin					
		Reclamation (2000)		NWIS Database			
		Navajo Reservoir		San Juan River at Archuleta (1970-2016)			
		No.	Mean	No.	Minimum	Maximum	Mean
Iron, total	µg/L	–	–	40	10	19,000	891
Manganese, total	µg/L	1	48	28	10	270	30

Notes: Orange highlighted values represent values above SMCLs.

The Animas Subbasin consists of historical mining areas around Silverton, Colorado, with hundreds of abandoned mines, mine tailings, and waste sites that contribute to acid mine drainage (AMD) in the headwaters of this watershed. The Animas River is the primary drainage for this subbasin. AMD occurs when water and oxygen react with sulfide containing minerals to produce acidic water. Acidic water dissolves metals in rocks and produces water with higher concentrations of iron, aluminum, cadmium, arsenic, and other elements in the local geological formations (Bureau of Reclamation, 2016a). The reactions that contribute to AMD can occur naturally without mining; this is called acid rock drainage (ARD). Waters influenced by AMD and ARD have higher concentrations of metals compared to surface water that is not impacted by these processes (Bureau of Reclamation, 2016a). A significant amount of the metal load in the Animas River is from ARD rather than mining related AMD (Church, et al., 1997) (Church, et al., 2007).

The historical data for the Animas River showed that the average dissolved manganese, total manganese, and total iron concentrations were higher than the SDWA SMCLs in the Colorado section of the Animas River (Table 4). For the NM section of the river, the mean dissolved manganese concentration (48 µg/L) was just under the SMCL (50 µg/L). Total manganese, total aluminum, total iron, and total lead mean concentrations were above SDWA limitations on the New Mexico section of the Animas River. NWIS data from the Animas River at Farmington, New Mexico, showed exceedances in total aluminum, total arsenic, total iron, total lead, total manganese, dissolved manganese, and total sulfate (Bureau of Reclamation, 2016a). Some constituents have SMCLs instead of MCLs because these constituents contribute to aesthetic qualities in treated drinking water rather than health implications; however, it is still important for the NGWSP SJL WTP to meet SMCLs to have consumer confidence in the water (Bureau of Reclamation, 2016a).

The Blanco Canyon Subbasin's main drainage is Cañon Largo, which is an ephemeral stream that is one of the largest contributors of suspended sediment and salinity to the San Juan River watershed. While the Animas River is known for water quality issues related to metals, it is not a major contributor of total suspended sediment. The high salinity from Cañon Largo is due to the mobilization and transport of weathered soils in the ephemeral watershed. There is not much historical data for this subbasin, but the data available show highly variable flows that peak during the summer and high suspended sediment concentrations. The historical data also showed exceedances in concentrations of dissolved aluminum, total arsenic, total barium, total beryllium, total chromium, dissolved iron, total iron, total lead, dissolved manganese, total manganese, total mercury, TDS, and sulfate that were higher than SDWA limitations (Table 5) (Bureau of Reclamation, 2016a). Total aluminum was not measured at this location.

Table 4. Historical SDWA Exceedances in the Animas Subbasin

Parameter	Units	Animas Subbasin							
		Reclamation (2000)				NWIS 2000-2016			
		Colorado		New Mexico		Animas River at Farmington, New Mexico			
		No.	Mean	No.	Mean	No.	Minimum	Maximum	Mean
Aluminum, total	µg/ L	2	0	56	2,860	3	1,270	4,490	2,407
Arsenic, total	µg/ L	243	21.1	304	8.8	3	1.3	26.3	9.7
Iron, total	µg/ L	344	501	26	3,650	3	2,000	36,500	13,697
Lead, total	µg/ L	338	13.5	198	29.4	3	6.6	552	192.4
Manganese, dissolved	µg/L	757	87.9	211	48.3	30	1.7	91	23.6
Manganese, total	µg/ L	244	416	148	231	3	141	448	250
Sulfate, total	mg/ L	4	67	291	154	38	32.9	390	145.4

Note: Red highlighted values represent values above MCLs. Orange highlighted values represent values above SMCLs.

Table 5. Historical SDWA Exceedances in the Blanco Canyon Subbasin

Parameter	**Units**	**Blanco Canyon Subbasin NWIS Database Cañon Largo (Dec 1977 – Sept 1981)**			
		No.	**Minimum**	**Maximum**	**Mean**
Aluminum, dissolved	µg/ L	4	30	200	115
Arsenic, total	µg/ L	21	2	480	69
Barium, total	µg/ L	5	100	10,000	2,400
Beryllium, total	µg/ L	5	10	50	23
Chromium, total	µg/L	5	4	400	143
Iron, dissolved	µg/ L	28	10	970	133
Iron, total	µg/ L	7	300	890,000	409,900
Lead, total	µg/ L	2	300	500	400
Manganese, dissolved	µg/ L	12	0	4,400	1,872
Manganese, total	µg/ L	8	180	48,000	22,318
Mercury, total	µg/ L	20	0.1	4	2
TDS	mg/L	23	615	10,200	3,853
Sulfate, total	mg/L	23	300	6,000	2,336

Note: Red highlighted values represent values above MCLs. Orange highlighted values represent values above SMCLs.

The Middle San Juan Subbasin's primary drainage above the Hogback Diversion is the La Plata River. The headwaters of this river are in the La Plata Mountains in southwestern Colorado. Water quality in this subbasin is impacted by agriculture and mining (although mining impacts are not as high as in the Animas Subbasin). According to historical data from the La Plata River, the water has the potential to be moderately saline and enriched in metals. High TDS concentrations above the SCML of 500 mg/L were observed. High sulfate concentrations were also observed above the SCML of 250 mg/L. The La Plata River data also showed total aluminum, total arsenic, total iron, total lead, dissolved manganese, and total manganese at levels above SDWA limitations (Table 6)

The Middle San Juan Subbasin also contains another section of the San Juan River. Historical data is available for this river at three locations: Farmington, Shiprock, and the Hogback Diversion. Parameters observed to exceed MCLs or SMCLs are dissolved aluminum, total aluminum, total cadmium, dissolved iron, total iron, total lead, dissolved manganese, total manganese, and TDS (Table 6).

Total iron and total manganese can be present at high levels in any of the four subbasins, but Blanco Canyon has seen the highest concentrations. High levels of total arsenic, total lead, dissolved manganese, and sulfate were seen at all subbasins, except the Upper San Juan Subbasin. Total arsenic, dissolved manganese, and sulfate concentrations were, by far, the highest in the Blanco Canyon Subbasin. Total lead had very high concentrations in the Animas and Blanco Canyon Subbasins. Dissolved aluminum, dissolved iron, and TDS exceeded SDWA limitations in the Blanco Canyon and Middle San Juan Subbasins. The maximum observed dissolved aluminum and dissolved iron concentrations were in the Middle San Juan Subbasin at the Hogback Diversion. The highest observed TDS sample was in the Blanco Canyon Subbasin. Total aluminum exceeded the SMCL in the Middle San Juan and Animas Subbasins. The highest observed concentrations were in the San Juan River at the Hogback Diversion and Shiprock (Middle San Juan Subbasin). Total cadmium was only observed to exceed the MCL in the Middle San Juan Subbasin at the San Juan River near Farmington. Total barium, total beryllium, total cadmium, and total mercury were only observed to exceed limitations in the Blanco Canyon Subbasin. The literature review provides the complete historical data and a much more detailed analysis of the historical water quality in each subbasin; refer to this report for further details (Bureau of Reclamation, 2016a).

Table 6. Historical SDWA Exceedances in the Middle San Juan Subbasin

Parameter	Units	Middle San Juan Subbasin											
		Reclamation (2000)								NWIS Database			
		Colorado		New Mexico		Farmington, New Mexico		Shiprock, New Mexico		Hogback Diversion			
		No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Minimum	Maximum	Mean
Aluminum, dissolved	µg/L	–	–	83	18.9	34	34.4	138	58.5	12	8.6	2,380	225
Aluminum, total	µg/L	–	–	65	2,612	30	5,283	83	15,636	12	935	105,000	17,204
Arsenic, total	µg/L	135	15.4	330	19.9	78	2.8	224	4.4	6	1	3.7	2.1
Cadmium, total	µg/L	–	–	8	1.8	12	5.7	29	3.6	12	0.1	2	0.5
Iron, dissolved	µg/L	–	–	69	14.3	164	47.2	251	31.2	12	5.7	3,600	316
Iron, total	µg/L	–	–	23	208,135	15	25,691	39	30,449	5	2,640	7,780	4,468
Lead, total	µg/L	–	–	165	18.7	79	30.3	222	27.6	12	1.9	149	32
Manganese, dissolved	µg/L	133	36.2	185	164	26	22.3	110	45	12	0.8	151	18
Manganese, total	µg/L	136	107	196	2,118	20	852	56	978	12	64.3	5,750	997
TDS	mg/L	–	–	74	1,437	374	382	667	498	12	186	550	349
Sulfate, total	mg/l	137	218	103	889	827	154	1,083	225	12	63.4	228	129

Notes: Reclamation (2000) for Colorado and New Mexico sampling at La Plata River. Reclamation (2000) for Farmington and Shiprock sampling at San Juan River. Red highlighted values represent values above MCLs. Orange highlighted values represent values above SMCLs.

1.2 Previous Work

Reclamation has been sampling the San Juan River since 2007 to compile data for the NGWSP SJL WTP design. Sampling at the Hogback Diversion has been a collaborative effort between Reclamation and USGS. During irrigation seasons, Reclamation used an in situ sensor to measure either turbidity or TSS. Reclamation also took grab samples to measure total organic carbon, dissolved organic carbon, turbidity, and TSS. USGS also used in situ monitoring to measure turbidity, gage height, and flow in the Hogback Diversion. An ISCO sampler also collected samples for suspended sediment concentration every 24 hours, unless the turbidity sensor recorded measurements of greater than 200 FNU. In this case, samples for suspended sediment concentration (SSC) were increased to every 2 hours. During irrigation season, USGS took monthly samples for a suite of parameters including temperature, dissolved oxygen, major ions, dissolved metals, and total metals.

Results from these previous sampling efforts guided the sampling plan development for this project. Historical data from the Hogback Diversion in the San Juan River showed that there are large variations in TSS and turbidity. Previous research demonstrated that large changes in riverflow produced high suspended solids events; however, there was a lot of variability in the frequency and magnitude of the suspended sediment events in relation to the riverflow. Reclamation completed a data analysis of U.S. Environmental Protection Agency (EPA) and Reclamation data collected after the Gold King Mine spill and found that high suspended solids events were accompanied by high metal concentrations (Bureau of Reclamation, 2016c). After the spill, the EPA collected daily total and dissolved metals data and found that high metal concentrations correlated to higher flows in the Animas River. The data also showed that increases in total metals concentrations correlated to increases in dissolved metal concentrations. Some knowledge gaps exist with this data, however, because solids events could occur over the course of hours to days. If only daily samples are available, valuable information may be missing because the data is too coarse.

This project was developed to fill knowledge gaps in the previously collected data. The sampling plan was designed to better provide answers for the question: "How can water quality fluctuations due to hydrological events be anticipated and adverse impacts mitigated through strategic intake operations?" This project also aims to understand how river hydrology, particularly precipitation events, impacts water quality that would enter the NGWSP SJL WTP. Another goal of this project is to provide necessary information that can be used to assess the need for suspended intake of water, when necessary, to facilitate WTP operations.

2. Methods

2.1 Water Quality Sampling

Due to the lack of storm-specific water quality sampling in the past, the goal of this project was to monitor the San Juan River closely during monsoon season. Reclamation partnered with USGS for the sampling in this study. USGS has sampling instrumentation installed at multiple locations of interest including Hogback Diversion (Site No. 09367580), Fruitland (Site No. 09367540), Farmington (Site No. 09365000), Aztec (Site No. 09364010), and Cedar Hill (Site No. 09363500)

(Figure 4). As discussed in the previous section, the proposed intake location for the NGWSP SJL WTP is near the Hogback Diversion. Reclamation (2016a) discussed previous sampling locations that USGS and Reclamation have used at the Hogback Diversion, as well as the equipment located at each of the sample spots. None of the sampling spots at the Hogback Diversion met all of the desired qualifications for this study; therefore, a different monitoring location (Fruitland) was chosen for this study. As seen in Figure 4, the Fruitland sampling location is just upstream from the Hogback Diversion sampling location. Fruitland already had a stream gage, turbidity sensor, and sediment gage installed. The only piece of equipment requiring installation at Fruitland (which would have been a required installation at any chosen location) is an autosampler (ISCO 6712) to collect water samples (such as total and dissolved metals) for water quality analyses. Table 7 summarizes the instrumentation and sampling frequency at Fruitland.

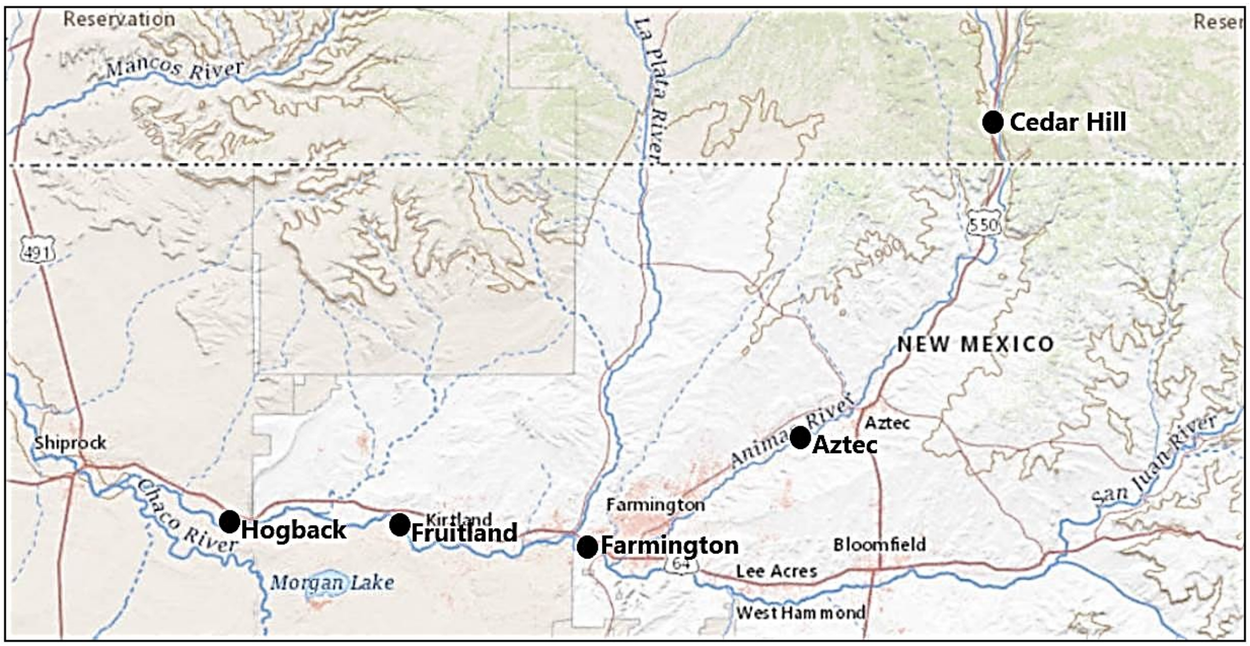


Figure 4. USGS sampling locations (black dots) relevant to this study.

Table 7. USGS Sampling Instrumentation and Sample Frequency

Unit	Description	Frequency
Stream gage	Online monitoring station measuring gage height	Every 15 minutes; uploaded to NWIS every 60 minutes
Turbidity sensor	Online sensor submerged in river	Every 15 minutes; uploaded to NWIS every 60 minutes
Sediment gage	Autosampler for suspended sediment concentration	1 sample per day; every 2 hours if turbidity > 200 FNU
Storm water sampler	Autosampler for water quality analyses	Triggered via modem by USGS

Historical data from the San Juan River show no statistically significant relationship between river discharge flow and turbidity (Bureau of Reclamation, 2016a). Sometimes, almost imperceptible changes in flow caused big spikes in turbidity, and sometimes the opposite was true; therefore, turbidity was chosen as the parameter to trigger storm sampling in this study, rather than streamflow. A peak turbidity event suitable for expanded water quality analysis was defined as an event in which turbidity sensors observe a peak turbidity value of at least 2,000 FNU for at least 2 hours.

Sampling for this study took place during monsoon season (June through October) in 2017 and 2018. During these two monsoon seasons, Reclamation worked with USGS to monitor for storms by checking the weather forecast for Durango, Colorado, and for Aztec and Farmington, New Mexico, a few times per week. If rain was in the forecast, Reclamation and USGS checked the forecast more frequently leading up to the storm day. If the forecast was correct, and it began raining at any location within the watershed, Reclamation and USGS monitored the USGS NWIS website for turbidity at Fruitland, as well as several gage locations upstream from Fruitland (Farmington, Aztec, and Cedar Hill). If increasing turbidity was observed at an upstream location and met the criteria outlined above, USGS calculated the length of time it could potentially take for the turbidity event to reach Fruitland, based on distance and flow in the river. When a suitable turbidity event was observed upstream from Fruitland, the autosampler was triggered to take the first sample at baseline or normal conditions. Reclamation and USGS then tried to time the sampling to capture the rise of turbidity, the peak turbidity, and when turbidity was returning to baseline conditions. This temporary change in water quality due to the storm is referred to as the "storm event," while the precipitation is what defines the "storm."

Table 8 shows the list of parameters measured by USGS for the ISCO samples. The table also lists the reporting limits and their codes. This suite of parameters, including bulk water chemistry, major ions, dissolved trace elements, and total recoverable elements, was chosen to get a comprehensive analysis of the water quality in the San Juan River during storm events in monsoon season. This study is specifically focused on making observations and identifying any trends related to dissolved and total metals during fluctuations in water quality caused by monsoons. Complete sample results from this study can be found in Appendix A, "Water Quality Data."

Table 8. List of USGS Parameters Measured from ISCO Sampler During This Study

USGS Group	Description	Parameter Code	Reporting Limit	Reporting Limit Code
Physical	pH, water, unfiltered, laboratory	00403	0.1 SU	MRL
Sediment	SSC	80154	1 mg/L	MRL
Major Ions (schedule 2701)	Calcium	00915	0.022 mg/L	DLDQC
	Chloride	00940	0.02 mg/L	DLDQC
	Fluoride	00950	0.01 mg/L	DLDQC
	Iron	01046	10 µg/L	DLDQC
	Magnesium	00925	0.011 mg/L	DLDQC
	Potassium	00935	0.1 mg/L	DLDQC
	Sodium	00930	0.1 mg/L	DLDQC
	Specific conductance, laboratory	90095	5 µS/cm	MRL
	Sulfate	00945	0.02 mg/L	DLDQC
Filtered metals (schedule 2710)	Aluminum	01106	3 µg/L	DLBLK
	Antimony	01095	0.03 µg/L	DLBLK
	Arsenic	01000	0.05 µg/L	DLBLK
	Barium	01005	0.1 µg/L	DLBLK
	Beryllium	01010	0.01 µg/L	DLBLK
	Boron	01020	5 µg/L	DLBLK
	Cadmium	01025	0.03 µg/L	DLBLK
	Chromium	01030	0.5 µg/L	DLBLK
	Cobalt	01035	0.03 µg/L	DLBLK
	Copper	01040	0.2 µg/L	DLBLK
	Lead	01049	0.02 µg/L	DLBLK
	Lithium	01130	0.15 µg/L	DLBLK
	Manganese	01056	0.4 µg/L	DLBLK
	Molybdenum	01060	0.05 µg/L	DLBLK
	Nickel	01065	0.2 µg/L	DLBLK
	Selenium	01145	0.05 µg/L	DLBLK
	Silver	01075	1 µg/L	DLBLK
	Strontium	01080	0.5 µg/L	DLBLK
	Thallium	01057	0.02, 0.04 µg/L	DLBLK
	Uranium, natural	22703	0.01 µg/L	DLBLK
	Vanadium	01085	0.1 µg/L	DLBLK
	Zinc	01090	2 µg/L	DLBLK

Table 8. List of USGS Parameters Measured from ISCO Sampler During This Study

USGS Group	Description	Parameter Code	Reporting Limit	Reporting Limit Code
Unfiltered metals (schedule 1080)	Aluminum	01105	3 µg/L	DLBLK
	Antimony	01097	0.09, 0.06 µg/L	DLBLK
	Barium	01007	0.1 µg/L	DLBLK
	Beryllium	01012	0.01 µg/L	DLBLK
	Cadmium	01027	0.03 µg/L	DLBLK
	Chromium	01034	0.5 µg/L	DLBLK
	Cobalt	01037	0.03 µg/L	DLBLK
	Copper	01042	0.2 µg/L	DLBLK
	Lead	01051	0.02 µg/L	DLBLK
	Lithium	01132	0.15 µg/L	DLBLK
	Manganese	01055	0.4 µg/L	DLBLK
	Molybdenum	01062	0.05 µg/L	DLBLK
	Nickel	01067	0.2 µg/L	DLBLK
	Selenium	01147	0.05 µg/L	DLBLK
	Silver	01077	0.03 µg/L	DLBLK
	Strontium	01082	0.5 µg/L	DLBLK
	Thallium	01059	0.02, 0.04 µg/L	DLBLK
	Uranium, natural	28011	0.03 µg/L	DLBLK
	Zinc	01092	2 µg/L	DLBLK
Individual analytes	Arsenic, water, unfiltered	01002	0.05 µg/L	DLBLK
	Bromide, water, filtered	71870	0.01 µg/L	DLDQC
	Iron, water, unfiltered, recoverable	01045	10 µg/L	DLDQC
	Mercury, water, filtered	71890	0.005 µg/L	DLDQC
	Mercury, water, unfiltered	71900	0.005 µg/L	DLDQC
	Vanadium, water, unfiltered	01087	0.5 µg/L	DLBLK

Notes:

If two numbers are listed under Reporting Limit, the first number corresponds with the first three storms, and the second number is for the fourth storm only.

DLBLK = detection limit by blank data. Lowest concentration that will be exceeded no more than 1% of the time when a blank sample is measured (<1% false positive risk) as determined using replicate blank data.

DLDQC = detection limit by DQCALC (USGS software to determine detection and reporting levels). Lowest concentration that with 90% confidence will be exceeded no more than 1% of the time when a blank sample is measured (<1% false positive risk). It is also the critical level by ASTM D6091 approximately equals the method detection limit.

MRL = minimum reporting level. The smallest measured concentration of a constituent that may be reliably reported using a given analytical method.

mS/cm = milli Siemens per centimeter

SU = standard units

2.2 Data Management and Analyses

After the ISCO samples were collected from a storm event, USGS collected the bottles in a timely fashion and sent the samples to a laboratory for analysis. It generally takes a few months for the lab analysis and USGS review before the results are posted on the USGS NWIS website, which is publicly available. The results from the analyses listed in Table 8 (in addition to online turbidity, discharge, and SSC) were downloaded when available. Two turbidimeters are located at Fruitland: one high range and one low range. For this study, only the high range turbidimeter was used because it was more accurate for high turbidity events. The maximum recording level for the turbidimeter was 3,000 FNU for Storm Events 1, 2, and 3, and it was 4,000 FNU for Storm Event 4.

Pairs plots (also known as scatterplot matrices) were used as an exploratory data analysis method to look for relationships between water quality parameters, river discharge, and monsoon events. The pairs plots were generated using R code (see Appendix F, "R Code for Pairs Plots") and include three panels: the diagonal panel, upper panel, and lower panel. The diagonal panel displays histograms of the values for each variable. The lower panel below the diagonal panel displays the scatterplots with Locally Weighted Scatterplot Smoothing (LOWESS) curves for each variable pair. The upper panel above the diagonal panel displays the Kendall's Tau rank correlation coefficients calculated for each pair. The Kendall's Tau values and visual inspection of the pairs scatterplots were used to identify correlated pairs of variables.

Due to the large number of variables included in the analysis (59 variables), it was not practical to include all variables in a single pairs plot. To evaluate every pair combination of these 59 variables, they were divided into six groups, and a pairs plot was generated for each combination of two of these groups (15 combinations). Pairs within the same group (i.e., two variables in the same group) are therefore repeated on several pairs plots, but the pairs that span two groups (i.e., a variable in one group paired with a variable in another group) are unique to a single pairs plot. If constituent concentrations were below a reporting limit, they were plotted at the reporting limit. If all data within a variable were below the reporting limit (i.e., no measurable concentrations), they were not included in the pairs plots. Several samples from Storm Event 3 were diluted 100x due to high metals concentrations; unfortunately, after the dilution several of the metals concentrations were below their reporting limits. Since results are published months after sampling, it was too late to repeat these analyses at appropriate dilutions. These nonquantitative measurements were not included in the pairs plots.

After analysis of the 15 original pairs plots, questions were raised about the validity of the Storm Event 3 turbidity readings, so three additional pairs plots were generated (excluding Storm Event 3 data) to reevaluate potential relationships between turbidity and all other variables. The 15 original pairs plots can be found in Appendix C, "Pairs Plots," and the three additional pairs plots (excluding Event 3 data) can be found in Appendix E, "R Code for Pairs Plots."

2.3 Watershed Delineation and Time of Concentration

The USGS Streamflow Statistics online application (USGS, 2020) was used to determine the watershed delineation for the Fruitland sampling location to identify which stream gages to monitor. This determination was made by generating a watershed delineation with the Fruitland sampling location as the outlet. A watershed delineation was also completed with Navajo Dam as the outlet. Using ArcMap (ESRI, 2020), a geographic information system (GIS) application, the Navajo Dam watershed delineation was subtracted from that of the Fruitland watershed to obtain a more realistic watershed area for Fruitland. The reasoning for this is that Navajo Reservoir is quite large, yielding long residence times and causing it to act as a settling basin. Because this project focused on water quality changes due to storm events, which is on the magnitude of hours, it was more realistic to remove Navajo Reservoir's watershed because any constituents in the runoff going into the reservoir would not occur in the San Juan River on the same timescale.

The time of concentration refers to the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. The hydraulically most distant point is the one that requires the most travel time to reach the watershed outlet. The time of concentration for the Fruitland watershed is 26 hours. This value was determined using the Kirpich Formula (Equation 1), which is one of the standard formulas for determining the time of concentration:

$$T_C = 0.0078 * L^{0.77} * S^{-0.385} \qquad \text{Equation 1}$$

Where:

T_c = the time of concentration in minutes
L = the longest flow path in feet
S = the average channel slope of that path (feet/feet)

For this watershed, the longest flow path comes from the Animas River and originates in the West Fork of the Animas River. The length of this flow path is 149 miles, with an average slope of 0.0106. The time of concentration for Fruitland was used to determine the start/end time of the precipitation in the watershed that contributed to the river response observed for each storm.

Daily precipitation data was downloaded from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information. The Fruitland watershed delineation was used to determine which precipitation gages to observe. In addition to the gages within the watershed, any gages within a 5-mile buffer of the watershed edge were looked at to provide more insight since the gages are spread out and not well dispersed throughout the watershed. Some gages did not have any data during some of the storms in this study. To visualize these data, maps of the watershed area were made that included the precipitation gage locations and amount of precipitation recorded on each day of each storm (Appendix B, "Precipitation Maps"). For each storm, the length of the river response and time of day the river response started/ended were used, in conjunction with the time of concentration, to determine which days of daily precipitation data should be downloaded. For example, if a storm started at midnight, the previous day was considered part of the storm because the time of concentration was approximately 26 hours. A judgement call was made to exclude the 2 days prior to the river response because it could be misleading, considering that the precipitation data applied for the entire day, not hourly.

3. Results

3.1 Storm Event 1

Storm Event 1 was the first, smallest, and briefest storm event sampled in this study. On August 20, 2017, only one precipitation gage within the watershed boundary near Farmington, New Mexico, recorded precipitation between trace amounts and 0.09 inch. Three other gages recorded precipitation within the 5-mile buffer zone outside of the watershed boundary. Of these three gages, two were located near the headwaters of the La Plata River, and one was located east of Durango, Colorado. Both gages near the La Plata River headwaters recorded precipitation between 0.01 and 0.29 inch, while the gage east of Durango recorded trace to 0.09 inch of precipitation. On the second day of Storm 1 (August 21, 2017), 24 additional gages recorded precipitation. The most intense precipitation (0.8 inch or more) was recorded at a gage near the La Plata River headwaters within the watershed boundary. Other gages downstream in the La Plata River recorded precipitation between 0.10 and 0.59 inch. High precipitation (0.60 to 0.79 inch) was also recorded within the watershed boundary east of Durango. Light precipitation occurred around Farmington, New Mexico. Refer to Appendix B, "Precipitation Maps," for precipitation gage locations and intensity. Most of the precipitation from this storm occurred in the Middle San Juan Subbasin, and a small portion occurred in the Animas Subbasin and Upper San Juan Subbasin.

The discharge of the San Juan River, measured at the Fruitland sampling location, stayed relatively constant around 650 cubic feet per second (ft^3/s) (Figure 5). There was a short, slight increase in discharge around 6 a.m. on August 21, 2017, but it soon stabilized. The turbidity began increasing around 1:30 p.m. that afternoon and reached a peak of 3,000 FNU at 6 p.m. The turbidity returned to normal low levels around 1 a.m. on August 23, 2017. For this storm, SSC followed the same trends as turbidity, reaching a maximum of 3,560 mg/L. Four samples were taken to be analyzed for more parameters: one sample at the start of the storm event, two at peak turbidity, and one near the end of the turbidity response.

Aluminum and iron were the only dissolved metals that exceeded SCMLs during this storm, and both exceedances occurred in Sample 2. The dissolved aluminum concentration was more than double the SMCL (Figure 6). Total aluminum concentrations were much higher, exceeding the SMCL (200 μg/L) in all four samples. Total aluminum concentrations reached a peak of 33,600 μg/L in Sample 3 (Figure 7). The SMCL for total iron (300 μg/L) was also exceeded in all four samples, with Sample 3 showing a peak concentration of 40,500 μg/L. Total beryllium exceeded the MCL in Sample 3. The MCL for total lead was exceeded in Samples 2 and 3 (Figure 8), with Sample 3 showing a peak concentration of 43.4 μg/L, which is almost three times higher than the drinking water limit. Table 9 shows sampling results with parameters that exceeded limitations for all four storm events. All sampling results can be found in Appendix A, "Water Quality Data."

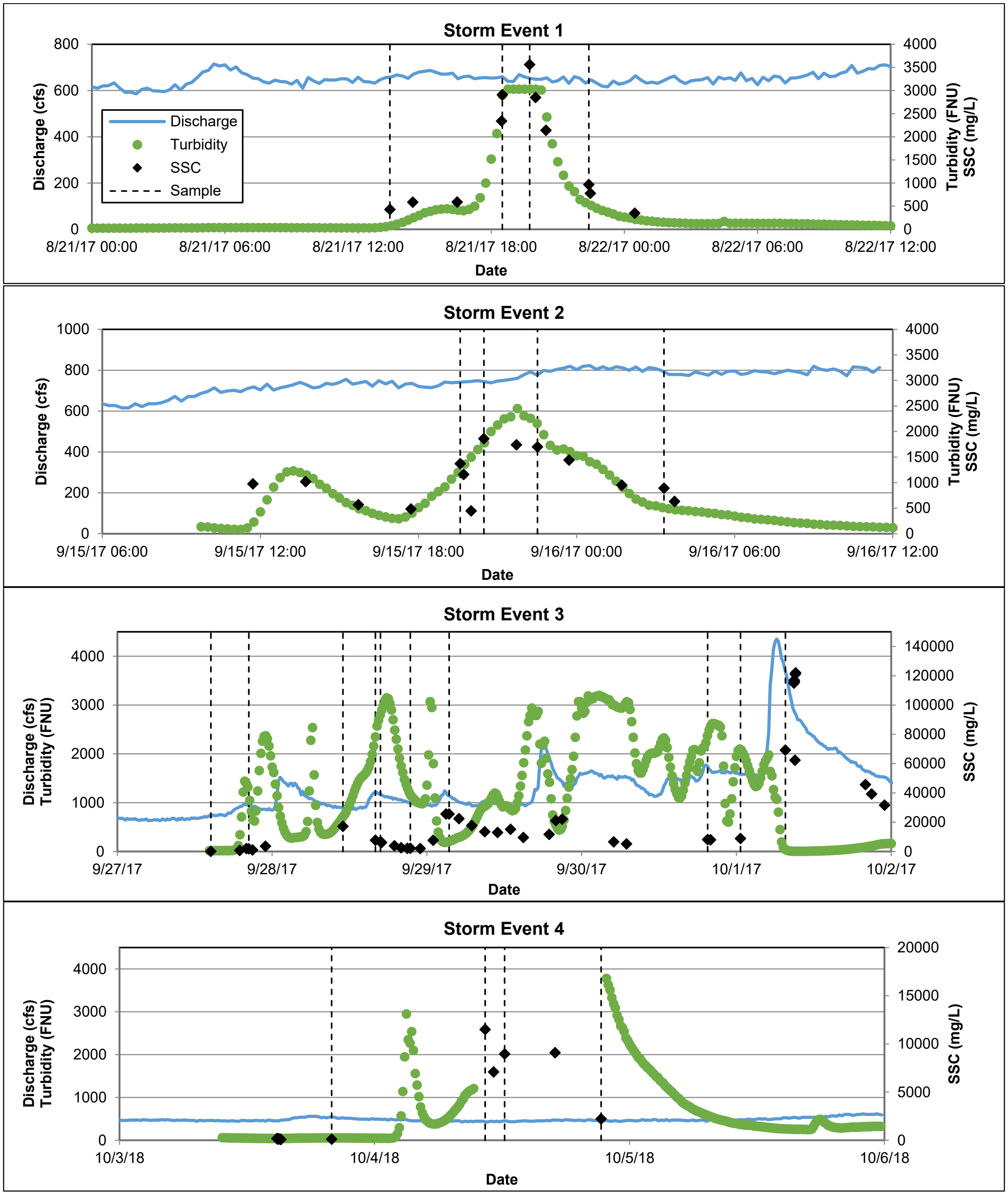


Figure 5. Discharge (blue line), turbidity (green circles), suspended sediment concentration (black diamonds), and sample time (vertical dashed lines) for each of the four storm events. Note the differences between the scales on each axis.

