COMMUNITY BASED RISK ASSESSMENT OF EXPOSURE TO WATERBORNE CONTAMINANTS ON THE CROW RESERVATION, MONTANA

by

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DEDICATION

For my long-time community advisors, Myra Lefthand, John Doyle, Sara Young and Larry Kindness, who shared their insights, provided guidance and support and set an example for all of us with their lifetime commitment to improving community health; for all my other colleagues on the Crow Environmental Health Steering Committee who are dedicated to the well-being of the Crow community: Brandon Good Luck, Urban Bear Don't Walk, Alma McCormick, Robin Stewart, Ada Bends, Roberta Fitch, Athalia Rose Morrison, Myron Shield and Ronnie Stewart; for the many Little Big Horn College science majors who have contributed to this project as research interns, especially long time interns and peer leaders Jonah Morsette, Micah White Clay and Candy Felicia; and for the more than 200 community members who gave of their time and expertise to participate in this project and help us understand the risks from contaminated water.

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TABLE OF CONTENTS

1. SCOPE OF THE DISSERTATION 1

References..... 15

2. COMMUNITY-BASED PARTICIPATORY RESEARCH IN INDIAN COUNTRY: IMPROVING HEALTH THROUGH WATER QUALITY RESEARCH AND AWARENESS 17

Contribution of Authors and Co-authors 17
Manuscript Information Page 19
Abstract..... 22
Introduction..... 22
Statement of the Problem: Battling for Healthy Water in Crow Indian Country 24
Health Disparities 25
Need for Data..... 28
Implementation of CBPR in a Native Community..... 29
The Project As A Model of CBPR Research Method 31
The Importance of Crow College Student Involvement..... 32
Conclusion 35
Acknowledgements..... 36
Disclosure of Funding..... 36
References..... 37

3. EXPLORING THE EFFECTS OF CLIMATE CHANGE ON NORTHERN PLAINS AMERICAN INDIAN HEALTH 40

Contribution of Authors and Co-authors 40
Manuscript Information Page 41
Introduction..... 44
Crow Elder Observations..... 46
Confirmation of Elders' Observations of Recent Climate Change Using Monitoring Data..... 49
Anticipated Vulnerabilities for the Crow Community and Local Ecosystems 59
Conclusion 63
Acknowledgements..... 65
References..... 67
Supplement 71

TABLE OF CONTENTS CONTINUED

4. TRIBAL WATERS: A RESOURCE FOR HEALTH AND A SOURCE OF HEALTH DISPARITIES 78

Abstract 79
Background 79
Study Area 81
Methods 85
Community Based Participatory Research 86
Estimating the Number of Native Families Relying on Wells 87
Tribal Approval 87
Household Survey 87
Volunteer Recruitment and Participation 88
Sample Analysis 89
Data Entry and Analysis 90
Cumulative Risk Assessment 92
Risk Communication 93
Results 95
Spatial Distribution of Well Water Contaminants by GIS Maps and Zip Codes 100
Manganese 102
Uranium 104
Nitrate 107
Cumulative Risk Assessment 110
Risk Communication 114
Health Disparities: Economics 116
Health Disparities: Lack of Public Environmental Health Education 118
Health Disparities: Legal and Jurisdictional Issues 119
Health Disparities: Underlying Health Conditions 120
Conclusion 120
Acknowledgements 122
References 124
Spatial Data Sources 132

5. DISSERTATION SYNTHESIS AND FUTURE DIRECTIONS 133

Future Directions – Publications 135
Student Mentorship and Community Capacity Building 136
New Research, Health Education and Mitigation Projects 138
Reference 141

CUMULATIVE REFERENCES 143

TABLE OF CONTENTS CONTINUED

Spatial Data Sources 158

APPENDICES 159

APPENDIX A. Supporting Information for Chapter 1 160
APPENDIX B. Supporting Information for Chapter 1 163
APPENDIX C. Supporting Information for Chapter 4 165
APPENDIX D. Supporting Information for Chapter 4 185

LIST OF TABLES

Table Page

3.1 Available regional weather station records. 71

3.2 Decadal average number of days per year exceeding 90°F and 100°F 71

4.1 Individual wells with hazard index for uranium, manganese and nitrate exceeding 1.0 111

4.2 Relationship of well water quality to consumption 117

LIST OF FIGURES

Figure Page

3.1 Map delineating Crow Reservation and proximity to Hardin, MT 45

3.2 Number of days per year with temperatue exceeding 90°F (32°C) in Hardin and Crow Agency, MT, plotted from National Weather Service daily records 52

3.3 Number of frost free days per year in Hardin, MT, calculated from historic daily observations 53

3.4 Plot showing annual snowfall in millimeters from Hardin, MT and Crow Agency, MT observation sites, calculated in water years 55

3.5 Monthly averages of daily mean discharge by decade for Little Bighorn River at state line near Wyola, Montana (station 06289000) 57

S3.1 Plot of average temperature of rHardin, MT 1948-2007 and Crow Agency, MT 1948-1991 showing increase in average temperatures (in Fahrenheit). 72

S3.2 Decadal averages of discharge for each day in May and June, defining spring runoff hydrographs for the Little Bighorn River near Wyola, Montana (station 06289000) 72

S3.3 Little Bighorn River above Wyola, MT. Mean of daily discharge in May, 1940-2011 73

S3.4 Little Bighorn River above Wyola, MT. Mean of daily discharge in June, 1940-2011 73

4.1 Percent of home wells exceeding EPA's secondary standards 96

4.2 Percent of home wells exceeding EPA's maximum contaminant level (MCL), maximum contaminant level goal (MCLG) or health advisory 97

LIST OF FIGURES CONTINUED

Figure Page

4.3 Maps of the Crow Reservation, showing location within Montana (USDA 2002); major rivers, towns and traditional districts of the Reservation (courtesy LBHC 2012); and zip code regions by town (prepared by Dirckx 2014) 101

4.4 Distribution of manganese contamination in home well water on the Crow Reservation, Montana 103

4.5 Average manganese concentrations in well water by zip code, on the Crow Reservation 104

4.6 GIS generated map showing geologic formations, locations of old uranium mines and well water data 105

4.7 Average uranium concentration in well water by zip code, Crow Reservation 106

4.8 Distribution of nitrate contamination in home well water on the Crow Reservation, Montana 108

4.9 Average nitrate concentration in well water by zip code, Crow Reservation 109

LIST OF DOCUMENTS

Document Page

S3.1 Montana Climate Division 5 temperature data..... 74

S3.2 Montana Climate Division 5 precipitation data..... 76

ABSTRACT

The goal of this collaborative research project undertaken by the Crow Reservation community, Little Big Horn College and Montana State University Bozeman has been to improve the health of Crow community members by assessing, communicating and mitigating the risks from local waterborne contaminants. The Reservation's surface waters have always been greatly respected by the Crow people, valued as a source of life and health and relied upon for drinking water. About fifty years ago, rural families switched to home well water instead of hauling water from the rivers. Many families went from having an unlimited supply of free, good quality river water, to unpalatable well water dependent upon an expensive-to-maintain plumbing system.

Tribal members questioned the health of the rivers and well water due to visible water quality deterioration and potential connections to illnesses and initiated this research project. We share what we have learned as tribal members and researchers about conducting community-based risk assessment and using our data to improve Tribal and river health.

Initial research on river water quality revealed significant microbial contamination. Collaborations with several microbiologists revealed substantial *E. coli* and *Cryptosporidium* river contamination as well as *Helicobacter pylori* in home water supplies.

We found that about 55% of home wells are unsafe to drink due to either mineral and/or microbial contamination. Depending on the river valley, 11% to 58% of home wells exceed the cumulative risk level of concern for mineral contaminants. Exposure to contaminated well water exacerbates the community's existing health disparities due to the confluence of the area's geology, extensive agriculture, lack of public environmental health education, jurisdictional complexities of reservations, already vulnerable health status and families' limited financial resources for mitigating poor quality well water.

Limited resources as well as the links among ecosystems, cultural practices and public health will increase the already existing impacts of climate change on reservation communities. Flood frequency, late summer water shortage and fire severity are increasing while water quality is declining.

Risk communication and risk mitigation, not just risk assessment, have been and continue to be central to our project and pursued through numerous venues and collaborations.

CHAPTER 1

SCOPE OF THE DISSERTATION

The goal of this collaborative research project undertaken by the Crow Reservation community, Little Big Horn College and Montana State University Bozeman has been to improve the health of Crow community members by assessing, communicating and mitigating the risks from local waterborne contaminants. The Crow Reservation is rich in water resources. The Little Big Horn River, Big Horn River, Pryor Creek, and the springs and tributaries which feed them, have always been greatly respected by the Crow people, valued as a source of life and of health and relied upon for drinking water. Crow Environmental Health Steering Committee members relate that about fifty years ago river water quality began visibly deteriorating with the expansion of agriculture, indoor plumbing was finally installed in rural homes, and rural families switched to relying on home well water instead of hauling water daily from the rivers. For many families with highly mineralized well water, this change was a hardship: they went from having an unlimited supply of free, good quality river water, to unpalatable water delivered by an expensive plumbing system. Community members became increasingly concerned about potential health effects from their poor quality drinking water.

Grassroots work on water quality began when Tribal members John Doyle, Larry Kindness and James Real Bird offered to serve as volunteer Directors of the Apsaalooke [Crow] Water and Wastewater Authority (AWWA) for the Reservation. In 2004, the AWWA, Myra Lefthand of the Crow/Northern Cheyenne Indian Health Service Hospital

and this author - the wife of a Crow Tribal member, a resident of Crow Agency since 1993 and a science faculty member at Little Big Horn College on the Reservation since 1996 - initiated and received assistance in conducting a community-wide environmental health assessment from volunteers with the Indian Country Environmental Hazard Assessment Program (ICEHAP) of the EPA (DuFault 2005). About ten Tribal members with various areas of expertise and Eggers participated in this week long process. The resulting assessment identified water contamination as the environmental health issue with the most serious and widespread impacts on community health. Doyle, Kindness, Lefthand, Eggers and several others formed the Crow Environmental Health Steering Committee (CEHSC) in 2004, and developed a formal Memorandum of Agreement among the Crow Tribe, Little Big Horn College (LBHC) and Montana State University (MSU) to collaborate on addressing water quality issues on the Reservation. This MOA was signed by Crow Tribal Chairman Carl Venne, LBHC President David Yarlott and MSU President Jeffrey Gamble.

With initial funding from the Montana INBRE program at MSU and the support of then MT INBRE P.I. Tim Ford, LBHC science faculty members Larry Istrate and Eggers took on the College's summer student research project monitoring local river water quality, which math faculty member Dianna Hooker had been leading. Istrate led this effort until he accepted another job, and Eggers became the lead beginning in the summer of 2006.

Over the next several years the CEHSC, consisting of about ten Tribal stakeholders with voting rights, Eggers as the LBHC academic partner and Tim Ford as the MSU partner, became increasingly active and involved in the water quality research.

We evolved into a "community based participatory research project," which has been defined as, "a partnership approach to research that equitably involves, for example, community members, organizational representatives, and researchers in all aspects of the research process and in which all partners contribute expertise and share decision making and ownership" (Israel et al. 2008). In such partnerships, the community and academic partners work together to ensure that research meets community needs, incorporates community expertise and environmental knowledge, is implemented in culturally appropriate and respectful ways, meets the standards of quality science and fulfills the requirements of the funders.

In our partnership, while the tribal members on the CEHSC have primary responsibility for the first three, and Eggers (and her academic advisors) have primary responsibility for conducting quality science and fulfilling federal funding requirements, we all take responsibility for sharing our respective areas of expertise and listening carefully to one another so that we can learn from each other and work together effectively. Additionally, we all share responsibility for data interpretation; dissemination of results (risk communication) to the Tribe, state and nation; risk mitigation; community capacity building and long range planning. This "community engaged" approach to conducting health and environmental health research in minority communities has been widely recognized in the literature and by federal funding agencies as effective, ethical and essential (EPA 2014, Israel et al. 2013, Minkler et al. 2008, Christopher et al. 2008, Christopher et al. 2011, NCAI et al. 2012).

Our initial baseline monitoring of the health of local rivers and discussions at CEHSC meetings soon led to the realization that the scope of the water contamination

Sources	Stressors	Pathway	Exposure Route	Receptors	Endpoints
Geology	Manganese	primarily well water	drinking, cooking	Tribal community; river water is sacred, consumed ceremonially. • Existing health disparities • Limited financial resources for H_20 treatment • Inadequate environmental enforcement • Limited environmental health literacy	Mn: neurotoxic U: kidney damage, cancer risk ↑, genetic, reproductive, more NO_3: SIDS risk ↑, methemoglobinemia, diabetes, possible cancer risks, more
Mining (?)	Uranium				
Geology	As, Rn, Ra				
Geology	Hardness Alkalinity	well-> scaling -> pipes leaks -> mold	inhalation		
Farming	Nitrates	shallow well water	drinking, cooking		
	Pesticides ?	river water	drinking		
Coal burning; Geology	Mercury	rivers & lakes -> -> fish -> subsistence	fish consumption		Hg: neurotoxic
Livetock; "Straight piping" from homes; Poorly treated municipal wastewater; Wildlife	Pathogens	river water	drinking (secular and ceremonial), swimming		As: diabetes, cancer risk, ↑BP, more Mold: asthma attacks, allergies, irritant
		river-> municipal	drinking		Pathogens: *Cryptosporidium* *E coli* serotypes *H. pylori* *Legionella*
		river->shallow wells			
		soil->shallow wells			
Septic systems	Pathogens	septic system -> shallow wells			
Unknown	Pathogens	springs			

Figure 1.1. Cumulative risk assessment conceptual model for exposures to waterborne contaminants, Crow Reservation. Well water study highlighted in blue; fish study highlighted in grey; microbial research highlighted in green, new research in ta

issues includes not only rivers and creeks, but also home well water, municipal water treatment and distribution, municipal wastewater treatment, exposure to mercury contamination of surface waters through fish consumption and – we've learned more recently – spring water (Figure 1.1).

In addition to the baseline river water quality monitoring Eggers and her LBHC students were conducting, in 2006 we initiated fish tissue sampling for mercury contamination. The ICEHAP training had alerted us to the possibility of mercury exposure through fish consumption, so Eggers and her students began working with fisheries biologist Robbin Wagner of the US Fish and Wildlife Service to sample local fish for mercury contamination. Analysis of fish tissue samples was conducted with training, supervision and equipment provided by Steve Hamner of MSU. The data showed that local species of edible fish over 12 inches in length were sufficiently contaminated with mercury to warrant fish advisories. An advisory flyer was produced and circulated locally, and after a second summer of fish sampling and tissue analysis, the results were presented at a national conference (Appendix A; Cummins et al. 2009).

The community context and the initiation and initial progress of our community-engaged research project is described in a manuscript published in Family and Community Health, "Community-Based Participatory Research in Indian Country: Improving Health through Water Quality Research and Awareness," included here as Chapter 2. In the article, we share what we learned as the Crow Environmental Health Steering Committee, including academic partners, about working together to examine surface and groundwater contaminants, assess routes of exposure and use our data to bring about improved health of Crow people and Crow waters. Eggers has served as

project leader (scientist) for this research since its inception, working closely with the CEHSC on all aspects of project design and implementation, supervising the local project coordinator and attending all CEHSC meetings, as described above. This article was developed through a collaborative group process in which all co-authors participated, facilitated primarily by CEHSC member Sara Young. Eggers did the majority of the writing, with editorial input from Camper and Young. All coauthors reviewed and approved the final article prior to submission. All coauthors agreed that Cummins – the project coordinator at the time and a Tribal member – would be the first author and Eggers the final author.

Our initial research on river contamination led to discussions at regular meetings of the CEHSC about how the Reservation climate has changed over the past 50 years. CEHSC member Sara Young emphasized how much the annual snowpack has declined since her childhood, triggering a series of interrelated observations about other ecological changes related to declining snowfall and milder winters. This local environmental knowledge corroborated data on local climate change which had been compiled several years earlier by hydrogeologist and Intergovernmental Panel on Climate Change author Margaret Hiza Redsteer, a Crow Tribal member, at the request of Eggers, then teaching environmental science at Little Big Horn College. A special 2013 edition of the journal Climatic Change about the health impacts of climate change on Native American and Alaska Native communities offered the opportunity to pursue this research further and publish the results. The subsequent article, "Exploring Effects of Climate Change on Northern Plains American Indian Health," is reproduced here as Chapter 3.

In brief, the analysis of meteorological data confirmed Tribal Elders' observations of declining annual snowfall and increasingly mild winters. In addition, the data show a shift in precipitation from winter to early spring and a significant increase in days exceeding 90 ^{o}F (32 ^{o}C). Streamflow data show a long-term trend of declining discharge. Elders noted that the changes are affecting fish distribution within local streams, plant species which provide subsistence foods, and traditional ceremonial practices. Additional community concerns about the effects of climate change include increasing flood frequency and fire severity, as well as declining water quality.

For this article, Hiza Redsteer researched and conducted the analysis of measured climate data and co-author Doyle verbally relayed to Eggers local knowledge about climate change effects he had learned from various Tribal members. Eggers wrote up Doyle's research, analyzed the hydrologic data, and wrote the overall article, incorporating and synthesizing the contributions of all three authors. Eggers served as the corresponding author throughout the writing process, revising and improving the article through numerous iterations in response to reviewer input. All three co-authors reviewed, edited and approved the final submission; Doyle is serving as the corresponding author for the published article as he can best speak on behalf of the Crow Reservation community.

In addition to this climate change research, Project Leader Eggers, the CEHSC and the Project Coordinator continued to work on our community-engaged risk assessment of exposure to waterborne contaminants in home well water. Eggers designed the well water testing protocol and drafted the survey for well owners, which was reviewed, edited and condensed by CEHSC members. She supervised and supported

the local project coordinator in implementing the well water testing and survey administration. These activities collected data on well water contaminant concentrations, home water treatment methods, well water consumption, other sources of home drinking water, and well and septic system protection and maintenance practices. Key informant interviews were also designed and conducted by CEHSC member Lefthand, Alma McCormick and Beldine Pease of the local non-profit, Messengers for Health (MFH) and Crow graduate student Dayle Felicia (with funding from a grant to MFH from the Institute for Translational Health Sciences, for which Eggers was the primary author).

Well test results showed that uranium, manganese and nitrate were the toxic inorganic contaminants found to most frequently exceed EPA drinking water standards. Considering only these three inorganic contaminants, the percent of home wells exceeding the cumulative risk level of concern varied from 11.1% to 58.3% depending on river valley. Individual well test results were explained in writing and in person to participating families and results were disseminated to the community through multiple venues. Exposure to contaminated well water contributes to the community's existing health disparities due to the confluence of the area's geology, extensive agriculture, lack of public environmental health education, jurisdictional complexities of Indian reservations, already vulnerable health status and especially, families' limited financial resources for mitigating poor quality well water.

This work is described in Chapter 4 of this thesis, entitled, "Tribal Waters: A Resource For Health and a Source of Health Disparities." Eggers has been the project leader/scientist for this research from its inception, writing the INBRE proposals for LBHC as well as the community sections of MSU's EPA and Center Grant proposals

which funded the work . She has been working and continues to work closely with the CEHSC on all aspects of project design and implementation; supported the daily work of the local Project Coordinator; wrote individual letters to and prepared packets for each of 160+ participating families about their well test results; managed the data, the equipment and supply purchasing and the multiple budgets; wrote all the press releases for the community and prepared and presented teacher training materials; co-presented project results in the Reservation community, regionally and nationally with her colleagues; wrote all the annual reports to four separate funders; and troubleshot issues as they arose. Eggers also conducted the entire literature review, entered all the data and did the quantitative analysis of the well water and survey data and wrote this chapter.

While Eggers served as the project leader/academic partner for this research, the project has truly been a partnership with the dedicated Crow Tribal members of the Crow Environmental Health Steering Committee, including Doyle who now serves a double role as Project Coordinator. Academic advisors and principal investigators Dr. Anne Camper and Dr. Tim Ford provided scientific and professional guidance and advice, and past and current local project coordinators Whiteman, Cummins, Old Coyote and Doyle recruited participants, conducted field work and home visits with the participants, explained the project and project results to the community, served as the daily liaison to the community and were essential partners in this work. Other MSU faculty and staff, additional outside collaborators and more than 20 student interns from Little Big Horn College and a dozen from Montana State University contributed to the project. The well water study was also made possible by 230+ Crow Tribal members who contributed their knowledge of water contamination issues through completing surveys or granting

interviews, and graciously welcomed project staff and LBHC student interns into their homes to collect well water samples. Messengers of Health Executive Director Alma McCormick and CEHSC member Myra Lefthand, advised by LBHC faculty member Timothy McCleary, led the qualitative research. Founding and longtime CEHSC members John Doyle, Larry Kindness, Myra Lefthand, Sara Young, Brandon Good Luck and Urban Bear Don't Walk deserve special recognition for their leadership, vision and years of dedication to improving the health of the Crow Reservation community.

Additional Mitigation Work and Research Collaborations

As mentioned above, well water quality was so poor that not a single well out of 151 wells tested met all the EPA primary and secondary standards for drinking water. Principal Investigator and Eggers' advisor Dr. Anne Camper suggested that the Amway Corporation's low cost, high tech home water filtration system might be an appropriate mitigation strategy for Crow families using poor quality well water. This idea was discussed with the Crow Environmental Health Steering Committee, who thought the filtration system was worth testing in the community. With the support of four Crow families, the staff at Chief Plenty Coup State Park and project coordinator John Doyle who volunteered to host and maintain the filters, and project facilitation by Doyle, MSU's Engineers Without Borders (EWB) student members offered to collect and analyze the source and filter-treated water samples and to manage and analyze the data. Financial support was provided by Amway Corporation's community service department, Anne Camper provided leadership and project leader Eggers provided additional staff support. Over a period of nine months, the filters were tested for efficacy at removing

waterborne pathogens from river water in each of the three watersheds of the Reservation. The filters were found to be very effective at removing microbial contamination from river and spring water. Project coordinator Doyle interviewed filter hosts about ways to improve the technology's ease of use for community members; this feedback was compiled by EWB member Eric Dietrich for the final project report.

Eric Dietrich, the student leader who had prepared the final report for Amway, went on to write an article describing this service learning project, entitled, "Industry-Partnered Service-Learning Addressing Drinking Water Quality with a Native Community." The article is currently being sent out for review to peer-reviewed publications. Eggers, one of the co-authors, contributed by helping facilitate student work in the community, working closely with Crow Project Coordinator Doyle to coordinate many aspects of the complex project and by reviewing and providing suggestions for multiple iterations of Dietrich's article (Dietrich et al. 2013).

There have been additional opportunities for Steering Committee members and project staff to disseminate lessons learned through publications. Eggers and former Project Coordinator Cummins contributed to an article which was a collaborative effort of both community and academic researchers in the Center for Native Health Partnership network (Christopher et al. 2011). The EPA invited Eggers to submit a blog for their website, which she subsequently co-wrote with various CEHSC members (Appendix B; Eggers et al. 2013). CEHSC members, project staff and P.I.s Ford and Camper also developed and gave two nationally broadcast webinars for the EPA, one of which remains available on-line (Ford et al. 2012).

As initial research revealed the scope of water contamination issues, it became clear that additional academic partners were needed to be able to investigate both inorganic and microbial contamination of the Reservation's rivers and rural residents' home wells. The CEHSC and Eggers subsequently collaborated with Montana State University Research Associate Steve Hamner, graduate students Sue Broadaway and Crystal Richards and others to investigate some of the community's concerns about waterborne pathogens. (Eggers' supportive role in facilitating these various research projects is reflected in co-authorships on the resulting articles, so the research is summarized here. However, as she did not play a major role in conducting the research, the articles are described briefly below but not included as separate chapters.)

Crystal Richards, in response to CEHSC and broader local concerns about *Helicobacter pylori* infections in the community, volunteered to investigate this pathogen, *Legionella pneumophila and Mycobacteria avium* in home drinking water and associated biofilms on the Reservation. Her research detected all three pathogens in both water sources and biofilms (Richards et al. 2010). Eggers and CEHSC member Doyle were actively involved in fieldwork design and implementation, provided oversight for the work performed on the Crow Reservation and participated in manuscript editing.

Montana State University Research Associate Dr. Steve Hamner offered to address community concerns about whether the extensive confined animal feeding operation upriver of the all the Reservation communities along the Little Big Horn River was contributing to the high levels of *E. coli* contamination polluting the river, especially during spring runoff. Hamner, his student interns and CEHSC member Brandon Good Luck found various pathogenic serotypes of *E. coli*, including O157:H7, some of which

harbored intimin and/or Shiga toxin genes, in the Little Big Horn River both below the CAFO and in a popular children's swimming hole at Crow Agency. Four MSU students interned with Hamner and became co-authors on the research, including Crow Tribal members Joseph Old Elk and Nita Big Man. Co-authors Doyle, Kindness and Eggers served in supporting roles, facilitating the research on the Reservation. Hamner's research was published in the International Journal of Environmental Health Research in 2013. (See References.)

Another community concern was the adequacy of municipal water treatment for Crow Agency, given the extremely high levels of *E. coli* contamination in the treatment plant's Little Big Horn River source water during spring runoff. Source water samples analyzed by an EPA-certified lab in Billings, Montana had documented concentrations of *E. coli* in excess of 7000 MPN/100 ml during spring runoff in 2008, placing the river in EPA's "Bin 4" – the highest risk category for the presence of other pathogens such as *Cryptosporidium.* With the support of the CEHSC and Treatment Plant staff, four MSU graduate engineering students and Eggers, led by Dr. Anne Camper, visited the treatment plant, conducted an analysis of its operation and offered suggestions for additional treatment options to reduce microbial risk in the treated water. The resulting report was presented to and discussed with the Treatment Plant operators and Bureau of Indian Affairs supervisor by the five student researchers. Student Connolly took the lead in authoring the report, and Eggers was the second author, collaborating with her co-authors in conducting the work and writing up the results (Connolly et al. 2010).

This analysis of the Crow Agency Water Treatment Plant made it clear to all involved that the existing treatment technology might not be sufficient to adequately

remove *Cryptosporidium* oocysts from the plant's source water, the Little Big Horn River. MSU graduate student Susan Broadaway and her advisor Dr. Barry Pyle took on the challenge of testing both source and treated water for *Cryptosporidium* oocysts, as they were working on an improved methodology to detect *Cryptosporidium* in water samples. Broadaway found oocysts in all nine source water samples taken from the treatment plant over the course of a year. In June and July, following a major spring flood, the concentration of oocysts peaked and subsequently broke through into treated municipal water. Her resulting article, "Detection of *Cryptosporidium* using Fluorescent *in situ* Hybridization and Solid Phase Laser Cytometry," has been submitted to the journal Applied and Environmental Microbiology for consideration. Eggers, a co-author on this article, contributed by providing suggestions for their EPA grant proposal as to how their research could help meet Crow community needs, collecting some of the samples at the Treatment Plant, serving as the liaison to the CEHSC, hosting a site visit of their EPA Project Officer and by reviewing the draft article (Broadaway 2013).

