

**PENNSYLVANIA SEA GRANT
FINAL REPORT**

PROJECT TITLE: Establishing a Link between Hydraulic Fracturing Activities and Streamwater Impacts in North-Central Pennsylvania

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Time Period:

June 1 2013 through May 31, 2014

Executive Summary:

The impacts of hydraulic fracturing related natural gas extraction activities on water contamination are poorly understood. Furthermore, while the majority of preliminary studies have focused on the impacts of hydraulic fracturing activities to groundwater little data exists with regards to impacts on overall streamwater quality. This study used a multi-faceted approach to determine whether there is a link between hydraulic fracturing related well pad density within a given watershed and associated stream and shallow groundwater quality.

A total of 77 streamwater samples, 19 groundwater samples, and one spring sample were collected from a total of 38 small watersheds (<20 km²) in Bradford, Susquehanna, and Wyoming Counties in north-central Pennsylvania during summer 2013. Three samples from three watersheds exceeded their USEPA National Recommended Water Quality Criteria (NRWQC) Criteria Maximum Concentration (CMC) or acute concentration for both Selenium and Cadmium. In addition, one watershed (#45) exceeded its USEPA NRWQC CMC for Zinc. Several additional samples exceed their USEPA NRWQC Criterion Continuous Concentration (CCC) or chronic concentration for Cadmium and Aluminum. Interestingly, while several watersheds exhibited metal concentrations in excess of their associated criterion values during both the early and late summer sampling events, other watersheds exhibited a surprising degree of temporal variation in concentration.

Groundwater sampling revealed barium concentrations in excess of the United State Environmental Protection Agency Maximum Contaminant Level (USEPA MCL) in two drinking water well samples (G25C and G29) and arsenic concentrations in excess of the USEPA MCL of in one of the groundwater samples (G46). Several of the groundwater samples also exhibited aluminum, iron, and manganese concentrations in excess of their respective USEPA List of National Secondary Drinking Water Regulations for aluminum, iron, and manganese. Detectable concentrations of methane were identified in twelve of the groundwater samples and ranged from 0 to 1.1 mg/l. None of the methane values were in excess of the US Department of Interior Action Level for Hazard Mitigation.

Finally, a principal component analysis (PCA) was performed to determine correlations between well pad density and land use practices within a given watershed and their associated water quality parameters and/or elemental yields. Temperature positively correlated with percent forest and grass land while potassium, nickel, and streamwater conductivity were positively correlated with percent agricultural land. Developed land exhibited the most impact on the elemental yields, positively correlating to conductivity, nickel, vanadium, iron, cobalt, arsenic, rubidium, strontium, and lithium. Lithium, cesium, lead, and uranium negatively correlated with the area of the watershed and the amount of water within each watershed. No correlations were observed between well pad density and any of the elemental yields. In addition, no correlations were observed between any of the principal components and pH, DO, sediment, chromium, manganese, copper, molybdenum, silver, cadmium, and barium.

The heterogeneous nature of the observed stream and groundwater impacts, coupled with the lack of correlation of elemental yields with well pad density within a given watershed, likely points to hydraulic fracturing related spills and/or localized releases from compromised wells as playing an important role on regional stream and groundwater quality. The data suggest that more extensive spatial and temporal sampling is required to determine the long-term imprint on stream and groundwater impacts to this region. The results also suggest the data should be compared with Pennsylvania Department of Environmental Protection (PADEP) records documenting known hydraulic fracturing well pad violations to determine whether there are any associated links.

A. Introduction

Marcellus Shale hydraulic fracturing has raised significant environmental concerns due to both the intensity of water use and production of waste fluids. It is estimated that current fracking practices require anywhere between 3-4 million gallons of water per well per each time it is “fracked”^{1,2,3,4}, only 25-75% of which returns to the surface as “produced” or “flowback” water⁴. This returned water is not only laden with the proprietary chemicals and sand used to increase the permeability of the source rock but also with deep groundwater brines which can contain harmful quantities of radioactive isotopes^{1,5,6,7} and high concentrations of dissolved salts (e.g., Na, Cl, Mg, Sr, Br and others)⁴⁻⁹. While this displaced brine is often temporarily stored in surficial lined pits designed to let evaporation reduce the overall quantity for off-site disposal, increased storage time runs the risk that improperly constructed pits may leak or tears in pit linings contributing to localized groundwater impacts^{3,4,10}. This avenue of delivery along with leaks from poorly constructed and/or maintained gas well casings has also been tentatively linked to negative impacts of drinking water wells^{3,9,10}.

However, with the exception of self-reported releases from individual fracking operations, little data exists to understand what impacts may occur to localized streamwater systems. One promising avenue is the geochemical fingerprinting of hydraulic fracturing fluids, which may allow us to understand the link between fracking, surface and subsurface flow paths, and water quality impacts. Recent studies using elemental ratios and stable and radioactive isotopes have shown these technique can work to fingerprint sources in localized groundwater^{7,8,9,11}. However, these projects have been limited in scope or have lacked an adequate system for deployment on a large spatial scale. Furthermore, additional challenges remain with the geochemical fingerprinting of hydraulic fracturing to stream and groundwater impacts. Scaling up an assessment technique for streams would require establishment of viable metric which can account for local variability in background contribution along with the timing of delivery of fluxes to channel itself. The latter would particularly important in determining whether the primary delivery mechanism is through surface or shallow groundwater pathways or both.

B. Methodology

i. Sample Collection and Analysis

A total of 77 streamwater samples, 19 groundwater samples, and one spring sample were collected from a total of 38 small watersheds (<20 km²) in Bradford, Susquehanna, and Wyoming Counties in north-central Pennsylvania (Tables 1 & 2; Appendix C). Samples were collected during individual sampling trips in June, July, and August of 2013. The watersheds are characterized by a well density gradient of 0 (i.e., reference sites) to 1.44 wells per km² and are further divided based on land cover (mix use land systems to 95% forest cover). The test and reference streams drain relatively small watersheds (< 10 km²) with similar surface lithology and land use, so that any signal from natural gas extraction activity can be separated from background signatures within the stream (Figure 1). Furthermore, all sites were located outside of DEP-recorded coal mining impact areas. The number of well pads was tabulated using ArcGIS (dataset publicly available via FracFocus, June 26, 2013).

The bulk of the water samples were collected during what was deemed baseflow through conditions by examination of the United States Geologic Survey (USGS) gauging station record for Tunkhannock, PA. In addition, streamwater samples were collected from a watershed characterized by 12 well pads and a control site during a localized precipitation event on June 27 June 28, 2014. Shallow groundwater samples from the drinking water aquifer were collected from residents' water supplies. Samples were drawn directly from the water storage tank after running the well pump for approximately 5 minutes prior to sampling. Field measurements for temperature, pH, dissolved oxygen, and conductivity were recorded at each site using a YSI Multiparameter Meter.

Samples for total suspended solids (TSS) were collected at each of the sampling locations using one gallon bottles. Samples were stored in the dark and transported to Villanova University for TSS analysis and filtration. 47 mm glass fiber filters for each individual samples were pre-weighed before filtering and TSS concentrations were determined by the weight difference of the filters before and after filtration.

Samples for trace element analysis were collected in brand new low density polyethylene (LDPE) bottles and returned to Villanova for analysis. The samples were syringe-filtered (0.45 μm) into 60 mL bottles and acidified to a pH of 2 with 1% trace metal grade nitric acid (Fisher Brand) upon return to Villanova University. Filter blanks were created by filtering deionized water into clean LDPE bottles using the same methods used for the samples. Field blanks were created prior to sample collection using MilliQ water (18.2 MΩ). The samples and field blanks were chilled at ~4 C until analysis. Major ion concentrations for cations (Li⁺, Na⁺, K⁺, Ca²⁺, and Mg²⁺) anions (NO₃⁻, Cl⁻, PO₄³⁻, and SO₄²⁻,) were determined via ion chromatography using a Dionex ICS-1000 ion chromatograph (IC) at Villanova University. Precision was determined using five replicate check standards per run with relative standard deviations (RSDs) usually better than 3% and never greater than 6%. Samples were analyzed for the following trace elements (Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mo, Ag, Cd, Cs, Ba, Pb,

and U) using an inductively coupled plasma mass spectrometer (ICP-MS) located at Bryn Mawr University. External standards were used and check standards were run every 3–4 samples to account for instrument drift. Triplicate analyses did not reveal RSDs greater than 5%.

Water samples for methane (CH₄) analysis were collected by filling a gas-tight syringe with either stream or groundwater samples and injecting 30 ml of the sample into an evacuated 60 ml headspace vial. In the laboratory, the headspace was analyzed for CH₄ concentrations on an Agilent 6890N gas chromatograph equipped with a Porapak Q column and flame ionization detector.