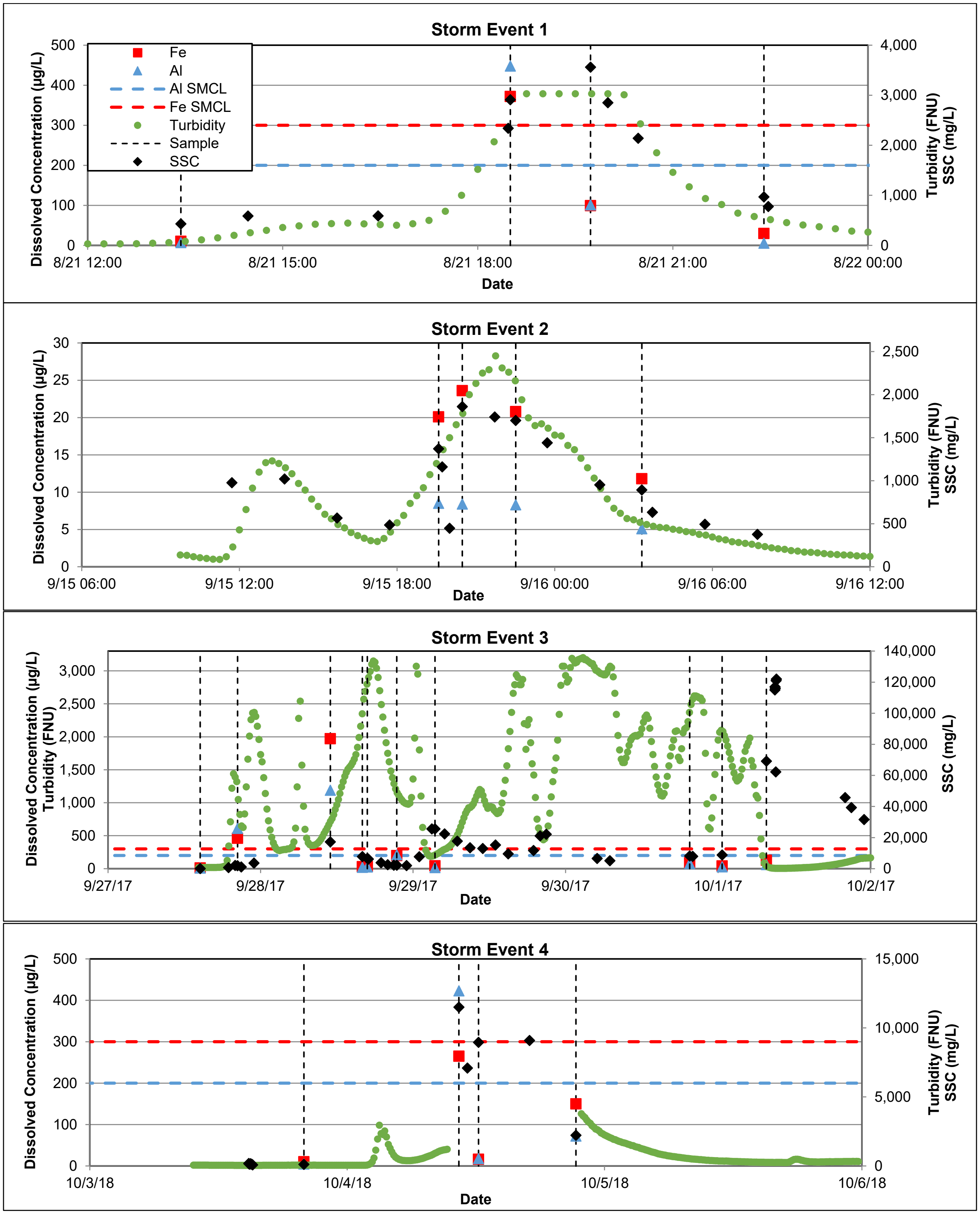


Figure 6. Turbidity, SSC, dissolved aluminum, and dissolved iron for each storm events. Note the differences between the scales on each axis. SMCL for aluminum and iron shown.

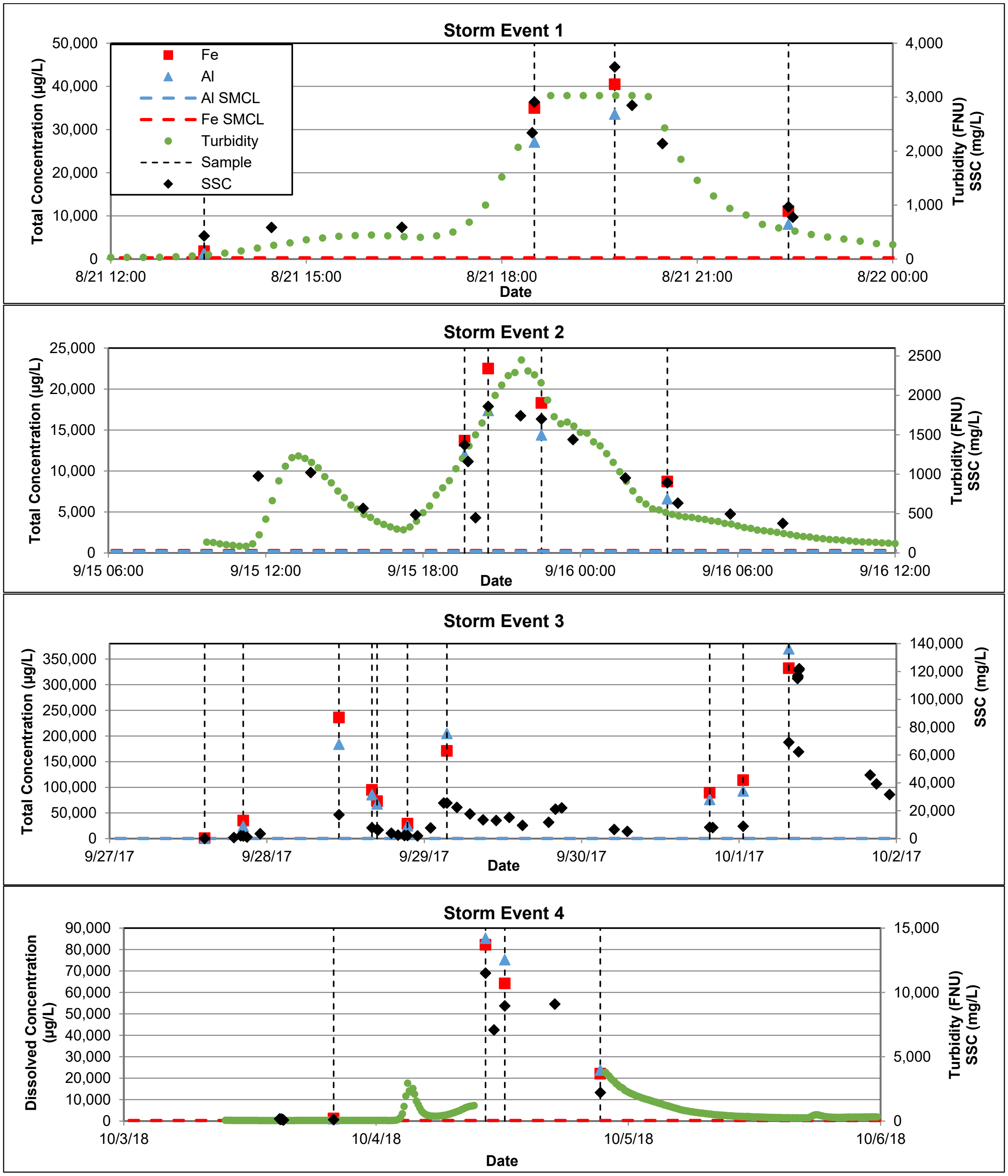


Figure 7. Turbidity, SSC, total aluminum, and total iron for each storm event. Note the differences between the scales on each axis. SMCL for aluminum and iron shown. Turbidity in Storm Event 3 is not shown so that the scale of the SSC and total metals can be easily seen.

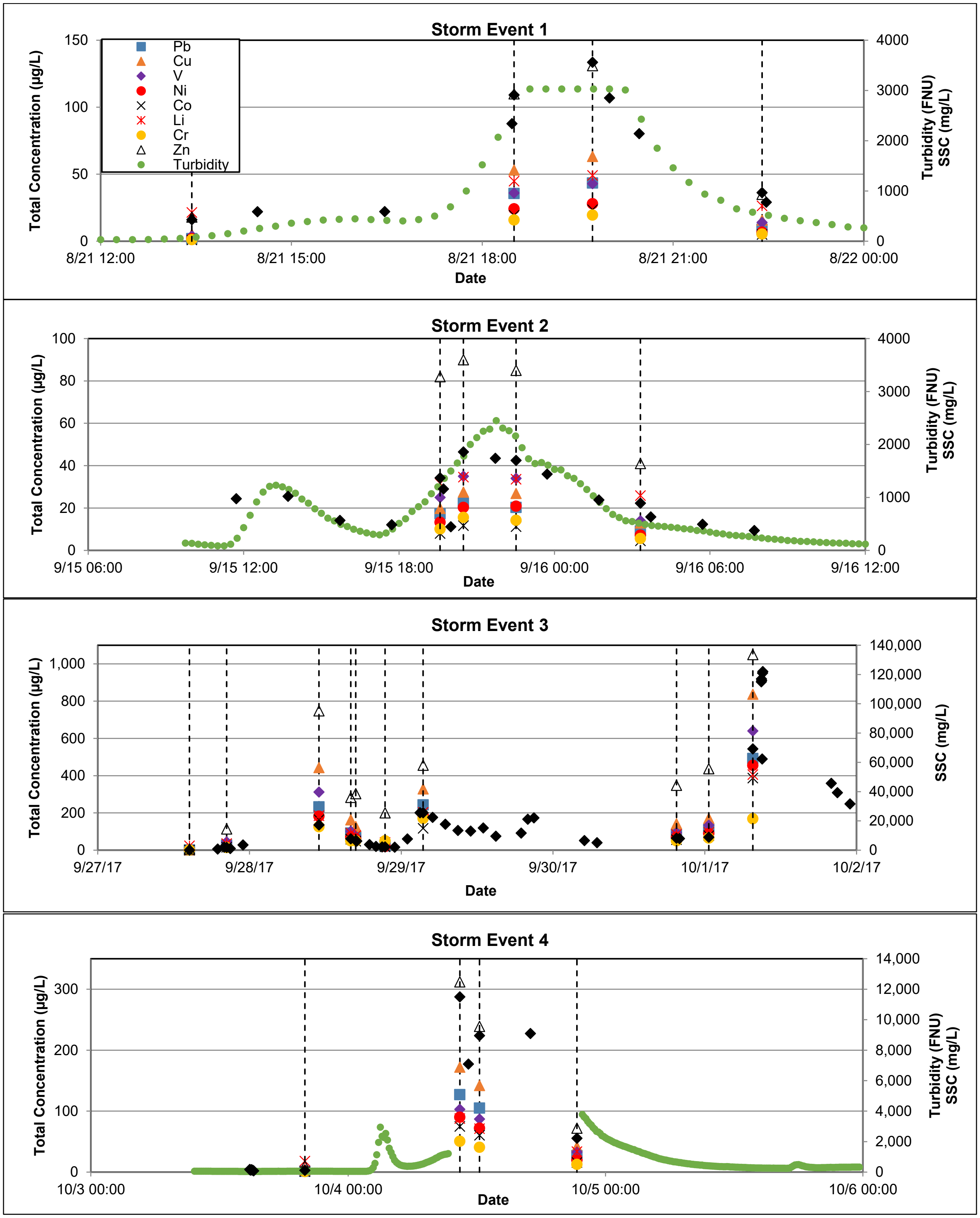


Figure 8. Turbidity, SSC, and several total metals concentrations for each storm event. Note the differences between the scales on each axis. Turbidity in Storm Event 3 is not shown so that the scale of the SSC and total metals can be easily seen.

Table 9. Sample Results for Each Storm Event Where Parameters Exceeded SDWA Regulatory Limitations

Storm No.	Sample Date	Suspended Solids Concen-tration (mg/L)	TDS (mg/L)	Sulfate (mg/L)	Dissolved Aluminum Concen-tration (µg/L)	Dissolved Iron Concen-tration (µg/L)	Total Aluminum Concen-tration (µg/L)	Total Antimony Concen-tration (µg/L)	Total Arsenic Concen-tration (µg/L)	Total Barium Concen-tration (µg/L)	Total Beryllium Concen-tration (µg/L)	Total Cadmium Concen-tration (µg/L)	Total Chromium Concen-tration (µg/L)	Total Iron Concen-tration (µg/L)	Total Lead Concen-tration (µg/L)	Total Manganese Concen-tration (µg/L)	Total Thallium Concen-tration (µg/L)	Total Uranium Concen-tration (µg/L)
1	8/21/17 13:26	429	279	106.0	7.0	10.0	1,460	0.11	1.4	105.0	0.15	0.04	1.2	1,820	1.90	71.4	0.03	1.29
	8/21/17 18:30	2,910	431	130.0	448.0	372.0	27,100	0.09	5.4	499.0	3.65	0.25	15.9	35,000	35.60	926.0	0.35	3.10
	8/21/17 19:44	3,560	337	129.0	101.0	99.2	33,600	0.09	5.5	555.0	4.44	0.29	19.5	40,500	43.40	1,150.0	0.41	3.59
	8/21/17 22:24	968	289	107.0	5.6	29.8	8,100	0.09	2.8	177.0	0.93	0.08	5.4	11,100	8.90	258.0	0.12	1.58
2	9/15/17 19:35	1,370	261	98.3	8.5	20.1	12,000	0.15	3.7	303.0	1.09	0.32	10.1	13,700	17.30	456.0	0.19	1.87
	9/15/17 20:29	1,860	271	102.0	8.4	23.6	17,400	0.12	4.5	428.0	1.60	0.49	15.6	22,500	22.30	610.0	0.26	2.22
	9/15/17 22:31	1,700	279	104.0	8.3	20.8	14,400	0.13	4.8	384.0	1.28	0.18	14.2	18,300	20.30	530.0	0.23	2.09
	9/16/17 3:19	892	294	106.0	5.1	11.8	6,620	0.11	2.8	210.0	0.60	0.03	5.6	8,710	9.18	313.0	0.12	1.61
3	9/27/17 14:30	77	293	106.0	9.9	10.0	591	0.11	0.9	85.4	0.05	0.24	0.5	742	0.85	53.0	0.02	1.32
	9/27/17 20:23	1,890	317	107.0	611.0	462.0	24,100	0.36	4.3	289.0	2.08	3.0	13.9	35,100	27.10	580.0	0.34	2.77
	9/28/17 10:59	17,200	539	258.0	1,190.0	1,970.0	184,000	9.00	29.7	2,570.0	23.00	3.0	126.0	236,000	232.0	5,690.0	2.00	19.30
	9/28/17 16:01	7,740	409	179.0	19.7	29.8	85,600	9.00	9.5	1,010.0	9.86	3.0	50.0	94,800	91.80	2,430.0	2.00	7.16
	9/28/17 16:48	6,570	407	174.0	27.0	33.4	67,500	9.00	6.6	840.0	7.98	3.0	50.0	72,900	74.10	2,060.0	2.00	5.87
	9/28/17 21:26	2,230	314	122.0	209.0	199.0	24,900	9.00	5	335.0	2.61	3.0	50.0	29,100	21.90	743.0	2.00	3.00
	9/29/17 3:27	25,600	501	229.0	17.2	42.4	205,000	9.00	11.1	3,540.0	20.70	3.0	170.0	171,000	243.0	8,400.0	2.00	19.50
	9/30/17 19:32	8,170	380	149.0	77.0	90.7	76,500	9.00	10.3	1,250.0	8.40	3.0	50.0	89,400	85.80	2,500.0	2.00	6.81
	10/1/17 0:38	8,830	380	161.0	27.9	40.6	92,900	9.00	12.9	1,460.0	10.60	3.0	64.8	114,000	112.00	3,370.0	2.00	7.23
	10/1/17 7:36	69,200	486	228.0	61.7	129.0	370,000	9.00	20.9	4,140.0	50.50	5.5	169.0	332,000	492.0	20,500.0	2.00	36.00
4	10/3/18 19:58	117	290	100.0	4.7	10.0	1,120	0.08	1.3	112.0	0.10	0.03	0.8	1,200	1.39	60.9	0.04	1.35
	10/4/18 10:25	11,500	346	131.0	423.0	265.0	85,300	0.60	8.6	2,340.0	11.50	1.45	50.6	82,200	127.0	3,660.0	1.35	9.48
	10/4/18 12:15	8,950	336	122.0	17.6	16.1	75,300	0.30	8.7	1,940.0	9.12	1.07	40.7	64,200	105.0	2,920.0	0.82	7.99
	10/4/18 21:20	2,220	315	113.0	72.1	150.0	23,800	0.08	4.2	548.0	2.26	0.24	12.8	22,100	27.20	778.0	0.32	3.63

Notes:

Orange highlighted cells represent values that are greater than SMCLs.

Red highlighted cells represent values that are greater than primary MCLs.

Green text represents values that are the reporting limits, and it can be assumed that actual measurements were below these values.

Blue text represents measurements that were diluted too much, so the reported value is a factor of the reporting limit. This means that the actual values may be lower than what is reported.

3.2 Storm Event 2

On September 14, 2017, the highest precipitation recordings were concentrated near the headwaters of the Animas River. Within the watershed boundary, one gage recorded more than 0.8 inch of precipitation. Several other gages in this area recorded between 0.3 and 0.79 inch. On this day, all of the recorded precipitation within the watershed boundary was in the Animas Subbasin, except for one gage in the Middle San Juan Subbasin and one gage in the Blanco Canyon Subbasin. On September 15, 2017, the precipitation expanded to include all of the subbasins, except for Blanco Canyon. The storm shifted to be a more localized storm of less intensity (0.1 – 0.59 inch) around Durango and Farmington, except for the Animas River headwaters area, which had a high precipitation recording (0.8 inch or above). On September 16, 2017, as the storm was ending, only light precipitation was recorded outside of Durango and higher up in the Animas River. Although this overall storm produced precipitation in the three other subbasins, most of it occurred in the Animas Subbasin.

Over the course of storm event 2, the river discharge gradually increased from 600 ft^3/s to 800 ft^3/s (Figure 5). The turbidity had one small peak (1,230 FNU) around 1 p.m. on September 15, 2017, and a second larger peak (2,310 FNU) around 10 p.m. the same day. The turbidity returned to a normal level around noon on September 16, 2017. SSC generally followed the same trend as turbidity; however, a few SSC points did not closely follow the trend. The maximum recorded SSC was 1,860 mg/L, occurring just before the second turbidity peak. Four samples were taken for further water quality analysis (two samples as the turbidity was rising toward the second peak, one sample shortly after the second peak, and one sample when the turbidity had returned to almost normal levels).

All of the dissolved metals concentrations were below the limitations shown in Table 1 and Table 2 (Figure 6). Total aluminum, total iron, and total manganese concentrations exceeded the SMCL in all four samples. Peak concentrations of total aluminum (17,400 μg/L), total iron (22,500 μg/L), and total manganese (610 μg/L) occurred in Sample 2 (see Table 9 and Figure 7). Samples 1-3 exceeded the MCL for total lead, and Sample 2 contained the peak concentration of 22.3 μg/L.

3.3 Storm Event 3

Storm 3 was the largest event sampled in this study. On September 26, 2017, moderate precipitation (0.10 – 0.29 inch) was observed near the La Plata River headwaters, the Animas River headwaters, and northeast of Durango, Colorado. Additionally, two gages near Durango recorded light precipitation (trace amounts – 0.09 inch). On September 27, 2017, the intensity of the storm increased and became widespread. Moderate to high levels of precipitation (0.30-0.79 inch) were recorded around the northern parts of the La Plata River and Animas River. Some precipitation was also observed around Durango and Farmington, New Mexico. Two gages recorded high precipitation in the Blanco Canyon Subbasin (one ranging from 0.60-0.79 inch, and one over 0.8 inch). On September 28, 2017, three of the four highest precipitation recordings (0.8 inch or higher) were outside of the watershed boundary south of Farmington, east of Durango, and west of Durango. The fourth gage with high precipitation was east of Farmington, but within the watershed boundary. Widespread precipitation with an intensity ranging from low to moderately high was observed throughout all four subbasins in this watershed. On September 29, 2017, the storm intensity had decreased in most areas but remained widespread.

The highest observed precipitation for this day occurred near Farmington, east of Farmington, and in the southeast part of the watershed (Blanco Canyon Subbasin). On September 30, 2017, precipitation continued in all four subbasins, but the highest intensity shifted to Farmington and Durango, where several gages recorded 0.8 inch or more in both locations. On October 1, 2017, the storm remained in the same general area, but at a reduced size and intensity. Although precipitation continued in all of the subbasins, it was more concentrated along the Animas River, near Durango, and near Farmington. Overall, this storm had heavy precipitation over all four subbasins and lasted several days.

Of all four storm events, Storm Event 3 caused the most dramatic variations in the San Juan River hydrology and water quality. At 6 p.m. on September 27, 2017, the discharge began at around 800 ft^3/s. The discharge then increased incrementally over time, reaching 2,010 ft^3/s by 6 p.m. on September 29. Afterwards, the discharge decreased to around 1,500 ft^3/s before spiking up to 4,300 ft^3/s at 6:30 a.m. on October 1, 2017. The turbidity had several peaks during this storm event and did not correlate to the discharge. The highest recorded turbidity was 3,190 FNU at 1 p.m. on September 30, 2017. SSC did not follow the trend of the turbidity. The highest measurement was towards the end of the storm event at 9 a.m. on October 1, 2017 with a concentration of 115,000 mg/L. This occurred shortly after the largest peak in discharge, and the turbidity reading at this time was less than 10 FNU.

Because this storm was of a greater duration, 10 samples were taken for further water quality analyses. During the tenth sample, which was very close to the previously mentioned very high SSC of 115,000 mg/L, a great deal of particulate was collected (Figure 9). The low turbidity readings taken during this time are assumed to result from errors in the turbidimeter measuring method. It is very unlikely that the river water had low turbidity, when Figure 9 clearly showed it contained a high amount of sediment. Likewise, an error in the turbidimeter measuring method is assumed to be responsible for the apparent decreases in turbidity over the course of this storm (Figure 5). Realistically, the river would be unlikely to show drastic turbidity changes in a relatively short amount of time. The turbidimeter was most likely overloaded by the amount of sediment, causing it to render faulty readings. A 2018 USGS study (Voichick, Topping, & Griffiths, 2018) revealed how turbidimeters can record false decreases in turbidity at high SSC levels (greater than several thousand milligrams per liter). Figure 5 shows SSC levels well above this threshold and an inverse relationship between SSC and turbidity. Voichick, Topping, and Griffiths (2018) observed this same inverse relationship when the turbidimeter was falsely recording decreases in turbidity. In fact, the peak in SSC matched up with what the turbidimeter showed as lower turbidity. It is therefore assumed that the turbidimeter was malfunctioning during part or all of Storm Event 3.

Figure 9. Sample bottles from the last three samples of Storm Event 3. Note the high amounts of particulate collected in the last sample.

Storm 3 caused the only river response that exceeded parameters other than dissolved or total metals (Table 9). The SMCL for TDS was exceeded in Samples 3 and 7. The SMCL for sulfate was exceeded in Sample 3. In addition, dissolved aluminum was measured at concentrations above the SMCL for Sample 2, 3, and 6, with the highest concentration (1,190 µg/L) occurring in Sample 3 (Figure 6). This is a substantially high amount for dissolved aluminum and is, by far, the highest in this study. The SMCL for dissolved iron was exceeded in Samples 2 and 3; the highest measurement (1,970 µg/L) occurred in Sample 3 and was the highest measured concentration of dissolved iron in the study as well.

The SMCL for total aluminum was exceeded in all 10 samples in this storm event, with the highest concentration (370,000 µg/L) occurring in Sample 10 (Figure 7). This is one to three orders of magnitude higher than other measurements in this study. The MCL for total antimony was exceeded in Samples 3-10; however, these samples were diluted too heavily by the laboratory, resulting in an end measurement below the reporting limit for the analysis method. The actual values for these samples are unknown, but are assumed to be near the reported 9 µg/L. The MCL for total arsenic (10 µg/L) was exceeded five times. The highest concentration of arsenic (29.7 µg/L) occurred in Sample 3. The MCL for total barium was surpassed for Samples 3, 7, and 10; the highest concentration (4,140 µg/L), occurring in Sample 10, was more than double the MCL. The MCL for total beryllium was exceeded in 7 of the 10 samples, with the highest concentration occurring in Sample 10. The MCL for total cadmium was exceeded in Sample 10, with a concentration two orders of magnitude higher than the lowest measurement during Storm Event 3. The MCL for total chromium was exceeded in Samples 3, 7, and 10 at levels that were one to two orders of magnitude greater than other measurements in this study. The SMCL for total iron (300 µg/L) was exceeded in all 10 samples, with a peak concentration (332,000 µg/L) occurring in Sample 10, which is three orders of magnitude higher than the SMCL. The MCL for total lead (15 µg/L) was exceeded in Samples 2-10 (Figure 8). The highest concentration of total lead (492 µg/L) occurred in Sample 10 and is much higher than the MCL. The SMCL for total manganese (50 µg/L) was exceeded in all 10 samples, and the highest concentration (205,000 µg/L) is five orders of magnitude higher than the SMCL. The MCL for total thallium was surpassed in Samples 3-10. Like the total antimony samples, the total thallium samples were diluted too much to obtain a precise reading; however, actual values should be near the reported 2 µg/L. The MCL for total uranium was exceeded in Sample 10, with a concentration two orders of magnitude higher than other measurements in this study.

One possible reason for the very high solids observed in this storm event is that Storm 3 had the highest recorded precipitation in the Blanco Canyon Subbasin. This subbasin contains Cañon Largo, an ephemeral stream that is one of the largest contributors of suspended sediment to the San Juan River watershed. Storm 3 also had high precipitation in the Animas Subbasin, which may help explain the high metals concentrations.

3.4 Storm Event 4

On October 3, 2018, the strongest part of the storm was located over Durango, and several gages recorded precipitation amounts of 0.8 inch or more. Moderate precipitation was also recorded along the Animas River and near the La Plata River. Light precipitation was observed around Farmington, Navajo Reservoir, and the southern part of the watershed. On this day, precipitation occurred in all four subbasins. On October 4, 2018, the storm remained in the same general locations but was less intense (trace-0.29 inch), except at one gage located near the Animas River headwaters, which recorded 0.30-0.59 inch of precipitation. No gages within the watershed boundary in the Blanco Canyon Subbasin area recorded precipitation, but one gage just outside the boundary recorded light precipitation, which suggests the possibility that light precipitation was occurring in the area, although it cannot be confirmed. On October 5, 2018, light to moderately light precipitation was observed along the Animas River, in Durango, near the La Plata River, as well as near Farmington. No precipitation was observed in or around the Blanco Canyon portion of the watershed on this day. Overall, this storm occurred in all four subbasins, but the highest amounts of precipitation occurred in the Animas Subbasin and Middle San Juan Subbasin.

During this storm event, the discharge stayed constant at about 500 ft^3/s (Figure 5). The turbidity sharply increased to the first peak of 2,950 FNU, then sharply decreased, followed by a gradual increase, at which time a malfunction occurred. As a result, data are not available from 9:30 a.m. on October 4, 2018, until 9:50 p.m. that evening. At this time, the turbidity was at 3,630 FNU, which is assumed to be the second peak in turbidity; however, without data for that time period, it cannot be confirmed. This storm event lasted from about 2 a.m. on October 4, 2018, until 3 p.m. on October 5, 2018. SSC did not follow the same trend as turbidity. In fact, during the maximum turbidity, the SSC was relatively low at 2,220 mg/L. Compared to the first two storms, this SSC value can be considered high; however, the maximum SSC measured in Storm Event 4 was 11,500 mg/L during the second water quality sample. Nevertheless, Storm Event 3 had the highest SSC values by far. There were four samples taken during this storm for further water quality testing.

The only dissolved metal that exceeded a SCML was dissolved aluminum, which occurred in Sample 2, at a concentration of 423 μg/L (more than double the limit) (Table 9, Figure 6). The SMCL for total aluminum was exceeded in all four samples, with Sample 2 showing the highest concentration (85,300 μg/L) (Figure 7). The MCL for total barium (2,000 μg/L) was exceeded in Sample 2, which showed a peak concentration of 2,340 μg/L. The MCL for total beryllium (4 μg/L) was exceeded in Samples 2 and 3, with Sample 2 showing a peak concentration of 11.5 μg/L. The SMCL for total iron was exceeded in all four samples; the highest concentration (82,200 μg/L) occurred in Sample 2 and is two orders of magnitude higher than the limit. The MCL for total lead (15 μg/L) was exceeded in Samples 2, 3, and 4 (Figure 8). Again, the highest concentration (127 μg/L) occurred in Sample 2. The SMCL for total manganese was exceeded in all four samples; with Sample 2 showing the greatest concentration (3,660 μg/L), which is approximately two orders of magnitude higher than the limit.

3.5 Correlation Between Water Quality Parameters

Pairs plots were created for all water quality parameters tested in this study to determine relationships between them. All of the pairs plots can be found in Appendix C, "Pairs Plots." The numbers to the right of the histograms represent the Kendall's Tau Coefficient for each pair of parameters. For this study, Kendall's Tau Coefficient's greater than or equal to 0.700 were considered to represent strong correlation between two parameters. These values are highlighted in the appendix to draw the reader's attention. The pairs plots were grouped into sets to avoid having too many plots on one page; therefore, some of the pairs are repeated on multiple pages (the repeated pairs, however, are not highlighted on subsequent pages). Figure 10 summarizes the parameters with strong relationships and shows them in three groups based on the value of the Kendall's Tau Coefficient. Many of the total metals have strong relationships with each other, and combinations of them appear in all three groups. As a result, it appears like the total metals are repeated in each grouping. Refer to Appendix D, "Kendall's Tau Coefficient Table," for a more detailed table showing each pair of parameters and the corresponding Kendall's Tau Coefficient.

Total aluminum showed a relationship with almost all other total metals that exceeded SDWA limitations. Total aluminum had very strong correlations ($\tau > 0.899$) to total iron, total thallium, total beryllium, total lead, total manganese, and total arsenic. Total aluminum also correlated ($0.899 > \tau > 0.799$) with total uranium, total chromium, and total barium. Total aluminum and total cadmium had a Kendall's Tau Coefficient of 0.734. Total antimony was the only total metal that exceeded SDWA limitations but did not have any correlations stronger than 0.699. Based on these results, if the WTP influent water had a high concentration of one metal, it may be assumed that the concentrations of other metals were also high.

Most dissolved metals did not correlate to other parameters, including other dissolved metals. Dissolved aluminum, iron, lead, molybdenum, selenium, and uranium are the only dissolved metals that correlated to another parameter, and all of them are in the 0.700 – 0.799 grouping. Dissolved aluminum is correlated to dissolved iron and dissolved lead. Like the total metals, dissolved aluminum and dissolved iron both exceeded SMCLs in this study, so this relationship may be useful for WTP engineers and operators. Total metals, however, did not correlate to dissolved metals, and knowledge of that relationship is also important.

SSC had very strong relationships ($\tau > 0.899$) with many of the total metals including aluminum, barium, beryllium, copper, cobalt, lead, lithium, manganese, nickel, silver, thallium, and uranium. SSC also correlated to total arsenic, total chromium, total iron, total vanadium, total cadmium, fluoride, sulfate, and specific conductivity, as well as a few others (Figure 10). Many of these total metals that correlate to SSC exceeded SDWA limitations (Table 9), which suggests that SSC would be a good predictor for total metals exceedances. SSC poorly correlated to both discharge ($\tau = 0.135$) and turbidity ($\tau = 0.251$). Discharge only correlated to potassium ($\tau = 0.700$). Turbidity only correlated to total silver, total thallium, total selenium, and total molybdenum. The correlation between turbidity and total molybdenum was negative, meaning that when turbidity was high, total molybdenum was low. This was the only strong ($\tau > 0.699$) negative relationship found in this study. Although these relationships with turbidity and discharge are interesting, they are not very useful to WTP designers and operators because, with the exception of thallium, they do not include parameters that are at high risk of exceeding regulatory limitations.

Specific conductivity correlated with many parameters: sulfate, TDS, fluoride, SSC, dissolved uranium, alkalinity, sodium, total aluminum, total arsenic, total beryllium, total cobalt, total copper, total iron, total lead, total lithium, total manganese, and total strontium (Figure 10 and Appendix D, "Kendall's Tau Coefficient Table"). This information may be more useful to WTP operators because specific conductivity can be measured continuously with a probe. Specific conductivity, however, could only predict the parameters listed above. Fluoride and sulfate also correlated to many parameters, including many of the total metals (Figure 10), but it may be less practical to measure for these two constituents.