We continue to collaborate with other researchers, which both brings in needed areas of expertise and provides opportunities for MSU faculty to work with the Crow Reservation community. For instance, we now have a new EPA Environmental Justice grant to address fecal contamination of Chief Plenty Coup Spring, thanks to joint planning (Doyle, Red Star, Eggers, Young and Galbraith, with input from other members of the CEHSC) and a collaborative writing effort (Eggers – narrative, Galbraith – all the supporting materials). MSU faculty members Carl Yeoman and Stephanie Ewing are contributing source tracking and isotope analysis expertise, respectively.

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CHAPTER TWO

COMMUNITY-BASED PARTICIPATORY RESEARCH IN INDIAN COUNTRY: IMPROVING HEALTH THROUGH WATER QUALITY RESEARCH AND AWARENESS

Contributions of Authors and Co-authors

Manuscript in Chapter 2

Co-authors: John Doyle, Larry Kindness, Myra J. Lefthand, Urban J. Bear Don't Walk, Ada Bends, Roberta Fitch, Athalia R. Morrison and Sara L. Young

Contributions: All served or serve on the Crow Environmental Health Steering Committee, guiding this project's design and implementation from its inception, through monthly meetings. All are Crow Tribal members. With the exception of Sara Young (who had moved from the Crow to the Northern Cheyenne Reservation at the time this was written), all currently live on the Crow Reservation. All contributed ideas to this article through a group writing and editing process. Young took the lead in facilitating the group writing process.

Co-authors: Dr. Steve Hamner, Susan C. Broadaway and Crystal L. Richards

Contributions: All carried out microbiological research on the Reservation, addressing water contamination issues of concern to the community. All attended and participated in multiple CEHSC meetings on the Reservation. All contributed ideas to this article through a group writing and editing process.

Co-author: Dr. Tim Ford

Contributions: Ford served as the initial P.I. on MSU's Center for Native Health Partnership – NIH sub-award which supported this work, and after accepting a job at another University in 2008, continued to help oversee the research as co-chair of Margaret Eggers' doctoral committee.

Co-author: Dr. Anne K. Camper

Contributions: After Dr. Ford's departure in 2008, Dr. Anne K. Camper served as the P.I. on MSU's Center for Native Health Partnership – NIH sub-award which partially supported this work, and supervised the research as co-chair of Margaret Eggers' doctoral committee. She was involved in advising Eggers on a weekly basis and frequently

Contributions of Authors and Co-authors, Continued

attended CEHSC meetings. Camper contributed ideas to this article through the group writing and editing process, and did the final editing of the article.

Co-author: Margaret Eggers

Contributions: Eggers served as the P.I. for Little Big Horn College for the NIH-INBRE award which supported this work, and for the NIH-Center for Native Health Partnerships subaward to LBHC, initiated the project along with Doyle, Kindness and Lefthand, and has served as the project leader (scientist) for this research since its inception. As project leader, she had primary responsibility for designing and conducting the science involved in the water quality research, supervised the project coordinator, managed the project budgets, wrote all grant reports and ensured the work of collaborating researchers was coordinated with the CEHSC. She attended all CEHSC meetings, contributed ideas to this article through the group writing and editing process, and compiled everyone's inputs by writing the initial draft of the article and worked with Camper on the final editing. Academic and research advisor Camper ascertains that Eggers, through her long term role in the CEHSC (see Chapter 1) was instrumental in identifying how to address the CEHSC's concerns about local water quality/health disparities. Consequently, she was key in the development of the community based participatory research direction and therefore the content of this manuscript. Eggers was also a major driver for the concept of the manuscript and the final submitted version.

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CHAPTER 2

COMMUNITY-BASED PARTICIPATORY RESEARCH IN INDIAN COUNTRY: IMPROVING HEALTH THROUGH WATER QUALITY RESEARCH AND AWARENESS

Cummins, C.,[1,2] Doyle, J.,[2,3] Kindness, L., [1,2,3] Lefthand, M.J.,[2,4] Bear Don't Walk, U.J.,[2,3,5] Bends, A.,[2,5] Broadaway, S.C.,[6] Camper, A.K.,[6] Fitch, R.,[2,5] Ford, T.E.,[7] Hamner, S.,[6] Morrison, A.R.,[2,5] Richards, C.L.,[6] Young, S.L.[2,6] and M.J. Eggers[1,6]

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Key Words

Community-based participatory research, Native American, water quality, health disparities

Abstract

Water has always been held in high respect by the Apsaálooke (Crow) people of Montana. Tribal members questioned the health of the rivers and well water due to visible water quality deterioration and potential connections to illnesses in the community. Community members initiated collaboration among local organizations, the Tribe and academic partners, resulting in genuine community based participatory research. The article shares what we have learned as tribal members and researchers about working together to examine surface and groundwater contaminants, assess routes of exposure and use our data to bring about improved health of our people and our waters.

Introduction

Environmental health concerns of Native American and Canadian First Nations people are increasingly being addressed through community based participatory research (CBPR) partnerships among tribal communities, university researchers and others.[1-6] A frequently cited review of community-based research in public health defines it as "[A] collaborative approach to research that equitably involves, for example, community members, organizational representatives and researchers in all aspects of the research process."[7] A number of health researcher teams conducting CBPR have shared their experiences in working with Native communities,[8-14] and in some cases the lead authors have been Native researchers.[15-18] However, rarely have Native American community members written about their perception of the value of the CBPR process to their

community, why they would participate in such research and how research should be conducted in their home community.[15,19] A better understanding of how to work with communities has been identified as a critical need in risk assessment research in particular.[20]

As members of the Apsaálooke (Crow) tribe in south central Montana, we identified deteriorating water quality as a critical environmental health issue in our community and recruited academic partners to help us conduct a local risk assessment of exposure to contaminants via water sources.[21-29] Data gathered in our collaborative efforts are quantifying our water quality problems, providing useful information to tribal members and are being successfully used to raise funds to improve water and wastewater treatment infrastructure in our community. We hope to also improve risk assessment modeling and methodology for Native American communities, in general. We meet monthly as a Steering Committee to work with our staff and academic partners to guide our collaborative work. Tribal members who are science majors at our local tribal college conduct most of the field work and community surveys; these students have been motivated to continue on in pursuing bachelor's degrees in environmental health and related fields and several are now in graduate school or are in the process of applying.

In this article, we describe how our project began, how our partnership with academic researchers developed and what we have learned and gained in the process. We hope that sharing our experiences will be helpful to other Reservation communities and possibly other minority communities who are faced with environmental health

challenges, as well as to University researchers partnering with communities to conduct community based research in environmental health.

Statement of the Problem: Battling for Healthy Water in Crow Indian Country

When First Maker created the people that eventually became the Apsaálooke or Crow, he asked a duck to dive down in the water and bring up some earth. From this wet earth he sculpted the first Crow man and woman and breathed life into them (Harry Bull Shows, deceased). This creation story instills in the Crows a respect for the animals and for the earth; the earth is one of the three mothers of the Crows.

Like respect for the animals and mother earth, a fundamental tenet of the Crow is to respect water. Water comes in many forms (snow, ice, sleet, hail, rain and mist) and is powerful. Water has sustained the Crow people since their creation. Past and contemporary Crows grew up along the rivers, where they learned to swim, fish, and hunt – it was a way of life for us. Rivers provide sustenance to us and were our major source of home drinking water until the 1960s.

From the very beginning of the creation of the Crows to present, Crows have faced many adversities. One incident involved an attempt by enemy tribes to join forces and wipe out the Crows. A pitched battle took place along Arrow Creek. The Crows were losing and facing certain annihilation as they were vastly outnumbered until some of the Crow warriors sought spiritual guidance (Bear Don't Walk). Obviously, the Crows survived, but whom or what came to help them is reserved for later in this article.

Currently, the Crows, about 13,000 enrolled members, are faced with another insidious and ominous enemy: contamination and degradation of the Little Big Horn and

other rivers which flow through the tribe's 2.2 million acre reservation located in south central Montana. As early as the 1950s, tribal members started filtering and boiling river water before drinking it. The river used to clear up after spring runoff, but by the mid 1960s it remained impaired and was aesthetically unpleasant (turbid, odiferous) throughout the summer. Although we no longer collect our drinking water directly from the rivers, the rivers continue to be essential to the maintenance of the Crow culture. Water from rivers and springs is used for spiritual ceremonies that are vital to the Crow people. Tribal members continue the traditional practice of feeding the river for protection and to show appreciation. For instance, after a successful hunt, a small portion of the raw meat is thrown into the river as an offering. The rivers are the municipal water source for the two largest communities in the area. Ground water sources are also impacted by contamination. Many rural residents obtain their water from wells that were drilled only to the first aquifer or "first water" to reduce costs. These wells are subject to over-flow from agricultural practices and are likely to be influenced by water drawn in from the nearby river. Another issue is the potential presence of radionuclides in water and air, since one reservation watershed has numerous abandoned uranium mines.

Health Disparities: Tribal members are concerned that the occurrence of disease seems greater on the Reservation than in other communities. A lack of Indian Health Service (IHS) funding for intervention and prevention has left the community with a sense of hopelessness. Health disparity data specific to the Crow Tribe are not readily available; however, individuals noticed clusters of cancers and other ailments. Although most tribal members receive their healthcare at the local IHS hospital, some receive benefits through Medicaid or Medicare and are able to seek healthcare at off reservation

clinics. Others have private health insurance; thus there is not a single source for tribal health statistics. This compounds the difficulty in collecting accurate health disparity data. Data from the Billings IHS Area Office includes eight Indian Reservations (seven in Montana and one in Wyoming) and is aggregated into a "Northern Plains Indian" group rather than by tribe or reservation. For example, a recent report by the Montana Central Tumor Registry (MCTR) indicates that American Indian residents in Montana have incidence rates of lung/bronchial cancer 1.6-fold higher and of stomach cancer 2.3-fold higher than white residents[30]. While smoking is believed to cause about 90% of lung cancer cases, radon exposure is responsible for about 10% and is the leading cause of lung cancer for non-smokers. The Reservation is in a high risk zone for radon but little is known about home air radon levels. Stomach cancer is also a concern: among Native Americans in Montana, *H. pylori* was associated with half of the cases of a specific stomach cancer, while this was one third for white Montanans[30]. As with home radon levels, little is known about exposure to *H. pylori*. Consequently, health disparities that are the focus of our efforts are lung and stomach cancers and gastro-intestinal illness.

The community began to suspect that increases in these diseases were associated with several environmental factors but primarily water. Additional changes in our rivers were noted in the early 1970s. The sewage lagoon at Crow Agency was leaking onto surrounding lands and into the river. Two community members went directly to the Bureau of Indian Affairs (BIA) Facilities Manager to report their observations, but their concerns were summarily dismissed. One recalls the response he received from the Facilities Manager was that "the Navy" (probably meaning the Army Corps of Engineers) "approved the discharge of the raw sewage and if you don't want to drink the water, you

shouldn't have been born." Another red flag was raised when we began catching fish with lesions, clearly unfit for consumption. Frog, crawfish and clam populations were declining. Children contracted shigellosis in the summer, apparently from swimming in the rivers, which resulted in bloody diarrhea, fever and stomach cramps. The community members' concerns were ignored by those who controlled the municipal water and wastewater systems.

As time passed, it became apparent no one else was going to take steps to clean up the rivers, thus two community members were compelled to organize and move forward with these issues. One had become a county commissioner and the other a respected construction manager; both had gained skills in voicing concerns. They began a campaign to improve the health of the rivers and the municipal water system. In 2000, these two men and others were appointed to the newly established Apsaálooke Water and Wastewater Authority (the "Authority"). This group was successful in acquiring BIA funding for a preliminary engineering report on the municipal water and waste water systems serving Crow Agency. Public recognition that the problems existed was finally confirmed.

The tribal health educator began sharing her concerns about health disparities related to the water with a local tribal college (Little Big Horn College, LBHC) science faculty member while in the sweat lodge. The above-mentioned construction manager also started talking about local water quality issues with this same faculty member. She in turn sought assistance from the Indian Country Environmental Health Assessment Program to provide training for the community. This initial five-day training involved participants from a broad range of community agencies and included a reservation wide

environmental health assessment. The assessment documented that water quality was the highest ranking environmental health issue. Some of the participants joined forces with the Authority and formed our working group, now known as the Crow Environmental Health Steering Committee (CEHSC). The Crow Water Project was on its way.

Need for Data: The Authority needed water quality data to submit grant applications for water and wastewater infrastructure improvements. The Tribe had neither the necessary data nor the capacity to generate it, but LBHC was already involved in local water quality monitoring. Data on the Reservation's rivers, collected by LBHC science majors with supervision from LBHC and Montana State University (MSU) faculty and staff and guidance from the CEHSC, has recently been used successfully by the Authority to attain grants. The data documents community concerns about water quality and its potential impact on our health. We now recognize that the pollution problems are worse than suspected.

Crow tribal members, like members of other Tribes, are sensitive about participating in research as we have been researched repeatedly with little or no benefit to the Tribe. This experience was different because Tribal members initiated the work, the data are useful to us and we are solving the problems we have identified. The fact that the impetus for this research originated with the community continues to be the single most important factor in the overall success of our Crow Water Project.

Research has expanded beyond the initial efforts. Currently Tribal and MSU researchers are addressing community concerns about perceived cancer clusters by conducting a community based risk assessment of exposure to contaminants via water sources and select subsistence foods. This includes conducting community member

surveys and comprehensive chemical and pathogen testing of drinking water sources. We focus on home well water, but we are also examining river water sources used for traditional activities and for municipal water systems.

Implementation of CBPR in a Native Community

The critical element in making community based participatory research (CBPR) work is clear, unbiased and empowering communication between the University researchers and Tribal community members. It is important for key players to have a full comprehension of CBPR and how it impacts the community. Outreach to a broad spectrum of Tribal members is very important in developing the CBPR concept. Cultural sensitivity training for the University research team members - in the day to day life of Native communities - is hands on and in real life.

Our CBPR design is a creative, collaborative process that respects and takes into consideration: (a) the community's extensive knowledge of the local environment, environmental degradation and potentially related human health issues; (b) the community's traditional respect for and relationship to the land and rivers; (c) the community's need for data to answer local questions; (d) Western scientific knowledge of environmental health and of risk assessment methodology; (e) legal considerations and (f) what research is valuable to other rural or minority communities and therefore worthy of outside funding. Community knowledge about cancer cases and historical and current sources of contamination has been invaluable in designing the research. Steering Committee members understand the scientific method and are able to connect it with tribal consciousness and knowledge.

Political support is critical to our ability to work together successfully. Since 2006, key officials of the Crow Tribe, LBHC and Montana State University (MSU) have all consistently supported our efforts and together signed a Memorandum of Understanding detailing conditions of the collaboration. The diversity of Tribal community members (age, gender, cultural and professional expertise, agencies represented) on our Steering Committee helps tremendously.

The CBPR concept pervades the organization of the research. We have a "flat hierarchy" for the CEHSC. Rather than elect a President, meeting facilitation is rotated through members of the Steering Committee. We share the responsibility of presenting our work, whether at local, state or national levels. Three Steering Committee members have traveled with LBHC project staff to co-present posters at national conferences. For the past three years our group has given a panel presentation annually at the state-wide Idea Network for Biomedical Research Excellence (INBRE) conference. This structure extends to our University partners and project principal investigators.

Much of the progress of the Crow Water Project has been accomplished on sheer people power. However, there was also a need for funding. After acquiring the initial data and working collaboratively, we have developed solid CBPR proposals. Community involvement was essential in every aspect from the initial planning to the writing of the proposals; collaboration was essential to express the community's initiative, commitment to and partnership in the research effort. Our partnership has grown from small projects to a much broader collaboration with INBRE funding from the National Center for Research Resources at the National Institutes of Health. The funding enhanced science education at the tribal college, including science faculty development and research capacity building.

Funding has also come from the National Center for Minority Health and Health Disparities.

The Project as a Model for a CBPR Research Method

From the researcher's perspective, the process developed to move the water related work forward serves as a model for how to develop a positive, functioning partnership between a community with health and environmental based research needs and university researchers. The learning experience is particularly helpful to those working with other Reservations, but is also applicable to other minority communities who are faced with environmental health challenges. The processes and insights are being viewed by the US EPA as a contribution to their initiative to incorporate community knowledge and insight into risk assessment. In particular, there is a growing need to manage risk in a community specific, culturally appropriate way that takes into account social, cultural and other non-chemical factors.

Our journey has also uncovered many of the challenges that are part of a community based effort. It is clear that the community has more trust if the research is driven by people in that community and when the main point of contact is a community member. Our project has been successful because the person who is conducting surveys and collecting samples on the Reservation is fluent in Crow and can communicate with those who value and routinely use their native language. Having students and staff from LBHC involved also demonstrates that the community is engaged in the work, rather than having it done by someone who is not local. It has been critical to know that cultural issues such as strong family ties will influence the pace of the work. Because there are

many critical needs in the community, the work must continue to be relevant so that it retains its importance and focus. To serve this purpose, it is essential that the community knows that the work is important and yielding valuable information for them and not just the researcher. These are just a few of the lessons that we have learned in the process of developing, funding, and accomplishing the work that we collectively believe will improve the health of the environment and the people.

The Importance of Crow College Student Involvement

Our projects are giving Crow science majors at LBHC and MSU the opportunity to participate in research in their home community on issues that are relevant and meaningful to them and to our Tribe as a whole. LBHC, like the majority of the 30+ tribal colleges around the country, offers Associates degrees and therefore student research experience is a relatively new addition to our educational programs. The CBPR work has provided a unique opportunity to develop research capacity at the LBHC while also providing a meaningful research opportunity for the students. For the current research projects, field, lab and community-based survey and community education work is being conducted on the Reservation and at LBHC, while genetic analyses of organisms in water samples are being carried out at MSU. This provides Crow students with an opportunity to participate in research as freshmen and sophomores, without having to leave home. When they transfer to MSU, they can continue to stay involved as juniors and seniors and mentor the LBHC student interns. At least fifteen Crow students have participated in our Water Quality Project, either at LBHC or MSU or both; most have completed their bachelor's degree or are still in school in various science disciplines.

One will finish her Master's degree this fall in science education, another will begin a Master's degree in community health this fall and others are now considering graduate school. For those of us who teach and mentor these students, it has been rewarding to see how much they are learning and how committed they are to the research.

The students contribute substantially to research in the community and in the university research laboratories. One intern commented that she sees her role, and that of other students as helping to connect the community and the academic researchers. In the Crow community, the term "researcher" has long had the connotation of "intruder." The survey and well water sampling work done by the research team simply could not be done by non-community members working alone. The interns and our project Coordinator are tribal members; they can translate the scientific language of water contamination into terms that make sense to other tribal members, thus increasing community knowledge of water quality and health related issues. Educating the community to protect our surface and ground water can only be done effectively in person, for instance, by showing them potential problems with their well head. Distributing printed materials alone isn't very effective.

Our current community Project Coordinator began her involvement as a student intern and went on to complete her bachelor's degree in Environmental Science. She initially heard about the water quality project from other LBHC interns and applied to participate. Once she began her internship, she realized how polluted the rivers were, raising her awareness of the degradation of this resource. For example, as a child her family drank the river water untreated and swam in the river in the summer months without becoming ill. This is no longer the case, and as stated earlier, the water is

sufficiently polluted that now it cannot safely be consumed without treatment. At LBHC she gained experience in baseline water quality monitoring. When she transferred to MSU for her bachelor's degree, she was accepted to work in our project's microbiology lab. There she was able to see what happened to the water samples when they got to the lab, and gained experience in molecular biology (polymerase chain reaction) techniques for identifying the isolated bacteria. This experience helped her in some of her other classes. Upon completing her bachelor's degree she was hired at LBHC as our Environmental Health Project Coordinator, where she is able to train, supervise and mentor the water quality interns. She finds that the students are eager to learn the protocols of water collecting and want to do the best job; they gain an appreciation for the importance of accuracy and precision in data collecting. The interns realize that their role in the research project is very important, both to the community and to the university researchers.

Another former project intern went on to complete a bachelor's degree in hydrogeology and has just been hired for a one year math/science teaching position at LBHC. From the MSU side, a non-Native microbiology doctoral student who has worked with the project since being an undergraduate has also found the experience invaluable. She has gained a greater understanding of how to conduct research and outreach in a Native American community. On a Reservation where "research" has a toxic legacy, the increased success of our students in pursuing careers in environmental science and health and especially their interest in graduate school, is simply transformative.

Conclusion

Earlier in this article, a survival story of the Crow was shared with a promise to tell what saved the Crows from certain annihilation. A warrior appeared seemingly from nowhere on the battlefield. He was invisible to the Crows, but the enemy said he was riding a beautiful pinto horse and wore a war bonnet with trailing extensions that nearly touched the ground. The Crows saw the enemy retreating, but they only learned of the appearance of this warrior upon parleying with the enemy years later. The enemy asked who the warrior was and the Crows did not immediately say, but after considerable discussion and thought, concluded that this must have been Isáahkawuattee, a key character in Crow oral history who not only plays tricks on them, but is willing to come to their rescue in times of great need (Bear Don't Walk). This begs the question: Is Isáahkawuattee in some way involved in this community-based effort regarding the sacred waters and lands that Crow ancestors had bargained for in treaties and had set aside for future generations for as long as the grass shall grow and the rivers shall flow?

After years of inaction, indifference and/or the lack of resources to address our water quality, water infrastructure and related health disparity concerns, we have found that we can successfully take on these problems, identify the necessary researchers and effectively collaborate with them on mutually acceptable terms. We want to restore the health of our rivers and of our community. We realize it will take a broad based, grassroots effort to make this change. Passion, tenacity, persistence, mutual support and not letting one another quit are making this process work. We continue to learn more about health issues and how to facilitate change so that we can improve the well being of our Native

community. We now feel empowered to take on other environmental health issues that affect our community.

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CHAPTER THREE

EXPLORING EFFECTS OF CLIMATE CHANGE ON NORTHERN PLAINS AMERICAN INDIAN HEALTH

Contributions of Authors and Co-authors

Manuscript in Chapter 3

Author: John T. Doyle

Contributions: Developed interview questions and interviewed Elders and middle-aged Tribal members from the different districts of the Reservation about their observations of climate change and its impacts on the community, on ecosystems and on culturally important plant and animal species. Explained the purpose of the research and writing project to the community. Discussed, reviewed and helped edit the article. Has served as the corresponding author since the article was published.

Author: Dr. Margaret Hiza Redsteer

Contributions: Served as the senior scientist and climate change expert for the research project and article writing. Conducted the analysis of measured data on climate change for the Crow Reservation/Big Horn County and corresponding climate region of Montana. Prepared graphs on climate change and drafted article sections describing climate changes (temperature, precipitation, number of frost free days/year, etc.). Discussed, reviewed and helped edit the article.

Author: Margaret Eggers

Contributions: Conducted the hydrological analyses, prepared the resulting graphs and wrote the article sections on hydrology. Wrote up the background on the Crow Reservation as well as the results of Doyle's research from his input. Served as the lead author, combining authors' contributions into an initial draft of the article and supplements, and editing and rewriting through multiple iterations of the article. Served as the corresponding author up until the point of publication. Camper, as academic and research advisor, ascertains that Eggers was the lead author on the paper, made substantive contributions to the content, and served as corresponding author.

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CHAPTER 3

EXPLORING EFFECTS OF CLIMATE CHANGE ON NORTHERN PLAINS AMERICAN INDIAN HEALTH

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Abstract: American Indians have unique vulnerabilities to the impacts of climate change because of the links among ecosystems, cultural practices, and public health, but also as a result of limited resources available to address infrastructure needs. On the Crow Reservation in south-central Montana, a Northern Plains American Indian Reservation, there are community concerns about the consequences of climate change impacts for community health and local ecosystems. Observations made by Tribal Elders about decreasing annual snowfall and milder winter temperatures over the 20th century initiated an investigation of local climate and hydrologic data by the Tribal College. The resulting analysis of meteorological data confirmed the decline in annual snowfall and an increase in frost free days. In addition, the data show a shift in precipitation from winter to early spring and a significant increase in days exceeding 90° F (32° C). Streamflow data show a

long-term trend of declining discharge. Elders noted that the changes are affecting fish distribution within local streams and plant species which provide subsistence foods. Concerns about warmer summer temperatures also include heat exposure during outdoor ceremonies that involve days of fasting without food or water. Additional community concerns about the effects of climate change include increasing flood frequency and fire severity, as well as declining water quality. The authors call for local research to understand and document current effects and project future impacts as a basis for planning adaptive strategies.

Keywords: Health, Climate Change, American Indians, Crow Reservation, Water Resources, Northern Plains

I. Introduction

Climate change impacts present distinct risks to human health throughout Indian country. Although documented in Alaska (Brubaker et al., 2011a) and the Southwest (Redsteer et al. 2013a, Redsteer et al. 2013b and Redsteer et.al. 2010), these issues are not as well researched for Northern Plains Tribal communities. To address this data gap, observations of Crow Tribal elders in addition to changes in monitored temperature, precipitation and streamflow in the Little Bighorn River valley, Montana are provided. Located in south central Montana, the Crow Reservation encompasses 2.3 million acres, including three mountain ranges and three large river valleys. Approximately 8,000 of the 11,000+ Tribal members reside on the Reservation, primarily along the rivers and creeks. The majority of communities, including the “capital” town of Crow Agency, are situated in the Little Bighorn River valley (Figure I). The Crow language is still widely spoken

and many cultural traditions continue to be practiced today. Water is one of the most important natural resources to the Crow community and has always been held in high respect among Tribal members. River and spring waters are still used in many ceremonies (Knows His Gun McCormick, 2012).

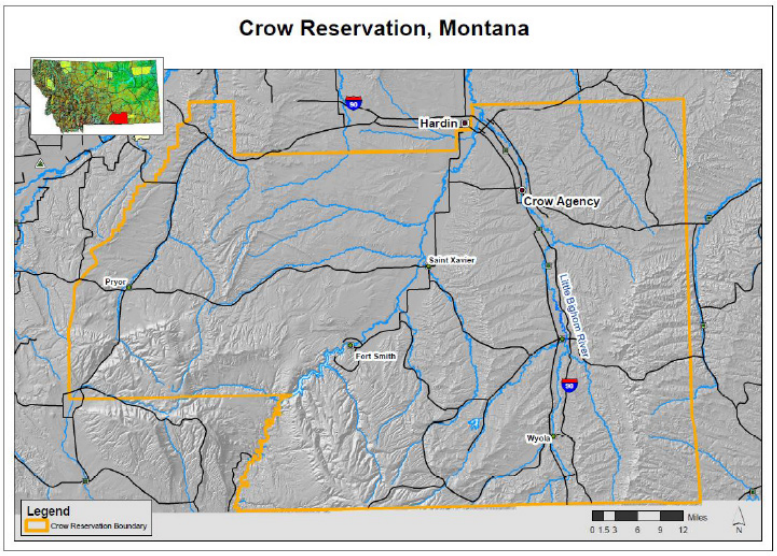

Figure I. Map delineating Crow Reservation (in yellow) and proximity to Hardin, MT where meteorological data for the study was collected, 15 miles northwest of Crow Agency, MT. The Reservation is southeast of Billings, MT, with the Reservation's southern border on the Wyoming- Montana State boundary. (Map prepared by Eggers; inset courtesy US Department of Agriculture)

The observations of local climate changes are those made by first author John Doyle, a Tribal Elder, and reflect experiences he and his peers have had over a span of many years. Additionally, other Elders shared their observations with Doyle for this article,[1] or contributed to discussions at meetings of the Crow Environmental Health Steering

[1] The eight named Tribal Elders and two younger Tribal members who provided comments specifically for this article all agreed to the use of their names.