Radium (Ra-226) activity in surface waters and groundwater was assessed by filtering large volumes (typically 130 L for surface water and 50 L for groundwater) through manganese impregnated acrylic fiber in the field. Ra-226 in the water sample is retained on the fiber, allowing for concentration of the Ra-226 contained in large volumes of water onto a small volume of fiber. Ra-226 is not measured directly, but rather the daughter products Bi-214 and Pb-214, which is measured by gamma counting. The acrylic fiber was sealed in an airtight container to prevent escape of Radon-222 (a gas) and stored for 1 month prior to measurement, to allow Ra-226 to come into secular equilibrium with its daughter products. Once in equilibrium, the sample was placed on a Canberra broad energy germanium detector (38 cm² active area) for gamma counting. The Bi-214 (609, 1112, and 1765 keV) and Pb-214 (242, 295, and 352 keV) gamma rays are quantified. The activities of these daughter products are in direct proportion to the activity of the parent Ra-226. Ra-226 activity was quantified after standardization of the germanium counter energies and efficiencies by counting a sample with certified activities (Rocky Flats Soil Number 2; NIST 4353A).

ii. Stream Discharge Measurements

Stream discharge measurements were taken at every site during the August 2013 sampling period using either a Teledyne RDI Stream Pro Acoustic Doppler Stream Profiler for the bigger streams or a FP101-FP201 Global Flow Probe for the small streams. When using the Teledyne RDI Stream Pro Acoustic Doppler Stream Profiler, the average discharge value was taken from at least 5 trials at each sampling location. When using the Global Flow Probe, discharge was calculated using existing United States Geological Survey methodology. Furthermore, a depth profile of the channel was determined at each location prior to using the FP101-FP201 Global Flow Probe to obtain flow readings at 50% above the base of the channel. If the channel depth exceeded six inches at a particular location, multiple depth measurements were taken and subsequently averaged. Instantaneous discharges were calculated by integrating over the river cross-sectional area.

iii. ArcGIS Analysis

ArcGIS was used to calculate percent land use in each watershed, which included the following classifications: open water, open space developed, low, medium, and high intensity developed, barren land, deciduous, evergreen, mixed forest, grasslands, shrubs, pasture/hay,

cultivated crops, and woody and herbaceous wetlands. The land use practices were obtained from the National Land Cover Database from 2001. To simplify, the land uses were classified into the following six classifications: agricultural, developed, forested, water, low-intensity developed, and grass (Table 3; Figure 1).

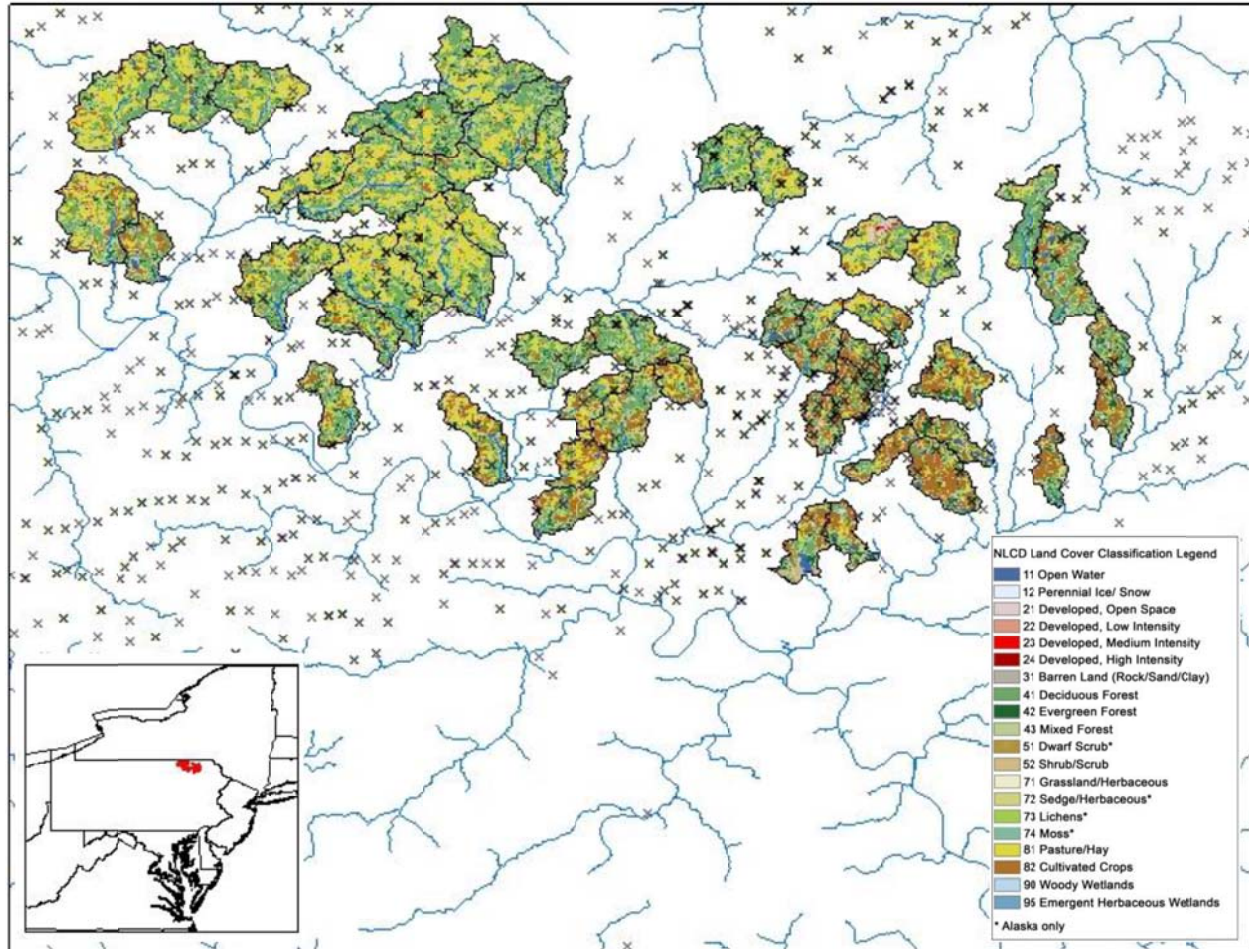


Figure 1: View of the 36 North Central Pennsylvania watersheds included in this study. Land use patterns within the watershed are noted by their respective shading. Locations of well pads (as of June 26, 2013) are noted by x symbols.

iv. Principal Component Analysis

A principal component analysis (PCA) was performed to determine correlations between well pad density and land use to elemental yields. The PCA joined land use practices of similar characteristics, where the given r values range from -1 (negatively correlated) to 1 (positively correlated) (Table 4). Principal component 1 (PC 1) encompassed forested, agricultural, and grassland. Agricultural is highly negative while forest and grassland are positive, indicating that when there is less agricultural land in a watershed, there is either more forest and/or grassland

as they are inversely related. Developed land (PC 2) is comprised of both developed and low-intensity developed land, which are both positively correlated. PC 3 consisted of the area of the watershed and the amount of water within it. Finally, the well pad density (PC 4) was a category on its own.

C. Results

i. Streamwater Samples

A summary of the streamwater samples is provided in Table 1. Three samples from three watersheds (#9, #29, and #30) exceeded their USEPA National Recommended Water Quality Criteria (NRWQC) Criteria Maximum Concentration (CMC) or acute concentration for both Selenium and Cadmium. In addition, one watershed (#45) exceeded its USEPA NRWQC CMC for Zinc.

A total of 25 samples from 19 watersheds exceeded their USEPA NRWQC Criterion Continuous Concentration (CCC) or chronic concentration for cadmium. In addition, a total of 39 samples from 27 watersheds exceeded the USEPA NRWQC CCC for Aluminum.

Interestingly, while several watersheds exhibited metal concentrations in excess of their associated criterion values during both the early and late summer sampling events other watersheds exhibited a surprisingly temporal variation in concentration. For example, many watersheds exhibited higher metals concentrations in the early summer or what was expected to be the more dilute sampling period. The data suggest that transient activities such as surficial spills could be potentially responsible for the observed patterns.

Higher TSS concentrations were observed during the May and June trips than observed in the August trip. The May and June trips had an average TSS value of 0.0045 grams of suspended sediment per liter of water (g/l), while the August trip had an average TSS value of 0.0024 g/l. This decline is largely attributed to a decrease in water discharge that occurs during late summer months, although no statistical analysis was conducted to confirm this result. A series of regression analyses revealed no significant correlations between August TSS yields and overall well-pad density ($r^2 = 0.05$, $p = 0.28$), distance of the closest well pad to the stream ($r^2 = 0.09$, $p = 0.13$), or average distance of the three closest well-pads to the stream ($r^2 = 0.01$, $p = 0.28$).

A comparison of instantaneous storm TSS yields was performed between a control watershed containing zero well-pads (#22) and a watershed containing 12 well-pads (Burdick) during a singular storm event on June 27-28, 2013. While initial instantaneous sediment yields before the event revealed comparable values, peak TSS yields for the Burdick watershed were almost twice the value of its counterpart (Figure 2). This suggests landscape disturbance associated with hydraulic fracturing (i.e., well pad or pipeline construction) could be playing a large role in the delivery of sediments in affected watersheds. Furthermore, a two-fold difference in the peak discharge values for the Burdick watershed despite a lower overall

watershed area, suggests a fundamental alteration of the hydrology of these systems due to the influx of impervious surfaces (i.e., compressed clay surfaces associated with well pads).