Kendall's τ > 0.899

Total metals with total metals
- Arsenic
- Aluminum
- Barium
- Beryllium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Lithium
- Manganese
- Mercury
- Nickel
- Silver
- Strontium
- Thallium
- Uranium
- Vanadium
- Zinc

SSC with total metals
- Aluminum
- Barium
- Beryllium
- Copper
- Cobalt
- Lead
- Lithium
- Manganese
- Nickel
- Silver
- Thallium
- Uranium

Specific Conductivity with
- Sulfate

0.899 ≥ Kendall's τ > 0.799

Total metals with total metals
- Aluminum
- Arsenic
- Barium
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Lithium
- Manganese
- Mercury
- Nickel
- Selenium
- Silver
- Strontium
- Thallium
- Uranium
- Vanadium
- Zinc

SSC with total metals
- Arsenic
- Chromium
- Iron
- Strontium
- Vanadium
- Zinc

Turbidity with total metals
- Silver
- Thallium

Fluoride with
- Alkalinity
- Total Lithium
- Total Strontium
- Specific conductivity
- Sulfate

Sulfate with
- Sodium
- TDS
- Total Strontium

TDS with
- Specific conductivity

0.799 ≥ Kendall's τ > 0.699

Total metals with total metals
- Aluminum
- Arsenic
- Barium
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Lithium
- Manganese
- Mercury
- Selenium
- Silver
- Strontium
- Thallium
- Uranium
- Vanadium
- Zinc

SSC with
- Fluoride
- Specific Conductivity
- Sulfate
- Total Cadmium
- Total Mercury
- Total Selenium

Turbidity with total metals
- Selenium
- Molybdenum (negative)

Sulfate with
- Alkalinity
- Dissolved Uranium
- Total Aluminum
- Total Arsenic
- Total Beryllium
- Total Cobalt
- Total Copper
- Total Iron
- Total Lithium

Bromide with total metals
- Iron
- Mercury
- Thallium

Dissolved Aluminum with
- Dissolved Iron
- Dissolved Lead

Dissolved Iron with
- Dissolved Lead

Dissolved Molybdenum with
- Dissolved Selenium

Dissolved Uranium with
- Fluoride
- Sodium
- Specific Conductivity

TDS with
- Alkalinity
- Sodium

Fluoride with
- Sodium
- TDS
- Total Aluminum
- Total Arsenic
- Total Beryllium
- Total Chromium
- Total Cobalt
- Total Copper
- Total Iron
- Total Manganese
- Total Lead
- Total Uranium
- Total Vanadium
- Total Zinc

Specific conductivity with
- Alkalinity
- Sodium
- Total Aluminum
- Total Arsenic
- Total Beryllium
- Total Cobalt
- Total Copper
- Total Iron
- Total Lead
- Total Lithium
- Total Manganese
- Total Strontium

Discharge with
- Potassium

Figure 10. Summary of Kendall's Tau Coefficients showing strong correlation between parameters.

4. Discussion

4.1 Storm Event Water Quality

One of the main objectives of this project was to identify the duration and magnitude of water quality fluctuations in the San Juan River during monsoon season. Based on the four storms sampled over two monsoon seasons, river responses could last up to about 4 days (Storm Event 3). Storm 1 had the shortest recorded river response at ~12 hours, Storm 2's river response lasted ~24 hours, and Storm 4's river response lasted ~33 hours. Even though Storm 1 was the shortest event measured in this study, shorter events could have occurred that were not measured in this study due to the project's limited budget. The magnitude of water quality fluctuations in the San Juan River are shown in Figure 5, Table 9, and Appendix A, "Water Quality Data."

Many parameters exceeded SDWA limitations. Storm Event 3 produced the highest concentrations of dissolved and total metals, as well as TDS, sulfate, and SSC. Additionally, some parameters exceeded limitations only in Storm Event 3: TDS, sulfate, total antimony, total arsenic, total cadmium, total chromium, total thallium, and total uranium. Storm 3 was the longest duration storm and had some of the highest intensity of rainfall recorded. Parameters that exceeded limitations in all storms include total aluminum, total iron, total lead, and total manganese. In view of this, engineers designing the WTP should be aware of the high likelihood that influent water will contain high concentrations of these metals during storm events. Total aluminum, total iron, and total manganese were even observed to exceed limitations for every sample taken in each storm of this study. Total lead was observed to exceed the MCL for most samples, but low values were recorded at the beginning of Storm Event 1, end of Storm Event 1, end of Storm Event 2, beginning of Storm Event 3, and beginning of Storm Event 4.

The fluctuations in water quality observed in this study have important implications for the design and operation of the NGWSP SJL WTP. Influent water characteristics are imperative for water treatment because they could impact operational parameters such as chemical dosing and filter run times. Dissolved metals are of particular concern because they may require different treatment strategies and could impact finished water quality and solids disposal.

Compared to the historical data, elevated levels of dissolved aluminum (greater than the SMCL) during these storm events were greater than the average dissolved aluminum concentration of 225 µg/L at the Hogback Diversion (Table 6). The maximum recorded concentration of 2,380 µg/L at the Hogback Diversion is greater than that observed during this project; however, this sample was collected during a summer monsoon event, so it does not represent the typical concentration (Bureau of Reclamation, 2016b). When dissolved iron exceeded the SMCL during these storm events, the concentrations were greater than the average recorded dissolved iron at the Hogback Diversion (Table 6). The historical maximum dissolved iron concentration at the Hogback Diversion was greater than the samples measured in this project. Again, this historical maximum measurement was obtained during a monsoon event.

4.2 Turbidimeter Limitations

As mentioned in Section 3.3, "Storm Event 3," the turbidimeter is believed to have malfunctioned during some or most of Storm Event 3. Turbidity is a measure of the scattering and absorption of light in water and is dependent on the particles that are scattering the light and their characteristics, such as concentration, grain size, grain shape, refractive index, and color (Voichick, Topping, & Griffiths, 2018). When SSC are relatively low, turbidity measured from a single-detector instrument increases linearly with increasing concentration. At high SSC, turbidity plateaus at the maximum recording level of the turbidimeter because the detector is saturated with light. When SSC becomes even higher (on the order of several thousand mg/L), the turbidity measurement may decrease (incorrectly) because a high percentage of the light is being absorbed by the suspended sediment, and less light is reaching the detector. This scenario results in progressively lower turbidity readings with increasing SSC, which is referred to as false low turbidity (Voichick, Topping, & Griffiths, 2018). Voichick, Topping, & Griffiths (2018) also observed an inverse relationship between turbidity and SSC when the turbidimeter reached its maximum recording limit. This trend is also observed for Storm Event 3 (Figure 5); therefore, it is believed that the turbidity measurements for Storm Event 3 are incorrect for at least parts of the storm event because the SSC was very high (way over the threshold of several thousand mg/L). Due to the inability to determine whether any turbidity data from Storm Event 3 is valid, pairs plots with turbidity data, excluding Storm Event 3, were completed and are included in Appendix E, "Pairs Plots without Storm Event 3 Data."

Without Storm Event 3 data, turbidity highly correlates to SSC ($\tau = 0.889$). This result is expected because as SSC increases, there are more particles to absorb the light, which yields high turbidity measurements. The turbidity results from Storm Events 1, 2, and 4 are believed to be accurate and do not exhibit false low measurements when SSC was high, suggesting that below a certain turbidity or SSC, it may be reasonable to use turbidity measurements to predict other parameters. These new pairs plots now show strong relationships between turbidity and many total metals including aluminum, arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, nickel, selenium, silver, strontium, thallium, vanadium, uranium, and zinc. These correlations make sense because total metals have particulate components and make up some of the suspended sediment. The new pairs plots also revealed a correlation between turbidity and dissolved lead ($\tau = 0.761$).

4.3 Relationship Between Parameters

Another objective of this project was to determine if there is a relationship between flow, turbidity, and SSC in the San Juan River near the Hogback Diversion. As previously discussed in Section 3.5, "Correlation Between Water Quality Parameters," discharge, turbidity, and SSC were all poorly correlated with each other. Even without Storm Event 3 data, discharge does not correlate with turbidity and SSC, which is most likely a characteristic of the San Juan River. This conclusion is also supported by the fact that there are ephemeral streams in this watershed that could cause drastic spikes in turbidity or SSC while minimally impacting discharge.

Turbidity and SSC do show a relationship without Storm Event 3 data; therefore, this relationship could potentially be utilized to advise or control intake operations for the NGWSP SJL WTP. Further testing should be completed to confirm this relationship. Aside from the false low turbidity readings in Storm Event 3, another possible explanation for the lack of relationship between SSC and turbidity could be that the four storms had varying particle size distributions. Different particle size distributions lead to different relationships between turbidity and SSC because turbidity readings are dependent on particle characteristics, including size. Whether or not particle size distribution was a factor in Storm Event 3's behavior cannot be determined because this type of data is unavailable for the current study. Based on knowledge about false low turbidity readings during high SSC and the turbidity data from Storm Event 3, however, it is still believed that the turbidimeter malfunctioned during that storm and recorded inaccurate results.

Turbidity is much easier to monitor than SSC because a turbidimeter can run continuously, while SSC measurement requires collection of grab samples for laboratory analysis. Perhaps an acoustic attenuation sensor could be used to measure SSC when turbidity levels approach the maximum reading level. Turbidity would still be measured online and could be used to predict total metals at lower SSC. If SSC is high and turbidity readings are close to the maximum limit of the turbidimeter, the operator or Supervisory Control and Data Acquisition (SCADA) system could start reading the acoustic attenuation sensor to observe the actual peak in solids. This system of measuring solids would prevent operators from believing that turbidity is decreasing when, in fact, the solids are increasing.

The fact that SSC correlated strongly with many of the total metals (Figure 10) suggests that the content of suspended sediment was very similar, in terms of total metals by mass, throughout all storms. The pairs plots show mostly linear relationships; any outliers are from Storm Event 3 (Appendix C, "Pairs Plots"). Although this may suggest that Storm Event 3 had a slightly different sediment profile, it is unlikely because strong relationships exist between SSC and many of the total metals when Storm Event 3 data is included. The concentration of total metals could be estimated based on an SSC measurement because most of these relationships are linear. This relationship would be useful to plant operators because they could predict total metal exceedances based on SSC measurements. In addition to faulty turbidity measurements in Storm Event 3, some of the metals concentrations appear to be maxed out, but they are actually not (Appendix A and Table 9). A laboratory error occurred during metals analyses when the samples for Storm Event 3 were diluted too much and resulted in readings below the method reporting limit. As a result, the lab reported the values as a multiple of the method reporting limit, which means that those values are less than what is reported but could not be quantified. Because Storm Event 3 produced the most extreme metals results, it is recommended that further work be completed to confirm these relationships. It is also important to make sure any future experiments ensure quantitative results.

The final objective of this study was to evaluate if suspended sediment or metals concentration is the primary water quality parameter that dictates temporarily suspending river water intake to the WTP. The maximum SSC in which the intake of water would be suspended temporarily is 12,000 mg/L. This is the limit determined from the 30% design phase and is subject to change as the design progresses. The SSC limit is based on several assumptions, including the flows and basin dimensions in Table 10 and Table 11. In addition, other assumptions include:

- Water entering the WTP from the presedimentation basins needs to have turbidity below 1000 NTU.

- Basin A will be a concrete basin with a chain and flight solids removal system and have an assumed waste percent solids of 8%.

- Basin B will be a pond with dredging equipment for solids removal and have an assumed waste percent solids of 4%.

- The target intake shutdown SSC should meet the previous three criteria, and the waste percent solids for both basins should meet their respective limit (Basin A: 8%, Basin B: 4%) under coarse gradation and finest gradation conditions. Gradation assumptions can be found in Table 12.

Table 10. Flow Assumptions to Determine Maximum SSC at Intake

Presedimentation Flow Rates	Flow (ft^3/s)	Notes
Intake flow	80.0	
Flow from Basin A to Basin B	70.9	
Flow to the WTP	62.7	Peak demand at WTP
Basin A waste flow	9.1	Maximum total wasting rate set to 17.3 ft^3/s (flow to WTP subtracted from intake flow)
Basin B waste flow	8.2	

Table 11. Basin Parameter Assumptions to Determine Maximum SSC at Intake

Parameter	Basin A	Basin B
Number of tracks in operation	5	3
Track length (feet)	300	550
Track width (feet)	43.33	87.00
Track depth (feet)	10	7
Hydraulic retention time (hours)	2.26	3.94

Table 12. Sediment Size and Gradation Definitions

	Sediment Size Definitions (mm)		Gradation Definitions	
Name	Lower Bound	Upper Bound	Finest	Coarse
Very coarse sand	1	2	0	0
Coarse sand	0.5	1	0	0
Medium sand	0.25	0.5	0	0.01
Fine sand	0.125	0.25	0.03	0.19
Very fine sand	0.062	0.125	0.04	0.18
Coarse silt	0.032	0.062	0.06	0.16
Medium silt	0.016	0.032	0.03	0.1
Fine silt	0.008	0.016	0.08	0.04
Very fine silt	0.004	0.008	0.12	0.03
Coarse clay	0.002	0.004	0.1	0.05
Medium clay	0.001	0.002	0.54	0.24

Based on a target intake shutdown SSC of 12,000 mg/L, most of the water from all four storms would have been able to enter the intake. Only three samples in Storm Event 3 had SSC values greater than 12,000 mg/L, and they were not consecutive samples. One of these samples had very high levels of dissolved aluminum and dissolved iron, but the other two samples had relatively low concentrations. Conversely, there were four samples with much lower SSC values that also had high dissolved metals concentrations. Three of the four samples had SSC values near 2,000 mg/L, and one sample had an SSC value of 11,500 mg/L. The three samples in Storm Event 3 with high SSC values also had the highest concentrations of total aluminum, arsenic, barium, beryllium, cadmium, chromium, iron, lead, manganese, and uranium. The current target intake shutdown SSC of 12,000 mg/L may be sufficient to eliminate most of the very high total metals concentrations; however, it would sometimes allow high levels of dissolved metals through the intake.

It is recommended that the intake design engineers reference this report when finalizing this target intake shutdown SSC to familiarize themselves with the implications of potential metals concentrations. Observed SDWA exceedances in this report are for reference only. They do not necessarily imply that regulatory enforcement would be enacted because these limitations are set for treated water, not intake water. Additionally, SDWA limitations are based on total concentrations, not dissolved concentrations. It is also expected that most of the total metals would settle out in the WTP pretreatment settling basin. Dissolved metals, however, would pass through this pretreatment. Because dissolved metals did not correlate with SSC or other easily monitored parameters, it is difficult to specify when high levels would be expected. Further research would be needed to determine why dissolved metals did not correlate with total metals.

5. Conclusion

This study was conducted to better understand the impacts of storm events in the San Juan River, particularly during monsoon season. The NGWSP SJL WTP is in the early design phases; therefore, this information could guide engineers designing the new WTP and intake presedimentation basin. Four storms were sampled in this study: three in 2017 and one in 2018. Storm Event 1 had the shortest duration (about 12 hours), and Storm Event 3 had the longest (about 4 days). During the river responses caused by these storms, high levels of suspended sediment and total/dissolved metals were observed. Dissolved aluminum and dissolved iron were the only dissolved metals that exceeded SDWA limitations. Dissolved aluminum exceeded the SMCL during all storm events, except Storm Event 2, and dissolved iron exceeded the SMCL during Storm Events 1 and 3. Total aluminum, total iron, total lead, and total manganese exceeded limitations during all four storm events. Total beryllium exceeded the MCL for all storm events, except Storm Event 2. Total barium exceeded the MCL during Storm Events 3 and 4. Total antimony, total arsenic, total cadmium, total chromium, total thallium, and total uranium only exceeded limitations during Storm Event 3. Table 13 summarizes the range of concentrations observed during this project for SSC and parameters that exceeded SDWA limitations. These variations in water quality during storm events could inform WTP operations by showing the benefit of halting water intake during storms where high concentrations of metals are present, particularly dissolved metals, which could impact finished water quality and solids disposal.

Table 13. Summary Table of Parameters of Interest with Range of Concentrations Observed During Four Storm Events

Parameter	Minimum Concentration During All Storms	Maximum Concentrations During All Storms	No. of Times Above SWDA Limit
Aluminum, dissolved (µg/L)	4.7	1,190	5
Iron, dissolved (µg/L)	10	1,970	3
Aluminum, total (µg/L)	591	370,000	22
Antimony, total (µg/L)	0.08	9	8
Arsenic, total (µg/L)	0.9	29.7	5
Barium, total (µg/L)	85.4	4,140	4
Beryllium, total (µg/L)	0.05	50.5	10
Cadmium, total (µg/L)	0.03	5.5	1
Chromium, total (µg/L)	0.5	170	3
Iron, total (µg/L)	742.0	332,000	22
Lead, total (µg/L)	0.85	492	17
Manganese, total (µg/L)	53	20,500	22
Thallium (µg/L)	0.02	2	8
Uranium, total (µg/L)	1.29	36	1
TDS (mg/L)	261	539	2
Sulfate (mg/L)	98.3	258	1
SSC (mg/L)	77	69,200	N/A

Note: Green text represents values that are the reporting limits, and it can be assumed that actual measurements were below these values. Blue text represents measurements that were diluted too much, so the reported value is a factor of the reporting limit, meaning that the actual values may be lower than reported.

Considering data from all four storms in this study, no relationship was shown between flow, turbidity, and SSC in the San Juan River near the Hogback Diversion, which is one of the proposed intake locations for the NGWSP SJL WTP. Observations in this study, however, support the belief that the turbidimeter may have falsely recorded low values during Storm Event 3. When data from Storm Event 3 is excluded, the relationship between turbidity and SSC is strong. Turbidity also strongly correlated with many total metals. As a result, turbidity could potentially be used to predict SSC and several total metals, as long as the turbidity is not near the maximum recording limit of the turbidimeter. When Storm Event 3 data is excluded, no correlation exists between discharge and turbidity ($\tau = 0.222$) or SSC ($\tau = -0.321$), which may be a characteristic of the San Juan River because many ephemeral streams in its watershed could increase solids without increasing riverflow.

Turbidity is much easier to monitor than SSC because a turbidimeter can run continuously, while SSC measurement requires collection of grab samples for laboratory analysis. It may be possible to implement an acoustic attenuation sensor to measure SSC when turbidity levels approach the maximum reading level. Turbidity would still be measured online and could be used to predict total metals at lower SSC, but if readings are close to the maximum limit of the turbidimeter, the operator or SCADA system would start reading the acoustic attenuation sensor to observe the actual peak in solids. Further experiments should be conducted to confirm the relationship between turbidity and SSC. This testing should involve particle size distribution to ensure that it is relatively constant for multiple storms in different areas of the watershed. Particle size distribution affects the measurement of turbidity, so it is important to make sure particle size distribution does not drastically change between different storm events.

As the project results show, the metals content of the suspended sediment in all four storms likely had similar composition. SSC displayed linear relationships with many of the total metals, even when Storm Event 3 data was included. This information could be useful for plant operators, who could use these linear relationships to calculate total metals exceedances based on the influent SSC. It is recommended that further testing be completed to confirm these relationships because some samples from Storm Event 3 were diluted too much to obtain an accurate reading for some of the total metals. It is also important to ensure that all total metals can be quantified by the laboratory.

The tentative target intake shutdown SSC is 12,000 mg/L. Only three samples taken during this study were above this limit, and all three were obtained during Storm Event 3 (Samples 3, 7, and 10). These samples were spaced out by approximately 1-2 days. For Samples 3 and 7, the SSC diminished to values around 8,000 mg/L by the time the next sample was taken (6 hours and 40 hours, respectively). The SSC is expected to reach 12,000 mg/L in a shorter amount of time. Sample 10 was the last storm sample obtained. The time of SSC decrease after that period cannot be determined. As a result, the potential maximum shutdown time could be between 6 and 40 hours. Future sampling could be conducted to confirm this shutdown duration.

Intake design engineers should consider the implications of potential metals concentrations when they finalize the target intake shutdown limit based on SSC. At 12,000 mg/L, water will be allowed into the intake that may have elevated total/dissolved metals concentrations. It is likely that dissolved metals would pass through the pretreatment sedimentation basins; therefore, it may be necessary to conduct further research to determine why dissolved metals did not correlate with total metals and if there is any way to predict high dissolved metals concentrations.

6. References

Bureau of Reclamation. (2016a). *Literature Review and Sampling Plan Development for the San Juan River Quality Study.*

Bureau of Reclamation. (2016b). *Navajo-Gallup Water Supply Project San Juan Lateral Water Treatment Plant Intake Settling Basin Analysis.*

Bureau of Reclamation. (2016c). *San Juan River Water Quality Before, During, and After the Gold King Mine Spill*. Retrieved from http://www.usbr.gov/uc/envdocs/reports/GoldKingMine/2016.SanJuanRiver WQ-GoldKingMineSpillFinal.pdf

Church, S., Kimball, B., Fey, D., Ferderer, D., Yager, T., & Vaughn, R. (1997). Source, transport, and partitioning of metals between water, colloids, and bed sediments of the Animas River, Colorado. *US Geological Survey open-file report*, 97-151.

Church, S., Owen, J., von Guerard, P., Verplanck, P., Kimball, B., & Yager, D. (2007). The effects of acid mine drainage from histoical mines in the Animas River watershed, San Juan County, Colorado. *Rev. Eng. Geol.*, 47-83.

ESRI. (2020). *ArcMap Geographic Information System Application, Version 10.8*. Redlands, California.

New Mexico Water Quality Control Commission. (n.d.). *Standards for Interstate and Intrastate Surface Waters.*

USDA Natural Resources Conservation Service. (2007). *Rapid Watershed Assessment Blanco Canyon Watershed*. Retrieved from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_067318.pdf

USGS. (2020). *StreamStats: Streamflow Statistics and Spatial Analysis Tools for Water-Resources Applications. Streamflow Statistics Online Application*. Retrieved from: https://www.usgs.gov/mission-areas/water-resources/science/streamstats-streamflow-statistics-and-spatial-analysis-tools?qt-science_center_objects=0#qt-science_center_objects.

Voichick, N., Topping, D. J., & Griffiths, R. E. (2018). False low turbidity readings from optical probes during high suspended sediment concentrations. *Hydrology and Earth System Sciences*, 1767-1773.

Appendix A – Water Quality Data

Storm #	Sample Date	Turbidity and Discharge Exact Time	Discharge (cfs)	Turbidity (FNU)	Suspended Solids Concentration (mg/L)	pH (SU)	Specific conductance (µS/cm)	TDS (mg/L)	Alkalinity (mg/L as CaCO3)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Bromide (mg/L)	Fluoride (mg/L)
1	8/21/17 13:26	8/21/17 13:30	659	80.3	429	8.5	442	279	107	49.4	7.92	30.8	2.18	9.48	106.0	0.023	0.23
	8/21/17 18:30	8/21/17 18:30	660	2,900.0	2,910	8.1	503	431	110	50.6	6.91	41.7	2.65	10.00	130.0	0.025	0.27
	8/21/17 19:44	8/21/17 19:45	653	3,030.0	3,560	8.0	505	337	111	41.1	5.32	36.5	2.24	10.10	129.0	0.028	0.28
	8/21/17 22:24	8/21/17 22:45	632	455.0	968	8.2	455	289	108	51.6	7.35	32.5	2.47	10.00	107.0	0.024	0.25
2	9/15/17 19:35	9/15/17 19:30	741	1,200.0	1,370	8.0	416	261	103	48.8	8.71	29.4	2.58	9.32	98.3	0.026	0.23
	9/15/17 20:29	9/15/17 20:30	744	1,780.0	1,860	8.1	416	271	103	49.5	8.50	29.3	2.62	9.11	102.0	0.023	0.23
	9/15/17 22:31	9/15/17 22:30	776	2,160.0	1,700	8.1	428	279	104	50.0	8.97	30.5	2.66	9.49	104.0	0.025	0.23
	9/16/17 3:19	9/16/17 3:15	797	515.0	892	8.1	440	294	109	52.9	8.58	31.7	2.64	10.50	106.0	0.022	0.24
3	9/27/17 14:30	9/27/17 14:30	721	17.8	77	8.2	440	293	116	50.1	8.00	26.3	2.21	11.20	106.0	0.021	0.25
	9/27/17 20:23	9/27/17 20:30	914	1,050.0	1,890	8.2	447	317	111	47.5	7.00	29.5	2.52	11.30	107.0	0.026	0.27
	9/28/17 10:59	9/28/17 11:00	880	718.0	17,200	8.1	862	539	135	29.2	3.18	126.0	3.06	22.60	258.0	0.073	0.41
	9/28/17 16:01	9/28/17 16:00	1,210	2,350.0	7,740	8.1	615	409	120	48.2	5.27	72.0	3.24	15.10	179.0	0.036	0.34
	9/28/17 16:48	9/28/17 16:45	1,190	2,800.0	6,570	8.1	605	407	119	53.0	5.69	66.0	3.26	15.00	174.0	0.035	0.33
	9/28/17 21:26	9/28/17 21:30	988	1,150.0	2,230	8.2	483	314	117	50.9	6.54	36.2	2.73	12.40	122.0	0.026	0.27
	9/29/17 3:27	9/29/17 3:30	1,130	210.0	25,600	8.0	759	501	137	56.1	6.17	92.5	3.35	14.10	229.0	0.040	0.47
	9/30/17 19:32	9/30/17 19:30	1,750	2,370.0	8,170	8.1	554	380	125	61.4	6.93	47.9	3.36	15.20	149.0	0.031	0.35
	10/1/17 0:38	10/1/17 0:45	1,580	2,080.0	8,830	8.0	593	380	113	71.5	7.07	39.3	3.41	14.90	161.0	0.038	0.31
	10/1/17 7:36	10/1/17 7:30	3,740	47.8	69,200	7.8	857	486	126	49.2	4.91	96.1	3.47	7.54	228.0	0.025	0.47
4	10/3/18 19:58	10/3/18 20:00	548	56.3	117	8.2	439	290	105	47.1	7.27	29.6	2.18	8.24	100.0	0.024	0.21
	10/4/18 10:25	10/4/18 10:30	425	*	11,500	8.1	549	346	114	45.4	5.54	43.2	2.60	8.91	131.0	0.030	0.30
	10/4/18 12:15	10/4/18 12:15	453	*	8,950	8.1	520	336	112	34.3	4.11	31.9	2.04	8.67	122.0	0.030	0.30
	10/4/18 21:20	10/4/18 21:15	453	~	2,220	8.2	491	315	109	44.6	5.79	29.8	2.26	10.10	113.0	0.028	0.25

Notes:

Green text means value is the reporting level

Gray, bold text means that sample was diluted too much. Actual data less than value shown

Turbidimeter did not record data for part of Storm 4, so the closest turbidity reading and time for Samples 2-4 are below.

*	10/4/18 9:20	1210
~	10/4/18 21:50	3780

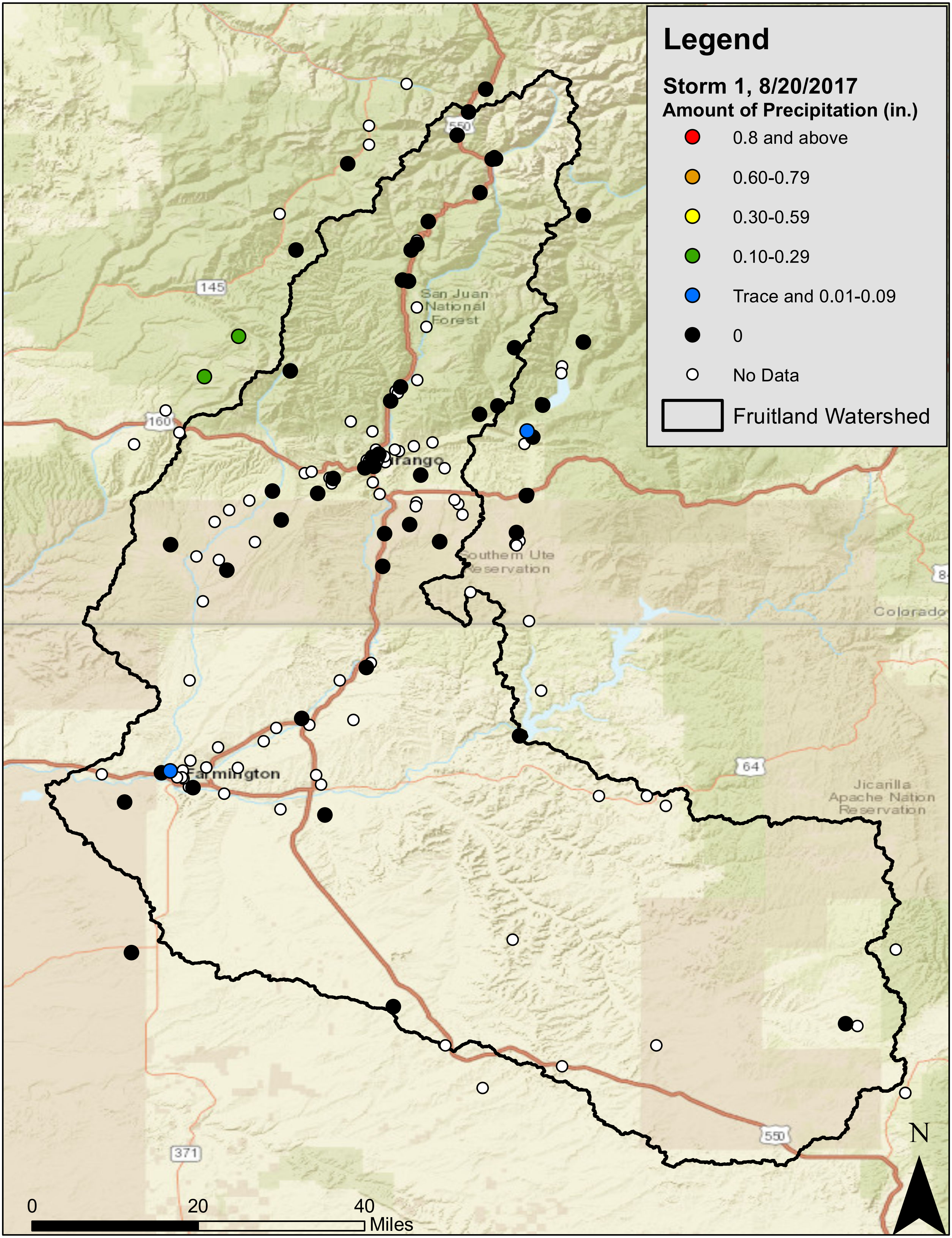
Storm #	Sample Date	Dissolved Aluminum Concentration (µg/L)	Dissolved Antimony Concentration (µg/L)	Dissolved Arsenic Concentration (µg/L)	Dissolved Barium Concentration (µg/L)	Dissolved Beryllium Concentration (µg/L)	Dissolved Boron Concentration (µg/L)	Dissolved Cadmium Concentration (µg/L)	Dissolved Chromium Concentration (µg/L)	Dissolved Cobalt Concentration (µg/L)	Dissolved Copper Concentration (µg/L)	Dissolved Iron Concentration (µg/L)
1	8/21/17 13:26	7.0	0.357	0.88	77.0	0.010	39	0.030	0.50	0.259	2.0	10.0
	8/21/17 18:30	448.0	0.306	0.89	79.2	0.051	41	0.030	0.50	0.547	2.7	372.0
	8/21/17 19:44	101.0	0.275	0.70	60.8	0.014	35	0.030	0.50	0.533	1.9	99.2
	8/21/17 22:24	5.6	0.129	0.87	70.8	0.010	40	0.030	0.50	0.164	2.0	29.8
2	9/15/17 19:35	8.5	0.160	0.94	72.3	0.010	33	0.030	0.50	0.159	2.0	20.1
	9/15/17 20:29	8.4	0.158	0.91	78.8	0.010	31	0.030	0.50	0.139	1.6	23.6
	9/15/17 22:31	8.3	0.194	0.89	74.6	0.010	31	0.030	0.50	0.133	1.7	20.8
	9/16/17 3:19	5.1	0.170	0.87	79.2	0.010	34	0.030	0.50	0.117	1.5	11.8
3	9/27/17 14:30	9.9	0.241	0.74	68.3	0.010	36	0.030	0.50	0.429	1.0	10.0
	9/27/17 20:23	611.0	0.564	0.84	48.7	0.048	33	0.030	0.61	0.564	2.2	462.0
	9/28/17 10:59	1,190.0	0.651	1.40	58.8	0.110	44	0.030	0.70	1.720	3.8	1970.0
	9/28/17 16:01	19.7	0.507	0.92	61.1	0.010	42	0.030	0.50	0.212	2.0	29.8
	9/28/17 16:48	27.0	0.213	0.92	64.1	0.010	44	0.030	0.50	0.284	3.2	33.4
	9/28/17 21:26	209.0	0.530	0.87	63.7	0.023	38	0.030	0.50	0.511	1.4	199.0
	9/29/17 3:27	17.2	0.166	1.20	94.5	0.010	41	0.046	0.50	0.103	2.1	42.4
	9/30/17 19:32	77.0	0.748	0.87	85.3	0.010	45	0.030	0.50	0.753	1.5	90.7
	10/1/17 0:38	27.9	0.771	0.78	84.7	0.010	44	0.030	0.50	0.957	1.3	40.6
	10/1/17 7:36	61.7	0.620	1.40	110.0	0.011	36	0.030	1.50	0.817	2.0	129.0
4	10/3/18 19:58	4.7	0.146	0.87	69.7	0.010	31	0.030	0.50	0.420	1.9	10.0
	10/4/18 10:25	423.0	0.200	0.97	81.3	0.017	28	0.030	0.93	0.226	2.2	265.0
	10/4/18 12:15	17.6	0.190	0.76	56.8	0.010	21	0.030	0.50	0.205	1.8	16.1
	10/4/18 21:20	72.1	0.094	0.87	71.2	0.010	27	0.030	0.50	0.101	1.7	150.0