Committee (Cummins et al. 2010). To compare and integrate the changes observed by the community with existing monitoring data, analyses were conducted of the local National Weather Service records as well as the US Geological Survey discharge data for the Little Bighorn River. Local knowledge and these physical measurements were in agreement, and provided complementary insights. This process has triggered further community discussions about potential impacts on water quality, forest and rangeland resources, subsistence foods and public health. Challenges facing these communities are broad in scope and demonstrate the need for vulnerability assessments and planning to reduce current and future climate-related health impacts.

II. Crow Elder Observations

Community Elders have observed long-term changes in the local climate, including declining winter snowfall, milder winters and warmer summers. Elders from all Districts of the Reservation remember that the ground used to be covered in deep snow and stayed frozen from November to March – while today the prairies are bare grass for much of the winter (S Young, J Doyle, personal communication, 2007; D Small, MA LaForge, K Red Star, D Yarlott, UJ Bear Don't Walk, personal communications, 2013). Sometimes the snow was so deep that it was a real struggle to feed cattle (D Small, personal communication, 2013). Children could ice skate throughout the winter; now winter days are often above freezing (S Young, personal communication, 2012). Even Tribal members in their thirties note that winters are not as cold as when they were children (W Red Star, V Buffalo, personal communications, 2013). Every spring, massive ice jams on

the Little Bighorn River used to break up and scour out the river bottom and banks; today the ice is thin by early spring and what remains melts quietly away (J Doyle, personal communication, 2012). A locally important mountain spring, visited repeatedly over the years, has been steadily moving down-slope, causing concern that the water table has been dropping due to reduced snowfall (J Doyle, personal communication, 2013).

Elders note that climate changes are affecting subsistence food plants. Many species of berries have long been gathered as staple foods, including juneberries, chokecherries, elderberries and buffalo berries. Now these shrubs and trees sometimes bud out sufficiently early in the spring that they are vulnerable to subsequent cold snaps that kill the blossoms, so they never fruit. In years that shrubs bear fruit, the timing has changed: chokecherries used to ripen after the juneberries, and now they ripen at the same time (V Buffalo, personal communication, 2013). Elderberries in the mountains now ripen in July instead of in August (J Doyle, personal communication, 2013). Buffalo berries were traditionally harvested after the first frost, as freezing sweetened the berries. Now buffalo berries are dried out before the first frost hits, so are no longer worth gathering (L Medicine Horse, personal communication, 2013). Additionally, some trees now come out of dormancy during mid-winter warm spells, and die when the temperature drops below freezing again. Similar trends in the phenology of lilacs and honeysuckle have been observed by the Western Regional Phenological Network: spring bloom dates in the 1980s -1990s were five to ten days earlier than they were in the 1960s - 1970s. This shift is attributed to warming spring temperatures in western North America by 2º to 5ºF (1º – 3ºC) during the period of observation (Cayan et al., 2001).

Ceremonial practices are being affected by high temperatures. In May and June, sundances are held; these are three- or four-day outdoor events during which the participants fast, dance and pray. One older sundance chief, who for decades has led this ceremony near Crow Agency every Father's Day weekend, notes that the June weather has gotten progressively hotter and therefore the sundance has become increasingly difficult for fasting participants. He remarked that the cattails, which community members bring to participants for relief from the heat, used to average six feet in length, and are now only about three feet long (L Medicine Horse, personal communication, 2013). Cattail (*Typha latifolia*) vigor, including both root and shoot biomass, has been found to decline with increasing soil dryness (Asamoah and Bork 2009). Other traditional sundancers have concurred that dancing has become tougher with progressively hotter summer weather (L Kindness and anonymous Crow Environmental Health Steering Committee member, personal communications, 2013).

The river ecosystems appear to be warming in parallel with surface temperatures, as has been documented both nationally and globally (NCADAC 2013). Reduced stream flows and warmer summers, in addition to increased agricultural non-point source pollution, is affecting the Little Bighorn River. Apparent impacts to fish and other aquatic species include changes in brown trout location, a species that prefers cooler waters. Although these trout used to be found at the tributary mouth of the Little Bighorn River, near Hardin, they are now more than 35 miles upstream (A Birdinground, personal communication, 2010). Recently, bass have been observed in the lower Little Bighorn

River, where they never lived before. Catfish with skin lesions have been caught. Freshwater mussel and frog populations have declined. These observations, along with knowledge of river contamination, have caused some families to give up subsistence fishing (J Doyle, personal communication, 2010). Others note declining fish populations, and believe the changes in climate are a contributing factor (V Buffalo, personal communication, 2013).

III. Confirmation of Elders' observations of recent climate change using monitoring data

The Elders' observations discussed in the previous section were compared to climate and hydrologic data available for the Crow Reservation and vicinity, as well as published regional climate trend information. While observational data are perhaps more subjective and less quantitative than monitored precipitation and streamflow, they have the potential to contribute greatly to understanding what ecosystem changes may be occurring as a result of multiple stressors, including climate change. They also provide information in regions where data is limited. The Reservation is part of the ancestral homelands of the Crow people, and so existing relationships with and uses of plants, game and water resources go back many generations. Parallel observations by Elders from all the Districts of the Reservation, such as of declining snowfall, provide multiple data points and are invaluable in the absence of SnoTel sites on the Reservation. Their observations

are also particularly relevant to daily life, illuminating for instance how climate change is impacting food supply, cultural activities and human health.

Climate and hydrologic analyses were focused on the Little Bighorn River valley of the Crow Reservation, which includes the majority of the Reservation's population. Stream flow records for the Little Bighorn River were used because it flows north through the entire Reservation, passing through Crow Agency, before joining the Bighorn River at Hardin (Figure I). Weather station data were selected based on station history, completeness and appropriateness of records that would elucidate local changes to the Little Bighorn River valley near Crow Agency, Montana.

Hardin and Crow Agency weather station data were combined in this evaluation in order to provide a more complete history of changes that have occurred over the longest period of time (National Climate Data Center 2013). These data were supplemented by information on trends in precipitation and temperature from Montana's Climate Division 5 (MT CD5), which covers south-central Montana, including all of the Crow Reservation as well as counties to the west and north (Supplement Documents I and II). Other available weather data relevant to the Crow Reservation are limited. There are no other weather stations within the Little Bighorn River valley with sufficiently complete data to be worth analyzing, nor in nearby river valleys within 75 kilometers of Crow Agency, Montana (Supplement Table I). Crow Agency data collection began operation in 1897, has reasonably complete data and is in a small rural community that has had no urban

growth (0%). However, the Crow Agency weather station was discontinued more than twenty years ago, limiting the usefulness of its data for an analysis of recent changes. Hardin, located 15 miles northwest of Crow Agency, began collecting data in 1909. Although the early record is missing much of the 1920s and 1930s, it has a nearly complete record of precipitation, temperature and snowfall from July 1948 to today (March 2013). The town of Hardin has had a negligible urban growth rate (2%) over the past 75 years, hence urban growth highly unlikely to have had a substantial impact on the weather data. The site is in an agricultural valley in the NOAA's Climate Division 5, south-central Montana. This weather station is 2905' (881 m) above sea level, and is located on the alluvial plain of the Bighorn River (Figure I).

Seasonal temperature variations in the Little Bighorn River valley are extreme, consisting of bitterly cold winters and very hot summers. These variations are reflected in the station data that show temperatures vary from -40°F (-40°C) in January and February, to above 100°F (38°C) in July and August, with an annual mean of 48.3^{o}F (9.1^{o}C). The number of days per year exceeding marked temperature thresholds has increased substantially from 1897 to 2012. (Figure II). The number of days per year exceeding 100 ^{o}F is highly variable. The decadal-average number of days per year exceeding 100 ^{o}F has doubled from 1900-1909 to 2000-2009 (Supplement Table II). The increase in high temperatures recorded does not coincide with any changes made to weather station operation, but is consistent with trends in increasing temperatures for Montana Climate Division 5 (CD5) (National Climate Data Center). Montana CD5 data shows average monthly temperatures over the past 110+ years have been steadily warming for the summer months of June

through September, by 0.1º to 0.2ºF per decade (Supplement Document I). The warming trend observed in monitoring data supports the accounts and observations of the Crow Tribal sundancers.

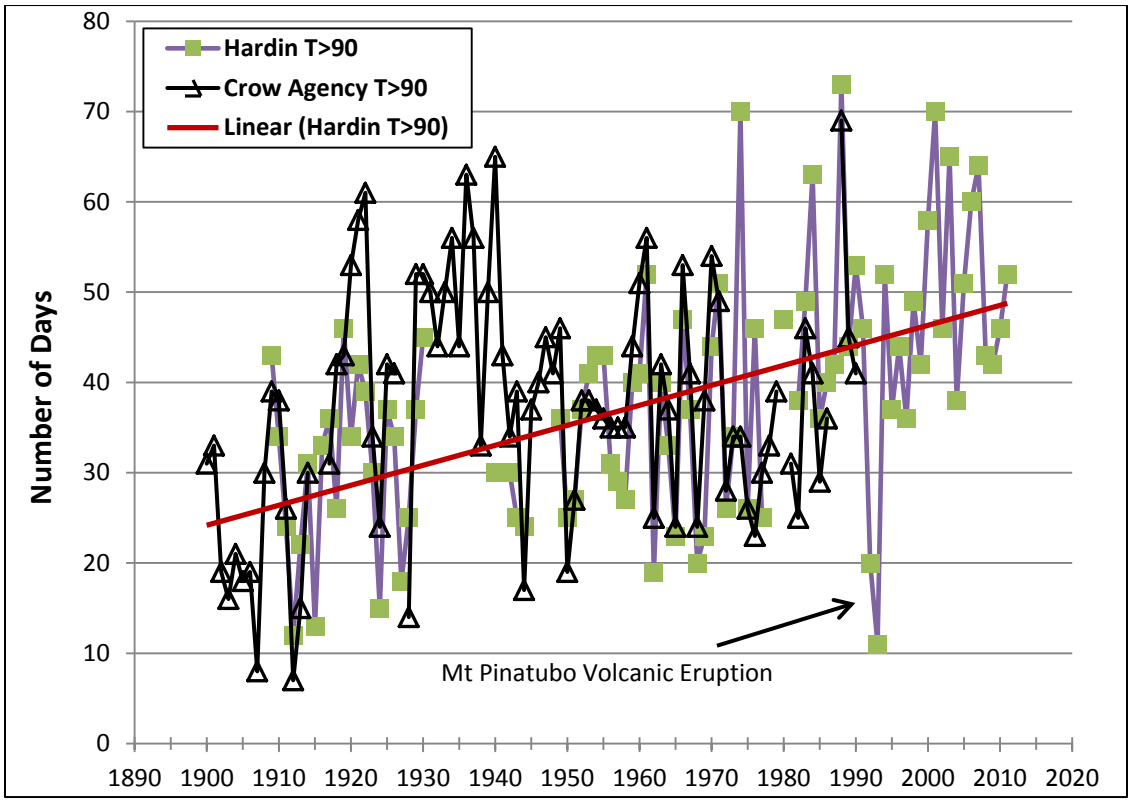

Figure II. Number of days per year with temperatures exceeding 90°F (32°C) in Hardin and Crow Agency MT, plotted from National Weather Service daily records (National Climate Data Center). The red line indicates a linear trend of increasing high temperatures based on the data. (A dip in temperature in the early 1990s corresponds to a cold period produced by the volcanic ash from eruption of Mt Pinatubo.)

Additional warming trends in winter temperatures are readily apparent in the number of frost-free days (days exceeding 32°F), which has increased by about 7.2 days per decade (Figure III). In the 1950s there were on average 178 frost-free days per year, whereas since 2000 there have been 213 such days. The number of frost-free days per year has important implications for ecosystems because cold winters are responsible for killing off

pests, such as bark beetles (Evangalista 2011). As warm season weather extends in length, pests can have more than one reproductive cycle, further increasing their numbers.

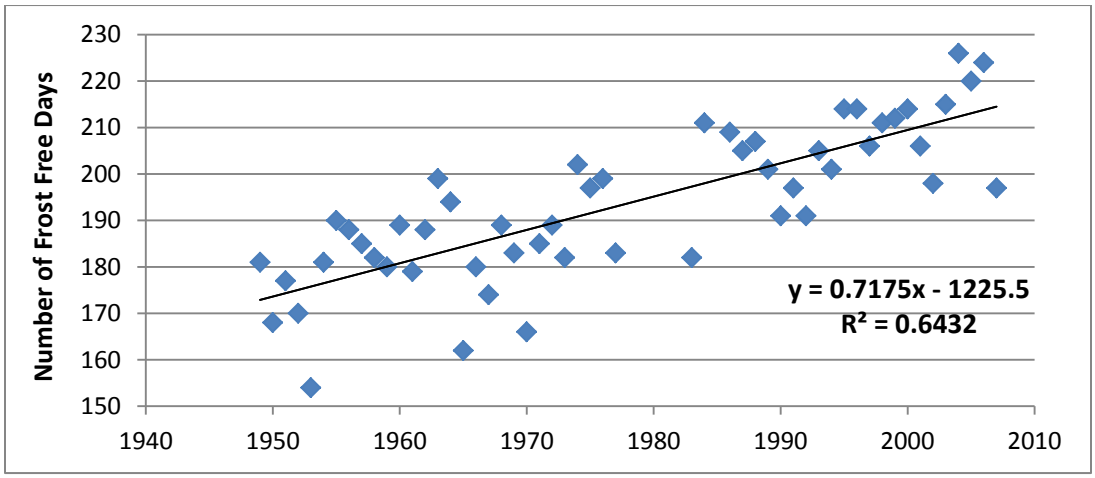

Figure III. Number of frost free days per year in Hardin, MT, calculated from historic daily observations. (Data source: National Climate Data Center.)

This increase in number of frost-free days is consistent with Montana CD5 data showing that over the past 110+ years, average temperatures for the months of January through March have been steadily increasing (by 0.2ºF, 0.4ºF and 0.5ºF per decade respectively) (Supplement Document I). Elders' accounts that they used to be able to ice skate all winter long as children, and that the river ice was once much thicker in wintertime is consistent with these trends in cold temperatures observed in monitoring data.

Overall, Hardin's average temperature has increased from a mean of 45.6^{o}F in the 1950s to 50.1^{o}F since 2000. Average temperatures from the Crow Agency weather station records are nearly identical to the Hardin data for the years that collection occurred at both sites (Supplement Figure I).

These increases in average annual temperature and in the number of hot summer days and frost-free winter days, demonstrates that the climate changes projected by the draft National Climate Assessment (NCA) for the Northern Great Plains are already underway (National Climate Assessment and Development Advisory Committee (NCADAC) 2013).

As temperatures warm, snowfall is likely to decrease because atmospheric temperatures are warm enough for precipitation to fall in a liquid rather than frozen state for a longer period during the year. Snowfall has decreased significantly in the region surrounding Hardin (Figure IV). A similar trend in reduced snowpack has been documented for the Northern Great Plains in general, and for other parts of the western U.S. over the past half century (NCADAC 2013). For Montana CD5, including the Crow Reservation, winter precipitation (December through March) has been declining on average 0.05" per decade since 1895 (Supplement Document II). This regional trend has serious implications for local ecosystems, local temperature trends, recharge of aquifers and summer runoff in local streams and river systems, and hence also for Crow Agency, whose municipal water source is the Little Bighorn River. Snow covers the surface with highly reflective water crystals that help keep the surface cool by reflecting the sun's heat back into the atmosphere. Snow melts slowly, and as a result, the moisture delivered as snow infiltrates the substrate more effectively than rain. Also, mountain snowpack melts slowly during spring and summer, reducing the likelihood of flooding and providing riparian areas and communities with a constant fresh water supply during the hot summer months when water is needed most. The decline in winter snow pack is not being made up during other

seasons; average annual precipitation in MT CD5 has been declining by 0.11 inches per decade (Supplement Document II).

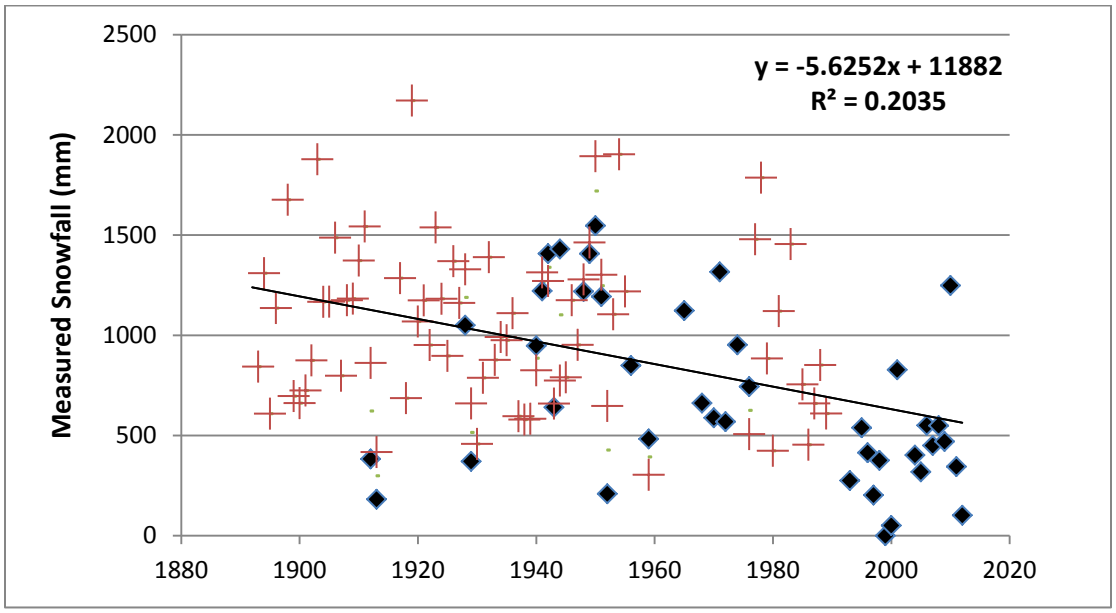

Figure IV. Plot showing annual snowfall in millimeters from Hardin MT (diamonds, 1912-2012) and Crow Agency MT (crosses, 1895-1990) observation sites, calculated in water years. The trendline is calculated from the average of measurements when both locations had measurements, and on the single site's measurements when only one station was operating. Years with more than one month of missing data were deleted from data plot, except for the earliest records. (Data source: National Climate Data Center.)

The Elders' observations of decreased annual snowfall is confirmed by the research of Stewart et al. (2005) that showed a trend towards an earlier onset of the spring runoff peak throughout western North America. In addition, the Elders' observations were confirmed by an analysis of streamflow data for the Little Bighorn River. The USGS gaging station 06289000 on the Little Bighorn River at State line near Wyola, Montana, measures discharge from a drainage area of 193 square miles in the Big Horn Mountains. The station is located where the river leaves the Big Horn Mountains and enters the

valley floor, documenting flow before any significant withdrawals for agriculture or municipal uses. The river is a critical water source because it provides the municipal water source for Crow Agency and because the majority of the Tribe's population lives in the river valley. A US Geological Survey study of the Valley's groundwater resources found that the water in the Quaternary alluvium had a median total dissolved solids (TDS) concentration of 1450 mg/L, while the median TDS concentration in the Judith River Formation was 1000 mg/L (Tuck 2003). The EPA Secondary Standard for TDS is 500 mg/L, hence these levels are considered objectionable for municipal drinking water (EPA 2013b). Neither aquifer provides a viable alternative water supply for Crow Agency's municipal use.

To reduce the "noise" from interannual variability in the spring runoff hydrographs, decadal averages of discharge for each day during May and June were calculated for the available data for the Little Bighorn River gaging station (06289000). The 1980s and 2000s had the earliest spring runoff peak of all decades on record (Supplement Figure II) (USGS 2012).

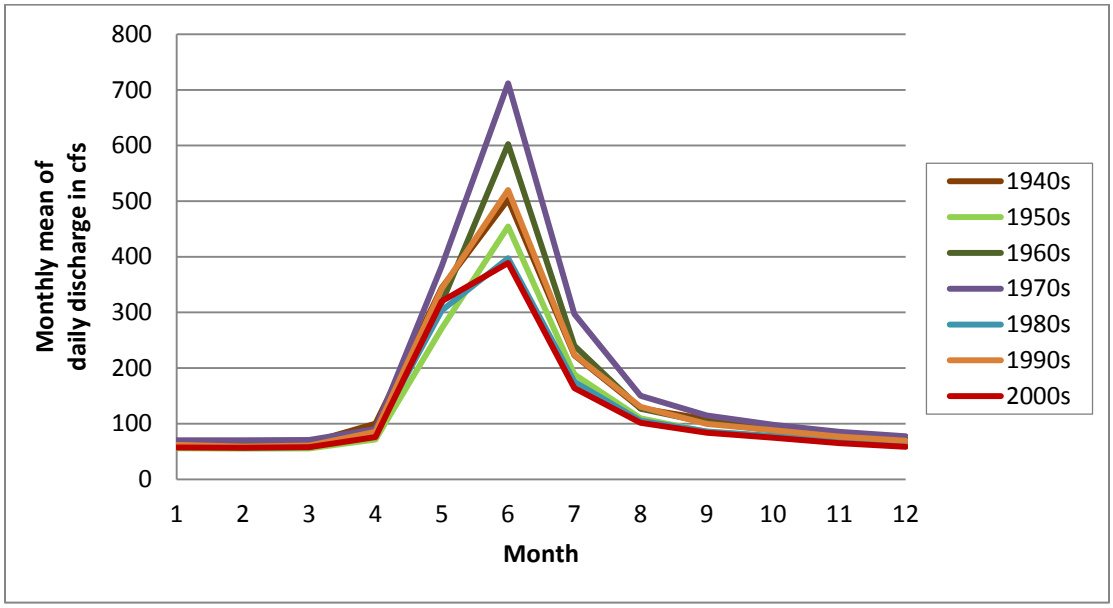

Figure V. Monthly averages of daily mean discharge by decade for Little Bighorn River at State Line near Wyola, Montana (station 06289000). (Data source: USGS 2012)

Decadal averages of monthly mean daily discharge from 1940 - 2009 were similarly calculated. Plotting these data show that the 1980s and 2000s had not only the earliest but also the lowest spring runoff of all decades on record (Figure V). If this pattern continues, it would be in agreement with research documenting the effects of warmer temperatures on decreased streamflow (Pederson et al. 2010; McCabe and Clark 2005).

Recent devastating spring floods of the town of Crow Agency in 2007 and 2011 warrant examination of flood history to see if their frequency is increasing. The data show that the mean daily discharge for May 2007 was more than 100 cfs higher than any other May on record for the previous 70 years of streamflow data (Supplement Figure III). The USGS data document the well-remembered "epic" June 1978 flood, when the nearest gauging station on the Little Big Horn River (close to Hardin), set an all-time record of

11.78 feet, which was 3.78 feet above flood stage. The devastating 2011 flood, in which more than 200 homes were damaged, set a new gauging station record of 12.32 feet (Olp 2011; Thackeray 2011) (Supplement Figure IV). Local oral history tells of a similarly major flood in the 1920s (Doyle, personal communication, 2012, citing Alice Yarlott Other Medicine). Note that high mean daily discharge of the Little Bighorn River at State Line near Wyola, Montana (at station 06289000) for the month of June has not always resulted in flooding of Crow Agency. Over the past century, the town of Crow Agency has experienced severe floods about every 40 to 50 years, but the unusual early season flood in May 2007, followed closely by a more damaging flood in 2011, has raised community concerns about increased flood frequency and severity. Trends in CD5 data show a shift in precipitation from winter months to the spring (increasing in April). These trends may also contribute to the probability of spring floods.

The physical data sets available, the descriptions of climate and ecosystem change by Elders, and recent flooding and fire events on the Reservation are almost all in accordance with descriptions of current and predicted climate impacts described in the draft National Climate Assessment (NCA) in the chapters on the Great Plains, Native Lands and Resources, and Water Resources (NCADAC 2013). The additional information contributed by Crow Tribal Elders provides a better understanding of climate impacts and phenological changes experienced by the community, compared to what can only be cautiously surmised from the monitored climate and stream discharge data. These local data are an essential complement to regional predictions, especially when evaluating local ecosystem change and vulnerable communities (e.g. Patz and Olson 2006). The

draft NCA's prediction of increased annual precipitation for the Northern Great Plains is contradicted by both the local mountain stream discharge data and the MT CD5 data. The MT CD5 data document an absolute long-term regional decline in annual precipitation for south-central Montana.

IV. **Anticipated vulnerabilities for the Crow community and local ecosystems**

The Apsaalooke [Crow] Water and Wastewater Authority ("the Authority"), which works with the Reservation communities of Crow Agency, Wyola and Pryor on their municipal water and wastewater systems, is particularly concerned about the effects of the apparently declining streamflow, increased agricultural demand and more frequent spring flooding on drinking water availability, water quality and community health. As the Little Bighorn River is the source water for the municipal water treatment plant supplying Crow Agency and the regional Indian Health Service Hospital, and low flows in August already strain the ability of the plant to obtain sufficient water to supply the town, further decreases in streamflow from reduced snowfall could be challenging. The monthly averages of daily mean discharge for the months of June and July were the lowest on record for the 2000s and 1980s (Figure V). The demand from agriculture for water for irrigation is already increasing (J. Doyle, personal communication, 2012). Clearly, running out of municipal drinking water for the town and the hospital would have deleterious health impacts.

Research conducted by Little Big Horn College (LBHC) and the Crow Environmental Health Steering Committee, with partners from Montana State University Bozeman and

the University of New England, has already found substantial microbial contamination of local rivers during spring and summer months. For instance, *E. coli* levels in the Little Bighorn River exceeded 1200 colony forming units (CFU)/100 mL during spring 2007 (Ford et al., 2012); surface waters with an *E. coli* geometric mean exceeding 126 CFU/100 mL are considered unsafe for swimming (EPA 2012). Testing initiated by the Crow Agency Water Treatment plant, and conducted at an EPA-certified lab, showed that the E. coli concentration in their Little Bighorn River source water exceeded 7100 CFU/100 mL during spring runoff in 2009 (Bright Wings 2009, cited in Connolly et al. 2010). The documented *E. coli* concentrations mean that under the EPA's Long-Term 2 Enhanced Surface Water Treatment Rule, the Treatment Plant falls into "Bin 4," the highest risk category for *Cryptosporidium* in the source water. *Cryptosporidium* is a protozoan pathogen, which in its oocyst form can survive in the environment for months, and is highly resistant to chlorination (US EPA, 2001). The infective dose for humans is low, and an infection can be fatal for immune-compromised individuals (US EPA, 2001). *Cryptosporidium* has contaminated public water systems elsewhere in the US, especially after heavy precipitation coinciding with spring snow melt (Patz and Olson, 2006). Hence, the Crow Agency Water Treatment Plant is required to meet additional treatment requirements for *Cryptosporidium* removal by October 1, 2014 (Connolly et al., 2010). The Tribe's limited operations and maintenance budget for water treatment strongly constrains technology choices. More frequent spring flooding will only exacerbate these municipal water treatment challenges.