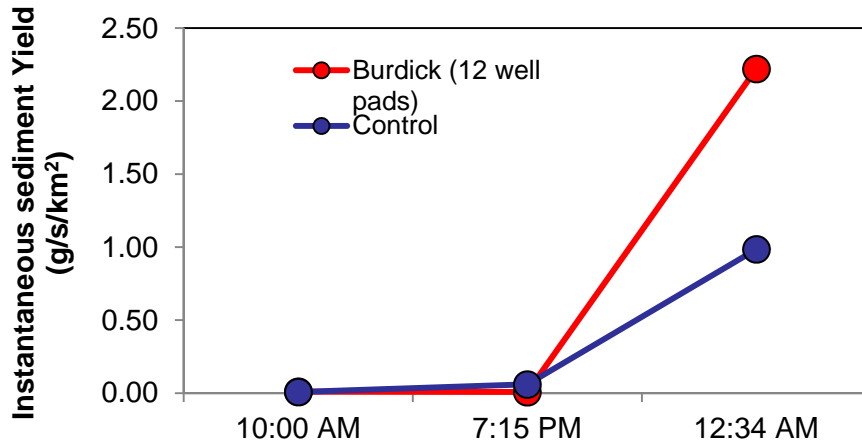


Figure 2: View of the instantaneous sediment yields for two watersheds (g/s/km²) over the course of a storm event between June 27 and June 28th 2013). The Burdick watershed contained a total of 12 well pads at the time of sampling while the control contained zero.

Groundwater Samples

On average, elemental concentration in groundwater were elevated with respect to their streamwater counterparts (Table 2). Barium concentrations in excess of the United State Environmental Protection Agency Maximum Contaminant Level (USPEA MCL) of 2 mg/l were identified in two of the drinking water well samples (G25C and G29). Arsenic concentrations in excess of the USEPA MCL of 0.01 mg/l were identified in one of the groundwater samples (G46). Several of the groundwater samples exhibited aluminum, iron, and manganese concentrations in excess of their respective USEPA List of National Secondary Drinking Water Regulations for aluminum, iron, and manganese (Table 2). Detectable concentrations of methane were identified in twelve of the groundwater samples and ranged from 0 to 1.1 mg/l. None of the methane values were in excess of the US Department of Interior Action Level for Hazard Mitigation.

None of the elements or compounds analyzed in groundwater revealed a statistical link with either well pad density within a given watershed.

Principal Component Analysis

The principal component analysis revealed that temperature is positively correlated with PC 1, indicating that as the percent of forest and grass land increased, the temperature of the streams also increased (Table 4). Potassium, nickel, and the conductivity were negatively correlated with PC 1, which indicated that a watershed with a higher percentage of agricultural land would have a greater amount of potassium, nickel, and a higher conductivity. Developed land exhibited the most impact on the elemental yields, positively correlating to conductivity, nickel, vanadium, iron, cobalt, arsenic, rubidium, strontium, and lithium. Lithium, cesium, lead, and uranium negatively correlated with the area of the watershed and the amount of water within each (PC 3). No correlations were observed between well pad density (PC 4) and any of the elemental yields. In addition, no correlations were observed between any of the principal components and pH, DO, sediment, chromium, manganese, copper, molybdenum, silver, cadmium, and barium.

It is not surprising that many of the elements correlated with agricultural and developed land as previous studies have shown that many of these metals are found in trace amounts in agricultural products or as contaminants on urban roadways. Fertilizer applications can potentially account for the potassium, nickel, and high conductivity levels, as they positively correlated with agricultural land (PC 1)¹². Furthermore, a study of water quality conditions in five agricultural regions in the United States: Delmarva Peninsula, Long Island, Connecticut, Kansas, and Nebraska found that potassium concentrations from commercial fertilizers were significantly elevated in waters in agricultural areas¹³. Nickel, vanadium, iron, and arsenic are some of the most abundant elements in motor oils and lubricants, which are then deposited on roadways from car traffic and are typically found in urban environments due to motor oil from roadways^{14,15,16}. Motor oil, lubricants, and paint on roadways in stormwater runoff are likely responsible for this positive correlation between trace metal contaminants and developed land. Road salt application also likely had an effect on conductivity levels, which positively correlated with developed land.

D. Conclusions

This study used a multi-faceted approach to determine whether there is a link between hydraulic fracturing related well pad density within a given watershed and associated stream and shallow groundwater quality. A total of 77 streamwater samples, 19 groundwater samples, and one spring sample were collected from a total of 38 small watersheds in Bradford, Susquehanna, and Wyoming Counties in north-central Pennsylvania during summer 2013. Three samples from three watersheds exceeded their USEPA NRWQC CMC or acute concentration for both Selenium and Cadmium. In addition, one watershed (#45) exceeded its USEPA NRWQC CMC for Zinc. Several additional samples exceed their USEPA NRWQC CCC or chronic concentration for Cadmium and Aluminum. Interestingly, while several watersheds exhibited metal concentrations in excess of their associated criterion values during both the early and late summer sampling events other watersheds exhibited a surprisingly temporal variation in concentration. However, a PCA analysis did not identify any link between

streamwater elemental yields and well pad density. The heterogeneous nature of the observed stream and groundwater impacts, coupled with the lack of correlation of elemental yields with well pad density within a given watershed, likely points to hydraulic fracturing related spills and/or localized releases from compromised wells as playing an important role on regional stream and groundwater quality. The data suggest that more extensive spatial and temporal sampling is required to determine the long-term imprint on stream and groundwater impacts to this region. The results also suggest the data should be compared with Pennsylvania Department of Environmental Protection (PADEP) records documenting known hydraulic fracturing well pad violations to determine whether there are any associated links.

E. Additional Research Indicated

Stream and groundwater sampling in the targeted watersheds continued to take place during the summer of 2014. The combined dataset is forming the basis of a research paper which is expected to be submitted to the Journal of Applied Geochemistry in spring 2015. Groundwater samples collected as part of this study have been combined with a resident survey (not part of this study) and initial results were presented at the Geological Society of America Annual Meeting in Denver Colorado in October 2013. An associated manuscript for this study is in its final stages of preparation and is expected to be submitted to the Journal of Environmental Science in January 2015.

Additionally, data collected from this study has formed the basis of a National Science Foundation proposal to be submitted in November 2014. This new study will incorporate colleagues from the Villanova School of Nursing as well as Muhlenberg College.

F. Citations

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Appendix A

Individuals/Employees Supported

Staff

i. Number of individuals

No individuals were directly supported from this grant.

ii. Number of full-time employees (as part of the grant)

No full time employees were supported as part of this grant.

iii. Number of full-time employees (as part of match)

No full time employees were supported as part of the match for this grant.

Students Supported

i. Number of Undergraduate Students

A total of four Villanova undergraduate students were supported as part of the match for this grant.

ii. Number of Graduate Students

No graduate students were supported as part of this grant or as part of the match for this grant.

iii. Number of Ph.D. Students

No Ph.D. students were supported as part of this grant or as part of the match for this grant.

iv. Degrees Awarded (please indicate level)

To date, two Villanova University undergraduate students (Sara Alesi [2014] and Toni Iaria [2014]) received their Bachelor of Science degree in Environmental Science. Two Villanova additional undergraduate students involved in this study (Katherine Wister and Brian Donnelly) will receive their Bachelor of Science degree in Environmental Science in May 2015 and May 2016, respectively.

Outreach/Extension

i. Number of meetings, workshops, or conferences, and number of attendees

Not applicable

ii. Number of public or professional presentations and number of attendees

To date, there has been one presentation at a national conference associated with this research. Current Villanova senior Kate Wister presented the results of her research at the 2013 Geological Society of America Annual Meeting in Denver, Colorado. PI Goldsmith also attended this meeting.

Wister, K.H., Weston, N.B., Haggerty, M.K., Donnelly, B.R., Alesi, S.C., Iaria, T.N., and Goldsmith, S.T. (2013) Evaluating a link between shale gas extraction activities and groundwater/societal impacts, *Abstracts with Programs – Geological Society of America*, 45, 7.

Appendix B

Impact Statement

This study used a multi-faceted approach to determine whether there is a link between hydraulic fracturing related well pad density within a given watershed and associated stream and shallow groundwater quality. A total of 77 streamwater samples, 19 groundwater samples, and one spring sample were collected from a total of 38 small watersheds in Bradford, Susquehanna, and Wyoming Counties in north-central Pennsylvania during summer 2013. Several streamwater samples exhibited metals concentration in excess of either their USEPA National Recommended Water Quality Criteria Criteria Maximum Concentration or Criterion Continuous Concentration. In addition, two groundwater wells exhibited barium concentrations in excess of its USEPA Maximum Contaminant Level while several of the groundwater wells exhibited aluminum, iron, and manganese concentrations in excess of their respective USEPA List of National Secondary Drinking Water Regulations. However, a PCA analysis did not identify any link between instantaneous streamwater elemental yields and well pad density. The heterogeneous nature of the observed stream and groundwater impacts, coupled with the lack of correlation of elemental yields with well pad density within a given watershed, likely points to hydraulic fracturing related spills and/or localized releases from compromised wells as playing an important role on regional stream and groundwater quality. The data suggest that more extensive spatial and temporal sampling is required to determine the long-term imprint on stream and groundwater impacts to this region. The results also suggest the data should be compared with Pennsylvania Department of Environmental Protection (PADEP) records documenting known hydraulic fracturing well pad violations to determine whether there are any associated links.