Storm #	Sample Date	Dissolved Lead Concentration (µg/L)	Dissolved Lithium Concentration (µg/L)	Dissolved Manganese Concentration (µg/L)	Dissolved Mercury Concentration (µg/L)	Dissolved Molybdenum Concentration (µg/L)	Dissolved Nickel Concentration (µg/L)	Dissolved Selenium Concentration (µg/L)	Dissolved Silver Concentration (µg/L)	Dissolved Strontium Concentration (µg/L)	Dissolved Thallium Concentration (µg/L)	Dissolved Vanadium Concentration (µg/L)	Dissolved Uranium Concentration (µg/L)	Dissolved Zinc Concentration (µg/L)
1	8/21/17 13:26	0.032	23.8	0.82	0.005	1.34	0.62	0.42	1	613	0.02	1.1	1.340	2.0
	8/21/17 18:30	0.471	21.3	12.50	0.005	1.20	0.98	0.51	1	661	0.02	2.0	1.510	2.3
	8/21/17 19:44	0.169	17.7	3.64	0.005	1.15	0.63	0.47	1	532	0.02	1.0	1.260	2.0
	8/21/17 22:24	0.037	22.7	0.66	0.005	1.42	0.64	0.47	1	659	0.02	1.1	1.360	2.0
2	9/15/17 19:35	0.041	18.0	1.16	0.005	1.31	0.62	0.48	1	647	0.02	1.0	1.040	2.0
	9/15/17 20:29	0.043	17.9	0.54	0.005	1.32	0.65	0.53	1	665	0.02	0.9	1.070	2.0
	9/15/17 22:31	0.038	17.8	0.46	0.005	1.34	0.79	0.54	1	665	0.02	1.1	1.060	2.0
	9/16/17 3:19	0.032	20.4	0.55	0.005	1.36	0.62	0.49	1	620	0.02	0.9	1.160	2.0
3	9/27/17 14:30	0.079	21.6	10.90	0.005	1.24	1.10	0.42	1	638	0.02	0.7	1.220	2.0
	9/27/17 20:23	0.511	19.5	16.50	0.005	1.09	0.99	0.41	1	631	0.02	2.3	1.290	3.0
	9/28/17 10:59	1.600	21.5	36.30	0.005	1.88	1.60	1.10	1	619	0.02	4.8	3.630	4.3
	9/28/17 16:01	0.130	23.8	1.15	0.005	1.67	0.86	0.69	1	826	0.02	1.6	2.230	2.0
	9/28/17 16:48	0.139	18.6	1.24	0.005	1.67	0.85	0.70	1	894	0.02	1.5	2.220	2.0
	9/28/17 21:26	0.306	21.8	7.78	0.005	1.25	0.84	0.43	1	783	0.02	1.6	1.470	2.2
	9/29/17 3:27	0.195	24.3	0.66	0.005	3.88	0.72	1.10	1	770	0.02	2.1	3.950	2.0
	9/30/17 19:32	0.170	22.9	3.06	0.005	1.96	1.10	0.83	1	881	0.02	1.5	2.250	2.0
	10/1/17 0:38	0.110	19.9	1.95	0.005	1.77	0.98	0.85	1	1,050	0.02	1.0	2.110	2.0
	10/1/17 7:36	0.486	16.5	19.80	0.005	5.81	1.30	1.70	1	693	0.02	2.7	3.990	6.0
4	10/3/18 19:58	0.020	16.7	1.13	0.005	1.10	0.89	0.41	1	550	0.04	1.0	0.917	3.1
	10/4/18 10:25	0.239	14.9	1.74	0.005	1.48	0.66	0.65	1	555	0.04	1.8	1.590	2.0
	10/4/18 12:15	0.056	11.1	0.48	0.005	1.21	0.61	0.45	1	389	0.04	1.0	1.130	2.0
	10/4/18 21:20	0.094	14.6	1.13	0.005	1.04	0.50	0.41	1	521	0.04	1.1	1.040	2.0

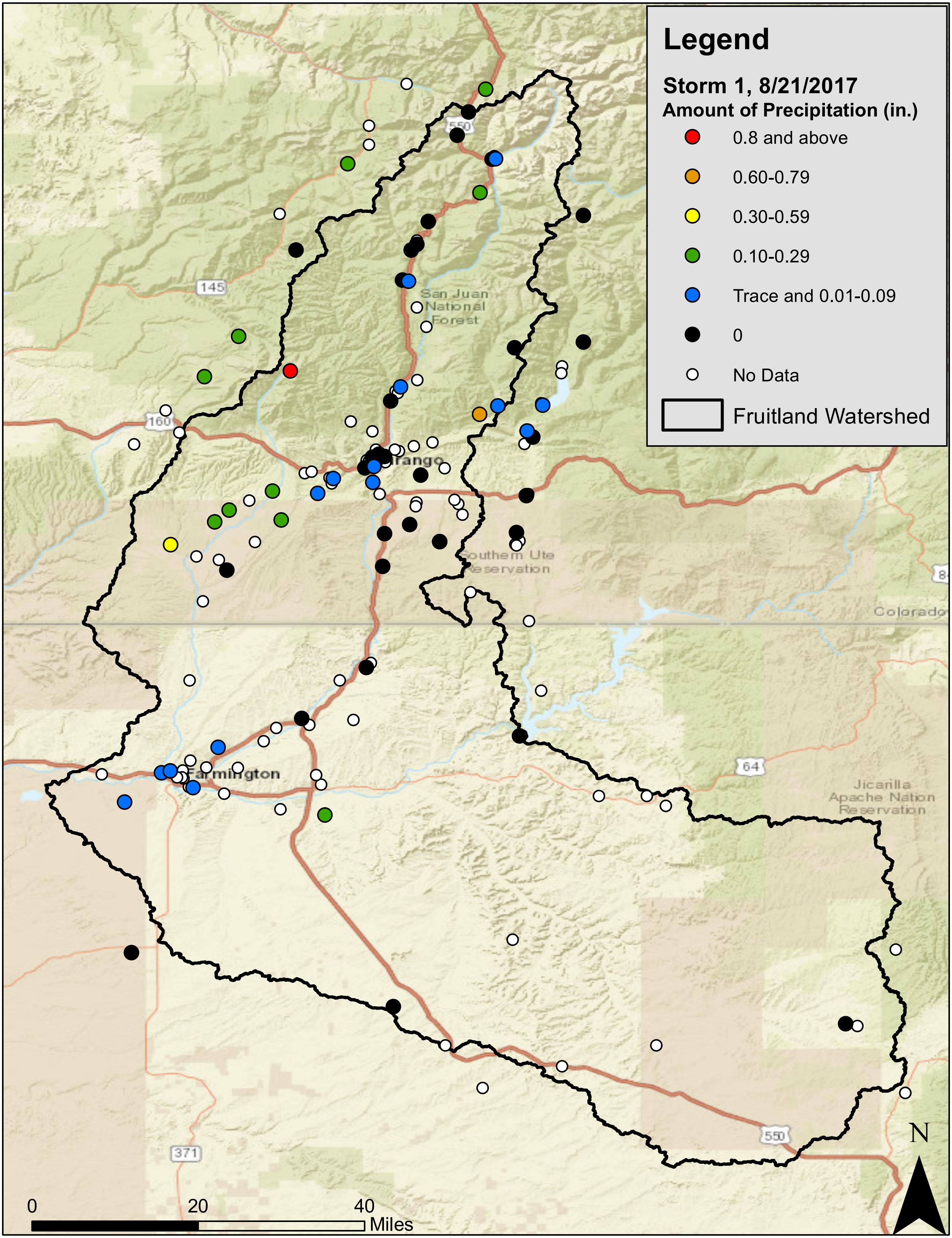
Storm #	Sample Date	Total Aluminum Concentration (μg/L)	Total Antimony Concentration (μg/L)	Total Arsenic Concentration (μg/L)	Total Barium Concentration (μg/L)	Total Beryllium Concentration (μg/L)	Total Cadmium Concentration (μg/L)	Total Chromium Concentration (μg/L)	Total Cobalt Concentration (μg/L)	Total Copper Concentration (μg/L)	Total Iron Concentration (μg/L)	Total Lead Concentration (μg/L)
1	8/21/17 13:26	1,460	0.11	1.4	105	0.15	0.04	1.2	1.02	5.3	1,820	1.90
	8/21/17 18:30	27,100	0.09	5.4	499	3.65	0.25	15.9	19.30	53.1	35,000	35.60
	8/21/17 19:44	33,600	0.09	5.5	555	4.44	0.29	19.5	23.50	63.3	40,500	43.40
	8/21/17 22:24	8,100	0.09	2.8	177	0.93	0.08	5.4	5.00	15.7	11,100	8.90
2	9/15/17 19:35	12,000	0.15	3.7	303	1.09	0.32	10.1	7.95	19.8	13,700	17.30
	9/15/17 20:29	17,400	0.12	4.5	428	1.60	0.49	15.6	11.70	27.5	22,500	22.30
	9/15/17 22:31	14,400	0.13	4.8	384	1.28	0.49	14.2	11.20	26.9	18,300	20.30
	9/16/17 3:19	6,620	0.11	2.8	210	0.60	0.18	5.6	4.52	12.9	8,710	9.18
3	9/27/17 14:30	591	0.11	0.9	85	0.05	0.03	0.5	0.43	2.0	742	0.85
	9/27/17 20:23	24,100	0.36	4.3	289	2.08	0.24	13.9	15.30	45.6	35,100	27.10
	9/28/17 10:59	184,000	9.00	29.7	2,570	23.00	3.00	126.0	164.00	443.0	236,000	232.00
	9/28/17 16:01	85,600	9.00	9.5	1,010	9.86	3.00	50.0	58.60	163.0	94,800	91.80
	9/28/17 16:48	67,500	9.00	6.6	840	7.98	3.00	50.0	48.50	127.0	72,900	74.10
	9/28/17 21:26	24,900	9.00	5.0	335	2.61	3.00	50.0	17.90	48.8	29,100	21.90
	9/29/17 3:27	205,000	9.00	11.1	3,540	20.70	3.00	170.0	117.00	329.0	171,000	243.00
	9/30/17 19:32	76,500	9.00	10.3	1,250	8.40	3.00	50.0	56.40	142.0	89,400	85.80
	10/1/17 0:38	92,900	9.00	12.9	1,460	10.60	3.00	64.8	77.60	171.0	114,000	112.00
	10/1/17 7:36	370,000	9.00	20.9	4,140	50.50	5.50	169.0	387.00	837.0	332,000	492.00
4	10/3/18 19:58	1,120	0.08	1.3	112	0.10	0.03	0.8	0.87	3.4	1,200	1.39
	10/4/18 10:25	85,300	0.60	8.6	2,340	11.50	1.45	50.6	74.80	172.0	82,200	127.00
	10/4/18 12:15	75,300	0.30	8.7	1,940	9.12	1.07	40.7	60.40	142.0	64,200	105.00
	10/4/18 21:20	23,800	0.08	4.2	548	2.26	0.24	12.8	15.70	41.5	22,100	27.20

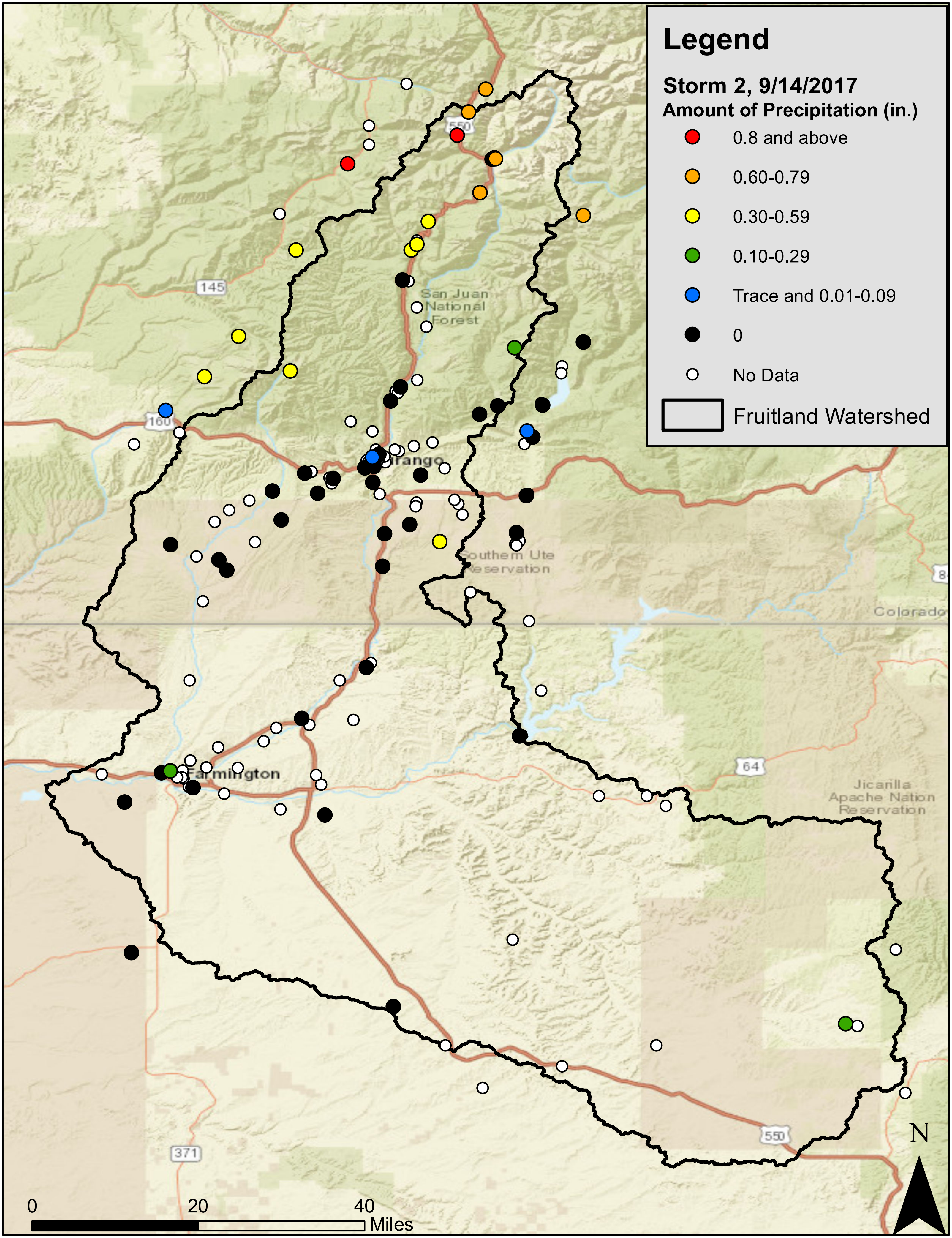
Storm #	Sample Date	Total Lithium Concentration (µg/L)	Total Manganese Concentration (µg/L)	Total Mercury Concentration (µg/L)	Total Molybdenum Concentration (µg/L)	Total Nickel Concentration (µg/L)	Total Selenium Concentration (µg/L)	Total Silver Concentration (µg/L)	Total Strontium Concentration (µg/L)	Total Thallium Concentration (µg/L)	Total Vanadium Concentration (µg/L)	Total Uranium Concentration (µg/L)	Total Zinc Concentration (µg/L)
1	8/21/17 13:26	21.5	71.4	0.006	1.24	1.8	0.4	0.03	646	0.03	4	1.29	18
	8/21/17 18:30	44.8	926.0	0.079	0.55	24.2	0.8	0.24	1,150	0.35	36	3.10	110
	8/21/17 19:44	49.1	1,150.0	0.093	0.66	28.0	0.8	0.29	1,250	0.41	43	3.59	131
	8/21/17 22:24	26.4	258.0	0.019	0.74	6.8	0.4	0.06	764	0.12	14	1.58	35
2	9/15/17 19:35	31.6	456.0	0.064	0.56	13.3	0.6	0.11	699	0.19	25	1.87	82
	9/15/17 20:29	34.6	610.0	0.068	0.55	20.3	0.7	0.17	777	0.26	35	2.22	90
	9/15/17 22:31	33.6	530.0	0.072	0.53	20.9	0.7	0.16	752	0.23	34	2.09	85
	9/16/17 3:19	25.9	313.0	0.025	0.70	7.2	0.4	0.07	703	0.12	14	1.61	41
3	9/27/17 14:30	23.1	53.0	0.005	1.27	1.5	0.5	0.03	715	0.02	2	1.32	7
	9/27/17 20:23	35.2	580.0	0.035	0.62	17.5	0.6	0.12	927	0.34	44	2.77	114
	9/28/17 10:59	185.0	5,690.0	0.413	5.00	182.0	5.0	3.00	4,230	2.00	312	19.30	748
	9/28/17 16:01	91.1	2,430.0	0.189	5.00	70.3	5.0	3.00	1,890	2.00	101	7.16	283
	9/28/17 16:48	78.6	2,060.0	0.152	5.00	59.8	5.0	3.00	1,710	2.00	74	5.87	303
	9/28/17 21:26	41.8	743.0	0.043	5.00	20.0	5.0	3.00	975	2.00	50	3.00	200
	9/29/17 3:27	203.0	8,400.0	0.420	5.00	187.0	5.0	3.00	3,670	2.00	190	19.50	456
	9/30/17 19:32	84.1	2,500.0	0.214	5.00	68.6	5.0	3.00	1,600	2.00	94	6.81	348
	10/1/17 0:38	95.5	3,370.0	0.251	5.00	89.5	5.0	3.00	1,990	2.00	134	7.23	437
	10/1/17 7:36	406.0	20,500.0	0.04	5.00	455.0	5.0	3.00	6,860	2.00	640	36.00	1,050
4	10/3/18 19:58	18.0	60.9	0.007	0.95	1.9	0.5	0.03	590	0.04	3	1.35	10
	10/4/18 10:25	87.8	3,660.0	0.378	0.84	90.1	1.2	1.23	1,860	1.35	103	9.48	312
	10/4/18 12:15	71.3	2,920.0	0.322	0.68	72.0	1.2	0.75	1,640	0.82	87	7.99	239
	10/4/18 21:20	33.6	778.0	0.079	0.51	19.5	0.7	0.17	906	0.32	33	3.63	72

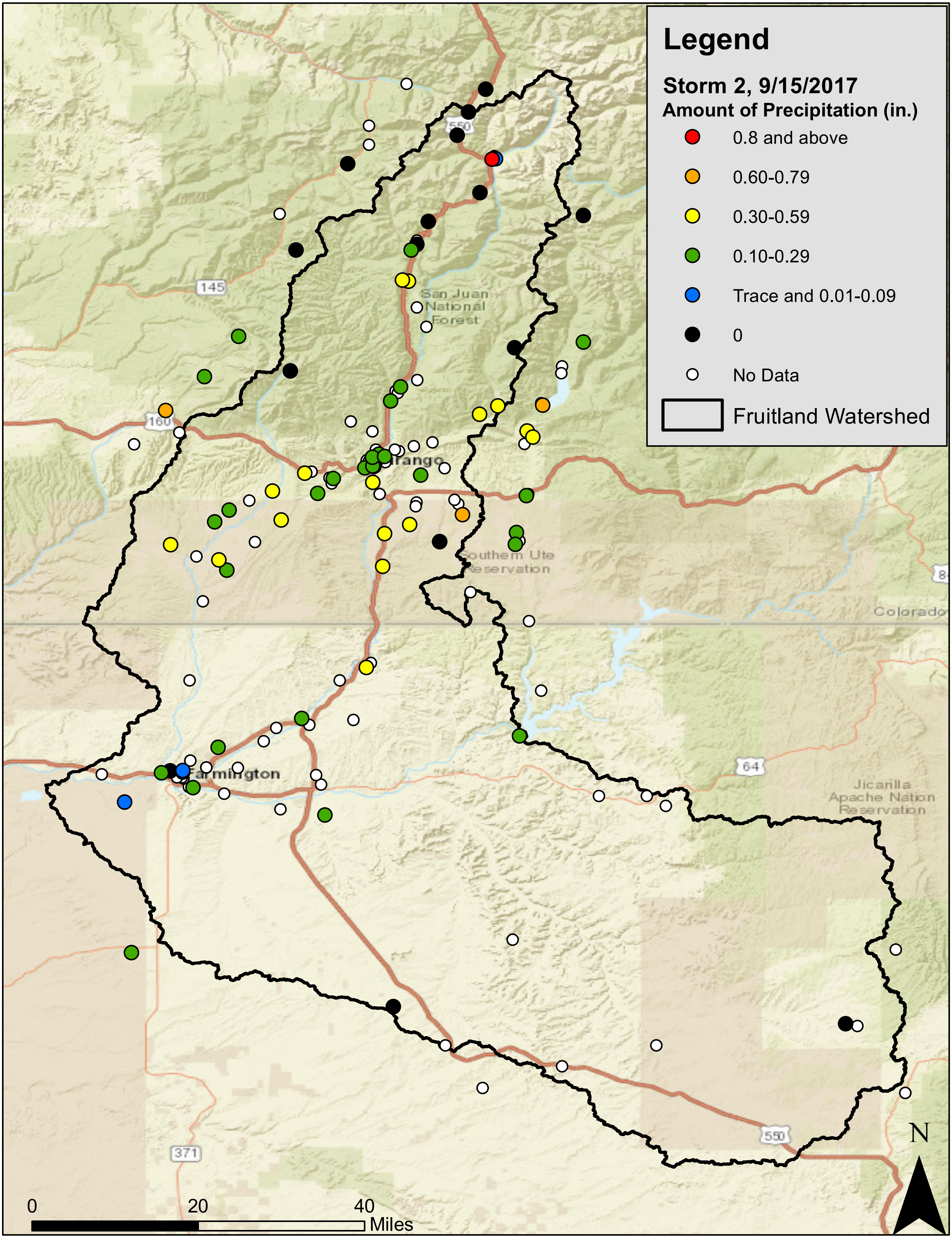
Appendix B – Precipitation Maps



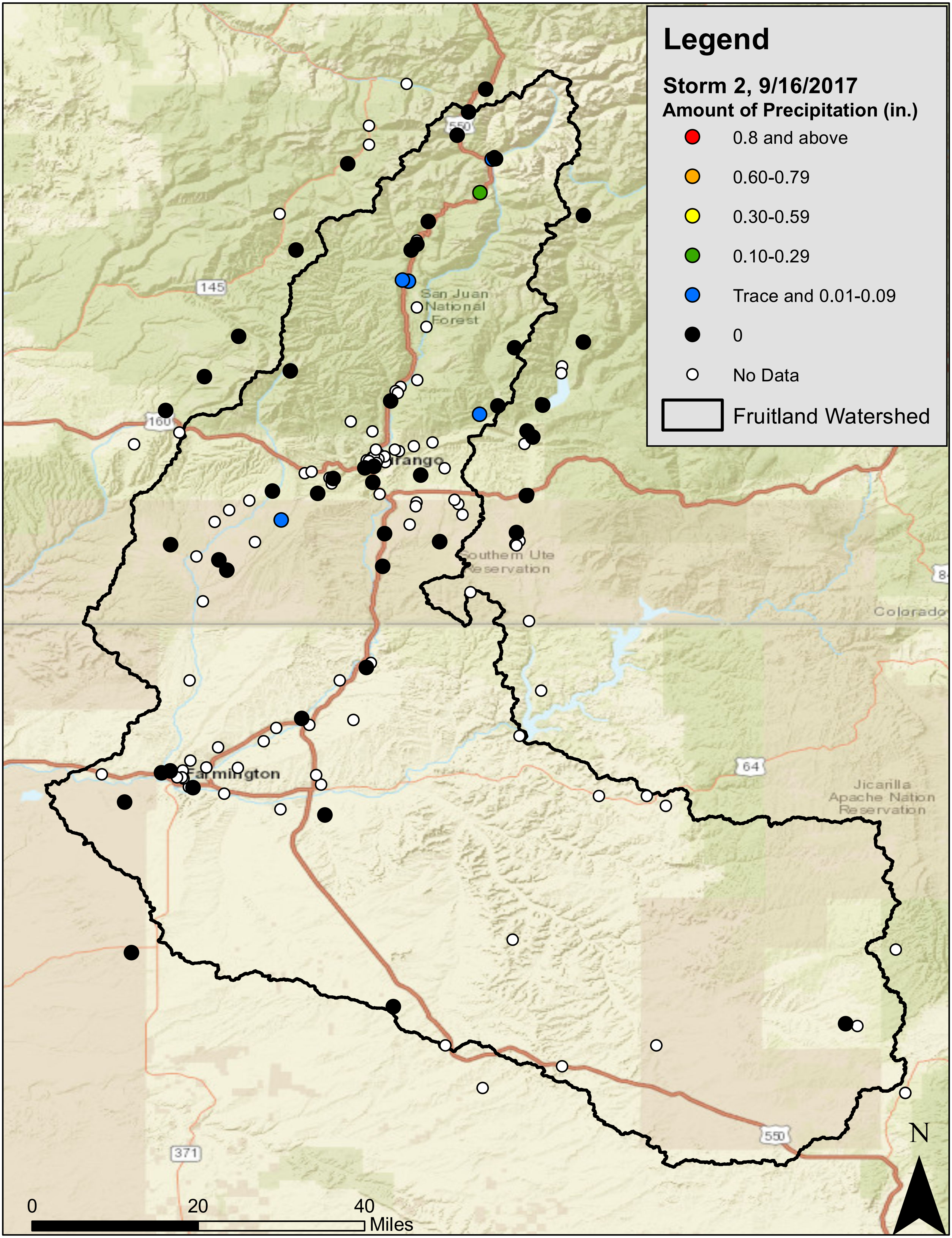
Legend
Storm 1, 8/20/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Durango
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
0
20
40
Miles
N

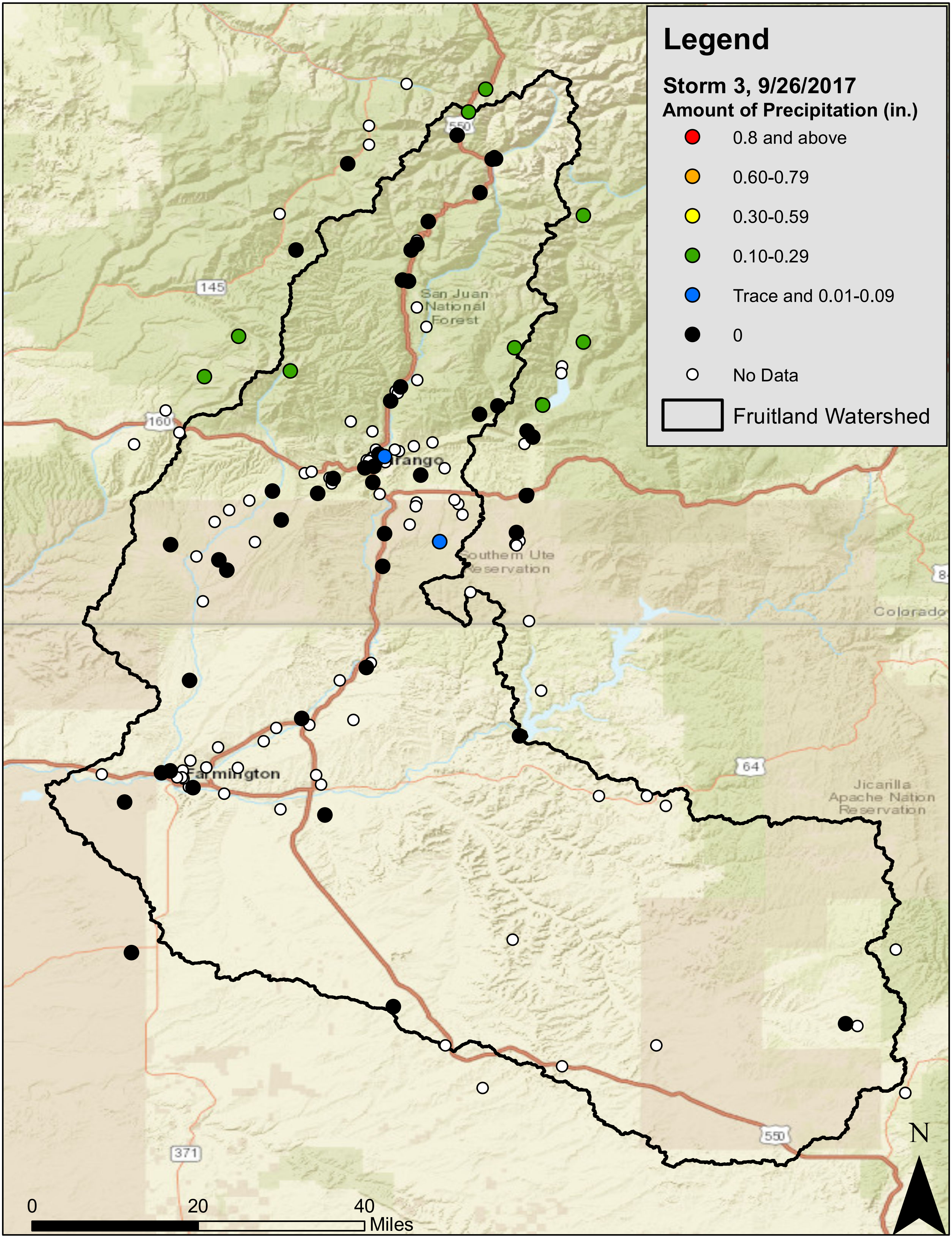

Legend
Storm 1, 8/21/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
N
0
20
40
Miles

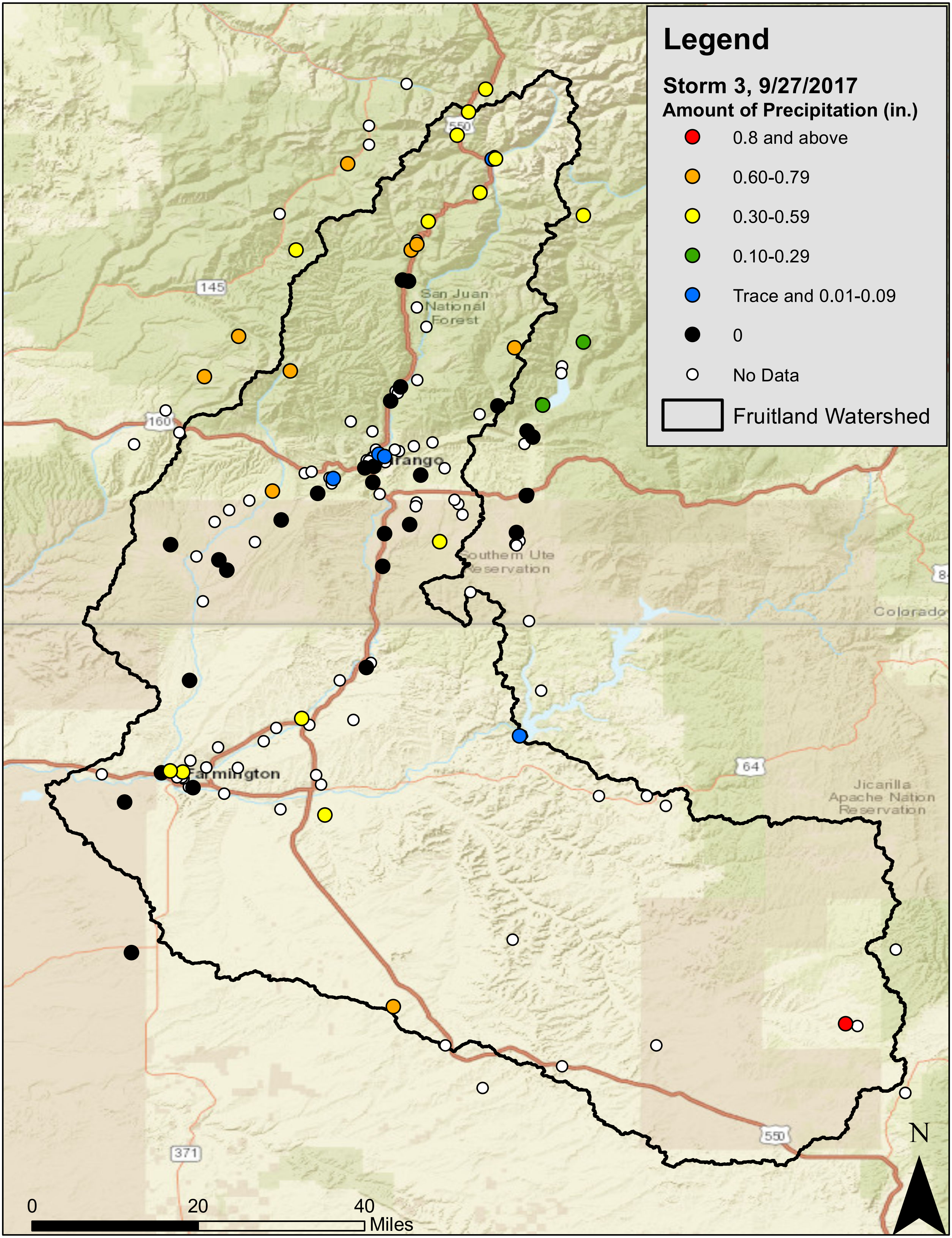

Legend
Storm 2, 9/14/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
145
160
550
64
371
0
20
40
Miles
N