Spring flooding incurs multiple health risks to community members. During the 1978 flood, the sewer clogged and sewage backed up into homes (Thackeray 2011). In 2011, the flood washed wastewater from the Lodge Grass lagoon into the Little Bighorn River, which in turn inundated downstream homes and businesses. Twenty-two homes were destroyed and over 200 were damaged (Olp 2011). There was an increase in complaints about water damage to homes leading to mold infestation (M Eggers, personal communication, 2011). Molds release irritants and allergens, and can cause asthma attacks in some asthmatics (EPA 2010). Many people's wells were flooded; the Tribe's Environmental Protection Department subsequently shock chlorinated many of these wells but could not reach everyone affected. The Federal Emergency Management Administration's Montana Disaster Declaration designated the Crow Reservation as eligible for both Individual Assistance and Public Assistance (FEMA 2012). Experiencing two severe floods within five years, there is community concern about the impacts of continued increased flood frequency and severity, possibly driven by climate change.

The Authority, the Crow Tribe, Little Big Horn College and the local Indian Health Service hospital, working together as the Crow Environmental Health Steering Committee, with the support of academic partner Montana State University Bozeman, are working on several mitigation strategies to reduce waterborne microbial health risks (Cummins et al. 2010; Eggers et al. 2012). First, a low cost, high tech home water filtration system was pilot tested for home use. This system is proving to successfully

treat river water for microbial contamination such as *E. coli* for only pennies a day, so it can be safely consumed. The filters could provide an option for safer ceremonial consumption of river water, for families who found this culturally acceptable. Second, EPA funding is being sought to work with local ranchers to reduce non-point source pollution from livestock manure. Third, there are collaborations with other researchers to better elucidate the health risks from microbial contamination of river water, especially *Cryptosporidium* and *E. coli*. Finally, there are community education events and partnerships with educators to expand water quality education in the schools.

Warmer summer temperatures are also affecting the Crow Agency municipal water supply's distribution system, with implications for community health. During summer 2012, the soils in Crow Agency became so dry and hard that soil surface impact more readily shattered the older, underground concrete-asbestos drinking water lines. Until breaks are detected and repaired, water lines are vulnerable to contamination, creating health risks for water consumers. This also wastes precious water and increases infrastructure maintenance costs for an already financially strained system. The Water Authority has successfully raised funds to upgrade the distribution system and is replacing these old, fragile water lines.

The effects of decreased snowfall and warmer temperatures on forest health, wildfire severity and hence also human health are another community concern. As mentioned above, drier and warmer weather improve conditions for forest pests such as bark beetles, resulting in more dead timber and greater fire risk (Voggesser et al., this issue). Across

the state of Montana, more than 1.2 million acres burned in 2012 (NOAA 2012) – the most acreage burned in recorded history, except for 1910 (Thackeray 2012).

The 2012 Sarpy Creek, Bad Horse, Plum Creek fires and more on the Crow Reservation resulted in the worst fire season in memory for the community. The fires were even worse on the adjoining Northern Cheyenne Reservation, where more than 60% of their 445,000 acre Reservation burned. Homes and livestock were lost; the town of Lame Deer was evacuated; some areas were burned so badly the soil blistered, creating concern that the pastures and wildlife forage would not recover. If so, ranching and subsistence deer and elk hunting, vital to local families, could be impacted. There were days when the smoke was thick and heavy, but there are no measurements of air quality, so people concerned about the health risks had no way to assess the danger (J. Doyle, personal communication, 2013). This coming spring (2013), erosion is expected to become an issue for both soil and water quality. The full extent of the impacts of the 2012 fire season on land, water and human health are still unfolding.

V. Conclusion

Meteorological data from Hardin and Crow Agency, the USGS streamflow-gauging station on the Little Bighorn River and MT CD5 exhibit trends predicted and observed to be the result of the Earth's average warming by 0.7^{o}C this last century due to the greenhouse effect, with one exception: annual precipitation and apparently streamflow are declining, in contradiction to the prediction for increased precipitation in the Northern Great Plains (NCADAC 2013). Observations from Tribal Elders and the small amount of

meteorological data available are in agreement. In addition, Elder observations suggest that the data trends are representative of the Little Bighorn River valley. Further investigation of these trends is needed to provide an account of when changes to ecosystems began, the magnitude of ecosystem changes that could be occurring, and any underlying mechanisms and stressors that may contribute to observed changes to plant and animal species.

The ecological effects of less snowfall, warmer temperatures, recently reduced streamflow, increasing flood frequency and fire severity are already being experienced by Crow Tribal members and other residents of Big Horn County. Additional research to understand and document the full extent of the consequent human health impacts has yet to be conducted. A "Climate Change Health Assessment," to include the steps of "scoping… surveying… analysis… and planning," as was conducted in northwest Alaskan villages (Brubaker et al. 2011b) would be invaluable. Such an assessment would be essential for the Crow Reservation community to plan for mitigation of the impacts on water and subsistence food resources, forest health, agriculture, ranching and community health. Other Northern Plains communities are encouraged to examine their local climate data and consider and plan for current and future impacts of climate change on their local ecosystems, water resources and public health.

While changes in climate and health impacts have been researched and documented for Alaskan Native and Southwestern Tribal communities, much less has been published about impacts on Tribes in the Northern Great Plains (NCADAC 2013). Recent publications documenting how climate change is affecting snowmelt hydrology and

streamflow timing in the northern Rocky Mountains (Pederson et al. 2010; Hamlet et al. 2007), as well as the draft National Climate Assessment (NCA) (NCADAC 2013), suggest that Crow Reservation climate changes and concerns might be relevant to other communities in the region. Additionally, as local changes in climate shown in the NOAA record are not completely in agreement with the changes projected for the Northern Great Plains by the draft NCA (NCADAC 2013), there is a need for analyses at both local and regional scales. The addition of local data to regional projections is resulting in more engaged community discussions and will provide a better basis for community policy development and long range planning (Brubaker et al. 2011b). Therefore, this article describes how the local weather and discharge data has been analyzed, and the potential public health impacts, as an example that could be useful for other communities.

Acknowledgements

Thank you to the many Crow Tribal members who contributed their personal observations of changes to the Reservation's climate, water resources and phenology over the recent decades, and particularly to Sara Young, whose initial observations inspired this work. Anne Camper (Montana State University Bozeman) and anonymous reviewers provided useful suggestions.

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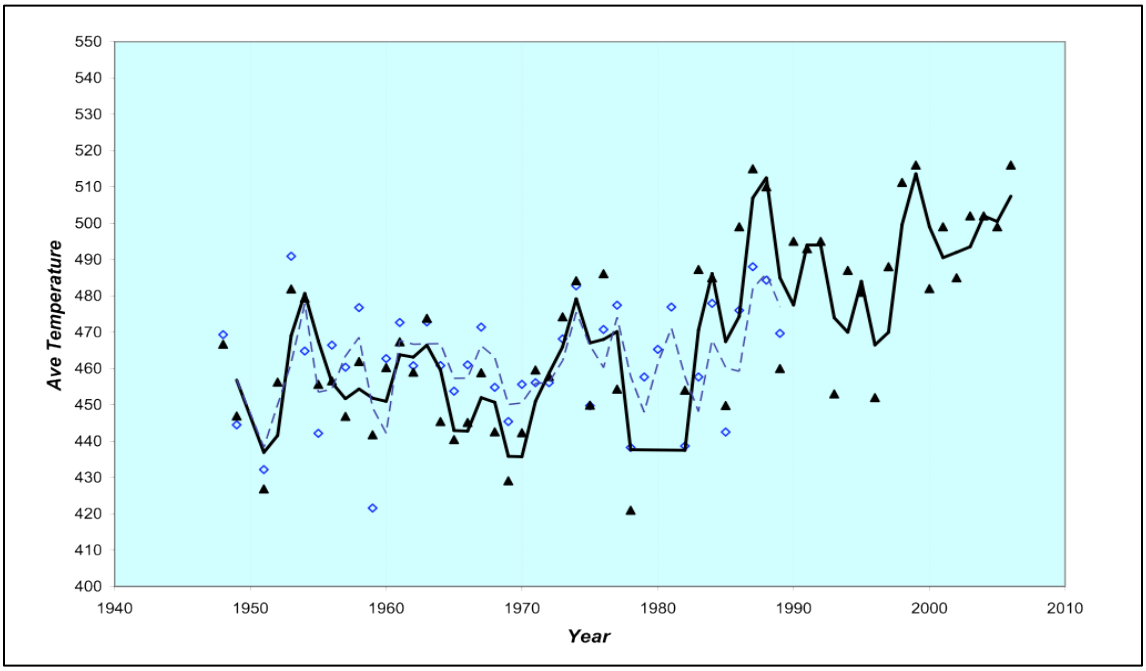
SUPPLEMENT

station name	urban growth	distance (km)	begin	end	length (yrs)	elev (m)	precip	tmax	tmin	snowfall
ASHLAND MT	none	104	7/1/1948	11/30/1949	1.1	1190	100%	100%	100%	100%
ASHLAND MT Ranger St.	none	103	4/1/1950	9/30/1951	1.9	896	99%	0%	0%	0%
BALLANTINE, MT US	none	110	4/1/1919	12/6/2011	90.7	914	86%	86%	86%	41%
BIG HORN, WY	none	129	11/1/1949	3/24/2013	62.3	1283	26%	13%	80%	26%
BILLINGS AIRPT MT	high (60%)	95	1/2/1948	3/23/2013	65.1	1092	100%	100%	100%	100%
BIRNEY 11 E, MT	none	102	9/12/1951	8/31/1954	2.9	1190	99%	100%	100%	98%
BIRNEY 15 N, MT	none	98	10/10/1969	10/31/1972	3	1257	97%	92%	92%	92%
CROW AGENCY, MT	**none**	**0**	**04/01/1897**	**7/31/1991**	**3.9**	**923.5**	**93%**	**93%**	**93%**	**83%**
DECKER, MT	moderate (10%)	80	6/1/1904	12/31/2004	100.5	1073	52%	8%	8%	42%
FORT CUSTER, MT	**none**	**4**	**12/01/1892**	**10/31/1897**	**4.9**	**929.6**	**72%**	**92%**	**91%**	**76%**
HARDIN, MT	**very low (2%)**	**22**	**7/1/1948**	**3/23/2013**	**64.5**	**886**	**93%**	**93%**	**93%**	**83%**
SHERIDAN AIRPT, WY	moderate (10%)	113	1/1/1948	3/23/2013	65.1	1202	100%	100%	100%	96%
PRYOR, MT	none	80	6/13/1950	3/23/2013	62.9	1227	92%	0%	0%	89%
PARKMAN, WY	none	78	2/1/1900	8/31/1903	3	1308	97%	94%	94%	40%
PARKMAN 5 WNW, WY	none	75	11/1/1949	11/30/1983	34	1352	97%	62%	65%	62%
LAME DEER, MT	moderate (10%)	71	1/1/1903	5/31/1998	95.3	1006	60%	59%	58%	55%
LODGE GRASS, MT	very low (1%)	37	4/1/1904	9/30/1951	47.5	995	11%	33%	36%	75%
WYOLA 1 SW, MT	none	58	6/1/1922	9/30/2006	84.2	1137	87%	67%	63%	83%
YELLOWTAIL DAM, MT	none	60	7/1/1948	3/21/2013	64.5	1007	81%	83%	83%	60%

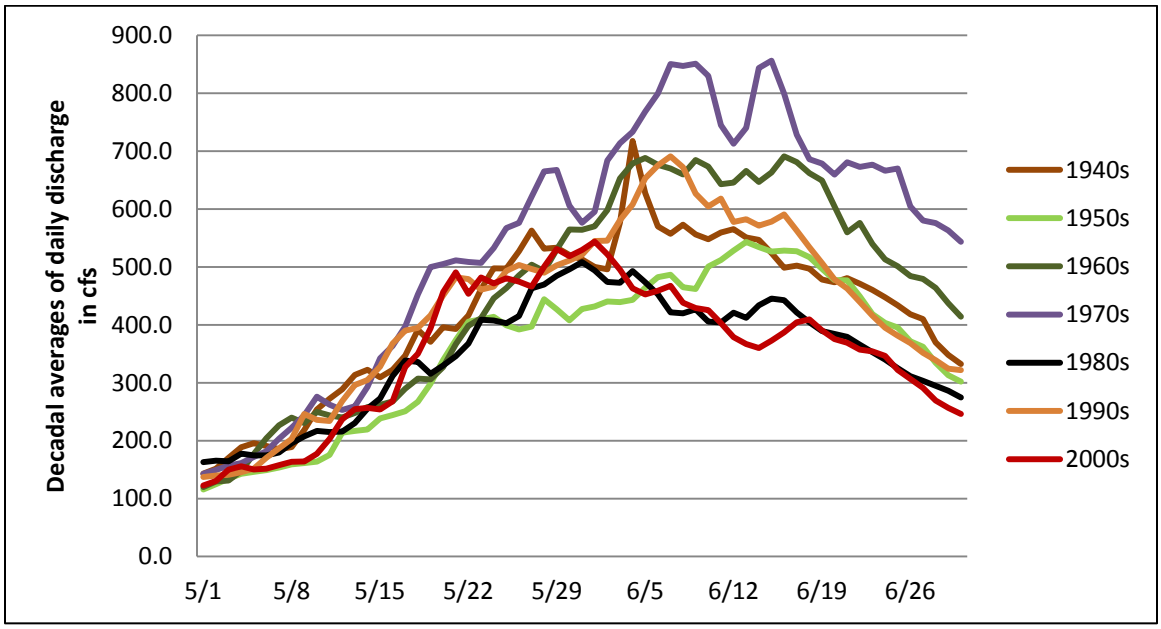
Supplement Table I. Available regional weather station records. Listing shows proximity, length and percent completeness and for types of data collected from weather stations within the Little Bighorn River valley. Most records in nearby river valleys, or within 75 kilometers of Crow Agency, Montana, lack sufficiently complete data to be worth analyzing. (Source: National Climate Data Center)

Decade	Ave Days >90	St. Dev	Ave Days >100	St. Dev2
1900-1909	23.6	9.8	1.6	1.8
1910-1919	27.8	11.1	4.6	6.3
1920-1929	35.4	12.5	4.3	2.4
1930-1939	49.5	8.2	14.7	7.2
1940-1949	37.3	7.7	5.6	4.3
1950-1959	34.4	6.5	4.1	2.5
1960-1969	36.3	11.7	6.5	5.5
1970-1979	37.2	9.9	4.3	3.6
1980-1989	43.7	12.1	8.8	8.8
1990-1999	38.4	13.2	5.6	5.3
2000-2009	53.7	11.2	12.8	7.6

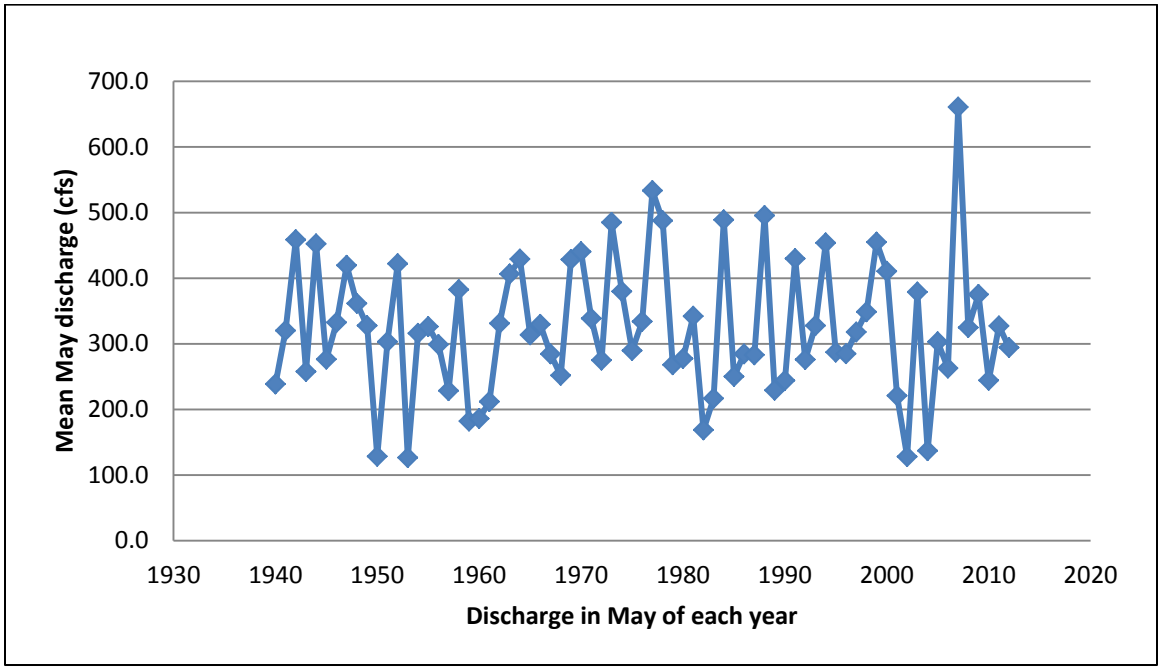
Supplement Table II. Decadal average number of days per year exceeding 90˚F and 100˚F, averaging Hardin, MT and Crow Agency, MT data. Calculated from historic daily observations. (Data source: National Climate Data Center)



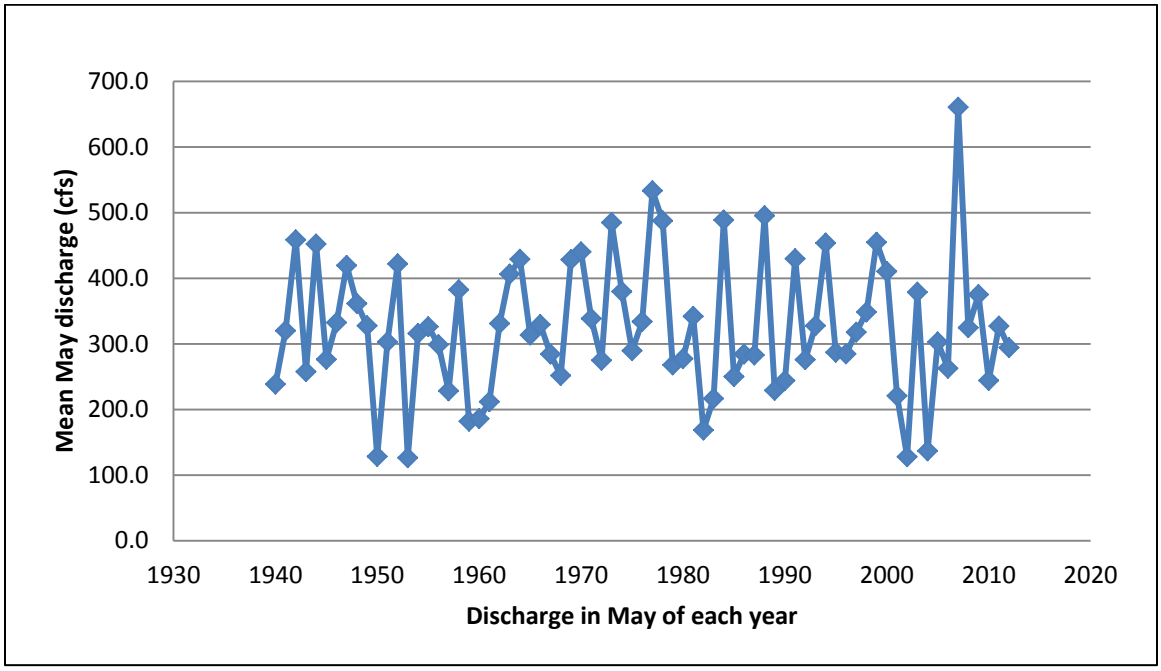
Supplement Figure I. Plot of average temperature for Hardin, MT 1948-2007 (solid triangles) and Crow Agency, MT 1948-1991 (hollow diamonds) showing increase in average temperatures (in Fahrenheit). Solid black line is 4-year moving average for Hardin data, dashed blue line is 4-year moving average for Crow Agency data. (Data source: National Climate Data Center.)



Supplement Figure II. Decadal averages of discharge for each day in May and June, defining spring runoff hydrographs for the Little Bighorn River near Wyola, Montana (station 06289000). (Data source: USGS 2012)

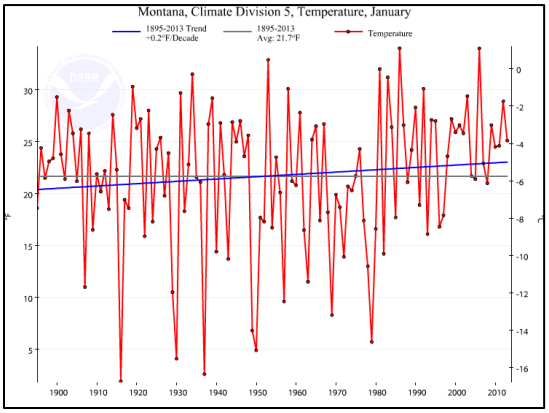


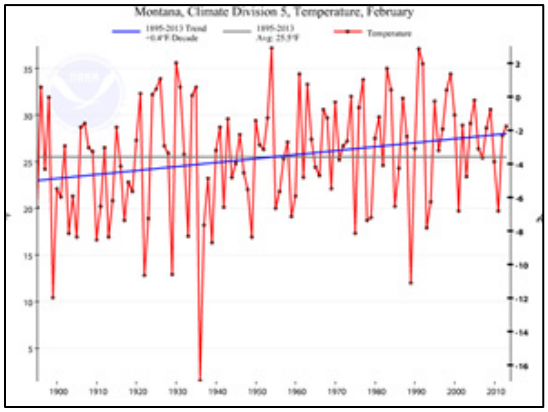
Supplement Figure III. Little Bighorn River above Wyola, MT. Mean of daily discharge in May, 1940 – 2011. (Data source: USGS 2012)

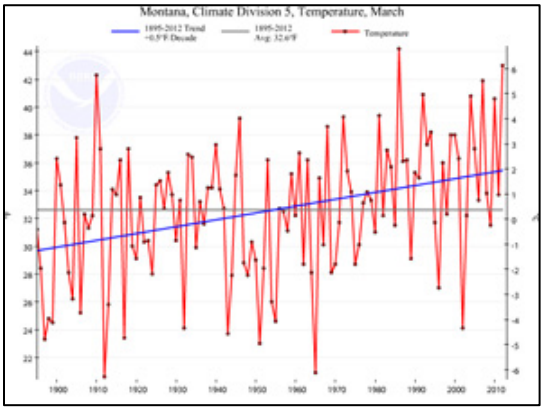


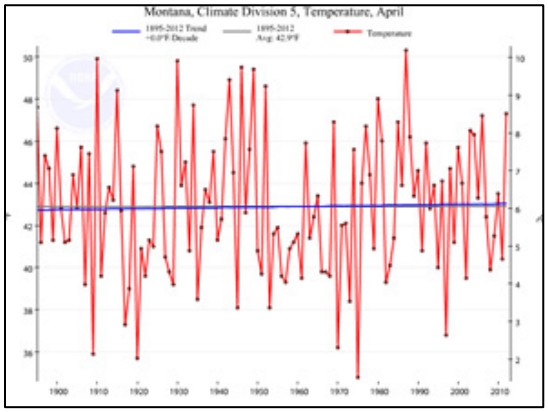
Supplement Figure IV. Little Bighorn River above Wyola, MT. Mean of daily discharge in June, 1940 – 2011. (Data source: USGS 2012.)