Appendix C

Data Tables

Table 1: Select chemical results for North-Central Pennsylvania Watersheds

Watershed Number	Total Wells	Area (km ²)	Wells per unit area (km ⁻²)	Date Sampled	Conductivity (µS cm ⁻¹)	T (°C)	pH	Dissolved Oxygen	TSS (g L ⁻¹)	CH ₄ (mg L ⁻¹)	Li (ppm)	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	F (ppm)	Cl (ppm)	Br (ppm)	NO ₃ (ppm)	PO ₄ (ppm)	SO ₄ (ppm)	
1	8	35.5	0.23	6/12/2013	131.4	13.3	7.95	98.5%	0.0089	0	0.00	7.76	2.09	2.79	9.50	0.08	10.9	0.03	0.91		7.57	
1	8	35.5	0.23	8/6/2013	154.2	22.3	9.05	82.5%	0.0008	0.000965	0.01	9.12	2.39	3.08	10.4	0.09	13.4	0.06	0.07		7.18	
2	5	11.6	0.43	6/12/2013	119.8	14.1	7.69	89.0%	0.0023	0	0.00	5.55	2.24	3.72	10.2	0.09	6.9	0.03	0.96		9.71	
2	5	11.6	0.43	8/7/2013	130.4	16.2	7.92	93.1%	0.0027	0	0.00	6.81	2.93	4.37	12.2	0.09	7.2	0.00	0.42		8.36	
8	6	22.5	0.27	6/12/2013	110.4	18.5	7.07	74.4%	0.0165	0	0.00	3.85	0.73	1.57	5.06	0.06	6.7	0.01	0.94		7.01	
8	6	22.5	0.27	8/6/2013	118.4	21	6.99	75.1%	0.0011	0.00028	0.01	5.62	1.15	2.33	7.71	0.08	7.5		0.34		6.24	
9	10	12.3	0.81	6/11/2013	175	16.7	7.8	88.5%	0.0054	0	0.00	6.19	2.12	4.53	26.0	0.09	5.5		0.94	0.06	8.37	
9	10	12.3	0.81	8/7/2013	190.2	18.3	8.05	87.2%	0.0006	0	0.00	4.63	1.61	3.76	22.0	0.11	6.3	0.00	0.53	0.05	7.32	
10	28	32.8	0.85	6/12/2013	170	19.9	8.19	95.3%	0.0016	0	0.00	7.13	2.23	3.77	19.8	0.07	10.6	0.03	2.17	0.02	9.50	
10	28	32.8	0.85	8/6/2013	180.4	19	8.77	97.2%	0.0017	0	0.00	2.96	0.82	1.64	8.38	0.08	12.4		0.48		10.3	
11	13	23.8	0.55	6/12/2013	129.4	19	7.39	90.3%	0.0025	0	0.00	5.91	2.26	2.66	9.42	0.06	9.64	0.04	1.03	0.03	7.52	
11	13	23.8	0.55	8/6/2013	143.1	19.1	6.43	61.5%	0.0003	0	0.00	5.69	1.98	2.55	9.49	0.13	10.8	0.08	0.76		7.05	
12	1	7.85	0.13	6/12/2013	97.2	18.3	7.18	89.9%	0.0024	0	0.00	3.63	1.37	2.58	7.40	0.05	3.43	0.01	0.99		9.27	
13	0	23.8	0.0	6/12/2013	101.8	19.1	7.33	88.2%	0.0031	0						0.06	3.62	0.02	2.05		7.17	
13	0	23.8	0.0	8/6/2013	106.3	19.1	8.12	97.1%	0.0017	0	0.00	2.93	1.10	1.92	5.58	0.08	5.09		4.35		6.24	
14	22	14.8	1.49	5/31/2013	119.6	21.8	7.54	92.8%	0.0020	0						0.05	3.27	0.00	0.36	0.01	4.30	
14	22	14.8	1.49	8/5/2013	168.9	18.7	7.66	84.1%	0	0	0.00	5.41	1.15	3.62	11.8	0.08	8.60	0.05	0.80		8.64	
15	5	14.1	0.36	5/31/2013	350	21.5	7.76	89.0%	0.0014	0						0.11	49.9	0.00	4.59	0.39	10.0	
15	5	14.1	0.36	8/5/2013	320.3	17.6	8.14	90.8%	0.0026	0	0.00	33.7	4.64	4.96	26.0	0.14	53.8	0.10	6.73	1.13	10.5	
16	6	11.5	0.52	5/31/2013	153	20.8	7.5		0.0098	0.000254						0.06	11.4	0.00	1.17		7.40	
16	6	11.5	0.52	8/4/2013	196.9	20.8	7.6	90.4%	0.0017	0.000223	0.00	6.37	1.93	3.55	16.4	0.07	11.1	0.06	0.93		7.65	
17	13	14.6	0.89	8/4/2013	200.2	23.3	7.51	75.7%	0.0024	0.00026	0.00	8.97	0.90	2.90	12.6	0.06	14.0	0.05	0.19		5.91	
19	1	8.08	0.12	5/30/2013	90.5	14.3	7.45		0.0043	0						0.06	5.95	0.00	1.10		7.00	
19	1	8.08	0.12	8/4/2013	172.5	16.3	7.64	84.8%	0.0036	0.000209	0.00	5.19	1.95	2.35	18.4	0.07	8.13	0.04	0.78		7.02	
20	4	8.36	0.48	5/30/2013	105.9	19.6	7.49		0.0037	0.000166						0.06	11.0	0.00	0.95	0.01	7.85	
20	4	8.36	0.48	8/4/2013	169.7	18.5	7.65	83.3%	0.0021	0.000647						0.06	10.9		0.66		5.40	
20	4	8.36	0.48	7/22/2013	166.2	18.4	7.23	39.8%														
21	11	16.1	0.68	5/30/2013	164.6	20.2	7.78	47.1%	0.0028	0.000676						0.07	11.0	0.00	1.14	0.14	6.76	
21	11	16.1	0.68	8/4/2013	215	16.4	7.9	86.8%		0.00051						0.08	22.9	0.05	1.96	0.23	9.34	

¹Bold values indicate those in excess of the USEPA National Recommended Water Quality Criteria (NRWQC) Criteria Maximum Concentration (CMC)

²Values in italics indicate those in excess of the USEPA NRWQC CCC

Table 1: Select chemical results for North-Central Pennsylvania Watersheds

Watershed Number	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	As (ppb)	Se (ppb)	Rb (ppb)	Sr 86 (ppb)	Sr 87 (ppb)	Sr 88 (ppb)	Mo (ppb)	Ag (ppb)	Cd (ppb)	Cs (ppb)	Ba (ppb)	Pb (ppb)	U (ppb)	
1		0.15	0.84	2.49	93.1	0.07	1.55	1.21	0.00	0.72	0.00	0.83	5.01	0.80	41.9	0.67	3.99	0.18	0.04	25.0	0.08	0.03	
1		0.24	0.24	5.95	107	0.09	1.12	0.57	0.00	0.90	0.00	0.95	5.51	0.88	0.65	4.01	0.22	0.04	22.9	0.04	0.04	0.05	
2	106	0.07	0.07	1.71	111	0.02	1.00	0.43	0.00	0.56	0.00	0.89	9.37	1.46	67.5	0.11	4.01	0.14	0.00	0.00	0.03	0.00	
2	80.2	0.08	0.03	2.33	101	0.07	1.36	2.88	0.00	0.58	0.00	1.01	10.0	1.57	73.0	0.11	3.95	0.14	0.00	0.00	0.19	0.00	
8	93.1	0.05	0.14	39.4	132	0.07	0.78	2.74	0.00	0.80	0.00	0.58	3.32	0.54	27.9	0.15	4.00	0.15	0.00	23.6	0.03	0.00	
8	40.3	0.02	0.16		123	0.05	0.93	0.39	0.00	0.83	0.00	0.64	3.76	0.60	31.6	0.15	3.99	0.37	0.00	27.0	0.00	0.00	
9	216		30.0		199		29.9			27.2			8.06			3.74		25.2					
9	55.1	0.22	0.04	8.43	45.3	0.10	2.05	0.67	0.00	1.56	0.00	0.64	7.95	1.22	55.2	0.57	4.04	0.17	0.06	68.9	0.16	0.13	
10	72.1	0.15	5.80	3.63	156	0.07	2.13	1.80	0.00	1.00	0.00	0.81	6.41	1.01	0.24	3.97	0.15	0.00	0.00	0.00	0.04	0.04	
10		0.15	0.15	1.41	109	0.06	1.85	0.78	0.00	1.04	0.00	0.67	6.69	1.04	0.23	4.02	0.13	0.00	0.00	0.00	0.04	0.04	
11	131	0.08	0.11	1.58	93.4	0.04	0.92	2.00	0.00	0.63	0.00	0.96	4.42	0.72	36.8	0.44	3.96	0.15	0.03	46.7	0.04	0.01	
11	107	0.09	0.14	9.68	104	0.03	1.29	0.80	0.00	0.70	0.00	1.21	5.72	0.93		0.21	4.03	0.14	0.00	50.5	0.00	0.00	
12		0.10	0.01	4.57	92.0	0.03	0.75	0.53	0.00	0.68	0.00	0.72	3.03	0.50	25.2	0.28	3.97	0.16	0.02	31.9	0.00	0.00	
13	95.7	0.09	21.5	45.4	177	0.06	1.38	1.32	0.00	0.82	0.00	0.86	3.99	0.65	33.4	0.49	4.03	0.33	0.04	38.1	0.03	0.00	
13	94.6	0.23	0.05	17.5	98.9	0.17	0.91	0.48	0.00	1.14	0.00	0.87	4.71	0.76	39.7	0.66	4.07	0.27	0.13	41.2	0.25	0.13	
14		0.27	34.5	6.11	204	0.17	2.27	3.58	14.3	1.02	0.00	1.07	4.32	0.71	36.0	0.87	4.19	0.41	0.25	39.8	0.43	0.08	
14		0.16	0.16	8.35	259	0.04	1.05	1.10	0.00	0.99	0.00	0.74	5.23	0.83		3.97	3.94	0.18	0.01	40.3	0.08	0.00	
15	93.1	1.75	36.5	6.49	161	1.37	4.76	4.72	19.2	3.24	0.00	5.48	9.39	1.72	68.5	2.76	6.76	1.47	2.56	46.7	2.19	1.06	
15	120	0.57	1.09	32.0	340	0.26	3.60	3.52	1.97	2.45	0.00	3.18	11.5	1.90	86.0	0.51	4.03	0.21	0.03	45.4	0.57	0.10	
16	106	0.39	37.0		212	0.30	2.99	2.92	18.9	1.22	0.00	1.33	6.15	0.99		0.81	4.40	0.39	0.42	40.9	0.60	0.17	
16		0.09	0.11	99.8	255	0.11	1.58	0.75	0.00	1.15	0.00	0.96	6.16	0.98		0.18	3.98	0.14	0.00	36.1	0.00	0.02	
17	61.2	0.10	0.11	25.5	131	0.05	1.10	0.20	0.00	1.16	0.00	0.71	9.97	1.55	73.8	0.42	3.97	0.15	0.01	41.7	0.00	0.00	
19	76.8	0.13	36.6	3.61	143	0.09	2.69	2.61	19.1	0.85	0.00	0.93	4.00	0.66	33.9	0.34	4.13	0.34	0.05	20.9	0.15	0.02	
19	178	0.32	0.37	12.5	272	0.23	1.80	0.73	40.8	1.11	0.00	1.02	5.05	0.82	42.5	0.59	4.09	0.25	0.09	24.3	0.28	0.13	
20																							
20		0.19	22.3	25.0	139	0.05	1.78	3.94	0.00	1.07	0.00	0.91	4.62	0.75	38.8	0.32	4.11	0.20	0.04	24.2	0.15	0.02	
20																							
21	61.9	0.34	35.9	3.52	130	0.15	3.07	2.93	21.1	1.24	0.00	1.36	5.84	0.96		0.48	4.10	0.27	0.09	35.3	0.29	0.12	
21		0.40	36.4	9.23	137	0.19	3.52	3.20	17.3	1.59	0.00	1.63	7.91	1.29	54.7	0.89	4.17	0.63	0.16	41.8	0.57	0.20	