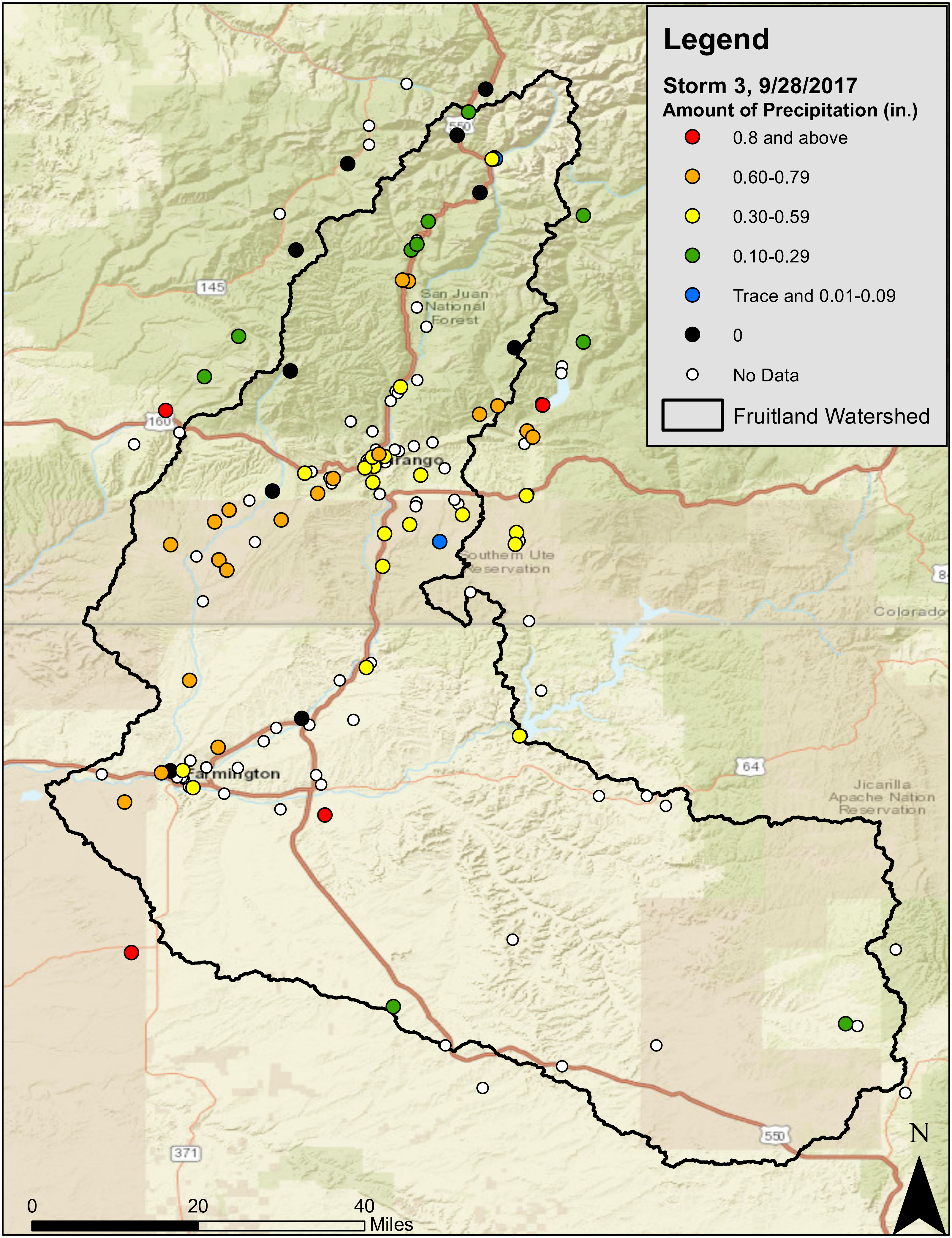


Legend
Storm 2, 9/15/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
0
20
40
Miles
N

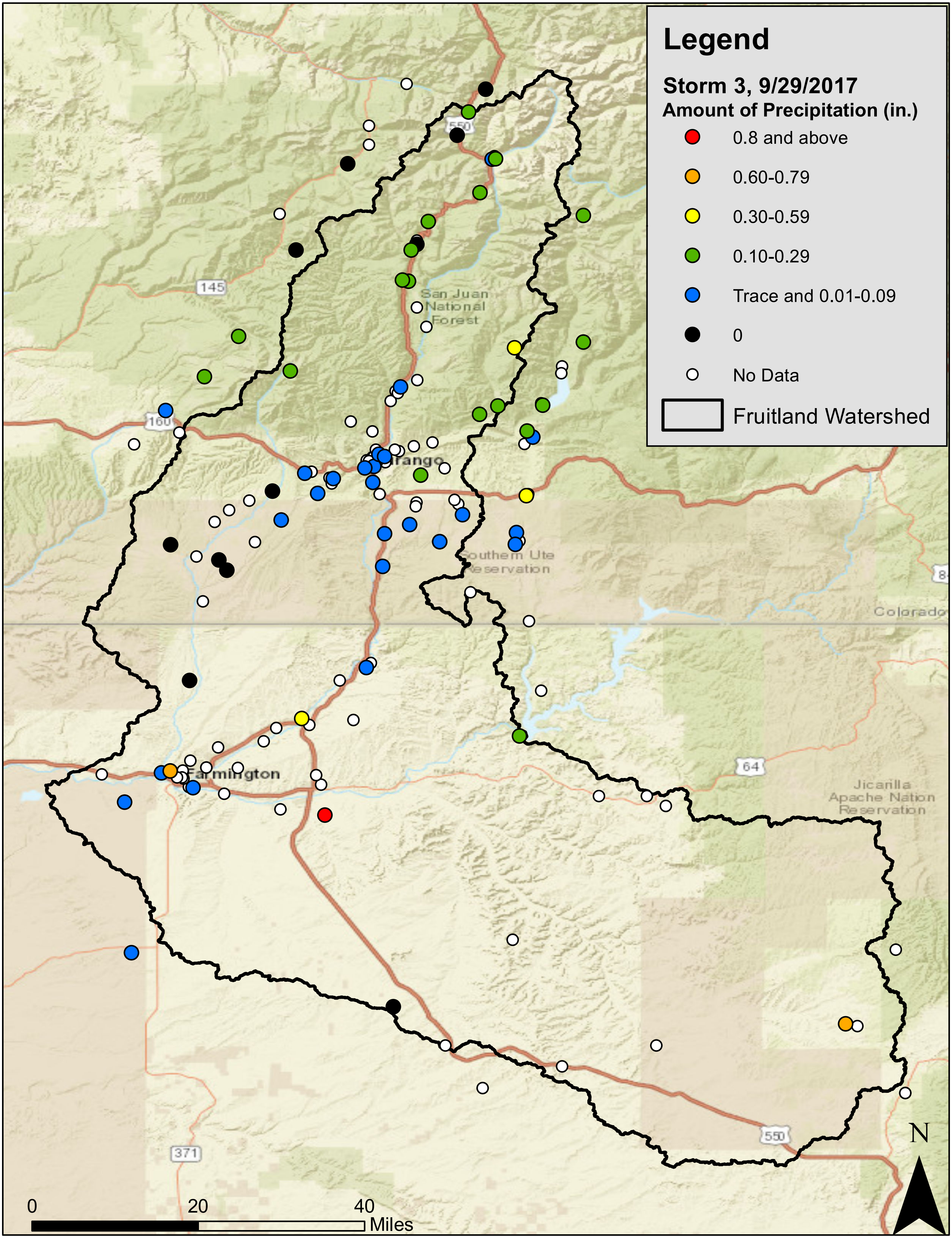

Legend
Storm 2, 9/16/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
0
20
40
Miles
N


Legend
Storm 3, 9/26/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Durango
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
0
20
40
Miles
N

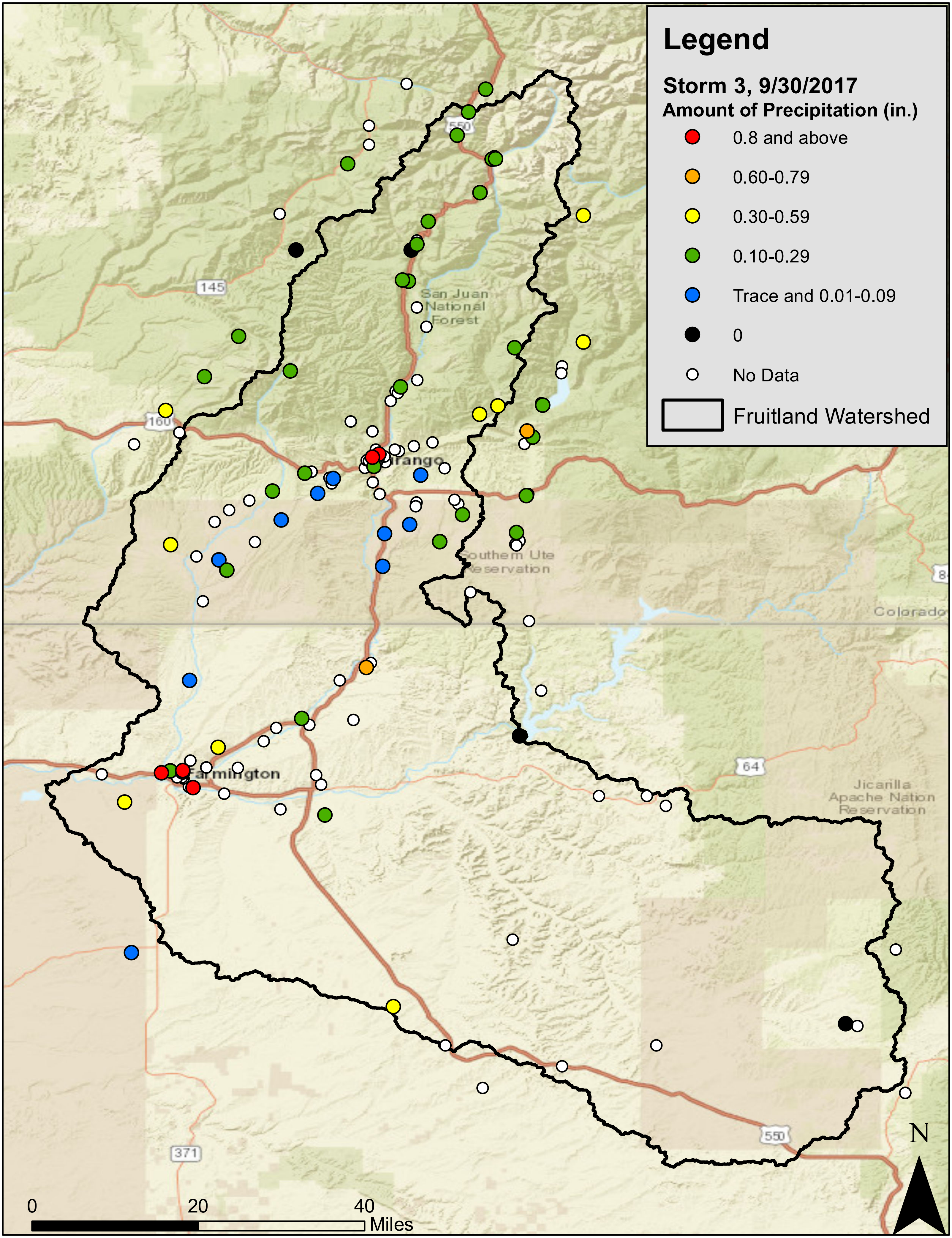

Legend
Storm 3, 9/27/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Durango
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
145
160
550
64
371
N
0
20
40
Miles

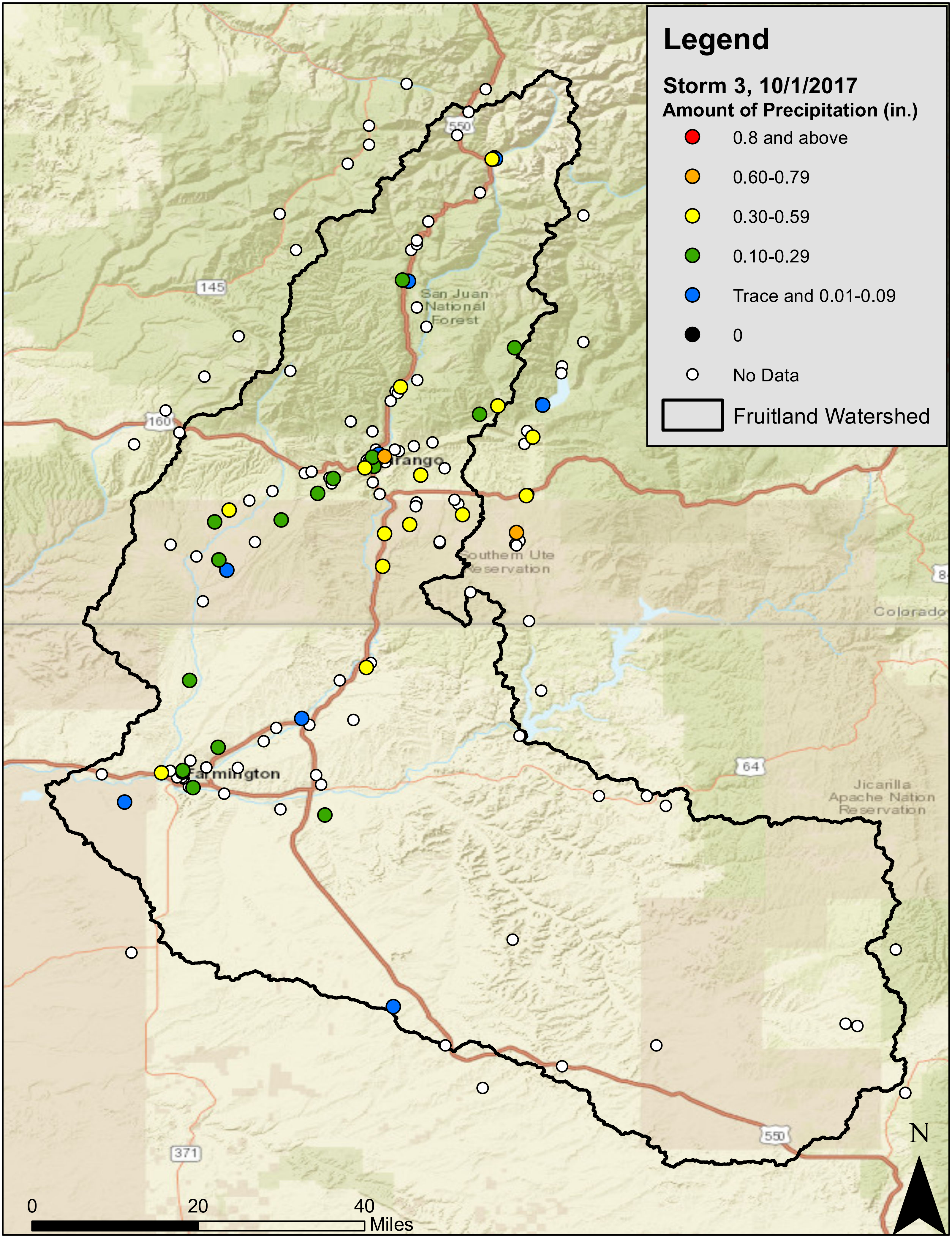


Legend
Storm 3, 9/28/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Durango
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
0
20
40
Miles
N

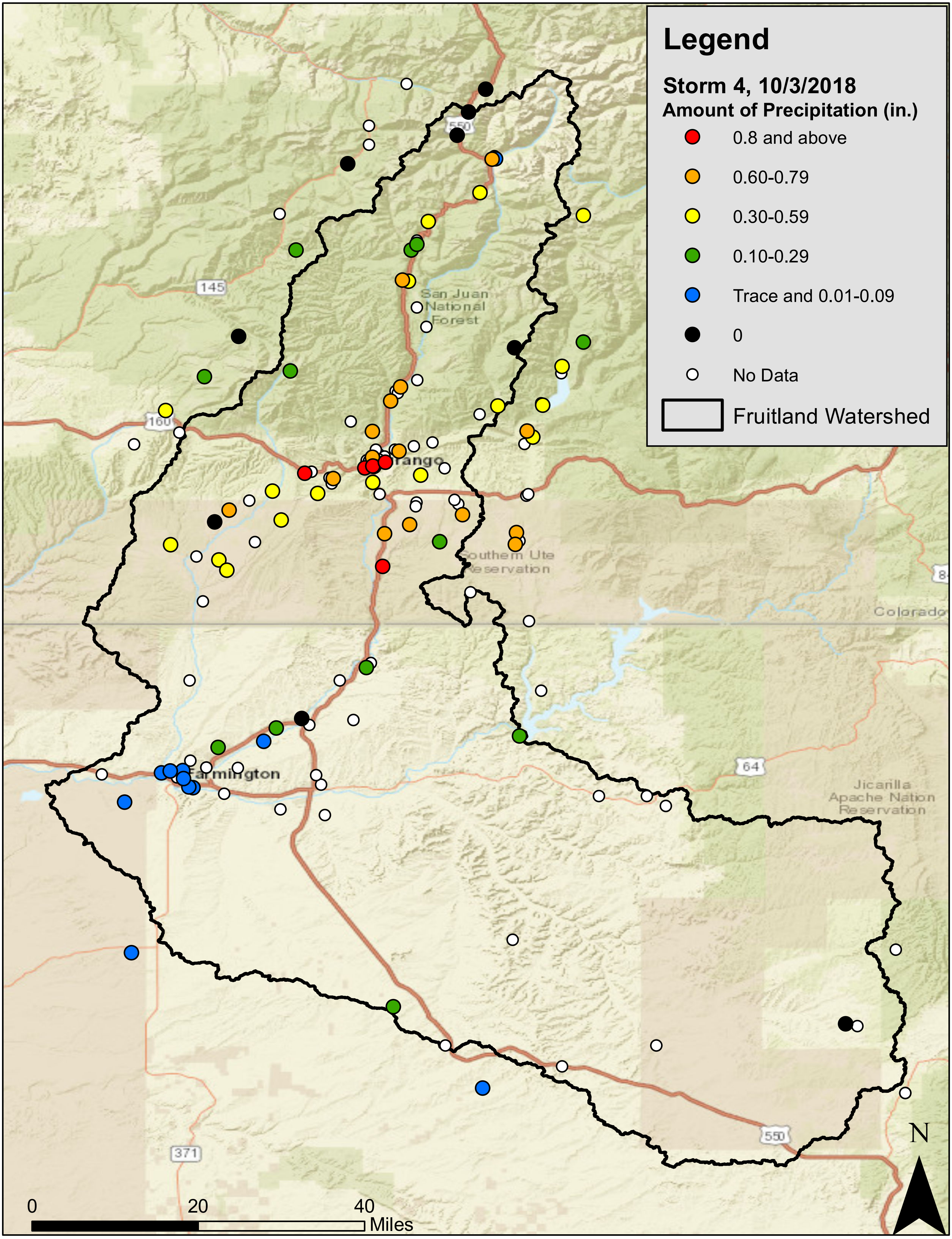


Legend
Storm 3, 9/29/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
145
160
550
64
371
0
20
40
Miles
N

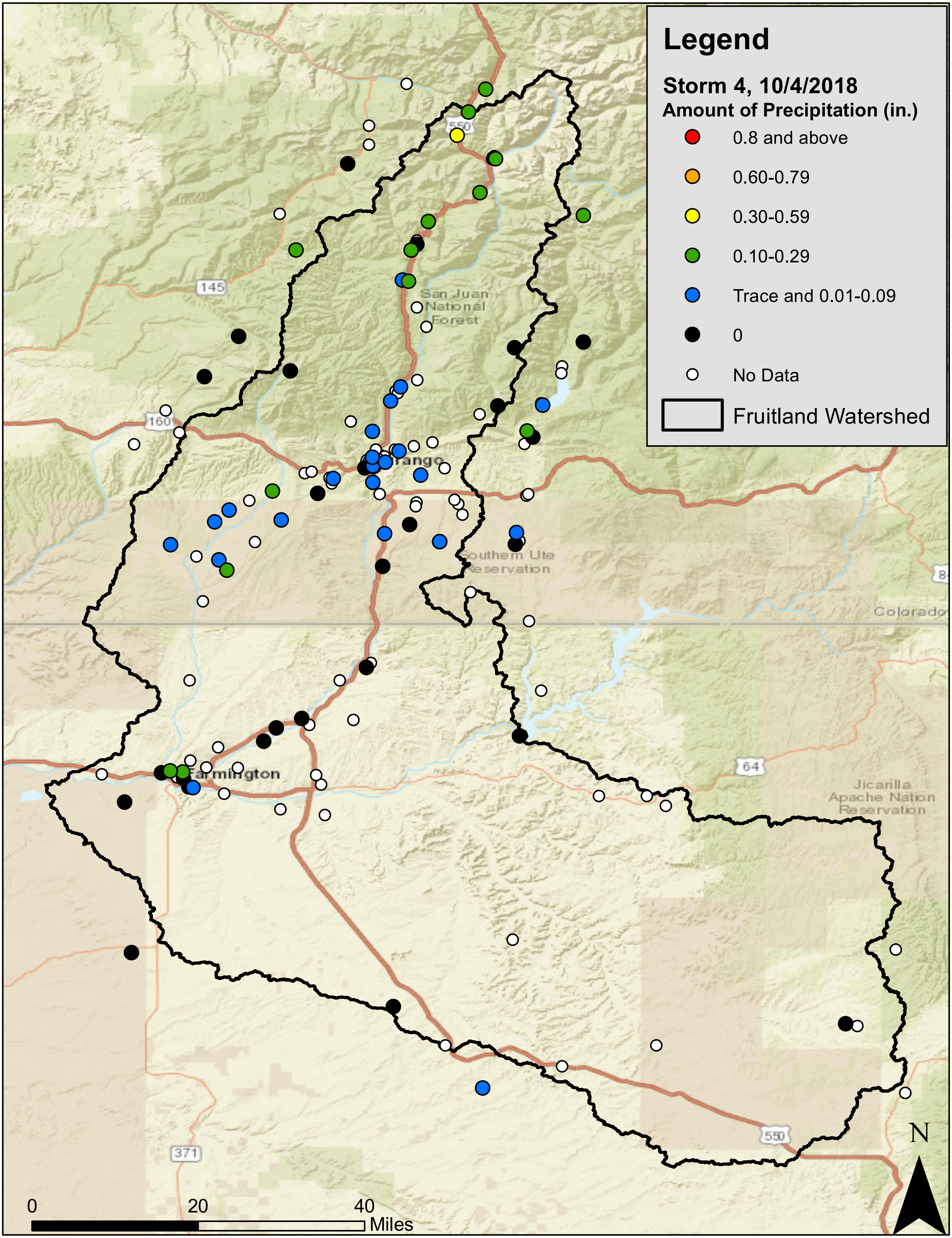

Legend
Storm 3, 9/30/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Durango
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
0
20
40
Miles
N



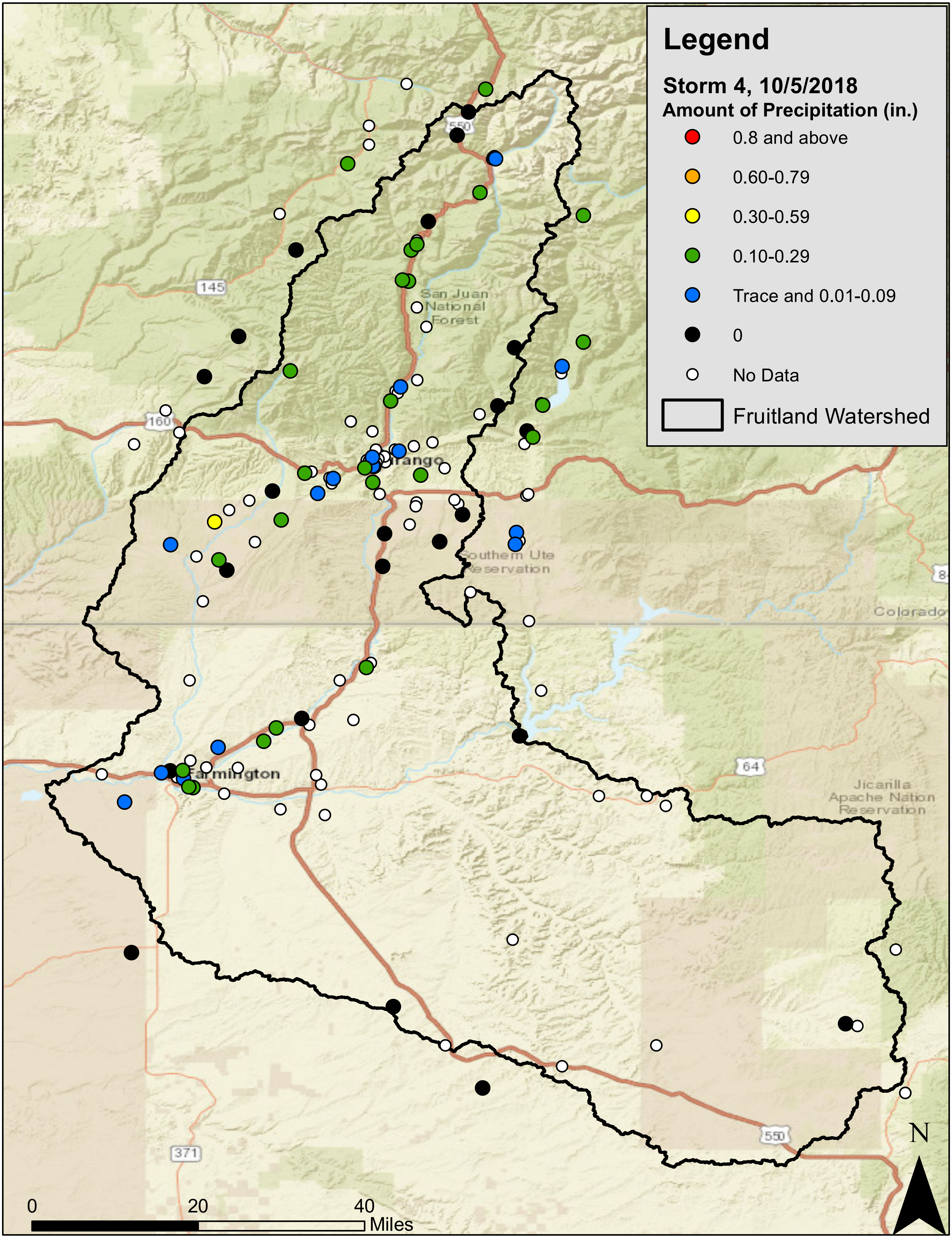
Legend
Storm 3, 10/1/2017
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
0
20
40
Miles
N



Legend
Storm 4, 10/3/2018
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
145
160
550
64
371
0
20
40
Miles
N



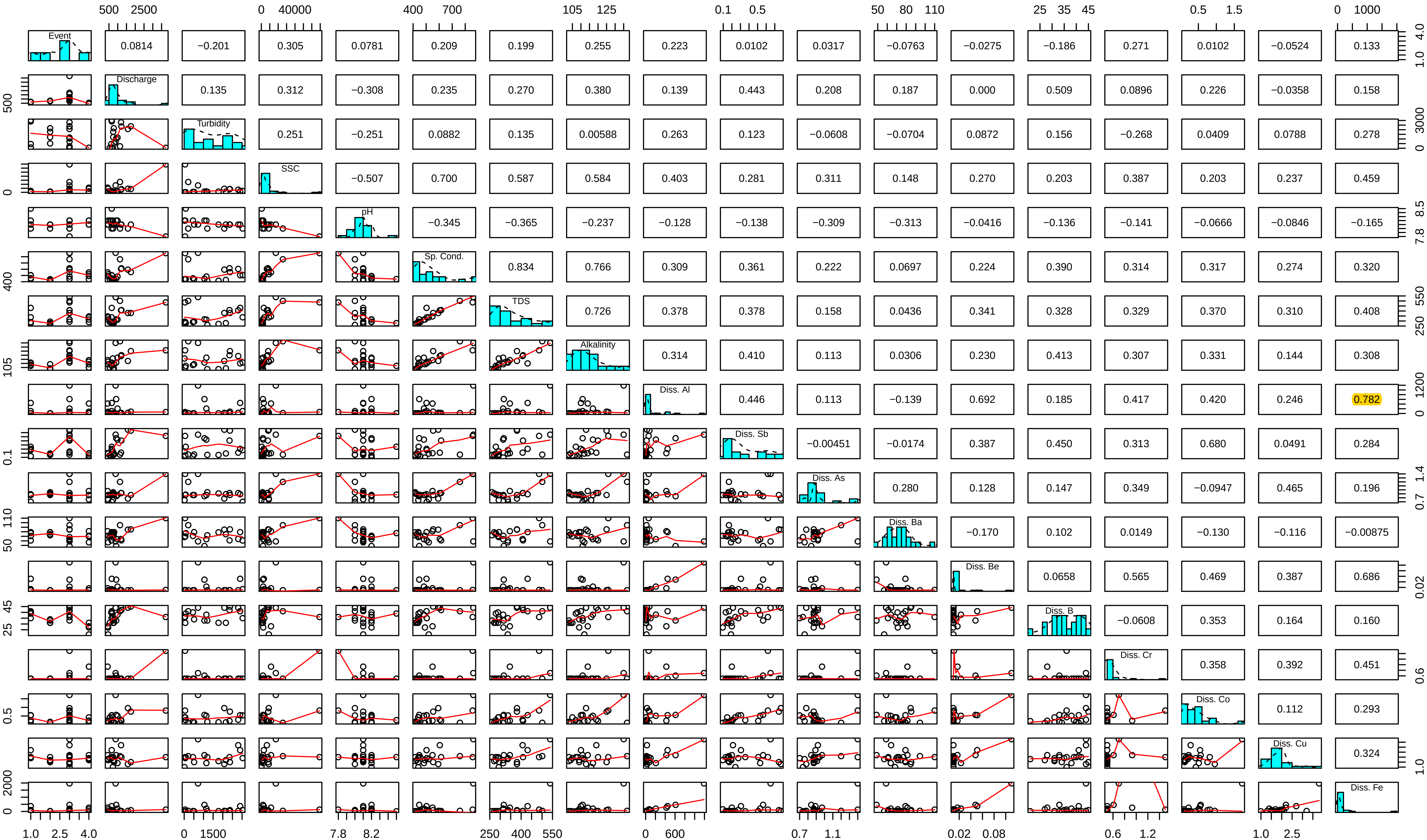
Legend
Storm 4, 10/4/2018
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
550
145
160
64
371
N
0
20
40
Miles

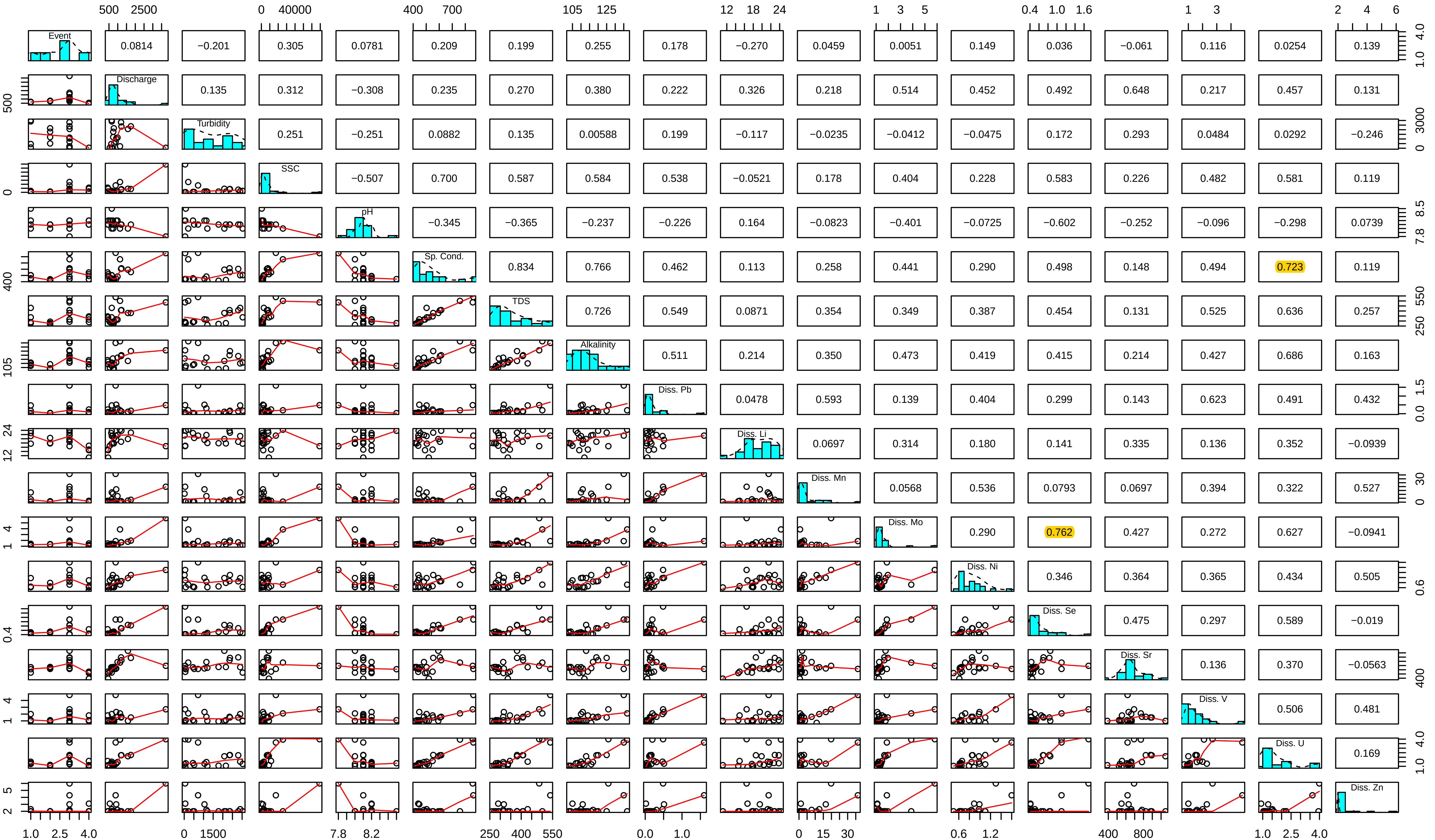


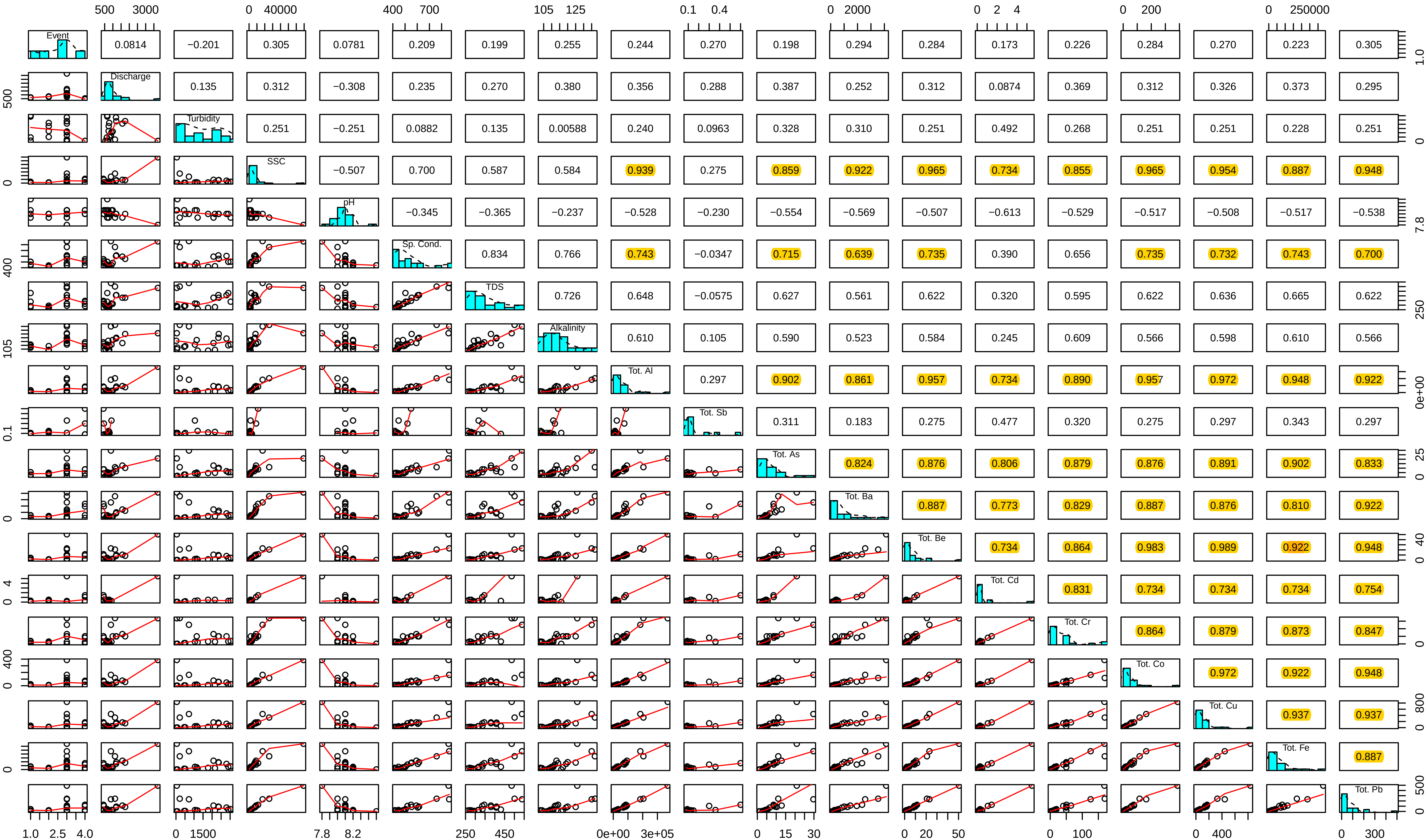
Legend
Storm 4, 10/5/2018
Amount of Precipitation (in.)
0.8 and above
0.60-0.79
0.30-0.59
0.10-0.29
Trace and 0.01-0.09
0
No Data
Fruitland Watershed
San Juan National Forest
Southern Ute Reservation
Colorado
Farmington
Jicarilla Apache Nation Reservation
145
160
550
64
371
N
0
20
40
Miles