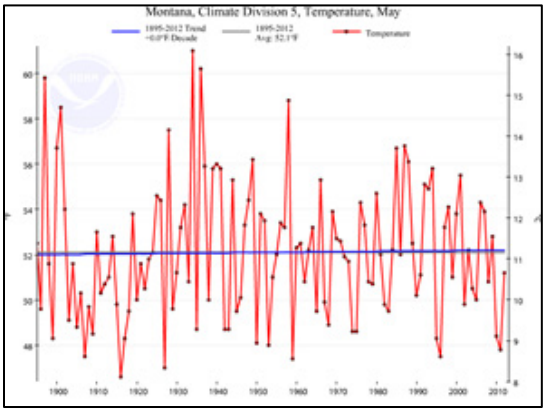
Supplement Document I. Montana Climate Division 5 Temperature Data (NCDC 2013)

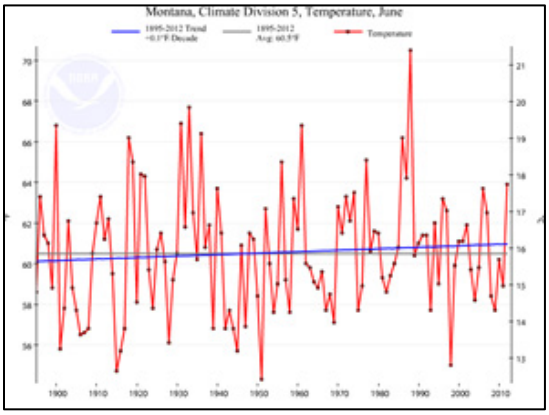


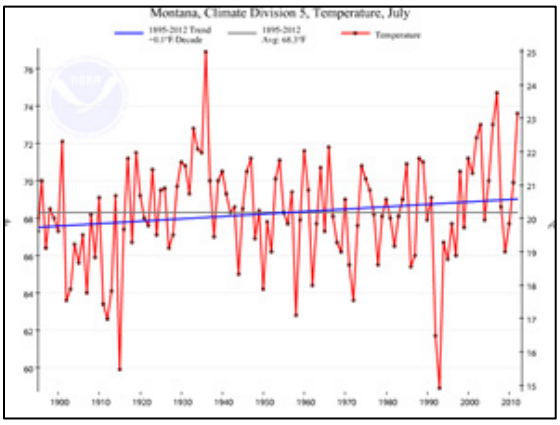


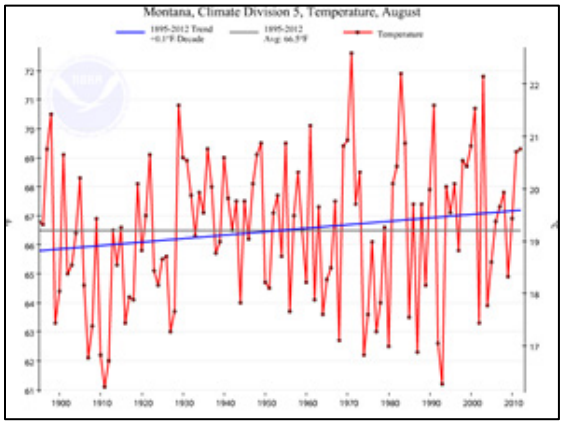









Montana, Climate Division 5, Temperature, July
1895-2012 Trend +0.1°F/Decade
1895-2012 Avg: 68.3°F
Temperature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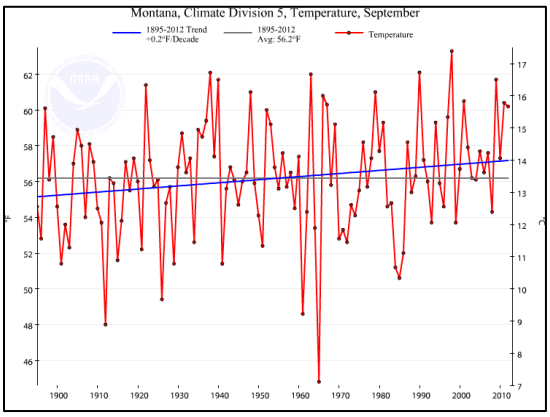
1895-2012 Avg: 66.5°F
Temperature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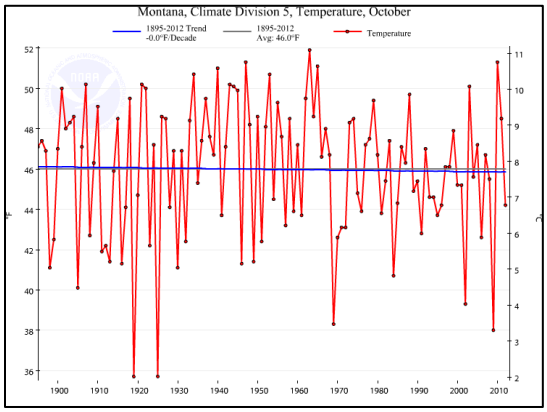
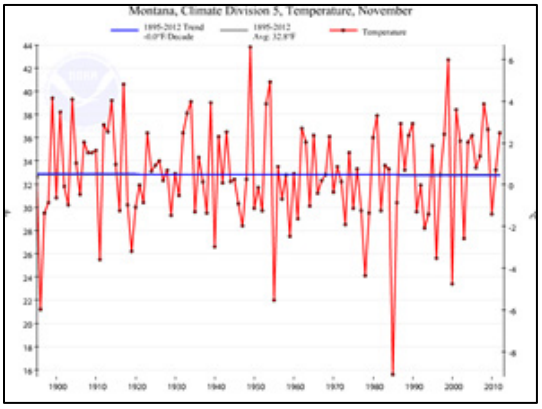
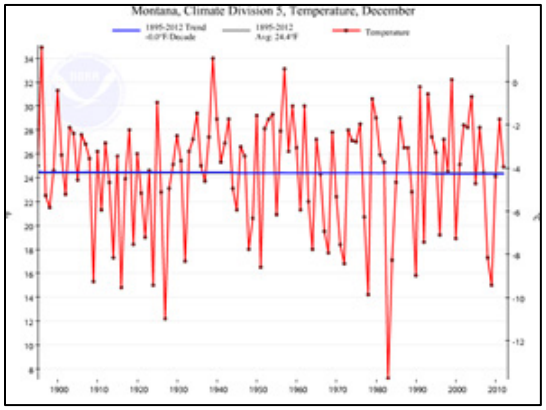
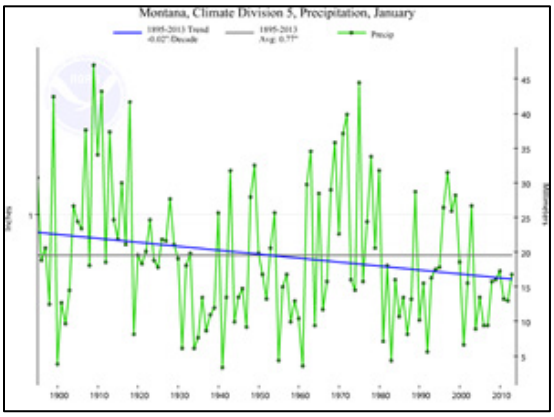
1895-2012 Avg: 56.2°F
Temperature

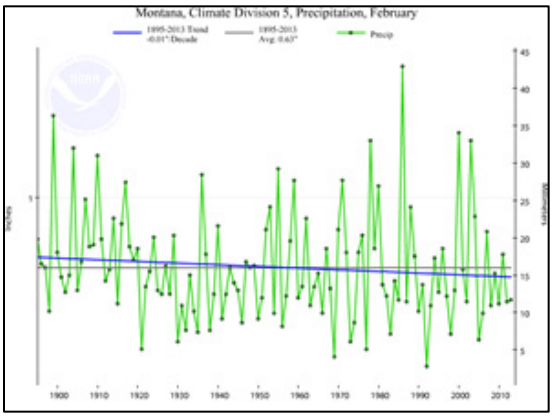

Montana, Climate Division 5, Temperature, October
1895-2012 Trend -0.0°F/Decade
1895-2012 Avg: 46.0°F
Temperature

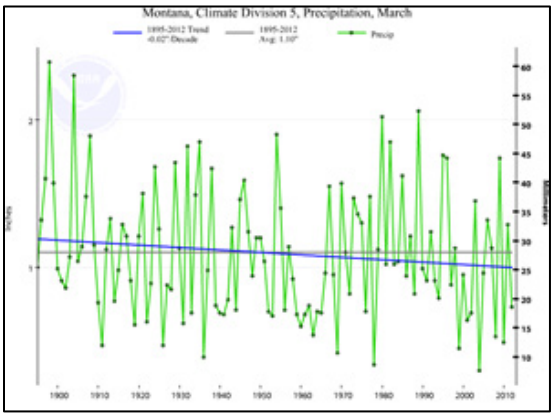

Montana, Climate Division 5, Temperature, November
1895-2012 Trend -0.0°F/Decade
1895-2012 Avg: 32.8°F
Temperature

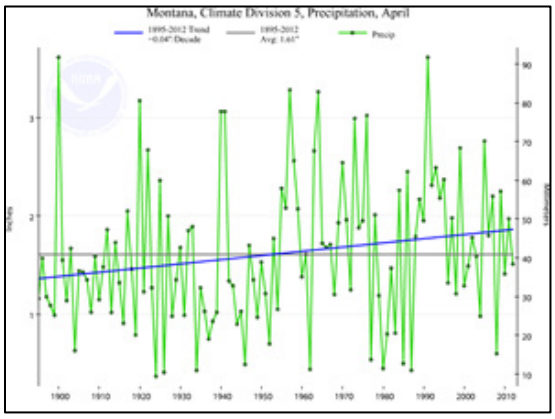

Montana, Climate Division 5, Temperature, December
1895-2012 Trend -0.0°F/Decade
1895-2012 Avg: 24.4°F
Temperature

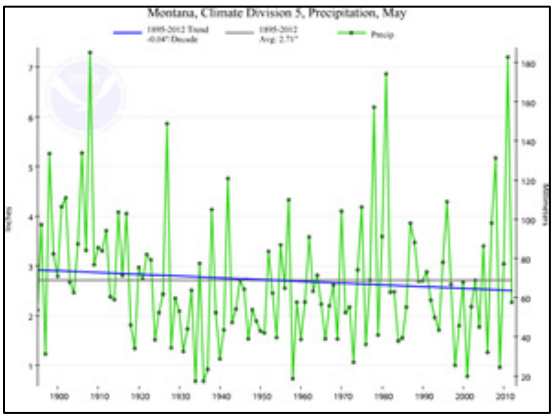
Supplement Document II. Montana Climate Division 5 Precipitation Data (NCDC 2013)

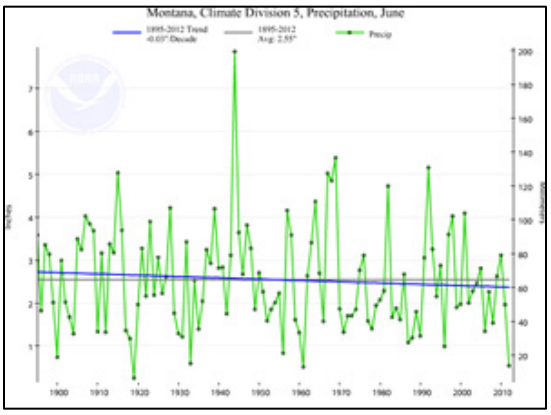


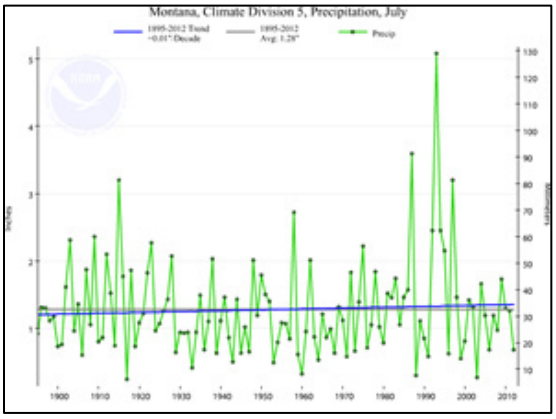


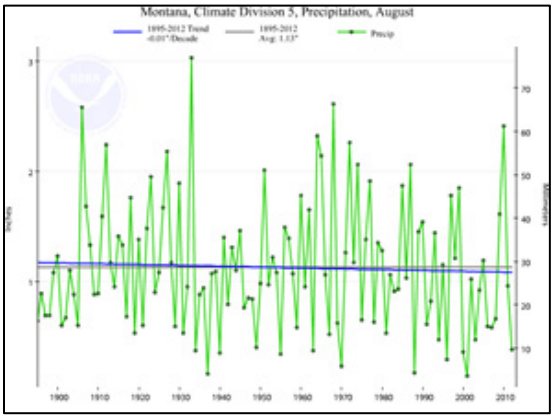


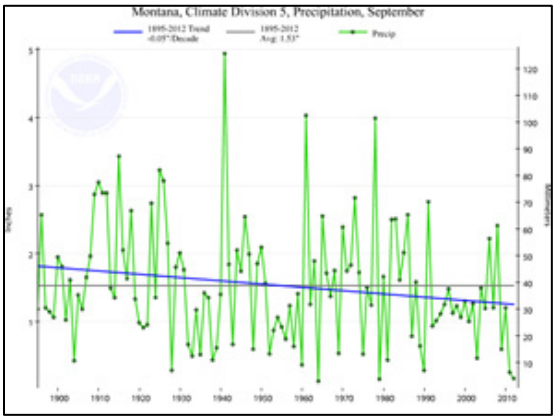


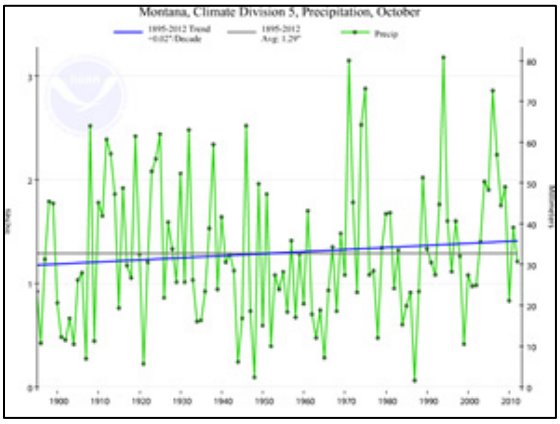


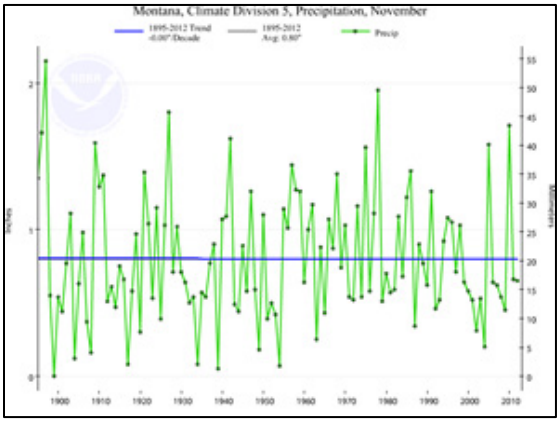


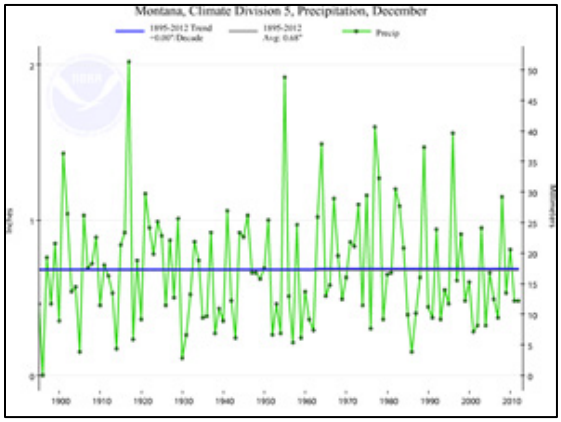

Montana, Climate Division 5, Precipitation, July
1895-2012 Trend +0.01"/Decade
1895-2012 Avg: 1.28"
Precip
Inches
Millimeters


Montana, Climate Division 5, Precipitation, August
1895-2012 Trend -0.01"/Decade
1895-2012 Avg: 1.13"
Precip
Inches
Millimeters


Montana, Climate Division 5, Precipitation, September
1895-2012 Trend -0.05"/Decade
1895-2012 Avg: 1.53"
Precip
Inches
Millimeters


Montana, Climate Division 5, Precipitation, October
1895-2012 Trend +0.02"/Decade
1895-2012 Avg: 1.29"
Precip
Inches
Millimeters


Montana, Climate Division 5, Precipitation, November
1895-2012 Trend -0.00"/Decade
1895-2012 Avg: 0.80"
Precip
Inches
Millimeters


Montana, Climate Division 5, Precipitation, December
1895-2012 Trend +0.00"/Decade
1895-2012 Avg: 0.68"
Precip
Inches
Millimeters

CHAPTER 4

TRIBAL WATERS: A RESOURCE FOR HEALTH AND A SOURCE OF HEALTH DISPARITIES

Abstract

Lack of access to safe drinking water has been shown to be an environmental health disparity for some rural, poor and minority communities in the United States. Although 15% of the U.S. population relies on private wells, the federal government does not generally regulate the quality of home well water. A recent US Geological Survey study found that 23% of private wells tested nationwide had one or more contaminants at concentrations exceeding human health benchmarks. However, in the absence of data on well water consumption, the health risks have not been assessed. The Crow Environmental Health Steering Committee and their academic partners conducted a community-engaged, cumulative risk assessment of exposure to well water contaminants on the Crow Reservation in Montana. Well water testing and surveys were used to collect data on well water contaminant concentrations, water treatment methods, well water consumption, and well and septic system protection and maintenance practices. Key informant interviews documented family strategies for coping with poor quality well water. Uranium, manganese and nitrate were the inorganic contaminants most frequently exceeding US EPA standards. The percent of home wells exceeding the cumulative risk level of concern considering only these three inorganic contaminants varied from 11.1% to 58.3% depending on river valley. Exposure to contaminated well water exacerbates the community's existing health disparities due to the confluence of the area's geology,

extensive agriculture, lack of public environmental health education, jurisdictional complexities of reservations, vulnerable health status and especially, families' limited financial resources for mitigating poor quality well water.

Background

Lack of access to safe drinking water for poor and minority communities in the United States is a little studied environmental health disparity. This disparity can take the form of poorer quality municipal water, denial of access to nearby municipal water, contaminated well water or even lack of access to in-home water service. Although small water systems in general face many challenges in producing safe water (Ford et al. 2005), a few studies conducted in California and New Mexico have shown that smaller community water systems serving a higher percentage of minority or low income residents and of renters receive drinking water with more frequent maximum contaminant level violations (Balazs et al. 2012) and/or with high levels of contaminants (Balazs et al. 2011; Balazs et al. 2012; Firestone et al. 2006; Pilley et al. 2009). Some municipalities have avoided extending public water and sewer services to adjoining poor communities, despite repeated requests for service (Olmstead et al. 2004; Wilson et al. 2008; Wilson et al. 2010). There are rural Native American communities in Alaska and the Southwest as well as unincorporated settlements in Texas that still lack piped water (USDA-EPA 2014; EPA 2013a; Murphy et al. 2009; CDC 2008; BIA 2008; Parcher et al. 2010).

Several recent publications have elucidated the challenges in researching drinking water disparities. Infrastructure disparities are difficult to study for multiple reasons: community water systems (CWS) are not usually geo-referenced, so it is difficult to link

demographic data with service areas; good data on the managerial and operational aspects of CWS are non-existent; and numbers of violations are not a comparable statistic among states due to differences in enforcement practices (VanderSlice 2011). Conducting risk assessments of exposure to chemicals in drinking water is complicated by long exposure periods, mixtures of chemicals, few valid biomarkers of exposure, temporal variability in contaminant levels and multiple routes of exposure (Villanueva et al. 2014). An ecological framework is needed for analysis as natural, built and sociopolitical environments act through multiple levels from the state down through individual households (Balazs and Ray 2014). The water and wastewater infrastructure challenges facing Native American communities are even more complex due to legal and jurisdictional factors (Doyle et al. 2013) and are currently being elucidated and addressed by a federal Interagency Task Force under a Memorandum of Agreement among the Departments of Agriculture, Health and Human Services, Housing and Urban Development and Interior and the Environmental Protection Agency (EPA 2013a).

The majority of existing research addresses community water systems and wastewater infrastructure; disparities related to home well water are even less understood. Although 15% of the US population relies on private wells for their drinking water, the federal government does not regulate home well water quality (DeSimone 2009, Magdo et al. 2007). Some states require testing when new wells are drilled or when homes are sold (DeSimone 2009), but state laws do not apply on trust lands within most reservations. Case studies of poor, rural, minority communities have found microbially and/or chemically unsafe water in varying percentages of wells (Heaney et al. 2011; Bischoff et al. 2012; VanderSlice 2011 citing multiple sources). Most relevant to the

research reported here, 22% of domestic water sources on the Navajo Reservation were found to exceed health standards for arsenic, uranium and/or other inorganic contaminants; 70% of these wells were coliform positive and 21% had *E. coli* (Murphy et al. 2009).

The most comprehensive effort to assess home well water quality was recently completed by the US Geological Survey, which tested 1,389 wells across 48 states. They found that 23% of these wells had one or more contaminant(s) at concentration(s) exceeding human-health benchmarks, primarily nitrate and naturally occurring inorganic chemicals. Coliform bacteria were found in 34% of 378 tested wells, and *E. coli* in 7.9% of 397 sampled wells (DeSimone 2009). The USGS concluded that consumption data matched to well water quality data are needed, and will be essential to assess and mitigate the human health risks from contaminated home wells (DeSimone 2009).

Study Area

The Crow Reservation in south-central Montana is home to the Apsaálooke (Crow) people, and encompasses 2.3 million acres in the center of the Tribe's original homelands. Of the Tribe's approximate enrollment of 11,000 people, 7900 live on the Reservation (MT DPHHS 2006). The Reservation is rich in water resources, including the Little Big Horn River, Big Horn River, Pryor Creek and their tributaries, fed by the Wolf, Big Horn and Pryor Mountain ranges. The Apsaálooke people still maintain their language, ceremonial practices, and relationships to the rivers, springs and other natural resources. Water as a "giver of life," an "essence of life," has always been held in high respect by the Apsaálooke people and considered a source for health; still today water is a

sacred resource essential to many prayers, ceremonies and other traditional practices (Cummins et al. 2010; Lefthand et al. 2012; EPA 2014). Contamination of water, a natural resource, has additional, unique impacts in Native American communities, as the U. S. EPA writes in *A Decade of Tribal Environmental Research*:

> American Indian and Alaska Native (AI/AN) communities have been inextricably linked to their environments for millennia. Because of their reliance on natural resources to maintain traditional diets, lifeways, customs and languages, there is a unique need for tribal-focused research to identify impacts of pollution, dietary exposure, cumulative risk and climate change as well as to inform decisions to reduce health risks in these areas (EPA 2014, p. 1).

As the Apsaálooke people continue to practice their culture and speak their language, our project is therefore a relevant case study for understanding health risks from water contamination in Native American communities.

Like many other tribes and minority communities, the Apsaálooke people also face health disparities and economic hardships which increase vulnerability to environmental contamination (EPA 2003). Statistics for Big Horn County give some idea of the health status of the Reservation, as 64% of the county's landbase is within the Reservation's boundaries and 66% of the county's population is Native American (US Census Bureau 2010a). In a comprehensive and thoroughly cited analysis of county health and socioeconomic status, the local Community Health Center describes the confluence of (1) disparities in physical health, as illustrated by the high diabetes prevalence rate of 12.1% in Big Horn County, compared to 6.2% statewide; (2) disparities in mental health, citing high rates of youth binge drinking, high suicide and homicide rates, exceedingly high death rates from unintentional injury and motor vehicle crashes, and very high mortality rates from cirrhosis of the liver; (3) an ongoing cycle of

poverty (US Census 2010) and (4) inadequate health care, as illustrated by low rates of childhood immunizations and adult cancer screenings, federal recognition as a "medically underserved area" and as a "health professional shortage area" for dental health, mental health and primary medical care, and a 2007 community needs assessment in which 86% of respondents considered accessible and affordable health care to be their most important need. These factors in combination contribute to an elevated infant mortality rate: 8.9 deaths per 1000 live births, vs. 6.1 for Montana, 6.9 for the U.S.(US Census 2000); a much higher age-adjusted death rate of 1153.3 (per 100,000) vs. 772.2 for Montana and 760.2 for the U.S. (MT DPHSS 2004-2008 and CDC 2010, cited in Mark and Byron 2010); and a *twenty year lower* life expectancy for Native Americans in the county (58 years) compared to Caucasian residents of the county (78 years), the Montana average (79 years) or the US average (78 years) (US Census 2000, cited in Mark and Byron 2010).

Many families' financial resources are limited. The Bureau of Indian Affairs estimates unemployment on the Crow Reservation at 47% (2005). County-wide, 29.2% of the population is below 100% of the federal poverty level (FPL), and 54% below 200% of the FPL (Montana Department of Public Health and Human Services 2006). 2010 per capita income for Big Horn County, at $15,066, is the lowest in the entire state and well below the statewide average per capita income of $23,836 and the national average of $27,334 (US Census Bureau 2010b). The per capita income in the primarily Native American reservation communities within the county is about half the already dismal county-wide average – ranging from $7354 for Crow Agency to $8130 for Lodge Grass (US Census Bureau 2010b).

CEHSC members reflect that in the past, there used to be a level of trust that the rivers and springs were clean. Traditionally, people lived along the rivers, hauled water from the rivers and springs for home use, knew they needed water to survive and kept the rivers clean. Rivers and springs were and are still today respected and considered sacred. Until the 1960s, many families on the Crow Reservation still hauled river water for home use, a practice most of the Tribal co-authors remember from our childhoods. At that time, agriculture was expanding and river water quality visibly deteriorating; wells and indoor plumbing finally became available and rural families switched to piped home well water. In many parts of the Reservation, this was a hardship, not a blessing: the groundwater tapped for home wells was high in total dissolved solids, including so much sulfate, iron and manganese that it was undrinkable (Eggers et al. 2013). Widespread high alkalinity and excessive hardness resulted in scaling ruining pipes and hot water heaters, making it expensive to maintain plumbing. There was no community education on how to protect one's well water or maintain and repair wells, plumbing and septic systems.

Decades ago, co-authors John Doyle and Larry Kindness, tribal members, publically questioned the evident contamination of the rivers from poorly maintained wastewater treatment infrastructure; their concerns were met with indifference by the agencies involved and so they subsequently began a volunteer effort to address these issues. They and other community members also became increasingly worried about the potential connection of widespread poor quality home well water to illnesses in the community. In 2004, Doyle's, Kindness' and co-authors Myra Lefthand's and Margaret Eggers's concerns resulted in a week-long collaborative environmental health assessment

of the Reservation, conducted with other local stakeholders and with technical assistance from the Indian Country Environmental Hazard Assessment Project (DuFault 2005). Participants prioritized river and well water contamination as the most serious health risk with the broadest impacts on the community, and formed the Crow Environmental Health Steering Committee (CEHSC) to work on addressing these issues (Cummins et al. 2011). With logistical and student intern support from Little Big Horn College, and financial and technical support from Montana State University, water sampling began in 2006. Although baseline data were also collected on river and spring water quality and on river sediments, most of our work has been on home well water and is reported here.

Methods

Our research assessed exposure to waterborne contaminants on the Crow Reservation, Montana. Our hypothesis was that shallow wells, traditional uses of river water, agricultural practices and additional aspects of Crow Reservation communities place residents at an increased risk of exposure to waterborne contaminants and pathogens. We address the limitations of the above studies of well water quality by combining testing of wells, springs and other domestic water sources with homeowner surveys and interviews with key informants, along with the use of secondary health and economic data. This has provided us with data on well water consumption, well and septic system maintenance practices and measures parents are taking to provide their families with safer drinking water, which in conjunction with well water quality data, enables us to better assess risks from well water contamination.

Community-based Participatory Research

Our collaboration follows the principles of community-based participatory research (CBPR), which has been defined as, "a partnership approach to research that equitably involves, for example, community members, organizational representatives, and researchers in all aspects of the research process and in which all partners contribute expertise and share decision making and ownership" (Israel et al. 2008). The CEHSC, composed of Tribal members from the Apsaalooke [Crow] Water and Wastewater Authority, the Crow/Northern Cheyenne Indian Health Service Hospital, the Crow Tribal Environmental Protection Department, the Crow Legislature, the Crow non-profit Messengers for Health and other local stakeholders in education and natural resource management, meet about ten times a year and guide this work. Our academic partners serve as non-voting members of the CEHSC. We believe that applying CBPR principles not only to our risk assessment research, but also to risk communication and risk mitigation, will be an effective way to reduce health disparities in Crow Reservation communities. This approach is working well in other Tribal communities addressing environmental health issues (EPA 2014). The author, the primary scientist, and the principal investigators from Montana State University and the University of New England, serve as non-voting members of the Committee. Additionally, Tribal college science majors have served as the research interns, gone on in their educations, and have come home to work – increasing community capacity to address environmental health issues. We have found that "community engaged research" is a better description of this collaborative process.

Estimating the Number of Native Families Relying on Wells

The number of Native families using home wells was estimated from several statistics: the 2010 census statistic that 8521 residents of Big Horn County self-identify as Native American (US Census Bureau 2010a), the USGS estimate that 40-60% of the county's population rely on home wells, and from our survey results: the average household size of 4.41 people/home. From these data, it is estimated that 966 Crow families in the county use home wells.