¹Bold values indicate those in excess of the USEPA National Recommended Water Quality Criteria (NRWQC) Criteria Maximum Concentration (CMC)

²Values in italics indicate those in excess of the USEPA NRWQC CCC

Table 1: Select chemical results for North-Central Pennsylvania Watersheds

Watershed Number	Total Wells	Area (km ²)	Wells per unit area (km ⁻²)	Date Sampled	Conductivity (µS cm ⁻¹)	T (°C)	pH	Dissolved Oxygen	TSS (g L ⁻¹)	CH ₄ (mg L ⁻¹)	Li (ppm)	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	F (ppm)	Cl (ppm)	Br (ppm)	NO ₃ (ppm)	PO ₄ (ppm)	SO ₄ (ppm)	
22	0	7.84	0.00	5/31/2013												0.10						
22	0	7.84	0.00	6/27/2013	180.1	19	7.62	86.8%	0.0015							0.07	11.2	0.01	2.03	0.05	9.02	
22	0	7.84	0.00	8/6/2013	175.5	14.6	7.59	86.2%	0.0056	0						0.08	12.5		1.93	0.05	9.36	
22 SS-1	0	7.84	0.00	6/27/2013	202.2	18.9	7.44	80.5%	0.0085	0.00013						0.06	11.0	0.01	2.07	0.08	8.68	
22 SS-2	0	7.84	0.00	6/27/2013	170.5	19.1	7.48	82.8%	0.0429	0	0.00	7.29	1.60	1.88	14.60		11.6	0.04	2.61	0.11	4.87	
22 SS-3	0	7.84	0.00	6/28/2013	140.5	18.4	7.52	85.0%	0.0153	0						0.08	10.1	0.01	1.51	0.09	8.41	
24	29	16.7	1.74	5/31/2013	114.2	23.9	7.41	81.1%	0.0050	0						0.10	5.70	0.00	0.02		5.96	
24	29	16.7	1.74	6/11/2013	107.4	17.3	7.35	83.4%	0.0134	0	0.01	5.38	1.08	2.51	9.01	0.07	8.63	0.04	0.83		5.98	
24	29	16.7	1.74	8/5/2013	131.3	20.4	7.58	83.2%		0	0.00	5.21	0.97	2.73	9.54	0.09	8.46	0.05	0.24		5.05	
25	10	13.3	0.75	6/11/2013	117.2	14.5	7.21	81.1%	0.0019	0	0.00	7.41	1.59	3.48	12.12	0.07	9.56	0.03	0.77	0.03	7.70	
25	10	13.3	0.75	8/6/2013	108	15.4	7.41	66.6%	0.0061	0.000285	0.00	2.89	0.50	1.47	5.14	0.09	10.1		0.82		6.82	
26	11	9.11	1.21	6/11/2013	131.1	16.9	7.57	88.2%	0.0085	0.000731	0.00	2.04	0.86	1.85	8.58	0.09	4.63	0.02	0.79	0.06	4.16	
26	11	9.11	1.21	8/6/2013	177.7	15.3	7.70	82.1%	0.0025	0	0.00	5.20	2.53	4.62	21.2	0.12	8.44	0.09	0.36	0.06	4.44	
27	4	10.6	0.38	6/11/2013	153.4	15.7	7.61	90.7%	0.0025	0	0.00	6.35	2.39	3.53	23.1	0.08	15.1	0.09	2.91	0.12	12.2	
27	4	10.6	0.38	8/6/2013	229	17.1	7.47	81.3%	0.0017	0	0.00	3.67	1.48	2.28	15.2	0.10	13.9	0.07	1.37	0.12	16.0	
28	10	14.7	0.68	6/11/2013	144.8	16.2	7.74	88.1%	0.0100	0	0.00	2.01	1.36	1.62	7.95	0.09	6.14		2.10	0.22	10.8	
28	10	14.7	0.68	8/6/2013	186.9	15	7.81	80.2%	0.0072	0						0.12	11.2	0.09	1.43	0.20	11.0	
28	10	14.7	0.68	7/23/2013	221.1	19.4	7.5	38.6%														
29	9	10.3	0.88	6/11/2013	172	15.5	7.87	83.4%	0.0045	0	0.00	6.55	2.13	3.04	16.3	0.07	19.7	0.09	1.63	0.08	8.65	
29	9	10.3	0.88	8/6/2013	227.8	15.3	7.19	52.0%	0.0057	9.79E-05	0.01	20.6	6.35	8.81	46.9	0.11	18.2	0.10	1.41	0.15	12.1	
30	8	16.0	0.50	6/11/2013	123.5	19.8	7.33	82.1%	0.0070	0	0.00	4.84	1.14	2.15	11.5	0.09	7.59	0.03	0.33		6.74	
30	8	16.0	0.50	8/5/2013	189.6	23.4	7.27	64.7%	0.0058	0	0.00	4.96	1.26	2.36	12.5	0.11	9.02	0.07	0.93		6.14	
31	4	7.64	0.52	6/11/2013	103.1	16.5	7.52	91.0%	0.0023	0	0.00	6.66	1.92	3.36	15.1	0.08	6.72		0.78	0.07	6.37	
31	4	7.64	0.52	8/5/2013	154.2	18.9	8.42	95.1%	0.0056	0	0.00	2.64	0.71	1.45	6.41	0.14	8.09		0.42		6.62	
32	13	13.8	0.94	5/31/2013	100.4	15.3	7.3	88.7%	0.0023	0.000116						0.07	9.93	0.00	0.85		6.71	
32	13	13.8	0.94	8/5/2013	152.4	16.4	7.36	82.5%	0.0007	0						0.08	14.8		0.67		6.27	
33	17	8.05	2.11	5/30/2013	206.8	22.3	7.23	31.3%	0.0053	0.00015						0.08	22.5	0.00	1.02	0.02	7.04	
33	17	8.05	2.11	8/5/2013	199.8	16.4	7.36	66.8%	0.0030	0.000717	0.00	17.5	2.15	2.87	20.4	0.07	29.4	0.05	0.55		9.35	

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Table 1: Select chemical results for North-Central Pennsylvania Watersheds