Appendix C – Pairs Plots

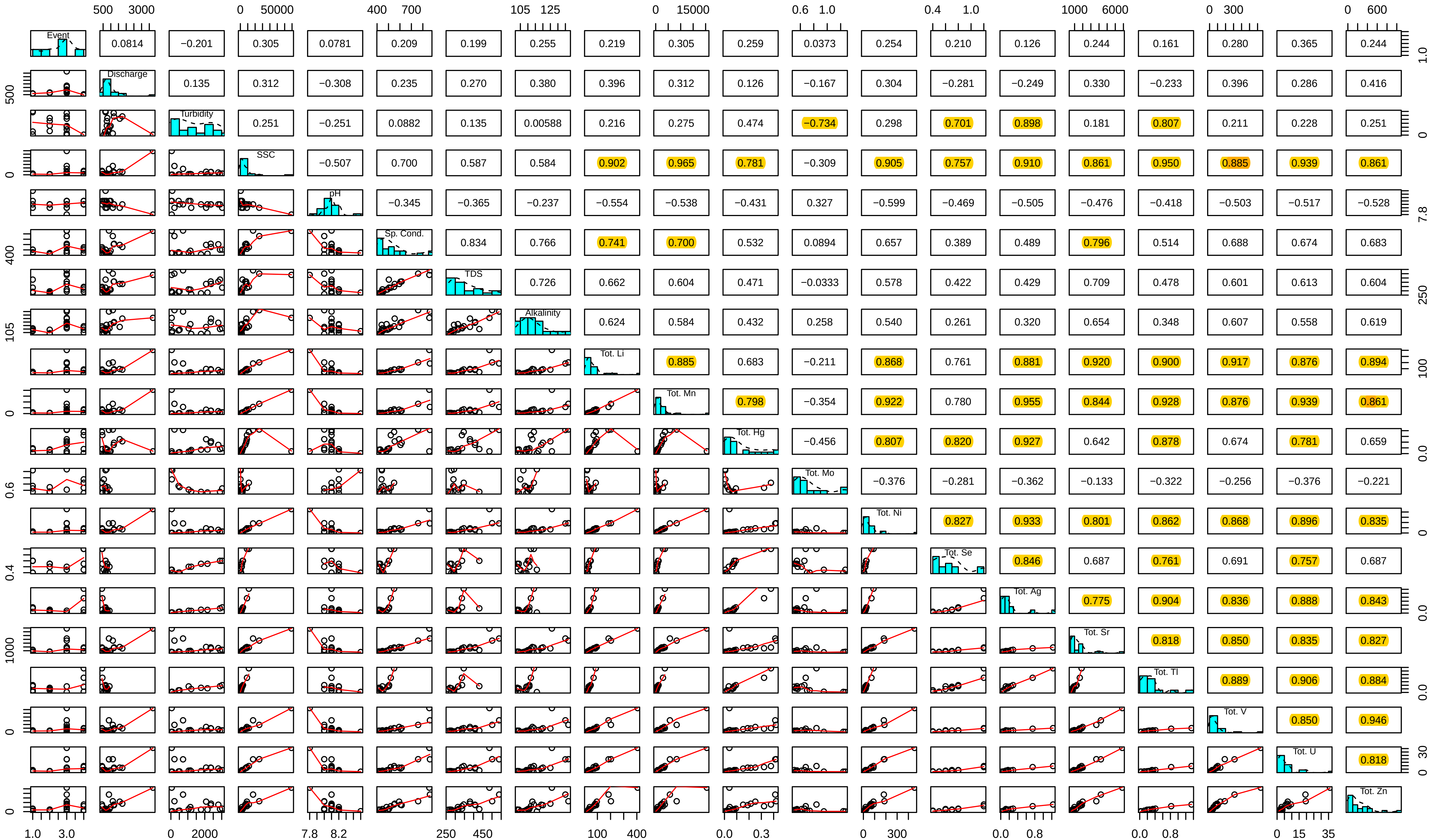

Event
Discharge
Turbidity
SSC
pH
Sp. Cond.
TDS
Alkalinity
Ca 2+
Mg 2+
Na +
K +
Cl −
SO4 2−
Br −
F −
0.0814 −0.201 0.305 0.0781 0.209 0.199 0.255 −0.213 −0.345 0.0711 0.0661 0.0357 0.169 0.291 0.220
0.135 0.312 −0.308 0.235 0.270 0.380 0.408 −0.0347 0.312 0.700 0.479 0.303 0.177 0.376
0.251 −0.251 0.0882 0.135 0.00588 0.076 −0.123 0.146 0.211 0.270 0.124 0.282 0.109
−0.507 0.700 0.587 0.584 −0.0563 −0.567 0.636 0.477 0.204 0.700 0.651 0.755
−0.345 −0.365 −0.237 −0.0973 0.200 −0.374 −0.472 −0.00514 −0.357 −0.351 −0.417
0.834 0.766 0.00435 −0.674 0.796 0.383 0.354 0.927 0.662 0.852
0.726 0.0304 −0.604 0.726 0.401 0.371 0.862 0.573 0.790
0.0959 −0.532 0.654 0.406 0.508 0.762 0.490 0.823
0.299 0.0649 0.443 0.326 0.0788 −0.111 0.0759
−0.532 −0.104 −0.170 −0.613 −0.500 −0.594
0.460 0.309 0.823 0.553 0.719
0.366 0.452 0.328 0.474
0.413 0.365 0.444
0.626 0.867
0.621
500 2500
0 40000
400 600 800
105 125
3 5 7 9
2.0 2.6 3.2
100 200
0.20 0.35
1.0 3.5
0 2500
7.8 8.4
250 550
30 60
40 120
10
0.02
500
0 70000
400
105
3 6 9
2.0 3.2
100 250
0.20
1.0 2.5 4.0
0 1500
7.8 8.1 8.4
250 400 550
30 50 70
40 80 120
10 20
0.02 0.05

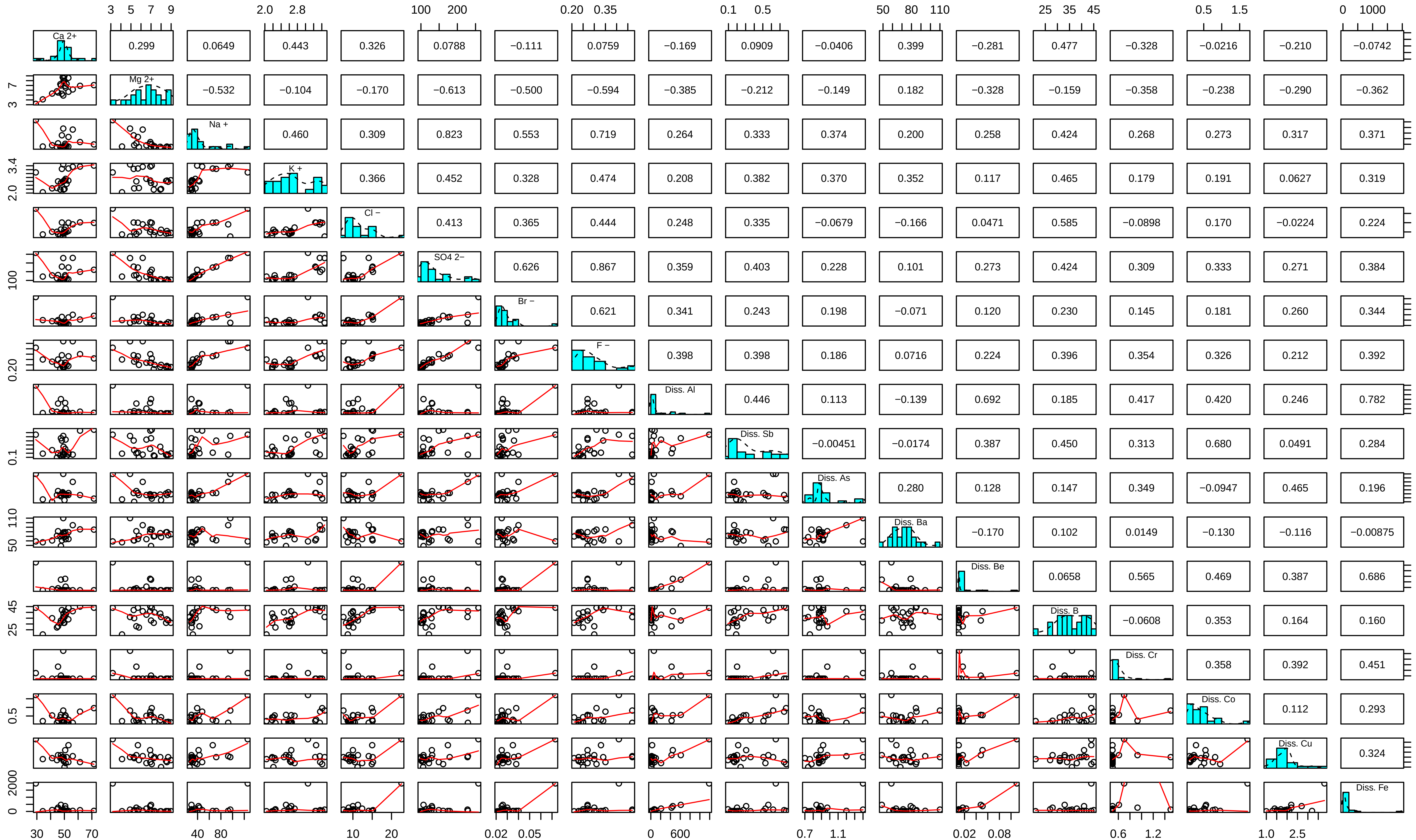

Event
Discharge
Turbidity
SSC
pH
Sp. Cond.
TDS
Alkalinity
Diss. Al
Diss. Sb
Diss. As
Diss. Ba
Diss. Be
Diss. B
Diss. Cr
Diss. Co
Diss. Cu
Diss. Fe
0.0814 −0.201 0.305 0.0781 0.209 0.199 0.255 0.223 0.0102 0.0317 −0.0763 −0.0275 −0.186 0.271 0.0102 −0.0524 0.133
0.135 0.312 −0.308 0.235 0.270 0.380 0.139 0.443 0.208 0.187 0.000 0.509 0.0896 0.226 −0.0358 0.158
0.251 −0.251 0.0882 0.135 0.00588 0.263 0.123 −0.0608 −0.0704 0.0872 0.156 −0.268 0.0409 0.0788 0.278
−0.507 0.700 0.587 0.584 0.403 0.281 0.311 0.148 0.270 0.203 0.387 0.203 0.237 0.459
−0.345 −0.365 −0.237 −0.128 −0.138 −0.309 −0.313 −0.0416 −0.136 −0.141 −0.0666 −0.0846 −0.165
0.834 0.766 0.309 0.361 0.222 0.0697 0.224 0.390 0.314 0.317 0.274 0.320
0.726 0.378 0.378 0.158 0.0436 0.341 0.328 0.329 0.370 0.310 0.408
0.314 0.410 0.113 0.0306 0.230 0.413 0.307 0.331 0.144 0.308
0.446 0.113 −0.139 0.692 0.185 0.417 0.420 0.246 0.782
−0.00451 −0.0174 0.387 0.450 0.313 0.680 0.0491 0.284
0.280 0.128 0.147 0.349 −0.0947 0.465 0.196
−0.170 0.102 0.0149 −0.130 −0.116 −0.00875
0.0658 0.565 0.469 0.387 0.686
−0.0608 0.353 0.164 0.160
0.358 0.392 0.451
0.112 0.293
0.324
500 2500
0 40000
400 700
105 125
0.1 0.5
50 80 110
25 35 45
0.5 1.5
0 1000
1.0 4.0
0 3000
7.8 8.5
250 550
0 1200
0.7 1.4
0.02
0.6
1.0
500
0
400
105
0.1
50 110
25 45
0.5
0 2000
1.0 2.5 4.0
0 1500
7.8 8.2
250 400 550
0 600
0.7 1.1
0.02 0.08
0.6 1.2
1.0 2.5

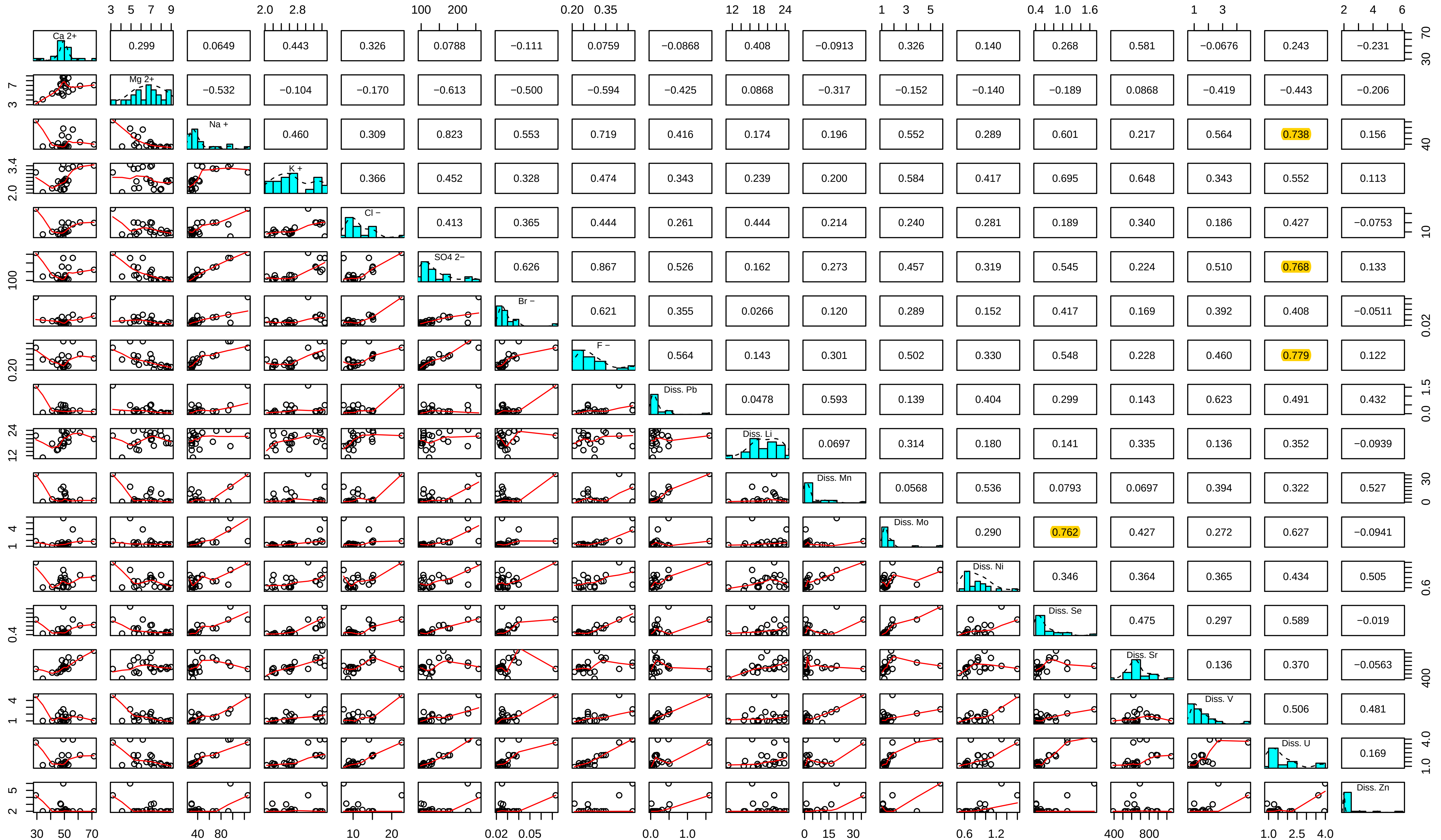

Event
0.0814 −0.201 0.305 0.0781 0.209 0.199 0.255 0.178 −0.270 0.0459 0.0051 0.149 0.036 −0.061 0.116 0.0254 0.139
Discharge
0.135 0.312 −0.308 0.235 0.270 0.380 0.222 0.326 0.218 0.514 0.452 0.492 0.648 0.217 0.457 0.131
Turbidity
0.251 −0.251 0.0882 0.135 0.00588 0.199 −0.117 −0.0235 −0.0412 −0.0475 0.172 0.293 0.0484 0.0292 −0.246
SSC
−0.507 0.700 0.587 0.584 0.538 −0.0521 0.178 0.404 0.228 0.583 0.226 0.482 0.581 0.119
pH
−0.345 −0.365 −0.237 −0.226 0.164 −0.0823 −0.401 −0.0725 −0.602 −0.252 −0.096 −0.298 0.0739
Sp. Cond.
0.834 0.766 0.462 0.113 0.258 0.441 0.290 0.498 0.148 0.494 0.723 0.119
TDS
0.726 0.549 0.0871 0.354 0.349 0.387 0.454 0.131 0.525 0.636 0.257
Alkalinity
0.511 0.214 0.350 0.473 0.419 0.415 0.214 0.427 0.686 0.163
Diss. Pb
0.0478 0.593 0.139 0.404 0.299 0.143 0.623 0.491 0.432
Diss. Li
0.0697 0.314 0.180 0.141 0.335 0.136 0.352 −0.0939
Diss. Mn
0.0568 0.536 0.0793 0.0697 0.394 0.322 0.527
Diss. Mo
0.290 0.762 0.427 0.272 0.627 −0.0941
Diss. Ni
0.346 0.364 0.365 0.434 0.505
Diss. Se
0.475 0.297 0.589 −0.019
Diss. Sr
0.136 0.370 −0.0563
Diss. V
0.506 0.481
Diss. U
0.169
Diss. Zn

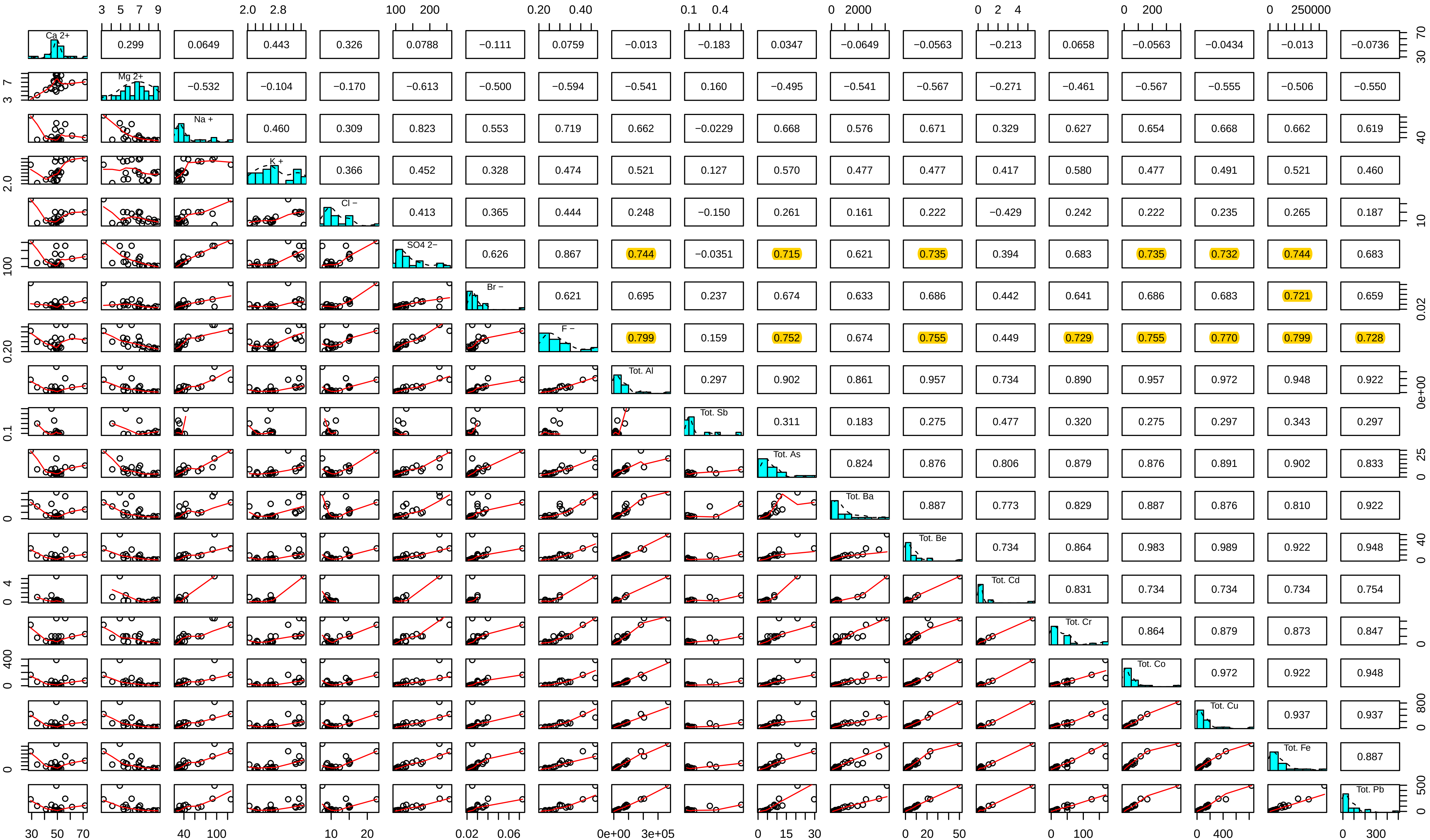


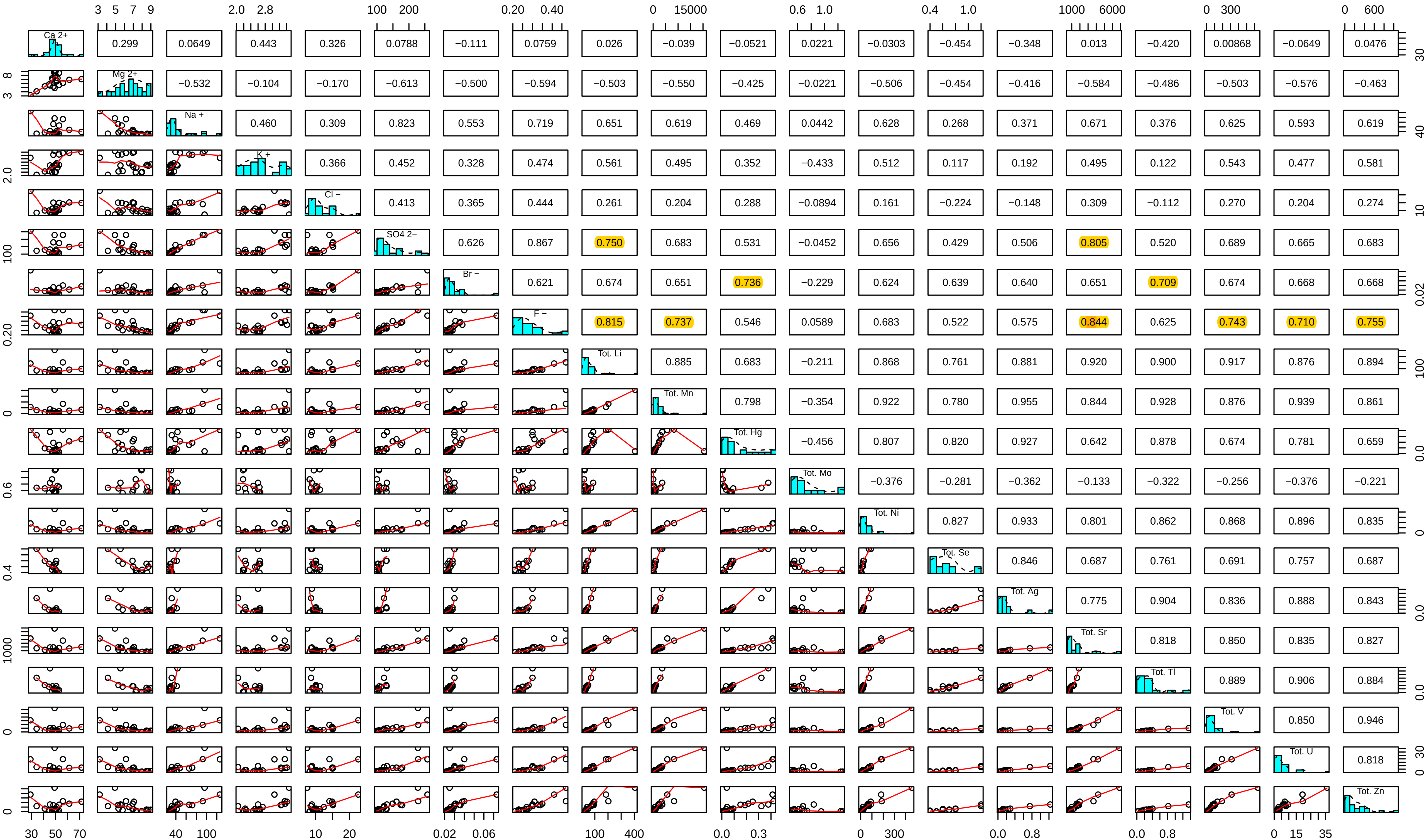
Event
Discharge
Turbidity
SSC
pH
Sp. Cond.
TDS
Alkalinity
Tot. Al
Tot. Sb
Tot. As
Tot. Ba
Tot. Be
Tot. Cd
Tot. Cr
Tot. Co
Tot. Cu
Tot. Fe
Tot. Pb


Event
Discharge
Turbidity
SSC
pH
Sp. Cond.
TDS
Alkalinity
Tot. Li
Tot. Mn
Tot. Hg
Tot. Mo
Tot. Ni
Tot. Se
Tot. Ag
Tot. Sr
Tot. Tl
Tot. V
Tot. U
Tot. Zn
0.0814 −0.201 0.305 0.0781 0.209 0.199 0.255 0.219 0.305 0.259 0.0373 0.254 0.210 0.126 0.244 0.161 0.280 0.365 0.244
0.135 0.312 −0.308 0.235 0.270 0.380 0.396 0.312 0.126 −0.167 0.304 −0.281 −0.249 0.330 −0.233 0.396 0.286 0.416
0.251 −0.251 0.0882 0.135 0.00588 0.216 0.275 0.474 −0.734 0.298 0.701 0.898 0.181 0.807 0.211 0.228 0.251
−0.507 0.700 0.587 0.584 0.902 0.965 0.781 −0.309 0.905 0.757 0.910 0.861 0.950 0.885 0.939 0.861
−0.345 −0.365 −0.237 −0.554 −0.538 −0.431 0.327 −0.599 −0.469 −0.505 −0.476 −0.418 −0.503 −0.517 −0.528
0.834 0.766 0.741 0.700 0.532 0.0894 0.657 0.389 0.489 0.796 0.514 0.688 0.674 0.683
0.726 0.662 0.604 0.471 −0.0333 0.578 0.422 0.429 0.709 0.478 0.601 0.613 0.604
0.624 0.584 0.432 0.258 0.540 0.261 0.320 0.654 0.348 0.607 0.558 0.619
0.885 0.683 −0.211 0.868 0.761 0.881 0.920 0.900 0.917 0.876 0.894
0.798 −0.354 0.922 0.780 0.955 0.844 0.928 0.876 0.939 0.861
−0.456 0.807 0.820 0.927 0.642 0.878 0.674 0.781 0.659
−0.376 −0.281 −0.362 −0.133 −0.322 −0.256 −0.376 −0.221
0.827 0.933 0.801 0.862 0.868 0.896 0.835
0.846 0.687 0.761 0.691 0.757 0.687
0.775 0.904 0.836 0.888 0.843
0.818 0.850 0.835 0.827
0.889 0.906 0.884
0.850 0.946
0.818
500 3000
0 50000
400 700
105 125
0 15000
0.6 1.0
0.4 1.0
1000 6000
0 300
0 600
1.0 3.0
0 2000
7.8 8.2
250 450
100 400
0.0 0.3
0 300
0.0 0.8
0.0 0.8
0 15 35