Tribal Approval

In 2006 when initial research funding was sought, the Crow Reservation had no institutional review board (IRB) or other formal mechanism for review of proposed research. Instead, the Crow Tribe, Little Big Horn College and Montana State University worked out a Memorandum of Agreement detailing each collaborator's responsibilities, which was signed by the Tribal Chairman and the College and University Presidents. In 2007 when funding was awarded by Montana State University (MSU) to Little Big Horn College (LBHC), IRB approval for project was sought and obtained from MSU. As the project has developed and expanded, amendments to the IRB approval have been obtained for additional human subjects work such as interviews.

Household Survey

In 2008 a survey covering treatment and uses of home well water; well water taste, color and odor; other sources of water for domestic, traditional and recreational uses; well and septic system knowledge and maintenance practices; potential sources of

well water contamination and other factors was developed, drawing from comprehensive environmental health surveys used in other studies (Riederer et al. 2006, Butterfield et al. 2011). By 2008, this author had lived on the Crow Reservation for 15 years, so was able to draw on her experience to adapt the survey to include local practices. The draft was reviewed, edited and shortened by two older members of the CEHSC who were Tribal members, had grown up on the Reservation and had prior social science research experience. The edited version was then pilot tested with several community members. Based on this feedback, additional questions were eliminated and others were consolidated (Appendix C).

Volunteer Recruitment and Participation

Beginning in 2009, participants were recruited from throughout the Reservation to complete the survey and receive a free comprehensive domestic analysis of their well water along with a stipend as compensation for their time. Conventional random sampling would have been entirely inappropriate and ineffective in this Tribal community, as invitations to participate in the project had to be based on personal relationships and interest in home well water testing. (In this, as in so many other Native American communities, there is a negative legacy left by past researchers and research projects (NCAI 2012), hence willingness to participate in based on personal trust in the person doing the recruiting.) Volunteers were recruited by CEHSC members and the Project Coordinator, through networks of family and friends and by snowball sampling, booths at community health fairs, articles in the local papers and flyers posted in public buildings. A concerted effort was made to recruit in less represented communities, for

instance, by hiring a Crow graduate student intern from Wyola who was able to effectively recruit participants in her home community.

Our local project coordinator, a Tribal member, arranged a time to meet each volunteer at their home, explain the project, answer questions and collect the water samples for microbial and chemical analyses. Water temperature, conductivity and pH were measured on site. Volunteers could choose to complete the survey on their own, or complete it with the project coordinator. Some older Tribal members who were more comfortable speaking Crow than reading English, worked with the coordinator to complete their surveys, but the majority of people completed it independently. (Translating the survey into written Crow would not have helped; Crow was not traditionally a written language, hence very few people are literate in Crow.)

Part way through the study, it became clear that the length of the survey was still discouraging participation. As a result, the survey was divided into two parts, with only the first half addressing water sources tied to the well water testing. However, almost all subsequent participants elected to complete the entire survey for the full stipend ($50 instead of $25). (See Appendix C.)

Sample Analysis

Water samples were placed on ice and delivered in less than 24 hours (usually within the same day) to Energy Laboratories, an EPA certified lab in Billings, Montana. The lab ran a full domestic analysis on each water sample, including physical properties (total dissolved solids, conductivity, corrosivity and pH); inorganics (alkalinity, bicarbonate, carbonate, chloride, sulfate, fluoride, nitrate + nitrite as N, hardness as

CaCO3 and sodium absorption ratio); and metals (aluminum, arsenic, cadmium, calcium, chromium, iron, lead, magnesium, manganese, potassium, sodium and zinc). Presence/absence tests for coliform bacteria and *E. coli* were conducted to assess fecal contamination risk.

After more than 50 wells were sampled, testing for cadmium and chromium was discontinued as these metals were rarely detected and if so, only at very low levels. Testing for lead was also discontinued, as it was rarely detected and the sampling protocol proved difficult for homeowners and staff to implement. (Homeowners had to refrain from using their water for any purpose overnight, collect a sample first thing in the morning before using any water, then return the sample to the project office at LBHC in Crow Agency.) At the suggestion of geologist and Crow Tribal member Anita Moore-Nall, testing for total uranium was added, an element that has not historically been tested for in Montana wells (MT DEQ 2009).

Data Entry and Analysis

One hundred ninety-seven participants from 165 households total completed the survey. The total number of wells tested was 151, as a few homes did not have wells in service. Well water data were entered into MS Excel™, and then into a geographic information systems map (ArcMap 9.3, ESRI).

Additionally, the local Indian Health Service Hospital (IHS) provided access to their hard copy records on about 650 wells they had drilled for Tribal members on the Reservation since the 1960s; these records included the water quality test results at the time the well was drilled, but many lacked location data. Data from the IHS paper

records were entered into a separate MS Excel™ spreadsheet, and wells with location data were entered into the GIS map. Maps showing the distribution of each contaminant were prepared and copies provided to the Environmental Health office of the Indian Health Service, along with electronic copies of all of their individual records. Average contaminant levels for each database – our project's and the IHS's – were calculated separately using MS Excel™. State wide average contaminant levels in well water were obtained from Montana State University's Water Quality Extension program.

Our project's well water data were further analyzed using IBM SPSS Statistics 22. As the Reservation includes three watersheds, each with distinctive water contamination issues, and the nine zip code boundaries conveniently fall within watershed boundaries, the mean and standard deviation for each contaminant concentration of concern were broken down by zip code of the homeowner. For further analysis, contaminant concentrations were log transformed to improve normality. Correlations between or among contaminants (e.g. iron concentration and TDS as potential predictors of manganese) were analyzed using regression (for two contaminants) or multiple regression (for three or more contaminants). Survey data were entered into MS Access™ and subsequently analyzed using IBM SPSS™ Statistics 22. Comparisons of categorical variables – such as the presence/absence of coliform contamination vs. the presence/absence of a sanitary well cap – were made using chi square ("cross-tabs" in SPSS). Comparisons of contaminant concentrations across categorical variables - such as TDS vs. water use group - were conducted with ANOVA. When SPSS calculated that there was significantly unequal variance between contaminant concentration distributions, a non-parametric test (Dunnett T3) was used.

Cumulative Risk Assessment

The US EPA and the US FDA began developing and adopting methods to assess risk from exposure to environmental chemicals in the 1970s (Callahan and Sexton 2007). The EPA's most recent guidance is the "Framework for Cumulative Risk Assessment," published in 2003 (EPA 2003, Callahan and Sexton 2007). The guidance explains that problem formulation for a cumulative risk assessment should include the identification of sources, stressors, pathways, exposure routes, receptors and endpoints (see Figure 1.1). In this case, the "receptors" are Crow Tribal community members and the "endpoints" are human health effects. While physical, chemical, biological and/or radiological stressors are easier to include, other stressors that affect health – such as economics and culture - *should be considered* even if the methodology for taking them into account "is not currently available" (EPA 2003). Stakeholder involvement in the process is important. Community characteristics need to be elucidated in order to understand and assess vulnerability. Qualitative methods are useful and valuable for aspects of the risk assessment that cannot readily be quantified. Cumulative risk assessments are far more complex than single stressor risk assessments, therefore it is important to identify and document sources of uncertainty in the analysis. In spite of all the effort that goes into a cumulative risk assessment, with currently available data and methods it is often impossible to connect exposures to environmental contaminants to disease incidence (EPA 2003). Nevertheless, cumulative risk assessment is a valuable tool both for the community and for government decision-makers (EPA 2003).

As mixture specific toxicity data are not available for uranium + manganese + nitrates, and as these chemicals have neither a common target organ nor a common

mechanism of toxicity, but reference concentrations are available, the EPA recommends using the hazard index approach to cumulative risk assessment (Callahan and Sexton 2007). The hazard index is calculated by summing "the ratios of the expected exposure (E) to the chemical divided by an acceptable level (AL) for exposure to that chemical" (Putzrath et al. 2000):

$$HI = \sum_{i=1}^{n} (E_i)/(AL_i)$$

If HI exceeds 1.0, the cumulative risk is a health concern. For this analysis, the calculation of the hazard index was limited to the most common chemical contaminants, uranium, manganese and nitrate:

$$HI = [U]/(MCL \text{ for } U) + [Mn]/(EPA\ HA \text{ for } Mn) + [NO_3]/(MCL \text{ for } NO_3).$$

Reference doses for well water used in this analysis are EPA's maximum contaminant levels (MCLs) and the EPA's health advisory for manganese. There is also a USGS health based screening level (HBSL) for manganese, which is the same as the EPA's health advisory (0.30 mg/L).

Risk Communication

Our methods include not just risk assessment, but also risk communication and risk mitigation. The lab sent results to project staff, who entered the results into a spreadsheet for the well owner, comparing well water contaminant concentrations with EPA's primary and secondary standards. Any contaminants exceeding standards were highlighted and brief summaries of the associated health risk and/or aesthetic or plumbing issues were added. In addition, an individualized letter was written to each

well owner reviewing and explaining their well water test results and providing further information on any other environmental health issues they noted in their survey. A DVD entitled "Taking Care of Your Ground Water: A Homeowner's Guide to Well and Septic Systems" (MSU 2009) and an MSU Extension publication "Household Drinking Water Protection and Treatment" (Vogel 1991) were also included in each well owner's packet. Well owners were provided with contact information for project staff, and invited to call if they wished to discuss their results or visit with us in person. We learned that many people preferred to have their well test results explained to them in person, rather than in writing. Consequently, follow up in person visits with as many well owners as could be reached were conducted in 2012 – 2013.

Ongoing project results, including the GIS maps of well contaminants, were presented and discussed regularly at meetings of the CEHSC, to the Crow Tribe's Water Resources office, the Pryor 107 Elders Committee, the Messengers for Health members and to the community at large through at least one open house a year. Copies of all our GIS maps showing the spatial distribution of each contaminant were also provided to the Environmental Health Department of the local Indian Health Service Hospital, which contracts to drill wells for well owners.

Project data were also provided to the Crow Tribe at the request of the Tribal Chairman, to the Crow Tribal Environmental Protection Department and to the Apsaalooke [Crow] Water and Wastewater Authority (AWWA). The AWWA subsequently was able to raise funds for and install a "water salesman," an automated dispensing system in the main Reservation town of Crow Agency, which allows rural residents to purchase municipal water at a very low cost. Other mitigation options for

well owners with unpalatable or unsafe well water have been and are being explored. An article summarizing final water quality test results by watershed, with specific recommendations for well water testing for those contaminants of most concern, was submitted to the Tribal newspaper and is pending publication.

Several two day professional development workshops on local water quality were held for local K – 12 teachers in conjunction with Montana State University or Little Big Horn College educators. Presentations have also been given in school classrooms and at several local health fairs. In a joint project with 4-H and Pretty Eagle School, middle school students learned to do basic well water testing and then provided this service to their families during a parent-teacher conference.

Results

Every well tested in this project exceeded one or more of the EPA primary and/or secondary standards set for municipal water supplies. Eighty-six percent of wells exceeded the secondary standard of 500 mg/L for total dissolved solids (TDS), 77% exceeded the secondary standard of 150 mg/L for hardness, 69% for sulfate (≥ 250 mg/L) and 25% for iron (≥ 0.3 mg/L) (Figure 4.1). Although none of these contaminants has been shown to be a serious health risk, high TDS and high sulfate can cause gastrointestinal distress and make the water taste awful. Hard water deteriorates plumbing by depositing scale in hot water pipes and hot water heaters (Vogel 1991). Each of these contaminants increases the costs of home well water treatment, as high TDS, high iron and excessive hardness each require separate water treatment equipment

to produce palatable water (reverse osmosis, iron removal unit and water softener, respectively).

Comparing our project's percentages to the Indian Health Service's (IHS's) local well water database shows that a slightly higher percentage of wells tested by the IHS reservation-wide exceeded the TDS and sulfate standards, and more than double the percentage of wells exceeded the iron standard. Statewide, only 18% of wells tested exceeded the TDS standard (n = 1174) and 11% exceeded the sulfate standard (n = 486) (Sigler 2012). The percentage of home wells exceeding the standard for hardness on the Reservation is slightly higher than the statewide percentage (77% vs. 64%) (Figure 4.1).

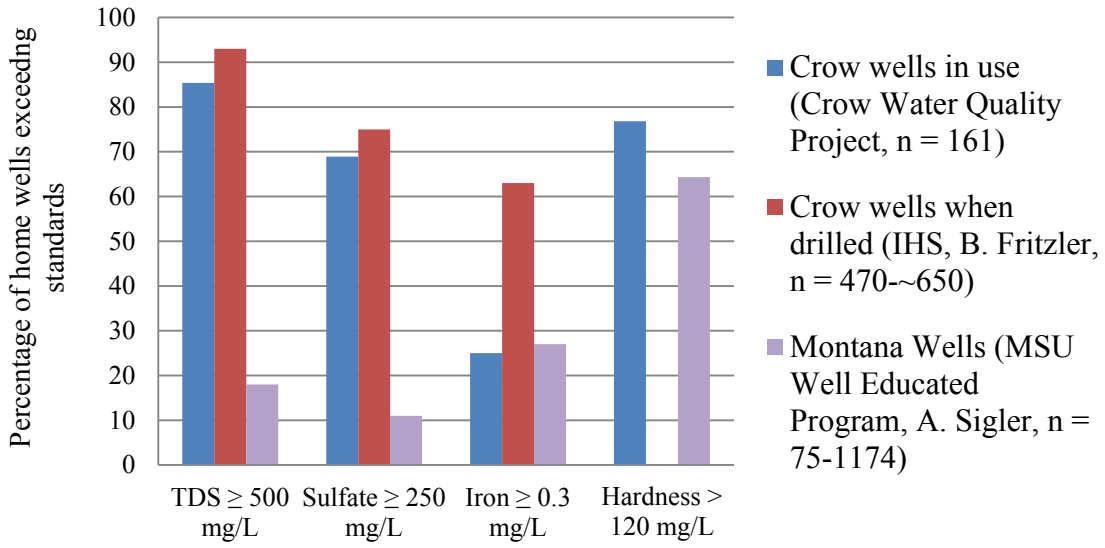


Figure 4.1. Percentage of home wells exceeding EPA's secondary standards

Fifty-five percent of the wells tested by our project exceeded an EPA primary standard for inorganic and/or microbial contamination. Uranium, manganese and nitrate were the inorganic contaminants most likely to exceed the EPA primary standard

(maximum contaminant level) or health advisory, and coliform bacteria were detected in > 40% of wells (Figure 4.2).

For manganese, there is a secondary standard of 0.05 mg/L based on taste and staining, and a health advisory of 0.30 mg/L based on increased risk of neurotoxic effects. Eleven percent of wells we tested and 17% of wells tested by the IHS exceeded the health advisory concentration. Statewide only 1% of wells exceed the manganese advisory (n = 480) (Sigler 2012) (Figure 4.2), and nationally 5.2% of wells exceed this standard (DeSimone 2009).

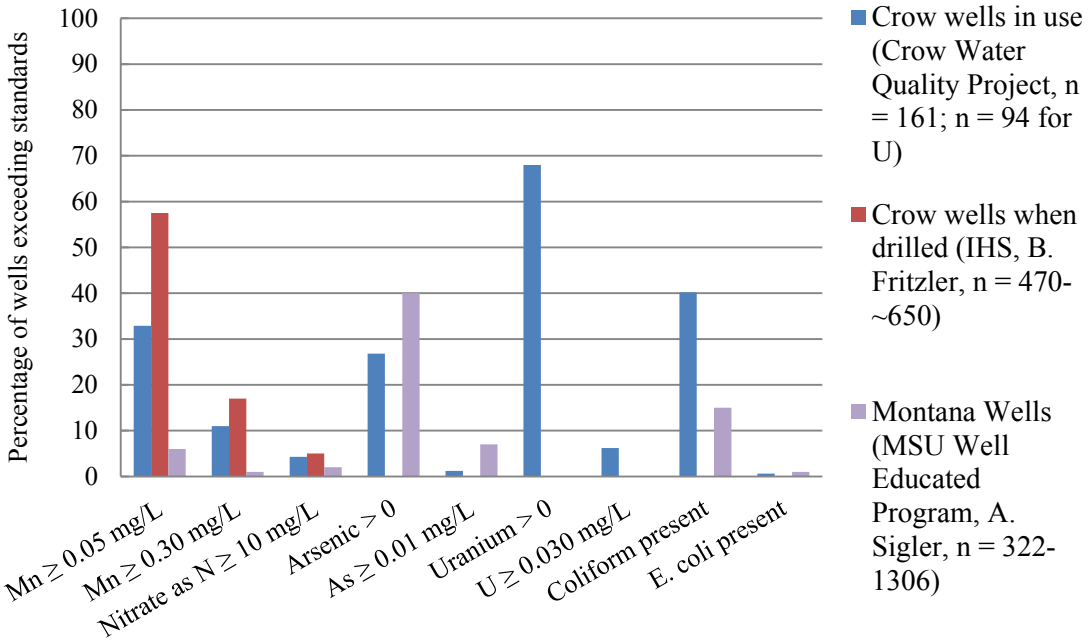


Figure 4.2. Percentage of home wells exceeding EPA's maximum contaminant level (MCL), maximum contaminant level goal (MCLG) or health advisory

The percent of wells exceeding the EPA MCL for nitrate plus nitrite as N (10 mg/L) is low (4.3 % our data, 5% IHS data) but double the statewide statistic of 2%

(Sigler 2012). Nationally, 4.4% of wells tested by the USGS exceeded the nitrate maximum contaminant level (DeSimone 2009).

There are two EPA standards for arsenic, a maximum contaminant level goal of 0.000 mg/L ("MCLG," based solely on health) and a maximum contaminant level of 0.010 mg/L ("MCL," based on health and economics) that community water systems must meet. Twenty-seven percent of home wells we tested had detectable arsenic, i.e. they exceeded the MCLG, while only 1% exceeded the MCL. The IHS only rarely tested home wells for arsenic. Statewide, arsenic in well water is a more common problem, with 7% of wells exceeding the MCL (Sigler 2012) (Figure 4.2), comparable to the 6.8% of wells over the MCL in the USGS national study (DeSimone 2009).

Sixty-eight percent of the tested wells were positive for uranium, exceeding EPA's MCLG for uranium of 0.000 mg/L – i.e. uranium presents some degree of health risk in two thirds of wells. EPA's MCL of 0.030 mg/L was exceeded in 6.2% of wells. Historically, home well water has not been tested for uranium (MT DEQ 2009); hence there are neither IHS nor statewide data for this contaminant (Figure 4.2). Nationally, only 1.7% of wells tested by the USGS exceeded the MCL for uranium.

Other national and international standards for uranium in drinking water are stricter. In Canada, the "maximum acceptable concentration" is 0.020 mg/L (Health Canada 2011), which was the standard initially proposed for the US EPA, but rejected based on a cost-benefit analysis (Brugge et al. 2005). The World Health Organization has recommended a guideline value of 0.015 mg/L (WHO 2004). Of Crow wells tested, 16.8% exceeded this WHO guideline value.

Presence/absence tests for coliform and *E. coli* in water are conducted to assess the risk of fecal contamination. The presence of coliform bacteria indicates that other harmful bacteria could be present; EPA's MCLG is zero total coliform (EPA 2013b). Of the wells we tested, 40.2% were positive for coliform and hence exceeded EPA's MCLG, nearly triple the statewide frequency of 15.0% (Sigler 2012), and higher than the 33.5% of wells tested by the USGS nationwide (DeSimone 2009). The MCL for coliform for municipal water is based on repeated sampling; our resources only allowed for one test per household, hence our data cannot be assessed against the MCL for total coliforms. The Indian Health Service only tested wells at the time of installation, when new wells were shock chlorinated, hence their data on coliform and *E. coli* presence are not a measure of usual microbial contamination. The presence of *E. coli* bacteria confirms that there is fecal contamination of the water source from warm blooded animals (EPA 2013b). This is uncommon both on the Reservation (0.6% of tested wells) and statewide (1.0%) (Figure 4.2)(Sigler 2012), and more common nationally (7.9% of wells)(DeSimone 2009).

Crow families are also exposed to microbially contaminated water sources through traditional and recreational uses of river water (Hamner et al. 2013; Hunnes 2014) and spring water (Dietrich et al. 2013). Even municipal water during and after spring flooding presents a risk, as standard municipal water treatment technology is unable to completely remove *Cryptosporidium* oocysts from the river water (Broadaway 2014). The microbial exposure risk could add to the chemical exposure risk. For instance, both exposure to nitrate in drinking water and enteric infections increase risk of methemoglobinemia in infants, as such infections can increase endogenous nitrite

production (Ward et al. 2005). Fecal contamination of well water could cause enteric infections. However, the cumulative risk assessment presented here will be limited to addressing the three most common serious inorganic contaminants: uranium, manganese and nitrate.

Spatial Distribution of Well Water Contaminants by GIS Maps and Zip Codes

Understanding the spatial distribution of well water contaminants is vital for risk assessment, communication and mitigation. The Reservation's three main river valleys, from west to east, are Pryor Creek, the Bighorn River and the Little Bighorn River, all of which flow south to north, separated by mountain ranges (Figure 4.3). Crow settlements have traditionally been along the rivers and creeks, and that pattern continues today. The resulting zip code boundaries follow watershed boundaries on the Reservation, and as zip codes are known to every resident, average contaminant concentrations by zip code proved to be a useful way to depict how exposure risk varies by location. The zip codes map to these watersheds: Pryor and South Billings comprise the Pryor Creek watershed, Fort Smith, St. Xavier and Hardin are in the Bighorn River watershed, and the Wyola, Lodge Grass, Reno and Crow Agency zip codes make up the Montana portion of the Little Big Horn River watershed. As shown in Figure 4.3, zip codes also largely correspond to the traditional "districts" of the Reservation, with the exception of the Black Lodge District which encompasses parts of two watersheds. (See Appendix D.)

Initially, GIS maps were prepared to show both spatial patterns and the considerable variability in contaminant levels even among neighboring wells. In the Little Big Horn River Valley, the presence of a second, deeper aquifer with better water

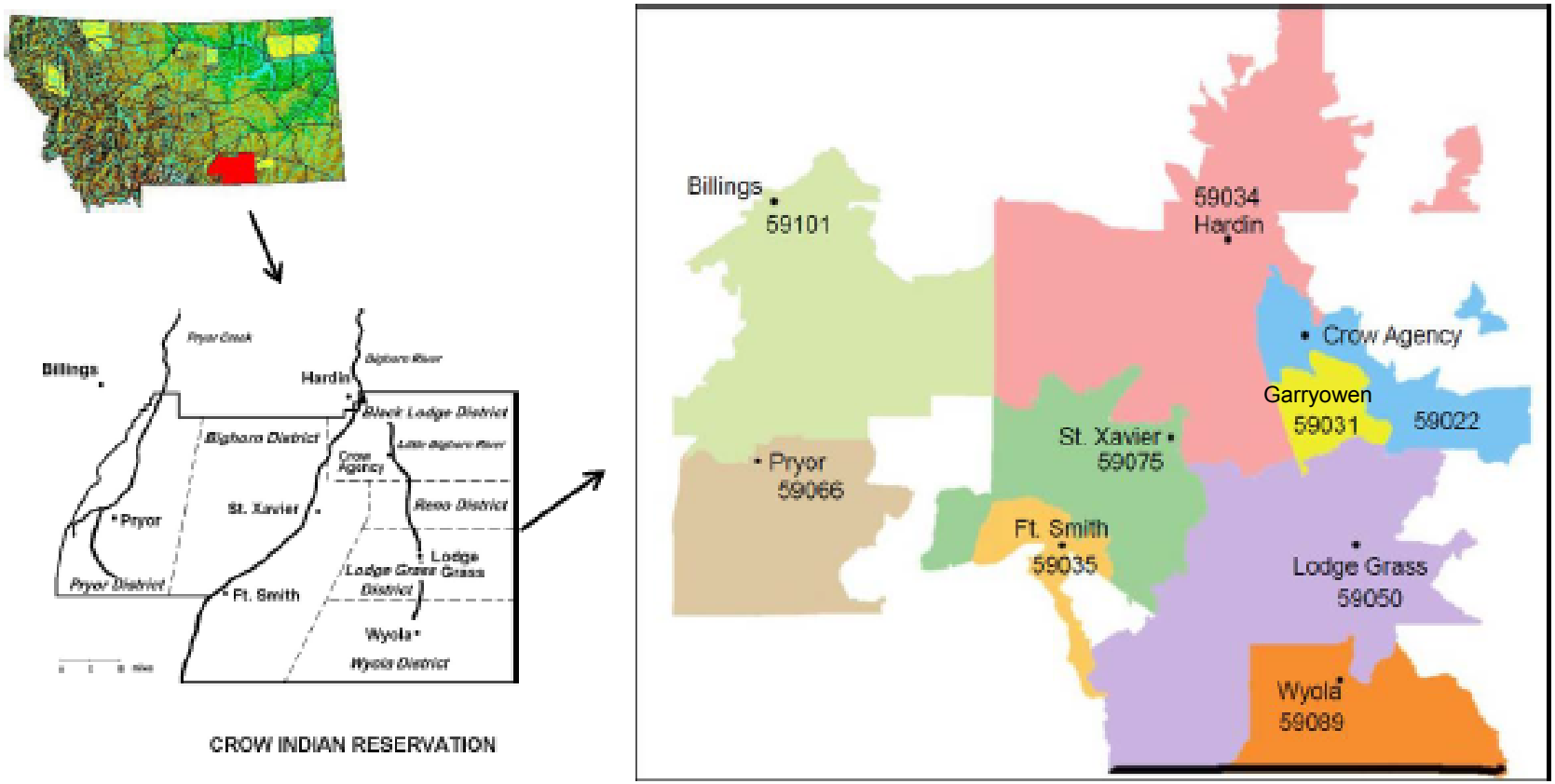


Figure 4.3. Maps of the Crow Reservation, showing location within Montana (USDA 2002); major rivers, towns and traditional districts of the Reservation (LBHC 2012); and zip code districts by town (Dirckx 2014).

quality in some parts of the valley (Tuck 2003) is probably a contributing factor. For inorganic contaminants, the data show differences among watersheds and generally worsening water quality with distance down gradient.

Manganese

Wells with manganese contamination at a concentration exceeding the EPA's health advisory are shown in Figure 4.4 as red and purple circles: wells in the lower (more northerly) Bighorn and Little Bighorn watersheds are most at risk, but well owners in all parts of these watersheds should consider testing for manganese. Averaging well water manganese concentrations by zip code shows that wells in the Hardin zip code exceed the EPA Health Advisory Standard, and wells in the South Billings, St. Xavier and Crow Agency zip codes have elevated manganese levels (Figure 4.5).

Manganese concentrations of 0.30 mg/L or more in drinking water cause neurologic damage in children, including lowered IQ and changes in behavior and memory. Even very short term exposure (ten days) can be damaging to infants. In adults, long term exposure can result in manganism, a disorder characterized by tremors, facial muscle spasms and difficulty walking (Bouchard et al. 2010; ATSDR/CDC 2012). Nuisance levels of manganese can give the water a poor taste and cause staining.