Watershed Number	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	As (ppb)	Se (ppb)	Rb (ppb)	Sr 86 (ppb)	Sr 87 (ppb)	Sr 88 (ppb)	Mo (ppb)	Ag (ppb)	Cd (ppb)	Cs (ppb)	Ba (ppb)	Pb (ppb)	U (ppb)
22																						
22	29.0	0.13	9.39	4.27	111	0.03	1.84	1.32	0.00	1.05	0.00	0.83	5.10	0.82		0.12	3.96	0.15	0.00	23.6	0.00	0.00
22	<i>111</i>	0.20	0.45	3.57	101	0.06	1.56	0.48	9.64	1.06	0.00	0.72	5.38	0.85		0.28	3.82	0.14	0.00	22.6	0.00	0.01
22 SS-1	<i>104</i>	1.57	22.6	7.94	110	1.32	3.28	2.99	0.00	3.02	0.00	3.36	5.03	0.95	42.6	2.47	6.73	1.50	2.37	24.9	1.74	1.12
22 SS-2	<i>93.9</i>	0.17	9.39	3.26	139	0.05	1.82	1.81	0.00	1.37	0.00	0.95	4.71	0.77	39.6	0.21	3.99	0.15	0.00	22.1	0.05	0.00
22 SS-3		0.44	22.0	11.2	164	0.28	2.35	2.49	3.43	1.54	0.00	1.30	4.32	0.72	36.2	0.68	4.27	0.37	0.35	21.1	0.41	0.18
24	<i>101</i>	0.33	36.4	21.4	357	0.24	2.60	3.00	20.3	1.42	0.00	1.04	3.97	0.65	33.1	0.56	4.25	0.36	0.21	81.5	0.41	0.13
24	<i>157</i>	0.22	0.33	84.7	736	0.13	1.59	0.91	0.00	1.43	0.00	0.81	4.59	0.74	38.5	0.19	3.80	0.15	0.01	99.5	0.18	0.00
24	0.00	0.13	0.34	30.5	499	0.05	1.54	1.76	0.00	1.45	0.00	0.81	5.10	0.81	42.9	0.19	3.98	0.15	0.00	89.7	0.05	0.00
25	<i>125</i>	0.22	0.15		257	0.13	1.27	0.67	0.00	1.19	0.00	0.66	5.54	0.88		0.60	4.00	0.20	0.03	108	0.06	0.05
25	<i>101</i>	0.08	0.03	183	190	0.10	1.25	2.53	0.00	1.06	0.00	0.64	6.60	1.04		0.24	3.98	0.14	0.00	123	0.00	0.00
26		0.12	0.03	13.1	224	0.09	1.89	0.92	0.00	1.22	0.00	0.68	5.57	0.88		0.12	3.99	0.14	0.00	96.83	0.00	0.00
26		0.10	0.12	5.38	125	0.12	2.48	1.20	0.00	1.20	0.00	0.91	7.11	1.12		0.18	4.04	0.14	0.00	136	0.00	0.01
27		0.28	0.27	3.35	114	0.19	2.55	1.52	0.00	1.54	0.00	0.68	8.38	1.31		0.65	4.03	0.26	0.07		0.08	0.19
27	<i>95.17</i>	0.27	0.17	6.57	93.0	0.12	2.33	0.91	0.00	1.52	0.00	0.72	9.24	1.43	67.3	0.75	4.02	0.18	0.05		0.01	0.16
28	0.00	0.14	0.15	6.29	273	0.08	1.97	1.56	0.00	1.51	0.00	0.86	6.32	1.01		0.20	3.79	0.13	0.00	76.9	0.00	0.04
28	<i>89.6</i>	0.21	21.4	5.74	164	0.13	2.85	2.02	2.86	1.84	0.00	1.07	8.02	1.27	56.7	0.53	4.00	0.23	0.11	79.4	0.12	0.12
28																						
29		0.29	0.42	6.87	136	0.18	2.31	1.00	0.00	1.34	0.00	1.13	8.79	1.38	63.3	0.64	3.86	0.20	0.06	71.3	0.13	0.15
29	<i>460</i>		98.7							68.9	56.8		10.0			7.10		70.6				
30	<i>589</i>				540						220					29.5						
30	67.6	0.09	0.03	116	110	0.07	1.29	0.48	0.00	2.41	0.00	1.11	5.66	0.92		0.33	3.40	0.16	0.03	78.0	0.07	0.02
31		0.14	0.67	2.47	137	0.06	1.29	0.74	0.00	1.00	0.00	0.71	3.94	0.63	33.2	0.23	4.00	0.16	0.00	37.2	0.00	0.01
31	<i>57.8</i>	0.10	0.08	2.27	102	0.02	1.23	0.35	0.00	0.91	0.00	0.71	4.35	0.71	36.7	0.16	4.06	0.36	0.00	35.5	0.00	0.00
32	<i>91.3</i>	0.17	35.02	7.66	122	0.10	2.37	2.28	16.4	0.91	0.00	0.92	4.64	0.75	39.0	0.40	4.03	0.25	0.07	48.2	0.23	0.02
32	<i>77.3</i>	0.14	0.15	18.2	127	0.03	1.43	0.25	0.00	0.97	0.00	0.75	5.91	0.93		0.20	3.98	0.15	0.00		0.00	0.00
33	<i>130</i>	0.32	38.71	4.75	399	0.18	3.50	3.19	20.1	2.04	0.00	1.47	6.89	1.12		0.66	4.32	0.28	0.13	36.5	0.53	0.06
33	<i>90.2</i>	0.24	0.37	553	354	0.15	2.02	1.07	0.00	2.40	0.00	1.28	6.88	1.10		0.30	4.05	0.15	0.00	44.8	0.14	0.03

¹Bold values indicate those in excess of the USEPA National Recommended Water Quality Criteria (NRWQC) Criteria Maximum Concentration (CMC)

²Values in italics indicate those in excess of the USEPA NRWQC CCC

Table 1: Select chemical results for North-Central Pennsylvania Watersheds

Watershed Number	Total Wells	Area (km ²)	Wells per unit area (km ⁻²)	Date Sampled	Conductivity (µS cm ⁻¹)	T (°C)	pH	Dissolved Oxygen	TSS (g L ⁻¹)	CH ₄ (mg L ⁻¹)	Li (ppm)	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	F (ppm)	Cl (ppm)	Br (ppm)	NO ₃ (ppm)	PO ₄ (ppm)	SO ₄ (ppm)
34	13	23.8	0.55	6/12/2013	153.6	15.5	7.93	91.8%	0.0018	0	0.00	3.02	0.89	2.30	11.9	0.07	6.34	0.02	1.46	0.02	9.15
34	13	23.8	0.55	8/7/2013	171.4	16.8	7.87	86.3%	0.0007	0						0.08	7.86	0.00	0.75	0.01	10.1
36	14	14.6	0.96	5/30/2013	95.4	19.2	7.41		0.0037	0.000116					0.06	5.70	0.00	0.54			5.81
36	14	14.6	0.96	8/4/2013	158.3	20.1	7.77	73.1%	0.0022	0.000206	0.00	4.05	1.23	1.94	13.2	0.06	6.90	0.09	0.65		4.35
39	65	31.1	2.09	6/12/2013	145.7	20.3	7.16	79.8%	0.0007	0	0.00	3.63	1.48	2.55	12.0	0.08	8.03	0.05	0.90	0.03	8.16
39	65	31.1	2.09	8/7/2013	170	20.4	7.24	82.1%	0.0017	0.000141	0.00	5.58	2.20	4.09	19.4	0.07	8.25	0.00	0.12		8.76
41	11	7.96	1.38	5/31/2013	79.3	21.1	7.28	87.7%	0.0057	0					0.06	6.77	0.00	0.52			6.76
41	11	7.96	1.38	8/5/2013	131.8	19.3	7.61	77.9%	0.0015	0.000109	0.00	4.95	1.00	2.09	9.13	0.09	7.97		0.66		6.45
42	5	7.72	0.65	5/30/2013	148.1	24.8	7.24								0.07	10.4	0.00	1.15	0.04		8.11
42	5	7.72	0.65	8/5/2013	158.3	14.7	7.5	71.4%	0.0037	0.000592	0.00	6.75	2.02	2.51	18.8	0.08	10.0	0.05	1.28	0.09	7.98
43	14	8.94	1.57	5/31/2013	94.3	17.6	7.58			0.000148					0.07	8.37	0.00	1.15	0.02		6.72
43	14	8.94	1.57	8/4/2013	181	18.9	8.02	83.4%	0.0011	0.000179	0.00	6.00	1.60	2.83	15.9	0.08	9.21	0.06	0.43		6.74
44	22	11.6	1.90	5/31/2013	144.3	22	7.46	94.1%	0.0038	0					0.07	12.1	0.00	1.12			8.22
44	22	11.6	1.90	8/5/2013	179.4	19.3	7.49	87.1%		0.000138	0.00	10.3	1.42	3.32	12.3	0.09	14.2	0.05	0.43	0.05	6.77
45	22	18.9	1.17	5/30/2013	84.1	17.9	7.78		0.0033	0.000146					0.06	6.45	0.00	0.95			7.39
45	22	18.9	1.17	8/4/2013	141.6	19.5	7.82	89.0%	0.0027	0											
46	5	9.27	0.54	5/30/2013	109.8	14.2	7.69		0.0093	0	0.00	1.95	0.90	0.97	6.03	0.07	9.74	0.00	0.85		8.54
46	5	9.27	0.54	8/4/2013	179.6	17.2	8.14	94.4%	0.0024	0.000125	0.00	7.80	1.88	2.30	19.3	0.10	12.2	0.06	1.15		9.30
Stevens		8.56	0.00	5/30/2013	164	20.7	7.49	40.4%		0.000347					0.09	10.9	0.00	1.68	0.10		7.21
Stevens		8.56	0.00	8/4/2013	231.9	15.4	6.3	53.5%	0.0005	0.000424	0.00	11.6	4.29	3.94	19.9	23.17	0.14	0.89	0.07	9.47	
Burdick		7.27	0.00	5/30/2013	143.6	16.2	7.6	42.0%		0					0.07	22.9	0.00	1.75			9.09
Burdick		7.27	0.00	6/27/2013	161.2	18.9	8.06	97.0%	0.0018	0.00011					0.07	20.5	0.02	2.41	0.06		9.88
Burdick		7.27	0.00	8/5/2013	180.9	16	8.12	97.5%	0.0002	0	0.00	13.1	1.80	2.88	14.7	0.06	22.3	0.00	1.70		10.0
Burdick SS-1		7.27	0.00	6/27/2013	189.1	18.3	7.51	78.2%	0.0013	0	0.00	12.9	1.97	2.73	14.0	0.03	20.0	0.01	2.63	0.02	9.83
Burdick SS-2		7.27	0.00	6/28/2013	189.9	18.1	7.45	85.1%	0.0216	0	0.00	11.1	1.97	2.26	11.7		17.4		2.22	0.06	5.43
Burdick SS-3		7.27	0.00	6/28/2013	187.1	18	7.64	89.6%	0.0016	0	0.00	14.6	19.9	2.50	14.8	0.07	24.4		1.54	0.07	9.37
Silver Creek				6/28/2013	126.5	18.4	7.37	87.5%	0.0002	0.000122	0.00	3.81	0.92	1.65	5.25	0.06	5.32	0.01	1.07	0.10	6.40
Silver Springs Park (methane seep)				6/28/2013					0.0047	0.000206	1.30	720	3.94	16.7	127						