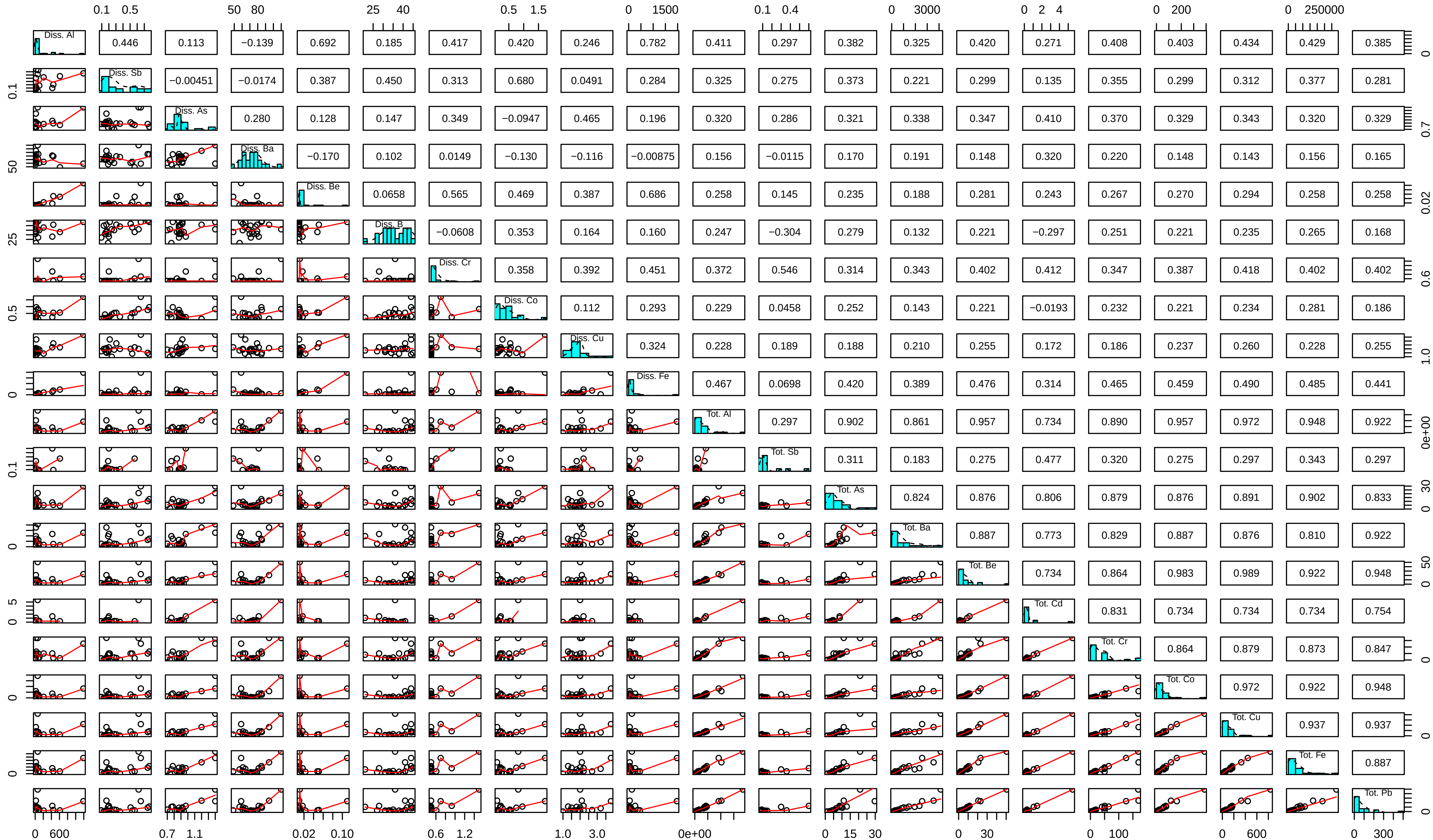

Ca 2+
Mg 2+
Na +
K +
Cl −
SO4 2−
Br −
F −
Diss. Al
Diss. Sb
Diss. As
Diss. Ba
Diss. Be
Diss. B
Diss. Cr
Diss. Co
Diss. Cu
Diss. Fe
0.299 0.0649 0.443 0.326 0.0788 −0.111 0.0759 −0.169 0.0909 −0.0406 0.399 −0.281 0.477 −0.328 −0.0216 −0.210 −0.0742
−0.532 −0.104 −0.170 −0.613 −0.500 −0.594 −0.385 −0.212 −0.149 0.182 −0.328 −0.159 −0.358 −0.238 −0.290 −0.362
0.460 0.309 0.823 0.553 0.719 0.264 0.333 0.374 0.200 0.258 0.424 0.268 0.273 0.317 0.371
0.366 0.452 0.328 0.474 0.208 0.382 0.370 0.352 0.117 0.465 0.179 0.191 0.0627 0.319
0.413 0.365 0.444 0.248 0.335 −0.0679 −0.166 0.0471 0.585 −0.0898 0.170 −0.0224 0.224
0.626 0.867 0.359 0.403 0.228 0.101 0.273 0.424 0.309 0.333 0.271 0.384
0.621 0.341 0.243 0.198 −0.071 0.120 0.230 0.145 0.181 0.260 0.344
0.398 0.398 0.186 0.0716 0.224 0.396 0.354 0.326 0.212 0.392
0.446 0.113 −0.139 0.692 0.185 0.417 0.420 0.246 0.782
−0.00451 −0.0174 0.387 0.450 0.313 0.680 0.0491 0.284
0.280 0.128 0.147 0.349 −0.0947 0.465 0.196
−0.170 0.102 0.0149 −0.130 −0.116 −0.00875
0.0658 0.565 0.469 0.387 0.686
−0.0608 0.353 0.164 0.160
0.358 0.392 0.451
0.112 0.293
0.324

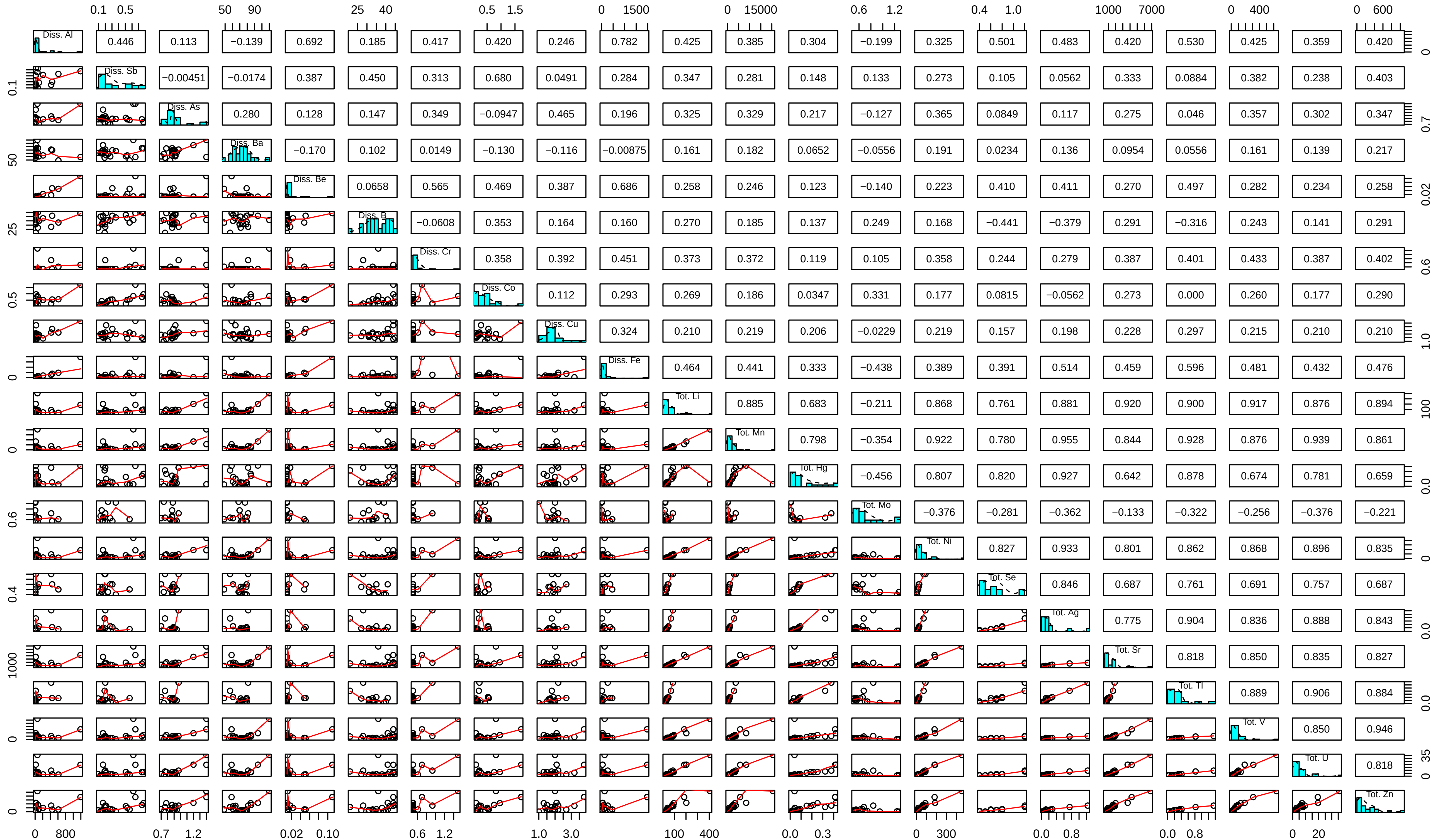

Ca 2+
Mg 2+
Na +
K +
Cl −
SO4 2−
Br −
F −
Diss. Pb
Diss. Li
Diss. Mn
Diss. Mo
Diss. Ni
Diss. Se
Diss. Sr
Diss. V
Diss. U
Diss. Zn
0.299 0.0649 0.443 0.326 0.0788 −0.111 0.0759 −0.0868 0.408 −0.0913 0.326 0.140 0.268 0.581 −0.0676 0.243 −0.231
−0.532 −0.104 −0.170 −0.613 −0.500 −0.594 −0.425 0.0868 −0.317 −0.152 −0.140 −0.189 0.0868 −0.419 −0.443 −0.206
0.460 0.309 0.823 0.553 0.719 0.416 0.174 0.196 0.552 0.289 0.601 0.217 0.564 0.738 0.156
0.366 0.452 0.328 0.474 0.343 0.239 0.200 0.584 0.417 0.695 0.648 0.343 0.552 0.113
0.413 0.365 0.444 0.261 0.444 0.214 0.240 0.281 0.189 0.340 0.186 0.427 −0.0753
0.626 0.867 0.526 0.162 0.273 0.457 0.319 0.545 0.224 0.510 0.768 0.133
0.621 0.355 0.0266 0.120 0.289 0.152 0.417 0.169 0.392 0.408 −0.0511
0.564 0.143 0.301 0.502 0.330 0.548 0.228 0.460 0.779 0.122
0.0478 0.593 0.139 0.404 0.299 0.143 0.623 0.491 0.432
0.0697 0.314 0.180 0.141 0.335 0.136 0.352 −0.0939
0.0568 0.536 0.0793 0.0697 0.394 0.322 0.527
0.290 0.762 0.427 0.272 0.627 −0.0941
0.346 0.364 0.365 0.434 0.505
0.475 0.297 0.589 −0.019
0.136 0.370 −0.0563
0.506 0.481
0.169
3 5 7 9
2.0 2.8
100 200
0.20 0.35
12 18 24
1 3 5
0.4 1.0 1.6
1 3
2 4 6
30 50 70
40 80
10 20
0.02 0.05
0.0 1.0
0 15 30
0.6 1.2
400 800
1.0 2.5 4.0


Ca 2+
0.299 0.0649 0.443 0.326 0.0788 −0.111 0.0759 −0.013 −0.183 0.0347 −0.0649 −0.0563 −0.213 0.0658 −0.0563 −0.0434 −0.013 −0.0736
Mg 2+
−0.532 −0.104 −0.170 −0.613 −0.500 −0.594 −0.541 0.160 −0.495 −0.541 −0.567 −0.271 −0.461 −0.567 −0.555 −0.506 −0.550
Na +
0.460 0.309 0.823 0.553 0.719 0.662 −0.0229 0.668 0.576 0.671 0.329 0.627 0.654 0.668 0.662 0.619
K +
0.366 0.452 0.328 0.474 0.521 0.127 0.570 0.477 0.477 0.417 0.580 0.477 0.491 0.521 0.460
Cl −
0.413 0.365 0.444 0.248 −0.150 0.261 0.161 0.222 −0.429 0.242 0.222 0.235 0.265 0.187
SO4 2−
0.626 0.867 0.744 −0.0351 0.715 0.621 0.735 0.394 0.683 0.735 0.732 0.744 0.683
Br −
0.621 0.695 0.237 0.674 0.633 0.686 0.442 0.641 0.686 0.683 0.721 0.659
F −
0.799 0.159 0.752 0.674 0.755 0.449 0.729 0.755 0.770 0.799 0.728
Tot. Al
0.297 0.902 0.861 0.957 0.734 0.890 0.957 0.972 0.948 0.922
Tot. Sb
0.311 0.183 0.275 0.477 0.320 0.275 0.297 0.343 0.297
Tot. As
0.824 0.876 0.806 0.879 0.876 0.891 0.902 0.833
Tot. Ba
0.887 0.773 0.829 0.887 0.876 0.810 0.922
Tot. Be
0.734 0.864 0.983 0.989 0.922 0.948
Tot. Cd
0.831 0.734 0.734 0.734 0.754
Tot. Cr
0.864 0.879 0.873 0.847
Tot. Co
0.972 0.922 0.948
Tot. Cu
0.937 0.937
Tot. Fe
0.887
Tot. Pb

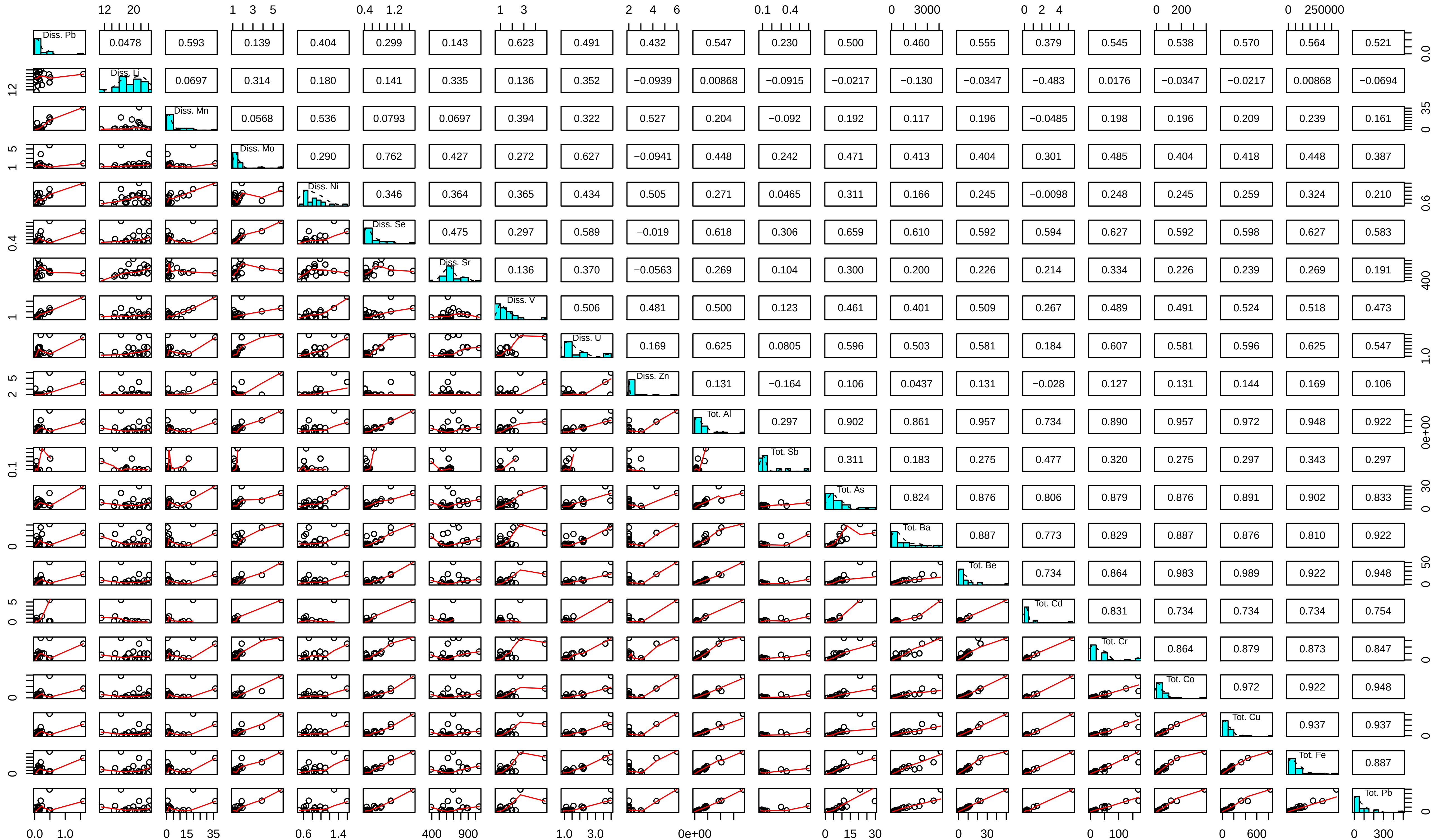

3 5 7 9
2.0 2.8
100 200
0.20 0.40
0 15000
0.6 1.0
0.4 1.0
1000 6000
0 300
0 600
Ca 2+
0.299 0.0649 0.443 0.326 0.0788 −0.111 0.0759 0.026 −0.039 −0.0521 0.0221 −0.0303 −0.454 −0.348 0.013 −0.420 0.00868 −0.0649 0.0476
Mg 2+
−0.532 −0.104 −0.170 −0.613 −0.500 −0.594 −0.503 −0.550 −0.425 −0.0221 −0.506 −0.454 −0.416 −0.584 −0.486 −0.503 −0.576 −0.463
Na +
0.460 0.309 0.823 0.553 0.719 0.651 0.619 0.469 0.0442 0.628 0.268 0.371 0.671 0.376 0.625 0.593 0.619
K +
0.366 0.452 0.328 0.474 0.561 0.495 0.352 −0.433 0.512 0.117 0.192 0.495 0.122 0.543 0.477 0.581
Cl −
0.413 0.365 0.444 0.261 0.204 0.288 −0.0894 0.161 −0.224 −0.148 0.309 −0.112 0.270 0.204 0.274
SO4 2−
0.626 0.867 0.750 0.683 0.531 −0.0452 0.656 0.429 0.506 0.805 0.520 0.689 0.665 0.683
Br −
0.621 0.674 0.651 0.736 −0.229 0.624 0.639 0.640 0.651 0.709 0.674 0.668 0.668
F −
0.815 0.737 0.546 0.0589 0.683 0.522 0.575 0.844 0.625 0.743 0.710 0.755
Tot. Li
0.885 0.683 −0.211 0.868 0.761 0.881 0.920 0.900 0.917 0.876 0.894
Tot. Mn
0.798 −0.354 0.922 0.780 0.955 0.844 0.928 0.876 0.939 0.861
Tot. Hg
−0.456 0.807 0.820 0.927 0.642 0.878 0.674 0.781 0.659
Tot. Mo
−0.376 −0.281 −0.362 −0.133 −0.322 −0.256 −0.376 −0.221
Tot. Ni
0.827 0.933 0.801 0.862 0.868 0.896 0.835
Tot. Se
0.846 0.687 0.761 0.691 0.757 0.687
Tot. Ag
0.775 0.904 0.836 0.888 0.843
Tot. Sr
0.818 0.850 0.835 0.827
Tot. Tl
0.889 0.906 0.884
Tot. V
0.850 0.946
Tot. U
0.818
Tot. Zn
30 50 70
40 100
10 20
0.02 0.06
100 400
0.0 0.3
0 300
0.0 0.8
0.0 0.8
0 15 35
3 8
40
2.0
10
100
0.02
0.20
100
0
0.0
0.6
0
0.4
0.0
1000
0.0
0
30 0
0

Diss. Al
Diss. Sb
Diss. As
Diss. Ba
Diss. Be
Diss. B
Diss. Cr
Diss. Co
Diss. Cu
Diss. Fe
Diss. Pb
Diss. Li
Diss. Mn
Diss. Mo
Diss. Ni
Diss. Se
Diss. Sr
Diss. V
Diss. U
Diss. Zn
0.446 0.113 −0.139 0.692 0.185 0.417 0.420 0.246 0.782 0.798 −0.026 0.587 −0.013 0.306 0.162 0.0781 0.500 0.312 0.343
−0.00451 −0.0174 0.387 0.450 0.313 0.680 0.0491 0.284 0.451 0.234 0.474 0.265 0.508 0.285 0.295 0.329 0.495 0.306
0.280 0.128 0.147 0.349 −0.0947 0.465 0.196 0.226 0.0904 0.0453 0.435 0.109 0.493 0.199 0.479 0.334 0.169
−0.170 0.102 0.0149 −0.130 −0.116 −0.00875 −0.0391 0.0739 −0.0871 0.410 0.0658 0.404 0.257 0.0361 0.239 −0.125
0.0658 0.565 0.469 0.387 0.686 0.658 −0.0587 0.600 −0.0824 0.338 0.0475 −0.106 0.519 0.270 0.617
−0.0608 0.353 0.164 0.160 0.217 0.589 0.302 0.461 0.415 0.376 0.540 0.230 0.589 0.051
0.358 0.392 0.451 0.493 −0.209 0.449 0.210 0.362 0.234 −0.134 0.528 0.343 0.548
0.112 0.293 0.443 0.0781 0.630 0.0739 0.595 0.145 0.139 0.293 0.382 0.493
0.324 0.295 0.0224 0.175 0.130 0.104 0.186 −0.0448 0.530 0.251 0.264
0.726 −0.035 0.513 0.154 0.291 0.274 0.114 0.623 0.341 0.384
0.0478 0.593 0.139 0.404 0.299 0.143 0.623 0.491 0.432
0.0697 0.314 0.180 0.141 0.335 0.136 0.352 −0.0939
0.0568 0.536 0.0793 0.0697 0.394 0.322 0.527
0.290 0.762 0.427 0.272 0.627 −0.0941
0.346 0.364 0.365 0.434 0.505
0.475 0.297 0.589 −0.019
0.136 0.370 −0.0563
0.506 0.481
0.169

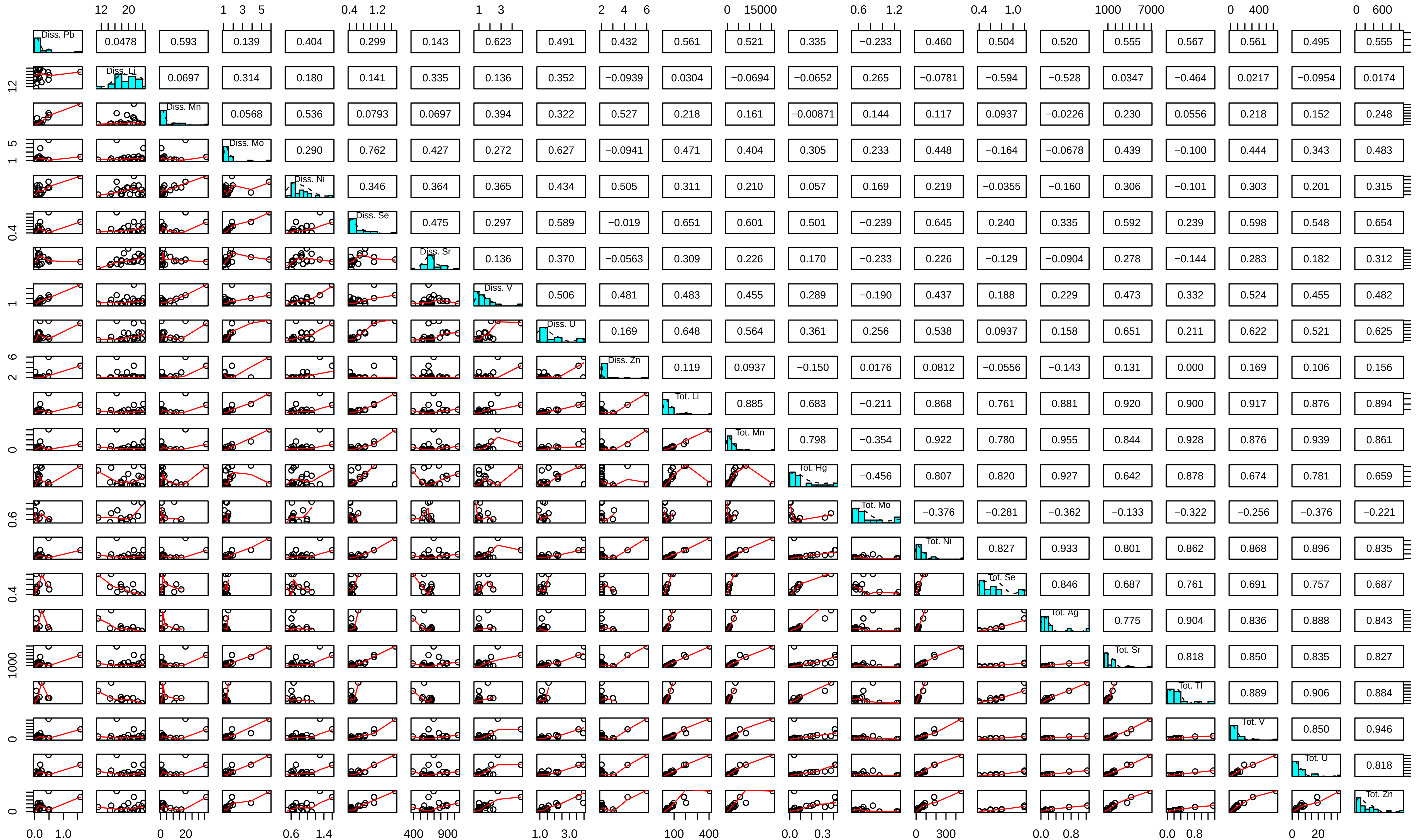

Diss. Al 0.446 0.113 −0.139 0.692 0.185 0.417 0.420 0.246 0.782 0.411 0.297 0.382 0.325 0.420 0.271 0.408 0.403 0.434 0.429 0.385
Diss. Sb −0.00451 −0.0174 0.387 0.450 0.313 0.680 0.0491 0.284 0.325 0.275 0.373 0.221 0.299 0.135 0.355 0.299 0.312 0.377 0.281
Diss. As 0.280 0.128 0.147 0.349 −0.0947 0.465 0.196 0.320 0.286 0.321 0.338 0.347 0.410 0.370 0.329 0.343 0.320 0.329
Diss. Ba −0.170 0.102 0.0149 −0.130 −0.116 −0.00875 0.156 −0.0115 0.170 0.191 0.148 0.320 0.220 0.148 0.143 0.156 0.165
Diss. Be 0.0658 0.565 0.469 0.387 0.686 0.258 0.145 0.235 0.188 0.281 0.243 0.267 0.270 0.294 0.258 0.258
Diss. B −0.0608 0.353 0.164 0.160 0.247 −0.304 0.279 0.132 0.221 −0.297 0.251 0.221 0.235 0.265 0.168
Diss. Cr 0.358 0.392 0.451 0.372 0.546 0.314 0.343 0.402 0.412 0.347 0.387 0.418 0.402 0.402
Diss. Co 0.112 0.293 0.229 0.0458 0.252 0.143 0.221 −0.0193 0.232 0.221 0.234 0.281 0.186
Diss. Cu 0.324 0.228 0.189 0.188 0.210 0.255 0.172 0.186 0.237 0.260 0.228 0.255
Diss. Fe 0.467 0.0698 0.420 0.389 0.476 0.314 0.465 0.459 0.490 0.485 0.441
Tot. Al 0.297 0.902 0.861 0.957 0.734 0.890 0.957 0.972 0.948 0.922
Tot. Sb 0.311 0.183 0.275 0.477 0.320 0.275 0.297 0.343 0.297
Tot. As 0.824 0.876 0.806 0.879 0.876 0.891 0.902 0.833
Tot. Ba 0.887 0.773 0.829 0.887 0.876 0.810 0.922
Tot. Be 0.734 0.864 0.983 0.989 0.922 0.948
Tot. Cd 0.831 0.734 0.734 0.734 0.754
Tot. Cr 0.864 0.879 0.873 0.847
Tot. Co 0.972 0.922 0.948
Tot. Cu 0.937 0.937
Tot. Fe 0.887
Tot. Pb



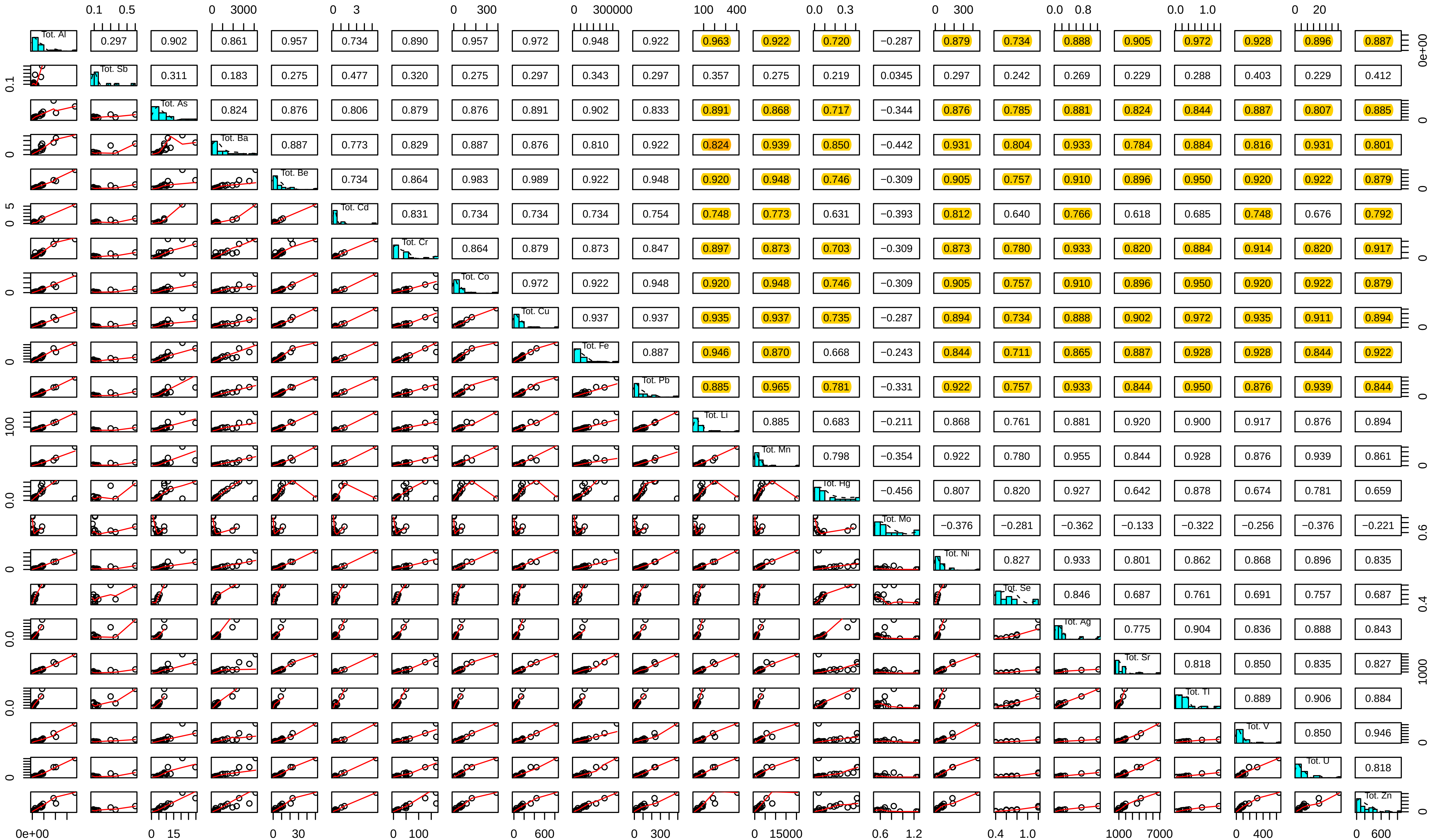
Diss. Al 0.446 0.113 −0.139 0.692 0.185 0.417 0.420 0.246 0.782 0.425 0.385 0.304 −0.199 0.325 0.501 0.483 0.420 0.530 0.425 0.359 0.420
Diss. Sb −0.00451 −0.0174 0.387 0.450 0.313 0.680 0.0491 0.284 0.347 0.281 0.148 0.133 0.273 0.105 0.0562 0.333 0.0884 0.382 0.238 0.403
Diss. As 0.280 0.128 0.147 0.349 −0.0947 0.465 0.196 0.325 0.329 0.217 −0.127 0.365 0.0849 0.117 0.275 0.046 0.357 0.302 0.347
Diss. Ba −0.170 0.102 0.0149 −0.130 −0.116 −0.00875 0.161 0.182 0.0652 −0.0556 0.191 0.0234 0.136 0.0954 0.0556 0.161 0.139 0.217
Diss. Be 0.0658 0.565 0.469 0.387 0.686 0.258 0.246 0.123 −0.140 0.223 0.410 0.411 0.270 0.497 0.282 0.234 0.258
Diss. B −0.0608 0.353 0.164 0.160 0.270 0.185 0.137 0.249 0.168 −0.441 −0.379 0.291 −0.316 0.243 0.141 0.291
Diss. Cr 0.358 0.392 0.451 0.373 0.372 0.119 0.105 0.358 0.244 0.279 0.387 0.401 0.433 0.387 0.402
Diss. Co 0.112 0.293 0.269 0.186 0.0347 0.331 0.177 0.0815 −0.0562 0.273 0.000 0.260 0.177 0.290
Diss. Cu 0.324 0.210 0.219 0.206 −0.0229 0.219 0.157 0.198 0.228 0.297 0.215 0.210 0.210
Diss. Fe 0.464 0.441 0.333 −0.438 0.389 0.391 0.514 0.459 0.596 0.481 0.432 0.476
Tot. Li 0.885 0.683 −0.211 0.868 0.761 0.881 0.920 0.900 0.917 0.876 0.894
Tot. Mn 0.798 −0.354 0.922 0.780 0.955 0.844 0.928 0.876 0.939 0.861
Tot. Hg −0.456 0.807 0.820 0.927 0.642 0.878 0.674 0.781 0.659
Tot. Mo −0.376 −0.281 −0.362 −0.133 −0.322 −0.256 −0.376 −0.221
Tot. Ni 0.827 0.933 0.801 0.862 0.868 0.896 0.835
Tot. Se 0.846 0.687 0.761 0.691 0.757 0.687
Tot. Ag 0.775 0.904 0.836 0.888 0.843
Tot. Sr 0.818 0.850 0.835 0.827
Tot. Tl 0.889 0.906 0.884
Tot. V 0.850 0.946
Tot. U 0.818
Tot. Zn