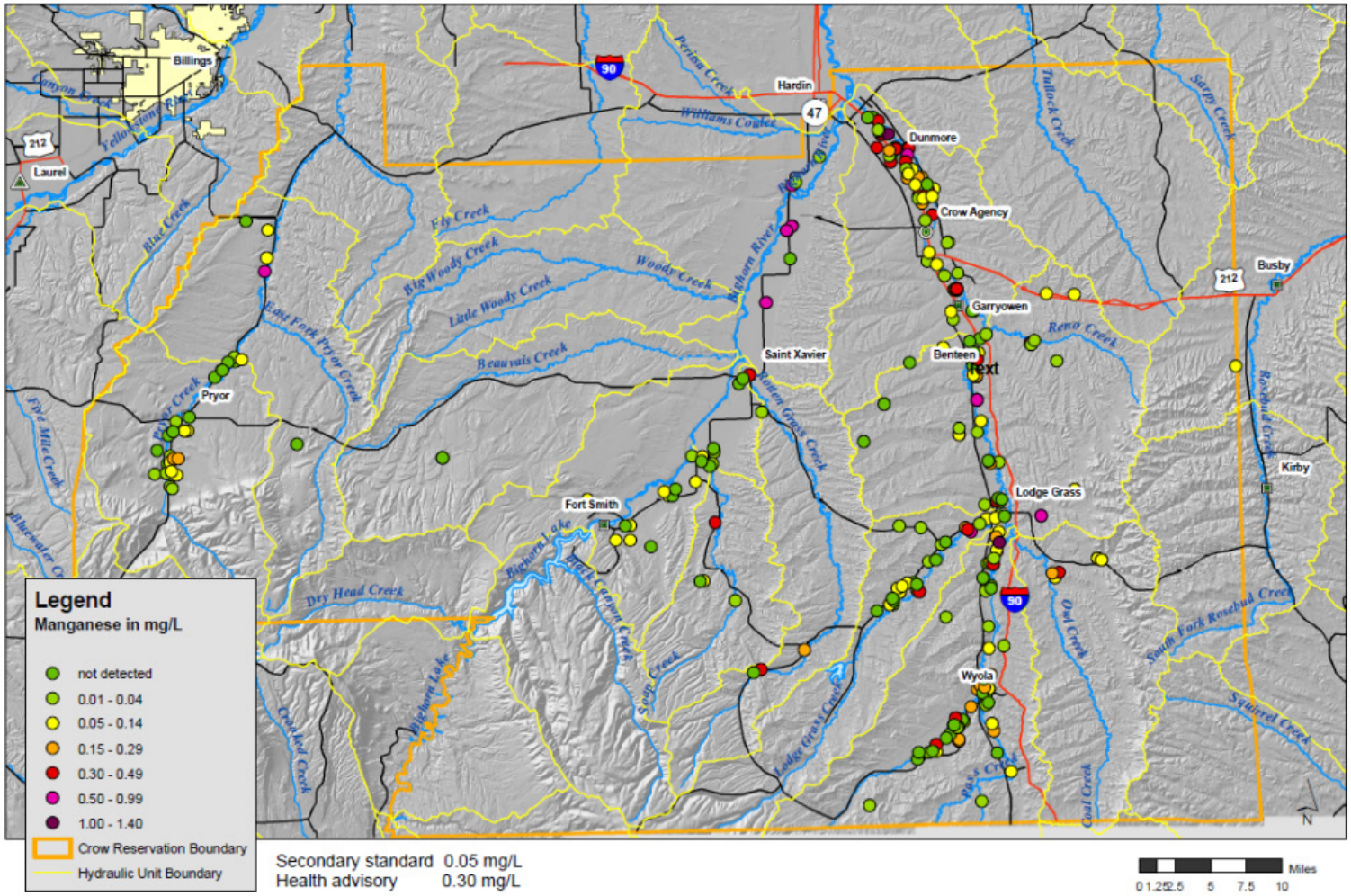


Figure 4.4. Distribution of manganese contamination in home well water on the Crow Reservation, Montana.

Pryor Creek	
South Billings	0.14 ± 0.29
Pryor	0.005 ± 0.001

Bighorn River Valley	
Hardin	0.35 ± 0.43
St Xavier	0.19 ± 0.29
Fort Smith	0.02 ± 0.02

Little Bighorn River Valley	
Crow Agency	0.14 ± 0.18
Garryowen	0.07 ± 0.11
Lodge Grass	0.05 ± 0.10
Wyola	0.08 ± 0.11

0 - 0.04 mg/L: Acceptable, below EPA Secondary Standard
0.05 - 0.29 mg/L: Nuisance. Exceeds EPA Secondary Standard but not EPA Health Advisory.
≥ 0.30 mg/L or more: Unacceptable, exceeds EPA Health Advisory.

Figure 4.5. Average manganese concentrations in well water by zip code, on the Crow Reservation.

Uranium

Uranium and vanadium were historically mined directly to the southwest of the Reservation, just outside of the Reservation boundary. The yellow dots on the map in Figure 4.6 show the two abandoned mining districts in the Mississippian-aged Mission Canyon formation which hosts the mineralized uranium/vanadium deposits (Moore-Nall et al. 2013). Mapping the uranium concentration in well water in relation to the geology of the Crow Reservation shows that the highest uranium values appear to be associated with Quaternary Terrace deposits in the lower Big Horn River Valley (Moore-Nall 2013). These valley fill sediments could have eroded from the uranium bearing upland bedrock, as is the case elsewhere in Montana (MT DEQ 2009).

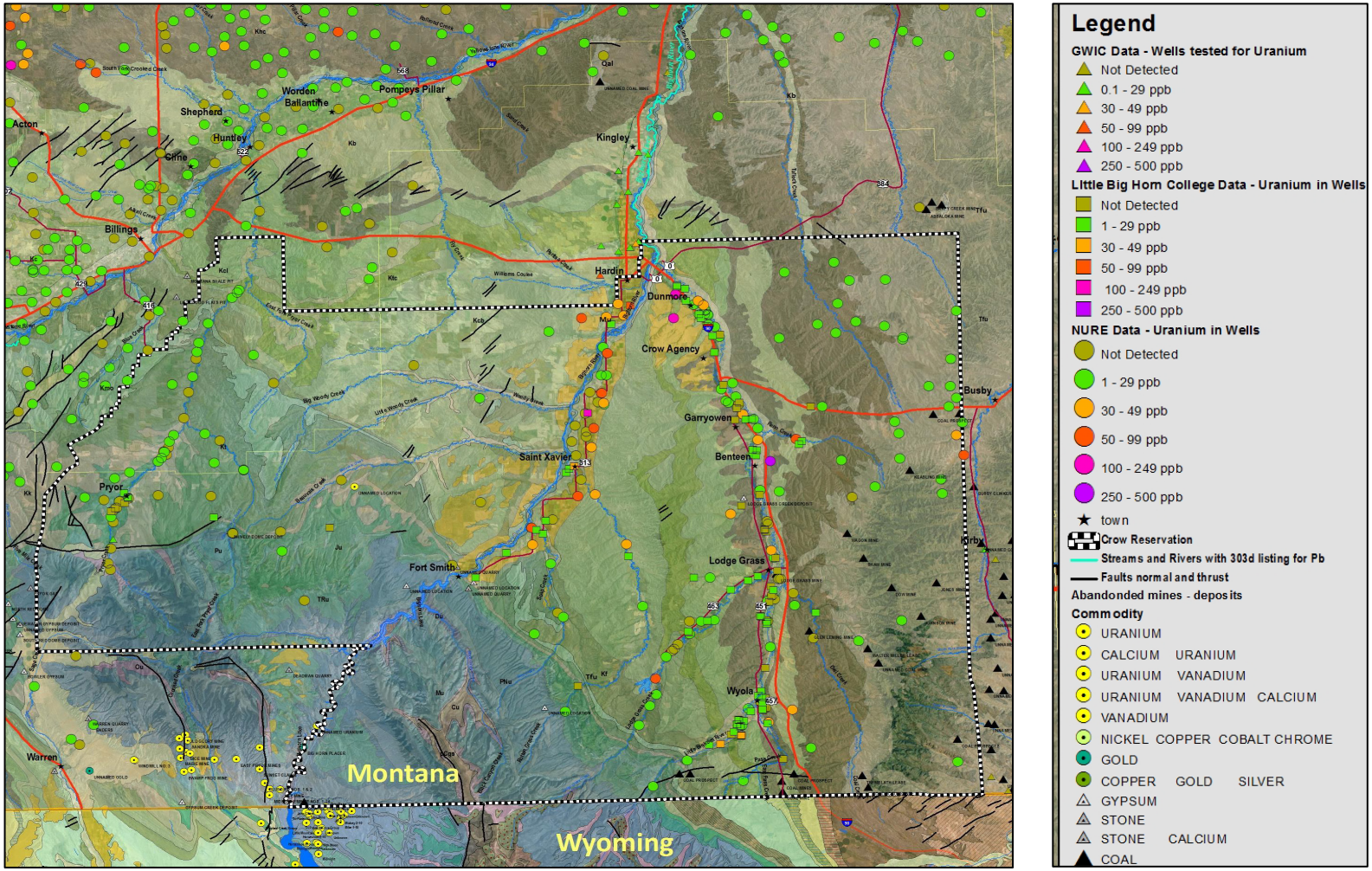


Figure 4.6. GIS generated map showing geologic formations, locations of old uranium mines and well water data from three data bases: the USGS NURE-HSSR data base; the Montana Bureau of Mines and Geology GWIC data base and our data.

Pryor Creek	
South Billings	not detected
Pryor	0.001 ± 0.002

Bighorn River Valley	
Hardin	0.010 ± 0.021
St Xavier	0.018 ± 0.030
Fort Smith	0.005 ± 0.008

Little Bighorn River Valley	
Crow Agency	0.006 ± 0.009
Garryowen	0.002 ± 0.004
Lodge Grass	0.002 ± 0.003
Wyola	0.007 ± 0.012

Not detected: Ideal
0 - 0.014 mg/L: Undesirable. Exceeds the EPA MCLG of 0 mg/L.
0.015 - 0.029 mg/L: Undesirable. Exceeds the EPA MCLG and the World Health Organizations' guideline value of 0.015 mg/L (WHO 2004).
≥ 0.030 mg/L: Unacceptable. Exceeds the EPA's MCL.

Figure 4.7. Average uranium concentrations in well water by zip code, Crow Reservation.

Averaging well water uranium concentrations by zip code (Fig. 4.7) shows that well owners in the St. Xavier zip code in the Bighorn River Valley are most at risk for contaminated wells. Rural homeowners throughout that valley, as well as those in the Crow Agency and Wyola zip codes should also consider testing their wells for uranium (Figure 4.7). As the two most populated local communities – Hardin and Crow Agency – use the Bighorn and Little Bighorn Rivers respectively for their municipal water supplies, water samples were collected monthly from both rivers over an eight month period, delivered to the EPA-certified lab in Billings and tested for the same parameters as well water, including uranium. The Little Big Horn River was found to have very low level uranium (up to 1.5 µg/L); the Big Horn River at Hardin averaged about 4 µg/L uranium.

Hence local well owners are at higher risk of uranium exposure through their drinking water than residents of towns which use surface water sources for their supply.

Uranium, a radionuclide which emits primarily alpha particles, has a variety of associated health risks. Although most of the uranium and daughter products consumed in drinking and cooking water are eliminated, small amounts are absorbed from the digestive tract and enter the bloodstream. Uranium in the bloodstream is filtered by the kidneys, potentially causing nephritis (WHO 2004). Uranium is deposited primarily in bones (Kurttio et al. 2005). Exposure can increase cancer risk and lead to liver damage (EPA 2012). Additional documented health outcomes of concern include effects on the brain, diminished bone growth, DNA damage and developmental and reproductive effects (Brugge et al. 2005, Brugge et al. 2011). The health risks from uranium in drinking water are greatest for infants and young children, who can suffer lasting damage from exposure at critical times in their growth (Georgia DHR 2013). Drinking and cooking with uranium contaminated water is the primary route of exposure to uranium in well water, as absorption through skin is minimal (Montana DEQ 2009).

Nitrate

Nitrate contamination of shallow groundwater is a concern on the Reservation as more than 1.7 million acres of the total 2.3 million acres - about 76% - of the land base is farmed (USDA 2007). Agricultural areas in the United States have been shown to have the highest nitrate levels of any major land use (Ward et al. 2005). Elevated nitrate in well water was found primarily in the Bighorn River Valley, where irrigated agriculture is most extensive (Figure 4.8). Nitrate levels in Bighorn River valley wells were

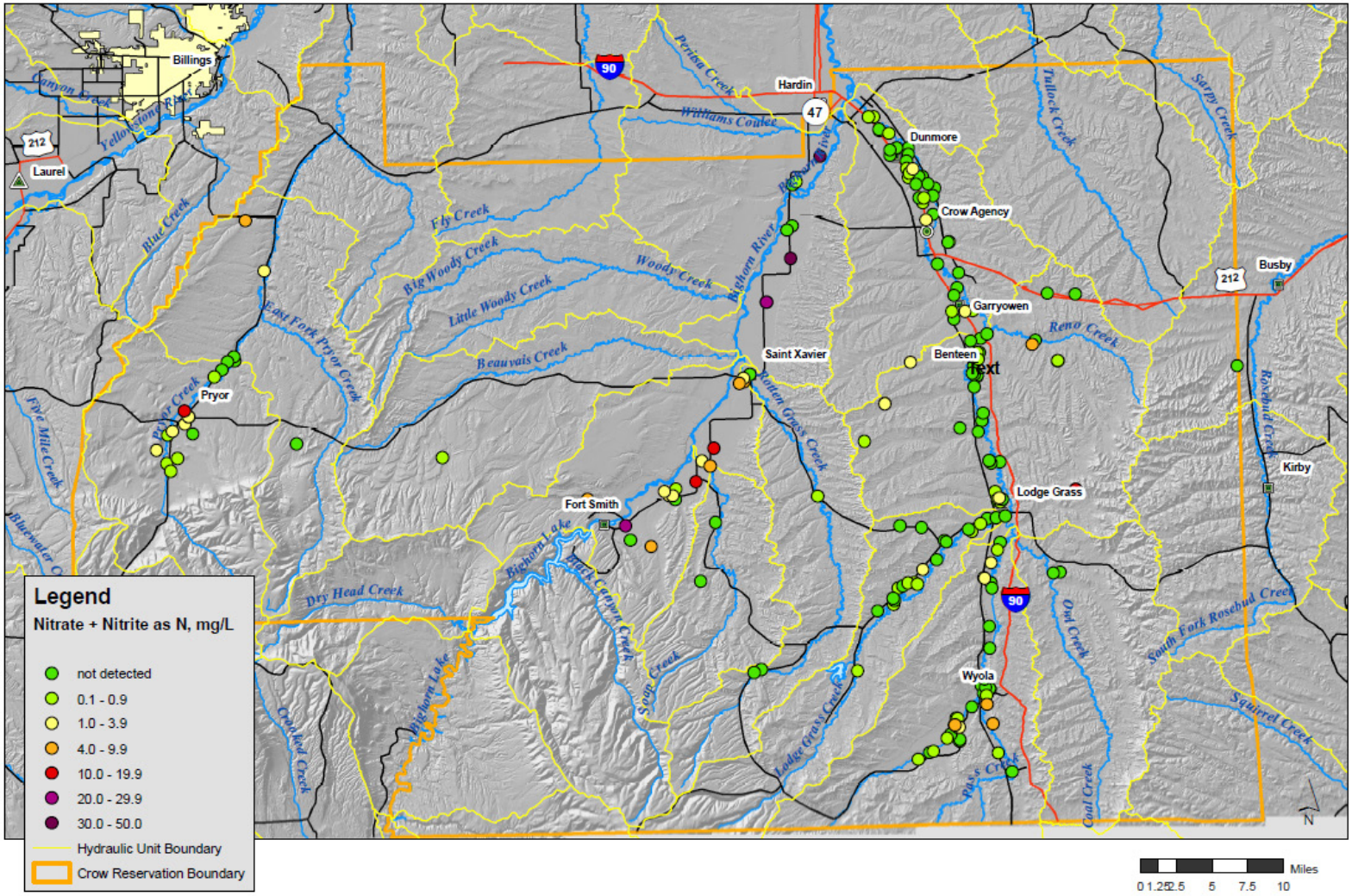


Figure 4.8. Distribution of nitrate contamination in home well water on the Crow Reservation, Montana.

Pryor Creek	
South Billings	1.68
Pryor	2.08

Bighorn River Valley	
Hardin	12.20
St Xavier	4.80
Fort Smith	7.10

Little Bighorn River Valley	
Crow Agency	0.28
Garryowen	0.44
Lodge Grass	0.20
Wyola	0.66

< 1 mg/L: Naturally occurring.
1.0 - 3.9 mg/L: Potential contamination from anthropogenic sources.
4.0 - 9.9 mg/L: Likely contaminated by anthropogenic sources.
10.0 mg/L or more: Exceeds EPA's MCL due to serious health risks.

Figure 4.9. Average nitrate concentrations in well water by zip code, Crow Reservation.

significantly higher than in Little Bighorn River valley wells ($p = 0.029$) (Fig. 4.9).

Nitrate levels exceeding 10.0 mg/L are a particular concern for pregnant women and families with infants and children. Infants exposed to high nitrate levels in their water or formula are at risk for methemoglobinemia, or "blue baby syndrome," in which nitrate binds to hemoglobin in their blood, resulting in reduced oxygen transport. This condition requires immediate medical attention and can be life threatening (EPA 2007). In a review of the effects of nitrate exposure on children's health, the EPA found that fetal exposure to elevated nitrate levels has been associated with higher risk of cardiac and nervous system defects, intrauterine growth retardation and sudden infant death syndrome (2007). Exposure to drinking water nitrate levels below the MCL has been repeatedly correlated with increased risk of developing Type I childhood diabetes (Ward et al. 2005). There is conflicting evidence of increased risks of leukemia, brain tumors and nose and throat tumors in children, and/or risks of stomach, gastric and other cancers

in adults (EPA 2007). Chronic exposure can cause spleen hemorrhaging in adults (EPA 2007). An excellent review of drinking water nitrate health effects is provided by Ward et al. 2005.

Common anthropogenic sources of nitrate include agricultural fertilizer, wastewater and septic systems. The significantly elevated well water nitrate levels in Bighorn River valley, which is the most intensively irrigated, points to primarily agricultural sources. Well water nitrate levels were also analyzed against well owner survey data, which showed that nitrate concentration did not significantly correlate with distance between the home well and the septic system (< or > 100 feet), whether the septic system had been pumped in the last two years nor whether livestock were present (at $p \leq 0.10$).

Cumulative Risk Assessment

Hazard indices (HI) based on exposures to manganese, uranium and nitrate were calculated for each well and then summarized in two ways. First, the percent of home wells with an HI exceeding 1.0 was calculated for each river valley, and broken down by zip code within the Little Bighorn River Valley. Next, the average well water HI for each of these regions was calculated (Table 4.1). The Bighorn River Valley had the worst average well water quality, with 58.3% of wells exceeding an HI of 1.0, and an average HI of 2.21. The Crow Agency and Wyola zip codes within the Little Bighorn River valley had moderate levels of contamination, with 30.0% and 23.1% of wells, respectively, exceeding the level of concern for cumulative risk, and average HIs of 0.90 and 0.65.

Table 4.1. Individual wells with Hazard Index for Uranium, Manganese and Nitrate Exceeding 1.0

River Valley	Number of wells tested	Percent of wells with Hazard Index > 1.0	Average Hazard Index
Pryor Creek	9	11.10%	0.38
Bighorn River Valley	12	58.30%	2.21
Little Bighorn River Valley	73	15.10%	0.52
Crow Agency	10	30.00%	0.9
Garryowen	12	8.30%	0.44
Lodge Grass	25	4.00%	0.28
Wyola	26	23.10%	0.65
Reservation Wide Average	*94*	*20.20%*	*0.72*

Sources of Uncertainty

The risks from radionuclides are probably underrepresented. Well water testing for uranium progeny such as radium and radon, and the inclusion of those data into the HI calculations, would likely increase the percentages of wells presenting health risks to residents. This was shown to be the case in southwest Montana, where the USGS tested home well water for uranium and its progeny. The study found that 14.1% of 128 wells tested exceeded the MCL for uranium, but when radon, radium 226, radium 228 and/or alpha or beta particles were considered along with uranium, 29% of wells exceeded the drinking water standard (Caldwell et al. 2011). Elevated levels of uranium progeny (along with uranium) have been found to occur in groundwater where there is uranium mineralization (Pelizza et al. 2013). Higher concentrations of radium have been found to be associated with manganese or iron-rich anoxic groundwater (Szabo 2013), and the

lower watersheds of all three river valleys are relatively high in manganese (Figure 4.5). Additionally, average iron concentrations in well water substantially exceeded the EPA secondary standard of 0.30 mg/L in every zip code in the Big Horn and Little Big Horn River valleys, with the exception of Fort Smith in the upper Big Horn River watershed. Nationally, radon is also a relatively common well water contaminant: the USGS found 4.4% of home wells tested in 48 states exceeded the EPA's proposed MCL of 4,000 pCi/L for radon, and 65% exceeded the alternate proposed MCL of 300 pCi/L (DeSimone 2009). Testing for uranium, radium and radon should be included in any future "complete domestic analysis" of home well water on the Reservation.

While concentrations of naturally occurring manganese and uranium in deeper groundwater are unlikely to change significantly, researchers in the eastern U.S. have found concentrations of naturally occurring inorganics in shallower groundwater to fluctuate with high precipitation events (Fields 2014). We lack data as to whether this applies in the drier northern Plains. Due to the expense of collecting and testing well water samples from homes distributed throughout a 2.7 million acre Reservation, each home was only sampled once. Nitrate contamination levels from agricultural sources might be more likely to vary seasonally. However, any temporal variability would be somewhat compensated for by our sampling year round throughout a two year period.

The hazard index method of calculating cumulative risk assumes that the health effects of each contaminant are additive, not synergistic nor antagonistic. In the absence of data on the toxicology of the combination of uranium, manganese and nitrate, this is the recommended approach for cumulative risk assessment (EPA 2003).

An additional source of uncertainty is whether pesticides are present and contributing to people's cumulative exposures. The USGS is currently conducting a pesticide assessment of the groundwater in the Big Horn River valley on the Crow Reservation, so those data will be considered in this assessment when they become available.

Further, 40% of wells were coliform positive, but this study does not address the magnitude of the health risk this poses nor the potential for exposure to microbial contaminants to interact with exposures to inorganic contaminants.

The sampling strategy for participation in this study could have biased results. While one might suspect that families with poor quality well water would have been more likely to participate, comparing our data with the IHS well water database shows that families with poor quality well water were *underrepresented*. Perhaps families who neither drink nor cook with their water had less reason to take the time to participate?

Finally, the USGS estimate that 40 – 60% of families in Big Horn County rely on wells is an inexact statistic, and it includes the one third of the County population which is non-Native. However, even if 60% of Native families on the Reservation rely on wells (about 1060 homes), our testing of 151 wells still represents a more than adequate sample size.

In sum, although there are numerous sources of uncertainty, particularly with regards to whether other potential (radionuclides and pesticides) and known (microbial) contaminants are contributing to the health risks, the potential for error is primarily in having *underrepresented* the health risks to families using wells.

Risk Communication

Efforts to communicate the risks from contaminated well water – to participating families, to the community at large and to local teachers – have been ongoing, as described above. Now with both GIS maps and zip code summaries of cumulative risk prepared, we sought to communicate the project's final results by answering the question, "How do I know if I should get my well water tested?" Readily observable indicators of serious contamination issues were needed.

Manganese and iron are chemically similar elements and tend to co-occur in rock formations, so iron staining of sinks and other fixtures was a candidate for indicating the presence of manganese. High total dissolved solids, which families can recognize as poorly tasting water, was a potential indicator for both high manganese and uranium. For project staff, pH could also be a useful indicator. Multiple regression analysis found that the log [iron] ($p < 0.001$), pH ($p < 0.001$) and log TDS ($p = p.004$) were useful predictors of manganese in the Little Bighorn River Valley ($R^2 = 0.605$). Log [iron] ($p < 0.001$), and log TDS ($p = 0.02$) were similarly significantly predictive in the Bighorn River Valley ($R^2 = 0.625$). The groundwater in the Pryor Creek watershed has much lower concentrations of manganese, and here only log TDS ($p = 0.076$) was marginally useful.

Similar regression analyses found that TDS was significantly associated with uranium in the Big Horn River Valley ($R^2 = 0.828$) and in Pryor ($R^2 = 0.719$). In the Little Big Horn River valley, both TDS ($p < 0.001$) and pH ($p < 0.001$) were predictive of uranium ($R^2 = 0.446$). This agrees with nationwide data that found a correlation between uranium and oxic waters with a pH in the range of 6.5 to 8.5 and the presence of high carbonate levels - and high TDS levels if the other criteria were true (Szabo 2013). Wells

on the Reservation with elevated uranium were all the in pH range of 7.0 to 8.0. Based on the wells we tested, bicarbonate levels are high in all three river valleys, ranging from a mean of 350 mg/L in Pryor to 495 mg/L in the Little Big Horn River Valley.

Sources of elevated nitrate are generally anthropogenic, primarily from sewage, wastewater and agricultural sources (WA State Department of Agriculture 2010), so the occurrence of high nitrate levels in well water was unlikely to be correlated with high TDS in groundwater on the Reservation, which consists primarily of sulfate, bicarbonate and sodium. Regression analyses of nitrate or log nitrate vs. TDS or log TDS gave at best an R^2 value of 0.074. Survey data on well and septic system factors were compared with well water nitrate concentrations to examine whether septic systems or livestock could be contributing to elevated nitrate levels. T-tests comparing well water data with survey data found that nitrate concentration did *not* significantly correlate (at $p \leq 0.05$) with distance between home well and septic systems (< or > 100 feet), with whether the septic system had been pumped in the past two years nor with livestock presence. However, nitrate was found to correlate significantly with river valley. Big Horn River valley residents were significantly more likely to have high nitrate levels in their well water than Little Big Horn Valley residents ($p = 0.02$). Seventy-six percent of the Reservation is in farmland (USDA 2007), with the majority of irrigated agriculture occurring in the Big Horn River Valley. The primary source of high nitrate levels in well water thus appears to be farming practices, rather than homeowner management of their septic systems or livestock.

Based on the above analyses, and the known health risks from uranium, manganese and nitrate, a press release was written for the Tribal newspaper advising rural

residents to test their wells for inorganic contaminants if any of the following factors applied: (1) home located in the Big Horn River valley or the Crow or Wyola Districts of the Little Big Horn River Valley, (2) nearby farming, (3) water unsuitable for drinking but in use for cooking, or (4) infants, children or pregnant women in their family (Appendix B).

Health Disparities: Economics

As the USGS acknowledged in its nationwide study, both well water quality data and well water consumption data are needed to assess the health risks from groundwater contamination (DeSimone 2009). Our survey results (Table 4.2) document that 20% of well owners neither drink nor cook with their well water (Group I), 20% only consume their well water through cooking (Group II) and 60% of well owners both drink and cook with their well water (Group III). All well owners who participated in this study use their well water for bathing, washing dishes and cleaning their house, regardless of the water quality.