¹Bold values indicate those in excess of the USEPA National Recommended Water Quality Criteria (NRWQC) Criteria Maximum Concentration (CMC)

²Values in italics indicate those in excess of the USEPA NRWQC CCC

Table 1: Select chemical results for North-Central Pennsylvania Watersheds

Watershed Number	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	As (ppb)	Se (ppb)	Rb (ppb)	Sr 86 (ppb)	Sr 87 (ppb)	Sr 88 (ppb)	Mo (ppb)	Ag (ppb)	Cd (ppb)	Cs (ppb)	Ba (ppb)	Pb (ppb)	U (ppb)
34	98.5	0.07	0.07	3.59	97	0.04	1.83	0.25	0.00	0.82	0.00	0.49	10.26	1.58	76.3	0.19	3.92	0.13	0.00		0.00	0.06
34																						
36	123	0.14	34.20	4.46	187	0.10	2.64	3.09	14.0	1.02	0.00	1.11	4.24	0.70	35.6	0.40	4.00	0.21	0.05	23.7	0.19	0.04
36	119	0.11	0.05		255	0.06	1.42	0.30	0.00	1.28	0.00	1.15	4.10	0.69	34.4	0.17	3.98	0.14	0.00	20.7	0.00	0.00
39	380	0.05	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.10	0.27	0.04	1.98	0.00	4.03	0.41	0.08	0.70	0.00	0.02
39		0.09	0.05	17.5	91.5	0.05	1.54	0.21	0.00	0.76	0.00	0.71	7.18	1.13	48.6	0.22	3.76	0.13	0.00		0.00	0.00
41		0.27	37.0	3.87	133	0.20	2.28	3.05	20.3	1.05	0.00	1.16	3.13	0.54	26.2	0.60	4.23	0.36	0.26	25.9	0.38	0.11
41	93.3	0.55	0.28	22.7	6.66	0.29	0.90	0.80	0.00	1.61	0.00	1.01	3.12	0.53	26.2	3.25	4.30	0.44	0.42	20.5	1.28	0.33
42																						
42		0.16	0.27	523	402	0.20	1.99	0.81	0.00	1.79	0.00	0.89	5.50	0.88		0.16	3.99	0.14	0.00	39.4	0.06	0.05
43		0.16	33.2	3.25	113	0.11	2.47	2.17	11.7	1.21	0.00	0.98	4.93	0.80	41.5	0.49	3.99	0.25	0.12	36.7	0.22	0.04
43	117	0.13	0.13	28.8	128	0.05	1.50	0.60	0.00	1.55	0.00	0.83	5.51	0.88		0.24	3.98	0.14	0.00	38.1	0.00	0.01
44	74.2	0.21	34.9	3.87	133	0.10	2.42	2.29	15.9	0.87	0.00	1.04	4.48	0.74	37.8	0.53	4.03	0.23	0.08	46.5	0.25	0.03
44	48.9	0.21	0.05	20.8	33.4	0.08	1.04	0.79	0.00	1.11	0.00	0.90	4.65	0.75	38.8	0.80	4.00	0.18	0.10	41.5	0.34	0.12
45	52.7	0.95	36.0	4.14	114	0.82	3.04	3.28	18.5	1.95	0.00	2.33	3.98	0.73	33.3	2.55	5.65	0.93	1.52	33.0	1.34	0.62
45	88.7	0.90	1.79	379	155	0.18	1.48	10.44	2603	1.14	0.00	0.83	4.10	0.66	34.5		4.03	56.7	0.14	31.2	1.10	0.11
46	95.6	0.15	34.5	3.31	121	0.11	2.63	2.10	15.7	0.81	0.00	1.00	4.82	0.78	40.5	0.33	3.96	0.28	0.09	24.2	0.17	0.06
46	0.0	0.13	0.48	4.39	149	0.06	2.26	1.60	0.00	0.96	0.00	1.14	6.55	1.05		0.16	3.74	0.14	0.00	28.9	0.00	0.08
Stevens		0.52	36.3	5.20	152	0.35	3.08	3.15	19.2	2.02	0.00	2.46	6.11	1.05		0.95	4.33	0.40	0.38	50.2	0.66	0.16
Stevens	0.0	0.22	6.02	36.2	173	0.10	2.30	1.51	0.00	1.84	0.00	1.70	7.51	1.23	51.3	0.22	3.93	0.16	0.00	50.7	0.01	0.04
Burdick		0.21	34.8	3.18	112	0.09	2.54	2.37	12.6	0.80	0.00	1.05	4.82	0.78	40.4	0.36	4.06	0.26	0.09	35.1	0.33	0.01
Burdick	76.1	0.15	9.60	2.55	110	0.03	1.51	1.05	0.00	0.73	0.00	0.85	4.53	0.74	38.0	0.13	4.08	0.16	0.00	30.1	0.02	0.00
Burdick	65.5	0.17	8.39	2.47	117	0.04	1.63	1.03	0.00	0.79	0.00	0.84	5.32	0.85		0.23	3.97	0.15	0.00	34.5	0.04	0.00
Burdick SS-1	0.0	0.14	8.05	3.34	107	0.03	1.54	0.97	0.00	0.74	0.00	0.90	5.03	0.81	42.1	0.14	3.99	0.14	0.00	36.4	0.00	0.00
Burdick SS-2		0.19	9.40	3.01	152	0.05	1.61	1.52	0.00	0.93	0.00	1.01	4.20	0.69	35.3	0.16	3.97	0.17	0.00	31.1	0.04	0.00
Burdick SS-3	98.7	0.24	9.75	3.87	149	0.08	1.91	1.78	0.00	0.93	0.00	1.17	4.92	0.80	41.2	0.24	4.01	0.18	0.02	35.5	0.13	0.00
Silver Creek	267	0.36	8.07	37.4	645	0.22	1.74		78.7	0.89	0.00	0.86	2.14	0.37	18.0	0.11	3.98	0.16	0.01	28.5	5.41	0.00
Silver Springs Park (162	5.20	15.9	91.7	953	0.55	10.3	3.98	29.4	1.91	47.8	9.59				1.07	4.37	0.37	1.64		1.88	0.12

¹Bold values indicate those in excess of the USEPA National Recommended Water Quality Criteria (NRWQC) Criteria Maximum Concentration (CMC)

²Values in italics indicate those in excess of the USEPA NRWQC CCC

Table 2: Select chemical results for North-Central Pennsylvania drinking water wells

Watershed Number	Total Wells	Area (km ²)	Wells per unit area (km ⁻²)	Date Sampled	Conductivity (µS cm ⁻¹)	T (°C)	pH	Dissolved Oxygen	TSS (g L ⁻¹)	CH ₄ (mg L ⁻¹)	Li (ppm)	Na (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	F (ppm)	Cl (ppm)	Br (ppm)	NO ₃ (ppm)	PO ₄ (ppm)	SO ₄ (ppm)
G11	13			6/12/2013	216.2	12.3	7.51	7.4%	0.0013	0.000122	0.01	11.7	0.69	5.74	25.6	0.14	13.0	0.05	0.74		12.7
G20	4			5/30/2013	185.6	10.5	7.54	46.0%	0.0000	0						0.11	5.06	0.00	2.27		10.1
G21				8/4/2013	264.4	13.9	7.98	3.1%		0.894242	0.05	24.6	1.91	3.19	31.0	0.16	8.95	0.12	0.32		8.67
G25A	10			6/11/2013	95.8	8.7	6.42	85.3%	0.0035	0	0.00	3.8	0.86	3.03	9.37	0.09	2.34	0.02	4.93	0.07	7.74
G25B	10			6/11/2013	175.6	11.1	7.09	27.1%	0.0651	0						0.10	1.54	0.01	0.55		8.20
G25C	10			6/11/2013	600.5	12.4	8.27	8.4%	0.0003	1.046711	0.29	150	2.45	6.37	20.5	0.38	216	1.23	0.29		0.38
G41	11			5/31/2013	214	11.1	7.64	13.0%	0.0019	0.009912						0.16	2.30	0.00	0.41	0.50	0.13
G46	5			5/30/2013	186.2	12.2	7.44			0.000346						0.09	13.4	0.00	0.03	0.02	7.93
GB-1 (old)				6/27/2013	625	13.2	7.59	10.0%	0.0170	0.0096	0.10	39.6	1.28	3.54	19.1	0.13	40.3	0.38	0.04		0.18
GB-2 (new)				6/27/2013	139.8	11.6	8.02	45.3%	0.0016	0.000469	0.01	2.64	0.78	2.82	23.3	0.09	1.81	0.01	1.06	0.02	12.6
GB-3 (Ray's)				6/27/2013	267.6	12.7	8.12	9.4%		0.025541	0.03	17.7	1.26	4.75	28.2						
GB-4				6/27/2013	262.8	16	8.17	10.6%	0.0013	0.000528						0.09	3.71	0.01			6.49
GB-5				6/28/2013	284.6		8.04		0.0001	0.050138	0.02	12.1	1.67	6.60	33.8		6.80		2.17		6.63
GB-6				8/5/2013	183	16.4	6.56	56.7%		0	0.00	13.0	1.64	2.14	11.5	0.07	25.3	0.06	6.72	0.07	10.1
G Silver Creek-1				6/27/2013	341.1		8.04		0.0104	0.0111565											
G Silver Creek-2				6/27/2013	343.3		7.32		-0.0001	0	0.00	20.7	0.98	1.18	7.5						
GM1				8/6/2013						0	0.01	8.74	1.53	5.86	21.1	0.87	77.2		0.50	1.21	29.2
GM2				8/6/2013						0						0.15	5.57		9.01		13.1
Owlett				8/7/2013	420.8	12.9	7.46	30.8%		0.085074	0.07	52.7	2.46	13.2	55.6	0.12	29.1		9.24		53.2