Diss. Pb
0.0478 0.593 0.139 0.404 0.299 0.143 0.623 0.491 0.432 0.547 0.230 0.500 0.460 0.555 0.379 0.545 0.538 0.570 0.564 0.521
Diss. Li
0.0697 0.314 0.180 0.141 0.335 0.136 0.352 −0.0939 0.00868 −0.0915 −0.0217 −0.130 −0.0347 −0.483 0.0176 −0.0347 −0.0217 0.00868 −0.0694
Diss. Mn
0.0568 0.536 0.0793 0.0697 0.394 0.322 0.527 0.204 −0.092 0.192 0.117 0.196 −0.0485 0.198 0.196 0.209 0.239 0.161
Diss. Mo
0.290 0.762 0.427 0.272 0.627 −0.0941 0.448 0.242 0.471 0.413 0.404 0.301 0.485 0.404 0.418 0.448 0.387
Diss. Ni
0.346 0.364 0.365 0.434 0.505 0.271 0.0465 0.311 0.166 0.245 −0.0098 0.248 0.245 0.259 0.324 0.210
Diss. Se
0.475 0.297 0.589 −0.019 0.618 0.306 0.659 0.610 0.592 0.594 0.627 0.592 0.598 0.627 0.583
Diss. Sr
0.136 0.370 −0.0563 0.269 0.104 0.300 0.200 0.226 0.214 0.334 0.226 0.239 0.269 0.191
Diss. V
0.506 0.481 0.500 0.123 0.461 0.401 0.509 0.267 0.489 0.491 0.524 0.518 0.473
Diss. U
0.169 0.625 0.0805 0.596 0.503 0.581 0.184 0.607 0.581 0.596 0.625 0.547
Diss. Zn
0.131 −0.164 0.106 0.0437 0.131 −0.028 0.127 0.131 0.144 0.169 0.106
Tot. Al
0.297 0.902 0.861 0.957 0.734 0.890 0.957 0.972 0.948 0.922
Tot. Sb
0.311 0.183 0.275 0.477 0.320 0.275 0.297 0.343 0.297
Tot. As
0.824 0.876 0.806 0.879 0.876 0.891 0.902 0.833
Tot. Ba
0.887 0.773 0.829 0.887 0.876 0.810 0.922
Tot. Be
0.734 0.864 0.983 0.989 0.922 0.948
Tot. Cd
0.831 0.734 0.734 0.734 0.754
Tot. Cr
0.864 0.879 0.873 0.847
Tot. Co
0.972 0.922 0.948
Tot. Cu
0.937 0.937
Tot. Fe
0.887
Tot. Pb
12 20
1 3 5
0.4 1.2
1 3
2 4 6
0.1 0.4
0 3000
0 2 4
0 200
0 250000
0.0 35 0 0.6 400 1.0 0e+00 30 0 50 0 0 0 0
12 1 5 1 0.4 1 2 5 0.1 0 5 0 0 0 0 0
0.0 1.0
0 15 35
0.6 1.4
400 900
1.0 3.0
0e+00
0 15 30
0 30
0 100
0 600
0 300



Diss. Pb
Diss. Li
Diss. Mn
Diss. Mo
Diss. Ni
Diss. Se
Diss. Sr
Diss. V
Diss. U
Diss. Zn
Tot. Li
Tot. Mn
Tot. Hg
Tot. Mo
Tot. Ni
Tot. Se
Tot. Ag
Tot. Sr
Tot. Tl
Tot. V
Tot. U
Tot. Zn


Tot. Al 0.297 0.902 0.861 0.957 0.734 0.890 0.957 0.972 0.948 0.922 0.963 0.922 0.720 −0.287 0.879 0.734 0.888 0.905 0.972 0.928 0.896 0.887
Tot. Sb 0.311 0.183 0.275 0.477 0.320 0.275 0.297 0.343 0.297 0.357 0.275 0.219 0.0345 0.297 0.242 0.269 0.229 0.288 0.403 0.229 0.412
Tot. As 0.824 0.876 0.806 0.879 0.876 0.891 0.902 0.833 0.891 0.868 0.717 −0.344 0.876 0.785 0.881 0.824 0.844 0.887 0.807 0.885
Tot. Ba 0.887 0.773 0.829 0.887 0.876 0.810 0.922 0.824 0.939 0.850 −0.442 0.931 0.804 0.933 0.784 0.884 0.816 0.931 0.801
Tot. Be 0.734 0.864 0.983 0.989 0.922 0.948 0.920 0.948 0.746 −0.309 0.905 0.757 0.910 0.896 0.950 0.920 0.922 0.879
Tot. Cd 0.831 0.734 0.734 0.734 0.754 0.748 0.773 0.631 −0.393 0.812 0.640 0.766 0.618 0.685 0.748 0.676 0.792
Tot. Cr 0.864 0.879 0.873 0.847 0.897 0.873 0.703 −0.309 0.873 0.780 0.933 0.820 0.884 0.914 0.820 0.917
Tot. Co 0.972 0.922 0.948 0.920 0.948 0.746 −0.309 0.905 0.757 0.910 0.896 0.950 0.920 0.922 0.879
Tot. Cu 0.937 0.937 0.935 0.937 0.735 −0.287 0.894 0.734 0.888 0.902 0.972 0.935 0.911 0.894
Tot. Fe 0.887 0.946 0.870 0.668 −0.243 0.844 0.711 0.865 0.887 0.928 0.928 0.844 0.922
Tot. Pb 0.885 0.965 0.781 −0.331 0.922 0.757 0.933 0.844 0.950 0.876 0.939 0.844
Tot. Li 0.885 0.683 −0.211 0.868 0.761 0.881 0.920 0.900 0.917 0.876 0.894
Tot. Mn 0.798 −0.354 0.922 0.780 0.955 0.844 0.928 0.876 0.939 0.861
Tot. Hg −0.456 0.807 0.820 0.927 0.642 0.878 0.674 0.781 0.659
Tot. Mo −0.376 −0.281 −0.362 −0.133 −0.322 −0.256 −0.376 −0.221
Tot. Ni 0.827 0.933 0.801 0.862 0.868 0.896 0.835
Tot. Se 0.846 0.687 0.761 0.691 0.757 0.687
Tot. Ag 0.775 0.904 0.836 0.888 0.843
Tot. Sr 0.818 0.850 0.835 0.827
Tot. Tl 0.889 0.906 0.884
Tot. V 0.850 0.946
Tot. U 0.818
Tot. Zn

Appendix D – Kendall's Tau Coefficient Table

Parameter 1	Parameter 2	Kendall's τ coefficient
Total Beryllium	Total Copper	0.989
Total Beryllium	Total Cobalt	0.983
Total Aluminum	Total Copper	0.972
Total Cobalt	Total Copper	0.972
Total Aluminum	Total Thallium	0.972
Total Copper	Total Thallium	0.972
SSC	Total Beryllium	0.965
SSC	Total Cobalt	0.965
SSC	Total Manganese	0.965
Total Lead	Total Manganese	0.965
Total Aluminum	Total Lithium	0.963
Total Aluminum	Total Beryllium	0.957
Total Aluminum	Total Cobalt	0.957
Total Manganese	Total Silver	0.955
SSC	Total Copper	0.954
SSC	Total Thallium	0.950
Total Beryllium	Total Thallium	0.950
Total Lead	Total Thallium	0.950
SSC	Total Lead	0.948
Total Aluminum	Total Iron	0.948
Total Beryllium	Total Lead	0.948
Total Cobalt	Total Lead	0.948
Total Beryllium	Total Manganese	0.948
Total Vanadium	Total Zinc	0.946
Total Iron	Total Lithium	0.946
SSC	Total Aluminum	0.939
SSC	Total Uranium	0.939
Total Manganese	Total Uranium	0.939
Total Barium	Total Manganese	0.939
Total Lead	Total Uranium	0.939
Total Copper	Total Iron	0.937
Total Copper	Total Lead	0.937
Total Copper	Total Manganese	0.937
Total Copper	Total Lithium	0.935
Total Copper	Total Vanadium	0.935
Total Nickel	Total Silver	0.933
Total Barium	Total Silver	0.933
Total Chromium	Total Silver	0.933
Total Lead	Total Silver	0.933
Total Barium	Total Nickel	0.931
Total Barium	Total Uranium	0.931
Total Manganese	Total Thallium	0.928
Total Aluminum	Total Vanadium	0.928

Total Iron	Total Thallium	0.928
Total Iron	Total Vanadium	0.928
Specific Conductivity	Sulfate	0.927
Total Mercury	Total Silver	0.927
SSC	Total Barium	0.922
Total Aluminum	Total Lead	0.922
Total Barium	Total Lead	0.922
Total Beryllium	Total Iron	0.922
Total Cobalt	Total Iron	0.922
Total Manganese	Total Nickel	0.922
Total Aluminum	Total Manganese	0.922
Total Beryllium	Total Uranium	0.922
Total Iron	Total Zinc	0.922
Total Lead	Total Nickel	0.922
Total Lithium	Total Strontium	0.920
Total Beryllium	Total Lithium	0.920
Total Beryllium	Total Vanadium	0.920
Total Lithium	Total Vanadium	0.917
Total Chromium	Total Zinc	0.917
Total Chromium	Total Vanadium	0.914
Total Copper	Total Uranium	0.911
SSC	Total Silver	0.910
Total Beryllium	Total Silver	0.910
SSC	Total Nickel	0.905
Total Aluminum	Total Strontium	0.905
Total Beryllium	Total Nickel	0.905
Total Silver	Total Thallium	0.904
Total Thallium	Total Uranium	0.903
Total Aluminum	Total Arsenic	0.902
Total Arsenic	Total Iron	0.902
SSC	Total Lithium	0.902
Total Copper	Total Strontium	0.902
Total Lithium	Total Thallium	0.900
Turbidity	Total Silver	0.898
Total Chromium	Total Lithium	0.897
Total Nickel	Total Uranium	0.896
Total Aluminum	Total Uranium	0.896
Total Beryllium	Total Strontium	0.896
Total Lithium	Total Zinc	0.894
Total Copper	Total Nickel	0.894
Total Copper	Total Zinc	0.894
Total Arsenic	Total Copper	0.891
Total Arsenic	Total Lithium	0.891
Total Aluminum	Total Chromium	0.890
Total Thallium	Total Vanadium	0.889
Total Silver	Total Uranium	0.888
Total Aluminum	Total Silver	0.888

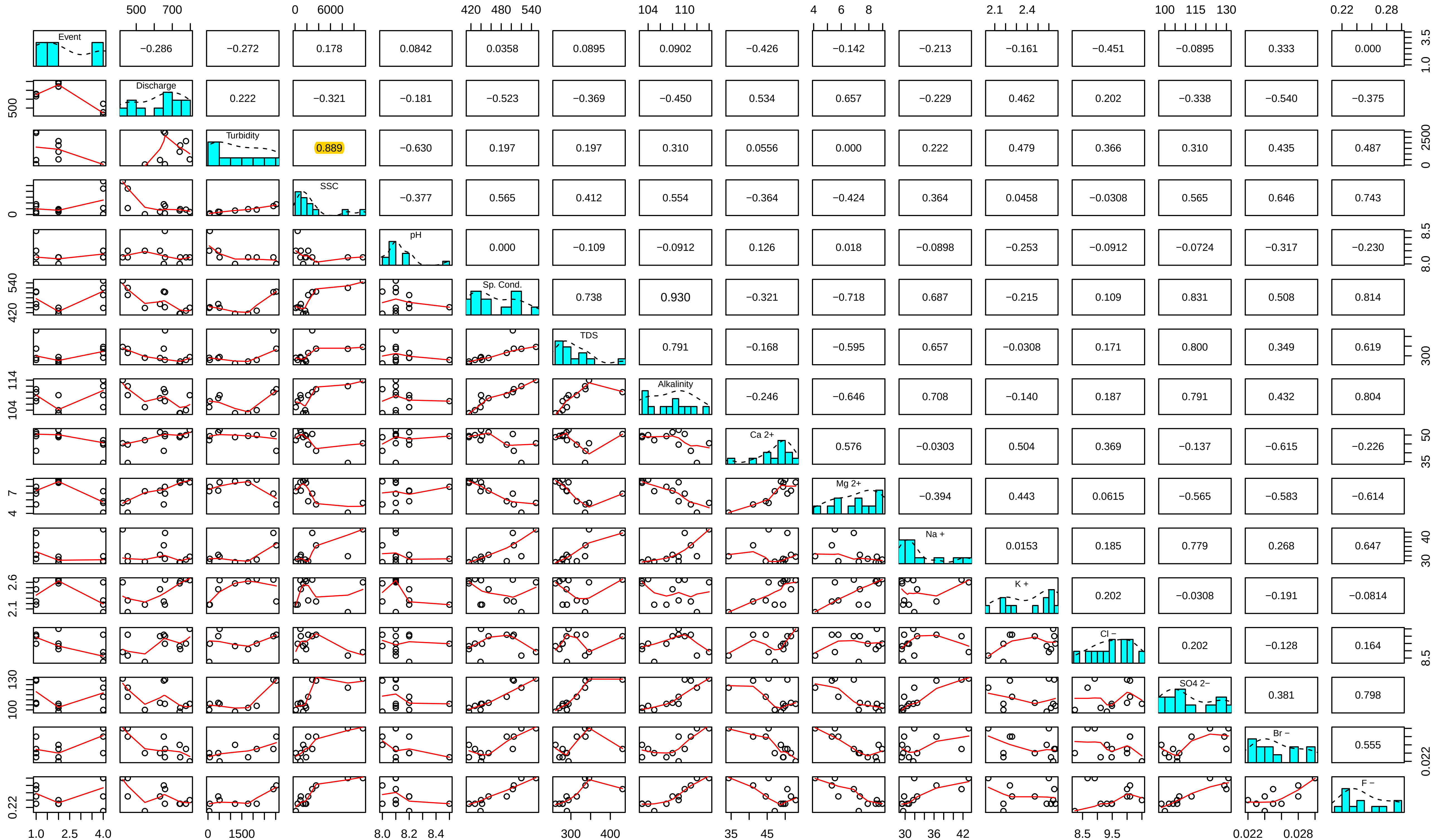
Total Copper	Total Silver	0.888
SSC	Total Iron	0.887
Total Barium	Total Beryllium	0.887
Total Barium	Total Cobalt	0.887
Total Iron	Total Lead	0.887
Total Aluminum	Total Zinc	0.887
Total Arsenic	Total Vanadium	0.887
Total Iron	Total Strontium	0.887
SSC	Total Vanadium	0.885
Total Lithium	Total Manganese	0.885
Total Arsenic	Total Zinc	0.885
Total Lead	Total Lithium	0.885
Total Thallium	Total Zinc	0.884
Total Barium	Total Thallium	0.884
Total Chromium	Total Thallium	0.884
Total Lithium	Total Silver	0.881
Total Arsenic	Total Silver	0.881
Total Arsenic	Total Chromium	0.879
Total Chromium	Total Copper	0.879
Total Aluminum	Total Nickel	0.879
Total Beryllium	Total Zinc	0.879
Total Mercury	Total Thallium	0.878
Total Arsenic	Total Beryllium	0.876
Total Arsenic	Total Cobalt	0.876
Total Barium	Total Copper	0.876
Total Lithium	Total Uranium	0.876
Total Manganese	Total Vanadium	0.876
Total Arsenic	Total Nickel	0.876
Total Lead	Total Vanadium	0.876
Total Chromium	Total Iron	0.873
Total Chromium	Total Manganese	0.873
Total Chromium	Total Nickel	0.873
Total Iron	Total Manganese	0.870
Total Lithium	Total Nickel	0.868
Total Nickel	Total Vanadium	0.868
Total Arsenic	Total Manganese	0.868
Sulfate	Fluoride	0.867
Total Iron	Total Silver	0.865
Total Beryllium	Total Chromium	0.864
Total Chromium	Total Cobalt	0.864
TDS	Sulfate	0.862
Total Nickel	Total Thallium	0.862
Total Aluminum	Total Barium	0.861
SSC	Total Strontium	0.861
SSC	Total Zinc	0.861
Total Manganese	Total Zinc	0.861
SSC	Total Arsenic	0.859

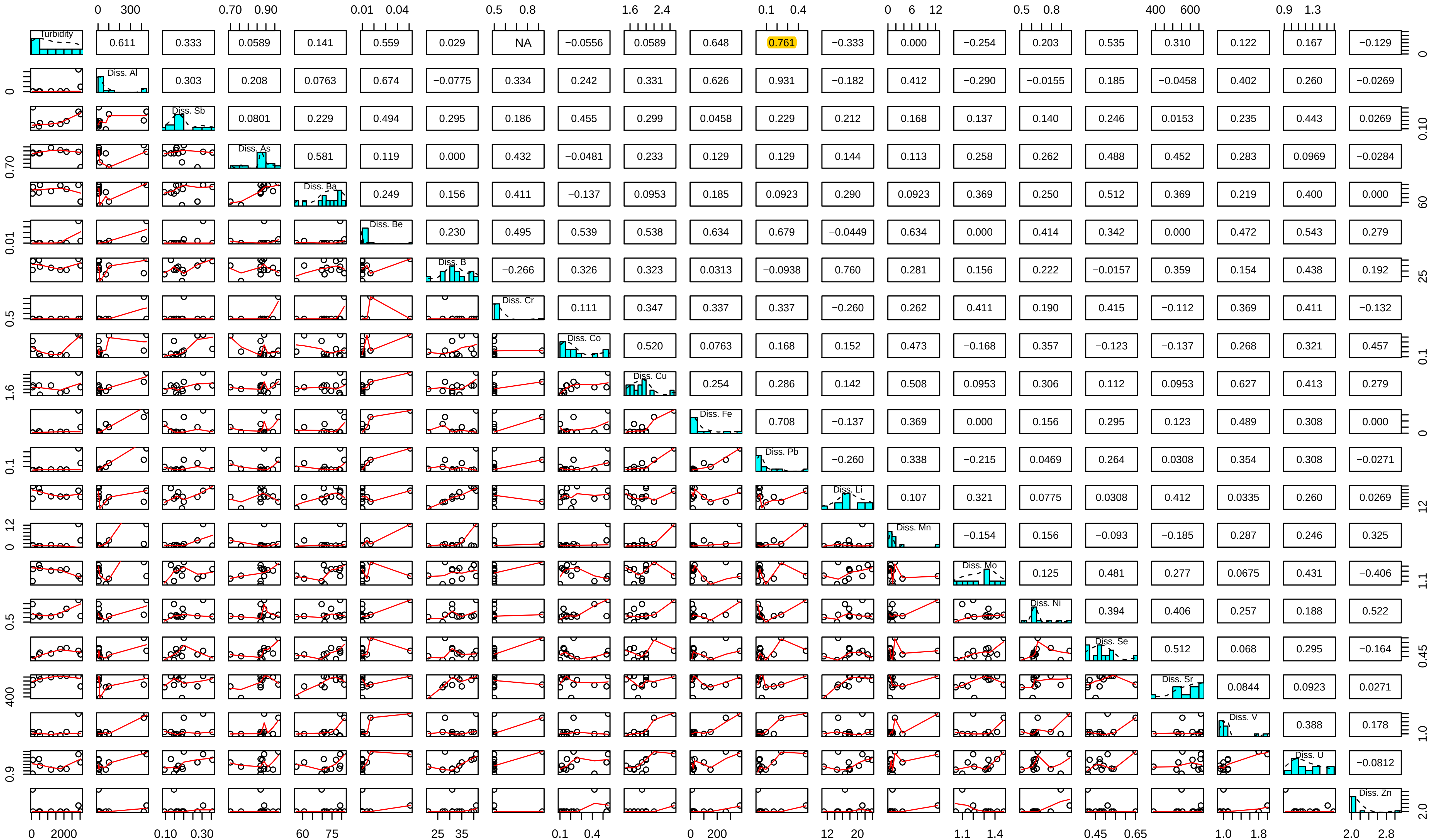
SSC	Total Chromium	0.855
Specific Conductivity	Fluoride	0.852
Total Strontium	Total Vanadium	0.850
Total Vanadium	Total Uranium	0.850
Total Barium	Total Mercury	0.850
Total Chromium	Total Lead	0.847
Total Selenium	Total Silver	0.846
Total Manganese	Total Strontium	0.844
Fluoride	Total Strontium	0.844
Total Arsenic	Total Thallium	0.844
Total Iron	Total Nickel	0.844
Total Iron	Total Uranium	0.844
Total Lead	Total Strontium	0.844
Total Lead	Total Zinc	0.844
Total Silver	Total Zinc	0.843
Total Silver	Total Vanadium	0.836
Total Nickel	Total Zinc	0.835
Total Strontium	Total Uranium	0.835
Specific Conductivity	TDS	0.834
Total Arsenic	Total Lead	0.833
Total Cadmium	Total Chromium	0.831
Total Barium	Total Chromium	0.829
Total Nickel	Total Selenium	0.827
Total Strontium	Total Zinc	0.827
Total Arsenic	Total Barium	0.824
Total Arsenic	Total Strontium	0.824
Total Barium	Total Lithium	0.824
Alkalinity	Fluoride	0.823
Sodium	Sulfate	0.823
Total Mercury	Total Selenium	0.820
Total Chromium	Total Strontium	0.820
Total Chromium	Total Uranium	0.820
Total Strontium	Total Thallium	0.818
Total Uranium	Total Zinc	0.818
Total Barium	Total Vanadium	0.816
Fluoride	Total Lithium	0.815
Total Cadmium	Total Nickel	0.812
Total Barium	Total Iron	0.810
Turbidity	Total Thallium	0.807
Total Mercury	Total Nickel	0.807
Total Arsenic	Total Uranium	0.807
Total Arsenic	Total Cadmium	0.806
Sulfate	Total Strontium	0.805
Total Barium	Total Selenium	0.804
Total Nickel	Total Strontium	0.801
Total Barium	Total Zinc	0.801
Fluoride	Total Aluminum	0.799

Fluoride	Total Iron	0.799
Dissolved Aluminum	Dissolved Lead	0.798
Specific Conductivity	Sodium	0.796
Specific Conductivity	Total Strontium	0.796
Total Cadmium	Total Zinc	0.792
TDS	Fluoride	0.790
Total Arsenic	Total Selenium	0.785
Total Barium	Total Strontium	0.784
Dissolved Aluminum	Dissolved Iron	0.782
SSC	Total Mercury	0.781
Total Mercury	Total Uranium	0.781
Total Lead	Total Mercury	0.781
Total Chromium	Total Selenium	0.780
Fluoride	Dissolved Uranium	0.779
Total Silver	Total Strontium	0.775
Total Barium	Total Cadmium	0.773
Total Cadmium	Total Manganese	0.773
Fluoride	Toal Copper	0.770
Sulfate	Dissolved Uranium	0.768
Specific Conductivity	Alkalinity	0.766
Total Cadmium	Total Silver	0.766
Alkalinity	Sulfate	0.762
Dissolved Molybdenum	Dissolved Selenium	0.762
Total Selenium	Total Thallium	0.761
SSC	Total Selenium	0.757
Total Selenium	Total Uranium	0.757
Total Beryllium	Total Selenium	0.757
Total Lead	Total Selenium	0.757
SSC	Fluoride	0.755
Fluoride	Total Beryllium	0.755
Fluoride	Total Cobalt	0.755
Fluoride	Total Zinc	0.755
Total Cadmium	Total Lead	0.754
Fluoride	Total Arsenic	0.752
Sulfate	Total Lithium	0.750
Total Cadmium	Total Lithium	0.748
Total Cadmium	Total Vanadium	0.748
Total Beryllium	Total Mercury	0.746
Sulfate	Total Aluminum	0.744
Sulfate	Total Iron	0.744
Specific Conductivity	Total Aluminum	0.743
Specific Conductivity	Total Iron	0.743
Fluoride	Total Vanadium	0.743
Specific Conductivity	Total Lithium	0.741
Sodium	Dissolved Uranium	0.738
Fluoride	Total Manganese	0.737
Bromide	Total Mercury	0.736

Specific Conductivity	Total Beryllium	0.735
Specific Conductivity	Total Cobalt	0.735
Sulfate	Total Beryllium	0.735
Sulfate	Total Cobalt	0.735
Total Copper	Total Mercury	0.735
SSC	Total Cadmium	0.734
Total Aluminum	Total Cadmium	0.734
Total Beryllium	Total Cadmium	0.734
Total Cadmium	Total Cobalt	0.734
Total Cadmium	Total Copper	0.734
Total Cadmium	Total Iron	0.734
Total Aluminum	Total Selenium	0.734
Total Copper	Total Selenium	0.734
Specific Conductivity	Total Copper	0.732
Sulfate	Total Copper	0.732
Fluoride	Total Chromium	0.729
Fluoride	Total Lead	0.728
TDS	Alkalinity	0.726
TDS	Sodium	0.726
Dissolved Iron	Dissolved Lead	0.726
Specific Conductivity	Dissolved Uranium	0.723
Bromide	Total Iron	0.721
Total Aluminum	Total Mercury	0.720
Sodium	Fluoride	0.719
Total Arsenic	Total Mercury	0.717
Specific Conductivity	Total Arsenic	0.715
Sulfate	Total Arsenic	0.715
Total Iron	Total Selenium	0.711
Fluoride	Total Uranium	0.710
Bromide	Total Thallium	0.709
Total Chromium	Total Mercury	0.703
Turbidity	Total Selenium	0.701
SSC	Specific Conductivity	0.700
SSC	Sulfate	0.700
Specific Conductivity	Total Lead	0.700
Specific Conductivity	Total Manganese	0.700
Discharge	Potassium	0.700
Turbidity	Total Molybdenum	-0.734

Appendix E – Pairs Plots without Storm Event 3 Data


Event
Discharge
Turbidity
SSC
pH
Sp. Cond.
TDS
Alkalinity
Ca 2+
Mg 2+
Na +
K +
Cl −
SO4 2−
Br −
F −
−0.286 −0.272 0.178 0.0842 0.0358 0.0895 0.0902 −0.426 −0.142 −0.213 −0.161 −0.451 −0.0895 0.333 0.000
0.222 −0.321 −0.181 −0.523 −0.369 −0.450 0.534 0.657 −0.229 0.462 0.202 −0.338 −0.540 −0.375
0.889 −0.630 0.197 0.197 0.310 0.0556 0.000 0.222 0.479 0.366 0.310 0.435 0.487
−0.377 0.565 0.412 0.554 −0.364 −0.424 0.364 0.0458 −0.0308 0.565 0.646 0.743
0.000 −0.109 −0.0912 0.126 0.018 −0.0898 −0.253 −0.0912 −0.0724 −0.317 −0.230
0.738 0.930 −0.321 −0.718 0.687 −0.215 0.109 0.831 0.508 0.814
0.791 −0.168 −0.595 0.657 −0.0308 0.171 0.800 0.349 0.619
−0.246 −0.646 0.708 −0.140 0.187 0.791 0.432 0.804
0.576 −0.0303 0.504 0.369 −0.137 −0.615 −0.226
−0.394 0.443 0.0615 −0.565 −0.583 −0.614
0.0153 0.185 0.779 0.268 0.647
0.202 −0.0308 −0.191 −0.0814
0.202 −0.128 0.164
0.381 0.798
0.555



Turbidity
Diss. Al
Diss. Sb
Diss. As
Diss. Ba
Diss. Be
Diss. B
Diss. Cr
Diss. Co
Diss. Cu
Diss. Fe
Diss. Pb
Diss. Li
Diss. Mn
Diss. Mo
Diss. Ni
Diss. Se
Diss. Sr
Diss. V
Diss. U
Diss. Zn
0.611 0.333 0.0589 0.141 0.559 0.029 NA −0.0556 0.0589 0.648 0.761 −0.333 0.000 −0.254 0.203 0.535 0.310 0.122 0.167 −0.129
0.303 0.208 0.0763 0.674 −0.0775 0.334 0.242 0.331 0.626 0.931 −0.182 0.412 −0.290 −0.0155 0.185 −0.0458 0.402 0.260 −0.0269
0.0801 0.229 0.494 0.295 0.186 0.455 0.299 0.0458 0.229 0.212 0.168 0.137 0.140 0.246 0.0153 0.235 0.443 0.0269
0.581 0.119 0.000 0.432 −0.0481 0.233 0.129 0.129 0.144 0.113 0.258 0.262 0.488 0.452 0.283 0.0969 −0.0284
0.249 0.156 0.411 −0.137 0.0953 0.185 0.0923 0.290 0.0923 0.369 0.250 0.512 0.369 0.219 0.400 0.000
0.230 0.495 0.539 0.538 0.634 0.679 −0.0449 0.634 0.000 0.414 0.342 0.000 0.472 0.543 0.279
−0.266 0.326 0.323 0.0313 −0.0938 0.760 0.281 0.156 0.222 −0.0157 0.359 0.154 0.438 0.192
0.111 0.347 0.337 0.337 −0.260 0.262 0.411 0.190 0.415 −0.112 0.369 0.411 −0.132
0.520 0.0763 0.168 0.152 0.473 −0.168 0.357 −0.123 −0.137 0.268 0.321 0.457
0.254 0.286 0.142 0.508 0.0953 0.306 0.112 0.0953 0.627 0.413 0.279
0.708 −0.137 0.369 0.000 0.156 0.295 0.123 0.489 0.308 0.000
−0.260 0.338 −0.215 0.0469 0.264 0.0308 0.354 0.308 −0.0271
0.107 0.321 0.0775 0.0308 0.412 0.0335 0.260 0.0269
−0.154 0.156 −0.093 −0.185 0.287 0.246 0.325
0.125 0.481 0.277 0.0675 0.431 −0.406
0.394 0.406 0.257 0.188 0.522
0.512 0.068 0.295 −0.164
0.0844 0.0923 0.0271
0.388 0.178
−0.0812
0 300 0.70 0.90 0.01 0.04 0.5 0.8 1.6 2.4 0.1 0.4 0 6 12 0.5 0.8 400 600 0.9 1.3
0 2000 0.10 0.30 60 75 25 35 0.1 0.4 0 200 12 20 1.1 1.4 0.45 0.65 1.0 1.8 2.0 2.8
0 0.70 0.01 0.5 1.6 0.1 12 0 0.5 400 0.9
0 0.10 60 25 0.1 0 12 1.1 0.45 1.0 2.0


Turbidity 0.889 0.177 0.986 0.889 0.889 0.648 0.944 0.889 0.889 0.889 0.944 0.889 0.944 0.944 −0.648 0.944 0.748 0.930 0.722 0.873 0.930 0.889 0.944
Tot. Al 0.299 0.870 0.909 1.000 0.687 0.909 1.000 1.000 0.970 0.970 0.962 0.970 0.901 −0.229 0.848 0.840 0.954 0.909 0.962 0.931 0.879 0.879
Tot. Sb 0.381 0.268 0.299 0.635 0.394 0.299 0.299 0.331 0.331 0.349 0.331 0.318 0.0635 0.394 0.286 0.336 0.205 0.286 0.381 0.236 0.426
Tot. As 0.809 0.870 0.738 0.931 0.870 0.870 0.901 0.870 0.923 0.870 0.862 −0.246 0.931 0.847 0.884 0.779 0.846 0.938 0.779 0.901
Tot. Ba 0.909 0.657 0.879 0.909 0.909 0.879 0.939 0.870 0.939 0.962 −0.321 0.879 0.840 0.954 0.818 0.962 0.870 0.970 0.848
Tot. Be 0.687 0.909 1.000 1.000 0.970 0.970 0.962 0.970 0.901 −0.229 0.848 0.840 0.954 0.909 0.962 0.931 0.879 0.879
Tot. Cd 0.779 0.687 0.687 0.718 0.718 0.738 0.718 0.677 −0.277 0.748 0.619 0.729 0.595 0.677 0.769 0.626 0.809
Tot. Cr 0.909 0.909 0.939 0.939 0.962 0.939 0.870 −0.198 0.939 0.840 0.954 0.818 0.901 0.992 0.848 0.970
Tot. Co 1.000 0.970 0.970 0.962 0.970 0.901 −0.229 0.848 0.840 0.954 0.909 0.962 0.931 0.879 0.879
Tot. Cu 0.970 0.970 0.962 0.970 0.901 −0.229 0.848 0.840 0.954 0.909 0.962 0.931 0.879 0.879
Tot. Fe 0.939 0.992 0.939 0.870 −0.198 0.879 0.840 0.954 0.879 0.931 0.962 0.848 0.909
Tot. Pb 0.931 1.000 0.931 −0.260 0.879 0.840 0.985 0.879 0.962 0.931 0.909 0.909
Tot. Li 0.931 0.862 −0.185 0.901 0.847 0.946 0.870 0.923 0.985 0.840 0.931
Tot. Mn 0.931 −0.260 0.879 0.840 0.985 0.879 0.962 0.931 0.909 0.909
Tot. Hg −0.338 0.931 0.863 0.946 0.809 0.954 0.862 0.931 0.840
Tot. Mo −0.260 −0.212 −0.264 −0.137 −0.277 −0.185 −0.351 −0.168
Tot. Ni 0.873 0.923 0.758 0.901 0.931 0.848 0.909
Tot. Se 0.870 0.743 0.879 0.847 0.808 0.808
Tot. Ag 0.862 0.977 0.946 0.923 0.923
Tot. Sr 0.870 0.840 0.788 0.788
Tot. Tl 0.908 0.931 0.870
Tot. V 0.840 0.962
Tot. U 0.818
Tot. Zn

Appendix F – R Code for Pairs Plots

R script used to import data from a Microsoft Excel spreadsheet into RStudio:

```
library(readxl)

Data_for_Pairs_Plots <- read_excel("Data for Pairs Plots.xlsx",
                          col_types = c("numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric", "numeric",
                                "numeric", "numeric"))

View(Data_for_Pairs_Plots)
```

R script used to generate a pairs plot (for the first two parameter groups):

```
panel.cor <- function(x, y, digits = 3, prefix = "", cex.cor) {
  usr <- par("usr"); on.exit(par(usr))
  par(usr = c(0, 1, 0, 1))
```

```
  r <- cor(x, y, use = "complete.obs", method = "kendall")
  txt <- format(c(r, 0.123456789), digits = digits)[1]
  txt <- paste(prefix, txt, sep = "")
  if(missing(cex.cor)) cex <- 0.8 / strwidth(txt)
  text(0.5, 0.5, txt, cex = max(cex * abs(r), 0.9))
}

panel.histFB <- function(x, ...) {
  usr <- par("usr"); on.exit(par(usr))
  par(usr = c(usr[1:2], 0, 1.5) )
  h <- hist(x, breaks = 9, plot = FALSE)
  breaks <- h$breaks
  nB <- length(breaks)
  y <- h$counts
  y <- y/max(y)
  rect(breaks[-nB], 0, breaks[-1], y, col = "cyan", ...)
  my.den <- density(x[!is.na(x)])
  lines(my.den$x, my.den$y / max(my.den$y), lty = 2)
}

pairs(Data_for_Pairs_Plots[,c("Event", "Discharge", "Turbidity", "SSC",
                              "pH", "Sp. Cond.", "TDS", "Alkalinity",
                              "Ca 2+", "Mg 2+", "Na +", "K +",
                              "Cl -", "SO4 2-", "Br -", "F -")],
      lower.panel = panel.smooth, upper.panel = panel.cor,
      diag.panel = panel.histFB)
```