¹Bold values indicate those in excess of the USEPA Maximum Contaminant Level (MCL) for Drinking Water

²Values in italics indicate those in excess of the List of National Secondary Drinking Water Regulations

Table 2: Select chemical results for North-Central Pennsylvania drinking water wells

Watershed Number	Al (ppb)	V (ppb)	Cr (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Zn (ppb)	As (ppb)	Se (ppb)	Rb (ppb)	Sr 86 (ppb)	Sr 87 (ppb)	Sr 88 (ppb)	Mo (ppb)	Ag (ppb)	Cd (ppb)	Cs (ppb)	Ba (ppb)	Pb (ppb)	U (ppb)
G11	<i>84.2</i>	0.02	0.13	<i>281</i>	120	0.08	2.61	0.00	0.00	0.40	0.00	0.09	20.2	3.04	161	1.26	3.95	0.16	0.00		0.00	0.68
G20	<i>93.8</i>	1.03	34.9	3.95	112	0.92	4.80	5.87	16.2	2.63	0.00	2.19			443	2.84	5.91	1.03	1.78	85.9	1.39	3.18
G21	<i>50.4</i>	0.02	7.69	<i>259</i>	<i>378</i>	0.25	3.21	0.62	0.00	3.90	0.00	0.95	150	21.6	1272	2.68	3.97	0.19	0.00	168	0.00	1.24
G25A	<i>94.2</i>	0.03	0.18	0.63	78.6	0.00	1.23	0.00	0.00	0.39	0.00	0.32	3.88	0.60	32.4	0.16	3.79	0.13	0.00	100	0.00	0.04
G25B	<i>66.6</i>	0.04	5.84	6.02	133	0.04	2.32	2.91	5.46	0.79	0.00	0.91	90.1	12.4	785	1.19	4.00	0.16	0.03	301	0.00	2.19
G25C	42.1	0.54	1.76	36.0	206	0.02	1.74	0.19	0.00	0.37	0.00	3.99	301	44.6	2527	0.45	4.04	0.16	0.33	5137	0.83	0.00
G41	<i>67.7</i>	0.09	35.8	<i>361</i>	121	0.16	3.47	2.23	20.5	44.5	0.00	2.02			517	1.46	4.22	0.30	0.23	2790	0.19	0.04
G46	<i>98.5</i>	2.24	36.2	5.89	110	1.97	5.55	5.77	25.0	3.93	0.00	4.44	98.6	13.95	852	2.84	7.57	2.17	3.17	364	3.05	4.15
GB-1 (old)	47.2	0.13	9.79		154	0.01	2.61	0.60	0.00	0.36	0.00	0.78			497	1.64	4.03	0.17	0.01	1398	0.16	0.00
GB-2 (new)	27.9	0.21	9.32	4.91	110	0.02	2.17	0.94	0.00	1.58	0.00	0.51	7.26	1.12		0.52	3.96	0.16	0.00	156	0.00	0.63
GB-3 (Ray's)																						
GB-4		0.08	8.95	<i>103</i>	240	0.11	2.76	4.05	0.00	4.73	0.00	0.74	67.7		593	2.93	4.02	0.23	0.07	703	0.08	2.47
GB-5	<i>56.1</i>	0.20	7.74	<i>138</i>	138	0.11	2.95	1.71	0.00	4.33	0.00	0.62	92.0	12.9	801	0.95	3.92	0.17	0.03	268	0.08	3.69
GB-6	<i>59.2</i>	0.22	0.48	1.93	99.9	0.09	1.25	31.8	5.47	0.60	0.00	1.05	4.69	0.77	39.4	0.48	4.02	0.22	0.06		0.32	0.05
G Silver Creek-1	35.1	0.00	8.87	<i>52.6</i>	225	0.02	1.87	0.66	0.00	0.32	0.00	2.58			482	0.57	4.00	0.16	0.23	1022	0.00	0.00
G Silver Creek-2	32.6	0.17	9.21	10.4	130	0.20	2.97	1.20	0.00	0.57	0.00	0.50	5.45	0.85		0.82	4.11	0.29	0.15		0.10	1.35
GM1	<i>84.7</i>	0.52	0.94	0.51	72.4	0.20	1.69	32.6	299	1.04	0.00	1.38	6.22	1.02		0.36	4.05	0.15	0.07	41.7	0.62	0.00
GM2		0.21	0.16	0.87	67.0	0.20	2.97	9.87	0.00	1.05	0.00	1.08	42.7	6.50	354	1.23	3.88	0.24	0.11	174	0.34	0.70
Owlett		0.24	0.79	11.93	198	0.20	4.93	4.61	0.00	1.58	0.00	2.71	220	32.6	1860	1.17	3.98	0.17	0.14	184	0.49	5.87

¹Bold values indicate those in excess of the USEPA Maximum Contaminant Level (MCL) for Drinking Water

²Values in italics indicate those in excess of the List of National Secondary Drinking Water Regulations

Table 3: Combined land use categories for sampled watersheds in north-central Pennsylvania.

Collective Land Use	Included Land Uses
Agriculture	Pasture/hay, cultivated crops
Developed	Medium-intensity, high-intensity
Forest	Deciduous, evergreen, mixed forest
Water	Open water, woody and herbaceous wetlands
Low-Intensity Developed	Low-intensity, open space, barren land
Grass	Grasslands, shrubs

Table 4. r and p values for each principal component and independent variable; statistically significant values are in bold ($p \leq 0.05$).

Parameter	r and p values	Forest, Ag.,	Developed	Area, Water	Well Density
		Grass	Land		
		PC 1	PC 2	PC 3	PC 4
Temperature	r	0.44	-0.03	0.288	0.068
	p	0.009	0.868	0.099	0.704
K	r	-0.464	0.005	0.311	-0.116
	p	0.007	0.977	0.079	0.522
Conductivity	r	-0.369	0.697	0.021	-0.118
	p	0.032	0	0.905	0.506
Ni	r	-0.519	0.502	0.058	-0.074
	p	0.002	0.003	0.744	0.679
V	r	0.124	0.356	-0.255	0.117
	p	0.485	0.039	0.145	0.512
Fe	r	-0.159	0.339	0.089	0.131
	p	0.37	0.05	0.617	0.459
Co	r	-0.1	0.388	-0.322	0.026
	p	0.572	0.023	0.063	0.884
As	r	-0.256	0.522	-0.194	0.152
	p	0.144	0.002	0.272	0.391
Rb	r	-0.261	0.799	-0.001	-0.103
	p	0.135	0	0.997	0.562
Sr 86	r	-0.204	0.542	0.15	-0.214
	p	0.248	0.001	0.398	0.223
Sr 87	r	-0.219	0.584	0.143	-0.217
	p	0.213	0	0.419	0.217
Sr 88	r	-0.198	0.613	0.18	-0.369
Li	r	0.186	0.533	-0.483	0.137
	p	0.293	0.001	0.004	0.439
Mg	r	0.004	0.13	0.535	0.128
	p	0.982	0.5	0.003	0.508
Cs	r	0.196	-0.069	-0.454	0.181
	p	0.266	0.698	0.007	0.306
Pb	r	0.197	0.201	-0.414	0.24
	p	0.263	0.255	0.015	0.171
U	r	0.037	0.065	-0.352	0.076
	p	0.837	0.717	0.041	0.671
pH	r	-0.121	0.155	0.251	-0.065
	p	0.494	0.381	0.153	0.716
Dissolved Oxygen	r	-0.014	0.082	0.166	-0.083
	p	0.935	0.643	0.348	0.64
Sediment	r	-0.302	-0.005	-0.218	-0.123
	p	0.093	0.98	0.231	0.503
Cr	r	-0.289	-0.087	-0.024	-0.117
	p	0.098	0.625	0.892	0.509

Mn	r	-0.12	0.101	-0.145	0.287
	p	0.514	0.582	0.429	0.111
Cu	r	0.071	0.17	-0.069	0.068
	p	0.69	0.335	0.697	0.704
Mo	r	0.316	-0.037	-0.259	0.259
	p	0.073	0.84	0.145	0.145
Ag	r	0.035	0.045	-0.169	0.069
	p	0.843	0.802	0.338	0.7
Cd	r	0.201	-0.026	-0.02	0.12
	p	0.255	0.884	0.913	0.499
Ba	r	0.019	0.025	-0.01	0.183
	p	0.918	0.896	0.955	0.325