Families who drink and cook with their well water (Group III) have an average TDS level of 959 mg/L in their water – almost double the EPA's secondary standard of 500 mg/L. Although their well water is thus on average considered "objectionable" for consumption (MSU 2014), they have significantly better well water quality, based on total dissolved solids (TDS), than families who consume well water through cooking (Group II) ($p = 0.002$) or don't consume it at all (Group I) ($p = 0.001$). (Table 4.2.)

Why are some families still cooking with their poor quality well water, while other families are not? Could differences in taste or odor account for this? A comparison

Table 4.2. Relationship of well water quality to consumption

Well water use	Number of families	Drink well water?	Cook with well water?	TDS in mg/L		Percent wells with Hazard Index > 1.0
				Mean	SD	
Group I	30	No	No	2262	1726	42.9
Group II	31	No	Yes	1970	1466	19.0
Group III	91	Yes	Yes	959	578	11.5

of well water quality between families in Group I vs. Group II found no significant difference in well water quality at the $p < 0.05$ level, whether quality was rated by log TDS ($p = 0.355$), log sodium ($p = 0.997$), log sulfate ($p = 0.723$), log uranium ($p = 0.291$), log manganese ($p = 0.581$), log hardness ($p = 0.101$), log iron ($p = 0.054$) or coliform contamination ($p = 0.81$). However, note that Group I wells did have higher iron concentration on average ($M = 1.33 \pm 2.15$ mg/L) than Group II wells ($M = 0.58 \pm 1.09$ mg/L), and the difference is nearly significant (log iron, $p = 0.054$). Possibly the taste and/or the color of iron in water is protecting some families from cooking with unpalatable water. The difference between families who use their well water for cooking and those who don't consume any well water is not due to water odor: while 87.5% of families in Group I noted their well water had an odor, compared to 71.4% of families in Group II, the difference was not statistically significant ($p = 0.27$, Fisher's 2-sided test).

The presence or absence of well water treatment technology account for this difference in well water use between Group I and Group II families. Although 77% of all wells tested have unacceptably hard water (in excess of the EPA secondary standard), only 3.3% of families had installed a water softener. While 85% of all wells tested exceed the EPA secondary standard for TDS, only 4% of families had a reverse osmosis

system. Despite the widespread high levels of iron and of manganese, no participating family had installed an iron removal unit (which also removes manganese). Crow Environmental Health Steering Committee (CEHSC) members explain that the cost of installing and maintaining treatment technology, including the monthly cost of chemicals, is simply prohibitive for most families. As noted above, when the U.S. and the Montana per capita incomes were $27,334 and $23,836 respectively, the per capita income for the four largest Crow Reservation communities ranged from $7,354 to $8,130 (U.S. Census Bureau 2010b).

If the cost of installing and maintaining water treatment systems is prohibitive, why aren't all or most families with poor tasting well water hauling water for cooking as well as drinking? The cost of obtaining safe drinking water is an important factor. Surveys documented that the most common alternate water source for home use was bottled water (53% of all families), with less common alternatives being municipal water (17%), another family's home well (12%) or springs (4%). In depth interviews with key informants (n = 30) documented that even purchasing and hauling bottled water was a significant expense, as families typically buy cases of individual bottles of water in the larger towns, 20 to 65 miles away (McCormick et al. 2013). As one well owner commented, *"On occasions like holidays and stuff, I even will buy extra water, so I cook with that so that my husband doesn't get sick or my daughter doesn't get sick."*

Health Disparities: Lack of Public Environmental Health Education

In addition to limited financial resources, lack of public environmental health education contributes to drinking water disparities on the Crow Reservation. CEHSC

members explain that indoor plumbing was not installed in rural homes until the 1960s, and when it arrived, there was no accompanying public education effort to explain how to maintain wells and septic systems, how to protect one's well water from contamination nor what the health risks could be from contaminated well water. Without generations of experience with indoor plumbing, there was no community knowledge base as a resource. Only 21% of survey respondents "felt confident" they understood well function, maintenance and safety procedures; this group was significantly more likely to have a sanitary (waterproof) cap on their well head, at the $p < 0.10$ level (Fisher 1-sided, $p = 0.058$). However, even this group was no more likely to have pumped their septic system in the past two years, nor to be keeping livestock away from their wellhead. Of other respondents, 20% skipped the question and 58% thought they would benefit from learning more (112/192 people). Of those 112 respondents, 55% preferred to have information mailed to their home, 36% were interested in having someone visit to explain in person, 27% thought articles in local papers would be helpful and only 22% would consider attending a public information session offered in their community. In response to a survey question about other suitable avenues for public education, no one suggested social media, although if those venues had been spelled out as options there might have been a positive response. These results will be useful in designing future public health education efforts.

Health Disparities: Legal and Jurisdictional Issues

Additionally, the Apsaalooke Water and Wastewater Authority identifies inadequate environmental enforcement and the complex legal, jurisdictional and

regulatory issues on Reservations as contributing factors to drinking water disparities (Doyle et al. 2013). Similar issues have been experienced by other Tribes (EPA 2013). For instance, the Reservation community currently has no control over groundwater contamination from the extensive agriculture all around them, almost exclusively carried out by non-Tribal members. Other minority communities have also described insufficient enforcement of environmental regulations and inadequate laws governing non-point source pollution from agriculture as factors contributing to drinking water health disparities (e.g. Firestone et al. 2006).

Health Disparities: Underlying Health Conditions

Community members burdened by existing health conditions are likely to be more vulnerable to the impacts of well water contamination. Hence health disparities from poor quality drinking water both contribute to and are exacerbated by existing health disparities. For instance, the high rate of diabetes on the Reservation (double the statewide average) could mean that more people are particularly vulnerable to the nephrotoxic effects of uranium. Children already exposed to lead paint in their older homes might be even more affected by the neurotoxic effects of manganese.

Conclusion

Based on recognized criteria for prioritizing and addressing exposures to environmental chemical mixtures (Sexton and Hattis 2007), home well water on the Crow Reservation should be addressed as a high priority public health issue:

(1) *Breadth of exposure.* Roughly 50% of Apsaalooke families rely on home wells for their domestic water supply (DeSimone 2009); 80% of these families drink and/or cook with their well water. Naturally occurring high levels of manganese, uranium and possibly other radionuclides are widespread in the Big Horn and Little Big Horn River valleys on the Reservation.

(2) *Nature of exposure.* People consume well water daily for many years. Survey data document that people who drink their well water consume about eight cups per day. Due primarily to economic constraints, half of families with unpalatable well water still use it for cooking.

(3) *Severity of effects.* All three inorganic contaminants of concern – nitrates, manganese and uranium – can have severe, lasting health effects on infants and children and can cause disease in adults (e.g. Ward et al. 2005, Bouchard et al. 2011). The nephrotoxic effects of uranium (WHO 2004) and the association of nitrates in drinking water with childhood diabetes (EPA 2007) are a particular concern given the high diabetes prevalence rate of 12.1% in Big Horn County, compared to 6.2% statewide (Mark and Byron 2010).

(4) *Interactions.* The interactive direct effects of uranium, manganese and nitrates on human health are unknown. Interactions as understood in an ecological framework include natural, built and sociopolitical factors (Balazs and Ray 2014), all of which contribute to local health impacts from water contamination.

As detailed above, well contamination exacerbates local health disparities, because of (a) the geology of the Reservation, (b) vulnerability due to an excessive burden of underlying health conditions and poor access to health care, (c) limited financial

resources, which preclude families from drilling deeper wells, installing cisterns, adequately treating poor quality well water or even purchasing and hauling sufficient water for all consumptive uses, (d) historic lack of community education and hence low environmental health literacy regarding water quality and well and septic system maintenance and (e) inadequate environmental regulation of non-point source pollution from agriculture and limited environmental enforcement, along with additional legal and jurisdictional complexities on Reservations.

In conclusion, for families on the Crow Reservation who rely on home wells and other rural families with similar circumstances, limited access or lack of access to safe drinking water contributes to existing health disparities and is a priority public health issue in the United States.

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CHAPTER 5

DISSERTATION SYNTHESIS AND FUTURE DIRECTIONS

The goal of this collaborative research project undertaken by the Crow Reservation community, Little Big Horn College and Montana State University Bozeman has been to improve the health of Crow community members by assessing, communicating and mitigating the risks from local waterborne contaminants. The Reservation's surface waters and springs have always been greatly respected by the Crow people, valued as a source of life and of health and relied upon for drinking water. About fifty years ago, river water quality began visibly deteriorating with the expansion of agriculture and rural families switched to relying on home well water instead of hauling water from the rivers. For many families with highly mineralized well water, this change was a hardship: they went from having an unlimited supply of free, good quality river water, to unpalatable water dependent upon an expensive plumbing system.

Tribal members questioned the health of the rivers and well water due to visible water quality deterioration and potential connections to illnesses in the community. Community members initiated collaboration among local organizations, the Tribe and academic partners, resulting in genuine community engaged research. The first article shares what we have learned as tribal members and as researchers about working together to examine surface and groundwater contaminants, assess routes of exposure and use our data to bring about improved health of the Crow people and Crow waters.

Initial research on river water quality revealed significant microbial contamination, with *E. coli* levels exceeding recreational standards during the spring and

late summer, especially in in lower reaches of the watersheds. Collaborations with several microbiologists to further investigate river contamination documented the presence of virulent serotypes of *E. coli* as well as other serotypes with virulence genes and the year round occurrence of *Cryptosporidium* oocysts and its breakthrough into municipal water after spring flooding. Analysis of home drinking water from both municipal sources and private wells detected *Helicobacter pylori* (and other pathogens) in both tap water and tap biofilms.

Research on home well water quality found that water from about 55% of home wells is unsafe to drink due to either inorganic and/or microbial contamination. The percent of home wells exceeding the cumulative risk level of concern for only inorganic contaminants varied from 11% to 58% depending on the river valley. Exposure to contaminated well water exacerbates the community's existing health disparities due to the confluence of the area's geology, extensive agriculture, lack of public environmental health education, jurisdictional complexities of reservations, already vulnerable health status and families' limited financial resources for mitigating poor quality well water.

Limited resources as well as the links among ecosystems, cultural practices and public health will increase the impacts of climate change on reservation communities. Flood frequency, summer heat, late summer water shortage and fire severity are increasing while water quality is declining. These changes and their effects on subsistence foods will impact Reservation public health. The authors call for local research to understand and document current effects and project future impacts as a basis for planning adaptive strategies.

Risk communication and risk mitigation, not just risk assessment, have been and continue to be central to our project and pursued through numerous venues, including a very productive collaboration with the Tribe's Water and Wastewater Authority.

Future Directions - Publications

Our partnership's initial goal is to support the publication of the Broadaway and Dietrich articles, described briefly in the Scope of Work, both of which are currently in review by journals.

We follow the principle of community-engaged research that all aspects of our work are conducted collaboratively, including preparing publications. We have an invitation to submit an article to the International Journal of Environmental Research and Public Health, for a special issue called "Evaluation of Rural Water Systems and Public Health." For this, we will work together to write up Doyle's, Kindness' and others plenary presentation to the National Congress of American Indian's Tribal Leaders/Scholars Forum on solving water infrastructure challenges in a reservation community.

Although Chapter 4 of this thesis was written by Eggers, as a requirement of her doctoral degree, it describes work conducted collaboratively by the CEHSC, local project coordinators, LBHC and MSU students and Eggers. The members of the CEHSC also contributed ideas and discussed and critiqued this chapter prior to thesis defense. If the CEHSC concurs, Eggers will work with them and under the guidance of PIs Camper and Ford to reduce and edit Chapter 4 of this thesis into a journal length article, ideally for submittal to Environmental Health Perspectives. Next, our data from both well water

testing and participant surveys will be reviewed and discussed to assess the potential for and the CEHSC's interest in publishing an article on microbial risk assessment.

Key informant interviews conducted by CEHSC members McCormick and Lefthand, collaborator Pease and former student intern Felicia contain invaluable insights on the broader impacts of water quality contamination. The interviews were initially analyzed by these four Crow women following collaborative ethnography practices and analyzed by Eggers using Atlas-ti software, with guidance from Dr. Tim McCleary. One of the editors of the journal Qualitative Health Research has urged us to further analyze the data using grounded theory and to prepare an article to submit to them for review. It will be up to the interviewers as to whether they wish to pursue this. Finally, Eggers proposes to her collaborators both in Crow and at MSU to combine all these works into an ecological analysis employing the "drinking water disparities framework" recently proposed by Balazs (2014).

Student Mentorship and Community Capacity Building

A vitally important part of our work together has been to provide students, especially Crow science majors, with the opportunity to learn through personally meaningful, community-engaged research experience – with the long term goal of increasing community capacity in research, environmental protection, health promotion, risk mitigation and related STEM fields. Former interns have gone on to pursue bachelor's degrees, and several have now completed Masters degrees. These individuals are among the first Crow Tribal members to obtain graduate degrees and are now role models for younger students. Seeing this increased interest in graduate school, Eggers –

with mentorship and substantial input from Anne Camper, Sara Young and Ann Bertagnolli (MSU INBRE program) – wrote a proposal to NIH to fund what is now MSU's Graduate Education in Health for Minority Scholars (GEhMS) program. Former water quality project intern Felicia was the first to complete her Masters through GEhMS, in Family and Community Health. Another LBHC alumnus and Tribal member who participated in undergraduate research at LBHC, Nathaniel Tucker, will graduate in May 2014 with his Masters, also in Family and Community Health. An additional Crow student has applied to GEhMS to begin this fall. In a related effort, Camper and Eggers are also working with a dedicated group of MSU faculty to improve the transfer experience for Montana Tribal College science majors into STEM degree programs at MSU, funded by MSU as a Recruitment and Retention Initiative.

Community capacity in environmental health research has also increased as Steering Committee members have taken on expanded leadership roles. Founding CEHSC member John Doyle is now the P.I. on an EPA environmental justice (EJ) grant, and the co-P.I. on another EPA grant that is in the award process. The CEHSC is collaborating with Dr. Vanessa Simonds on a health literacy proposal and founding member Lefthand has offered to step into the community leadership role on that project. Former student intern and now CEHSC member Brandon Good Luck was recently elected as a Wyola Representative to the Crow Legislature. We are committed to continuing to support student and community capacity building in STEM disciplines, particularly in health and environmental fields. It is my personal goal to help create funded opportunities for Tribal community members to complete their doctorates in health, environmental or environmental health fields, and become the next generation of

academic P.I.s to teach and inspire students and collaborate with their communities, as Dr. Vanessa Simonds is now doing.

New Research, Health Education and Mitigation Projects

One new research and mitigation project is underway and three other projects are pending funding decisions. The ongoing new project is the EPA EJ grant being led by P.I. John Doyle to address the fecal contamination of Chief Plenty Coup Spring, the most culturally important spring on the Reservation. This grant was planned by Doyle, Young, Red Star (then the Director of Chief Plenty Coup Park) and Eggers, with input from other CEHSC members and Camper, and co-written by Eggers and Galbraith. Our goals are to identify the source(s) of contamination in order to be able to plan for remediation, and to conduct community education on microbial contamination of both surface and groundwater. Camper and Eggers both consult part time on this grant. New collaborators on this effort include new Park Director Chris Dantic, Dr. Carl Yeoman, whose lab is sequencing *Bacteroides* and other bacterial species in the spring water to determine source(s) of fecal contamination, and Dr. Stephanie Ewing, who brings expertise in isotopic analysis of water sources to the project.

Second, we are currently in the award process for a new EPA grant to (1) research current and projected climate change impacts on the Crow Reservation, incorporating both community climate and ecological knowledge as well as western climate science and microbiology, and (2) plan and begin implementation of adaptation measures, such as working with well owners to better protect their well heads (and hence well water) from the increasingly frequent and more extreme spring floods. This grant is being led by Co-

PIs John Doyle for LBHC and Dr. Anne Camper for MSU. Two internationally known climate change scientists will be key collaborators: Dr. Cathy Whitlock of MSU's Institute on Ecosystems and Dr. Margaret Hiza, Crow tribal member, hydrogeologist and Intergovernmental Panel on Climate Change author. Planning for this grant was a major collaborative effort of all involved partners; most of the narrative was written by Eggers and all the supporting materials were written or prepared by grantwriter Galbraith, who also assembled and submitted the grant for LBHC. If funded, Eggers will work part-time on this project on the climate change data, as a post-doc.

Two additional proposals are currently under development with new collaborators. Toxicologist Dr. Deborah Keil has submitted an INBRE proposal to pilot test a home mitigation and health assessment project with adult members of Crow families with seriously contaminated well water. This project includes a toxicological study of the health effects of the uranium-manganese-nitrate mixture, including potentially epigenetic effects, using a mouse model. Physicians Dr. David Mark and Dr. Rob Byron of Hardin's Bighorn Valley Health Center (a federally designated community health center) are new collaborators on this proposal. This proposal was written primarily by Dr. Keil, with sections on the Crow Water Quality project's data and contributions drafted by Eggers. If funded, a Tribal member will be the community coordinator and Eggers will be involved in a part-time capacity for MSU.

New MSU faculty member and Crow Tribal member Dr. Vanessa Simonds is working with CEHSC members and GEhMS scholar Deb LaVeaux on developing a health literacy project focused on river water quality and human health. If funded, CEHSC member Lefthand will become the Community Coordinator and Eggers will play

a small role (0.05 FTE) consulting on water quality issues until Simonds, LaVeaux and Lefthand gain more expertise in this area.

While this writer sees clear needs for expanded, subsidized well water testing and interventions to improve rural families' access to good quality drinking water, seeking intervention research funding may not be the best fit. Infrastructure funding, for instance, could be sought to meet community needs. Future research, intervention, capacity building and/or mitigation efforts will depend on the priorities of the Crow Environmental Health Steering Committee and the larger Crow Tribal community.

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APPENDICES

APPENDIX A

SUPPORTING INFORMATION FOR CHAPTER 1

Choose smaller fish to eat

Benefits of eating fish: Fish are a great source of protein, and eating fish regularly can help reduce your risk of death due to heart disease. *Smaller, younger fish are the healthiest choice.*

Why are younger fish a healthier choice? Chemical contamination in lakes and rivers accumulates in fish as they grow older. Mercury is a widespread contaminant of fish. "Mercury can damage the nervous system, especially the brain. Fetuses and babies are the most at risk because their nervous systems are rapidly developing. Children exposed to unsafe levels while in the womb have been found to experience delayed development in walking and talking, even though the mother was not affected. Mercury cannot be removed by trimming or cooking." (DeWeese et. al., 2009, Great Lakes Indian Fish & Wildlife Commission). Coal burning power plants are the largest source of mercury emissions (http://www.epa.gov/mercury/reportover.htm).

Rainbow Trout

Brown Trout

Brook Trout

Channel Catfish

Smallmouth Bass

Fish Advisories for the Crow Reservation			Women of childbearing age & children less than 15	Women beyond childbearing age & men 15 and older
Water Body	Type of Fish	Size of Fish	Maximum # of meals/month	Maximum # of meals/month
Based on Little Big Horn College data on mercury levels & 2005 State of Montana guidelines:				
Little Big Horn River	Brown Trout	4-12"	Unlimited	Unlimited
Little Big Horn River	Brown Trout	12-16"	2 meals/wk	Unlimited
Little Big Horn River	Brown Trout	16-20"	1 meal/mo	1 meal/wk
Little Big Horn River	Smallmouth Bass	4-8"	Unlimited	Unlimited
Little Big Horn River	Smallmouth Bass	8-12"	1 meal/mo	1 meal/wk
Little Big Horn River	Channel catfish	8-16"	2 meals/wk	Unlimited
Little Big Horn River	Mountain whitefish	4-16"	Unlimited	Unlimited
Willow Creek Reservoir	Rainbow Trout	4-12"	Unknown	Unknown
Willow Creek Reservoir	Rainbow Trout	12-16"	1 meal/mo	1 meal/wk
Pryor Creek at the Gap	Rainbow Trout	4-12"	Unlimited	Unlimited
Pryor Creek at the Gap	Brook Trout	4-12"	Unlimited	Unlimited
Based on Montana 2005 Sport Fish Advisory:				
Bighorn Lake	Walleye	9.8-15.1"	1 meal/mo	1 meal/wk
Bighorn Lake	Walleye	19.2-20.7"	1 meal/mo	1 meal/wk
Bighorn Lake	Walleye	27.0-27.5"	*Don't eat any*	1 meal/mo

Technical assistance provided by Robbin Wagner, US Fish & Wildlife Service & Montana State University Bozeman. Fish images courtesy Montana Fish, Wildlife & Parks. LBHC contacts: T Old Coyote, M Eggers, (406) 638-3145.

APPENDIX B

SUPPORTING INFORMATION FOR CHAPTER 1

EPA Greenversations

It All Starts with Science: An EPA blog about science matters

When It Comes to Water, We Are All Close Neighbors

2013 June 6

MJ Eggers, MJ Lefthand, SL Young, JT Doyle and A Plenty Hoops, with contributions from other team members: UJ Bear Don't Walk, A Bends, B Good Luck, L Kindness, AKHG McCormick, DL Felicia, E Dietrich, TE Ford, and AK Camper.

Little Big Horn River, Montana. Photo by John Doyle.

Until the 1960s, many families on the Crow Reservation still hauled river water for home use, a practice most of us remember from our childhoods. As agriculture expanded and river water quality visibly deteriorated, wells and indoor plumbing became available and rural families switched to home well water.

In many parts of the Reservation, this was a hardship, not a blessing: the groundwater tapped for home wells is high in total dissolved solids and often so rich in iron and manganese that it's undrinkable. The hard water build-up or "scale" also ruins hot water heaters. We have learned that the majority of home wells (55%) have water that presents a health risk, due to inorganic or microbial contamination or both.

As a country, we may imagine our citizens have universal access to safe drinking water—but for millions of rural residents with poor quality well water, and who can't afford cisterns, treatment systems, or all the bottled water they might want—this simply is not the case. In our communities, people are cooking with poor tasting, contaminated water, and living with the health consequences.

In 2004, Tribal members who were—and still are—passionate about and dedicated to addressing community-wide water quality issues and health disparities joined forces as

the Crow Environmental Health Steering Committee. They recruited academic partners and Little Big Horn College science majors to help.

We have been working together to research what is contaminating local groundwater and surface waters, what the health risks are from domestic, cultural, and recreational uses of these water sources, and how best to educate the community about the risks.

One challenge is that various traditional practices involve respectfully consuming (untreated) river and spring water right from the source. Maintaining these cultural practices "is part of what makes us Crow," so, instead of expecting people to simply give them up, we are collaborating with the Tribe on pursuing additional funding opportunities to address the pollution sources affecting our rivers and a culturally-important spring. We are also helping to make clear that traditional uses of river water, including drinking it untreated, need to be considered in planning, risk assessments, and policy decisions.

We are working to restore the health of our rivers and of our community. We realize it takes passion, commitment, mutual support and a broad-based, grassroots effort. We have learned that we are all close neighbors when it comes to water. How we treat our water is the respect we show to our neighbors, and how we would want them to treat us.

About the Authors: MJ Lefthand, SL Young and JT Doyle are members of the Crow Environmental Health Steering Committee (CEHSC). The Committee is made up of Crow Tribal members with varied expertise in environmental science, water resources, health, law and culture. MJ Eggers is an academic partner from Little Big Horn College and Montana State University Bozeman. A Plenty Hoops works for the Crow Tribal Environmental Protection Program. Additional contributors are members of the CEHSC, academic partners or student interns.

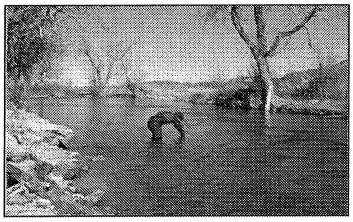
APPENDIX C

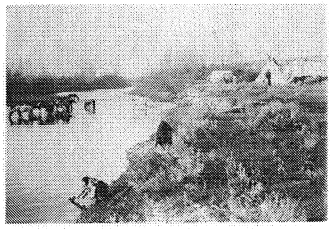
SUPPORTING INFORMATION FOR CHAPTER 4

Crow Water Project

Little Big Horn College #638-3145 or #994-3064

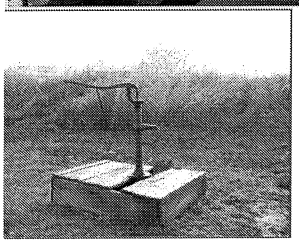
Apsaalooke Water & Wastewater Authority

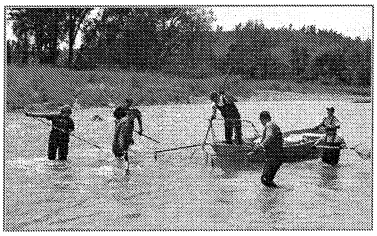




Participate in our community project:

Get your well water tested for free ($150 value)
$25-50 credit card for completing survey
Learn what you can do to protect your well
Service available until ~ May 2011, as long as funds last





Surveys can be dropped off or mailed to:
Little Big Horn College
attn. Tamra Old Coyote
PO Box 370
Crow Agency, MT 59022

Little Big Horn College

Crow Water Project

Well and Water Survey

12/12/2010

Purpose of this survey: This survey, home well water testing and home radon testing our part of the Crow Water Project. We are trying to find out if there are contaminants in people's home wells which could be contributing to health problems on the Reservation. We are concerned about cancers, especially lung and stomach cancers, and other gastrointestinal illnesses. The information obtained will be kept STRICTLY CONFIDENTIAL. As the homeowner, we will report back to you on your home radon and home well water results. We will also explain to you if there are any contaminants in your well, and if so, what you can do about them. No one's personal information will ever be released to the public. However, the overall average results for each District will be reported back to the community (without anyone's names or addresses used). Our goals are to improve local health, and to get the information needed to raise funds to improve our drinking water supplies.

Compensation: *You will receive a $25 gift card & free well water testing (worth $150+) for completing this survey.*

Household Survey Number

District _____

Name of household head _____

Name of person completing survey _____

Street Address _____

_____

Mailing Address _____

_____

Phone _____ (hm) _____ (wk) _____(cell)

Did anyone on our project staff or student intern work with you on completing this survey?

_____ No, I completed this survey independently.

_____ Yes, the following person worked with me on completing this survey: _____

To be filled in by Project staff					*Date measurements taken:*			
Lat/Long. of well head (in NAD 1983 State Plane Montana FIPS 2500)	N	°	'	"	W	°	'	"
Datum confirmed as NAD 83? Y N		Elevation (ft)			Accuracy (ft)			
Tap measurements	Temp (C)		pH		Cl		Cond	

Field Recorder	Project Coordinator	Data Entered by:
NAME _____	NAME _____	NAME _____
DATE	DATE	DATE

SECTION 1: HOUSEHOLD MEMBERSHIP

It would help to know how many people are currently living with you and also using the same well water. We don't need to know names, but it would be helpful to know ages (to nearest decade for adults), and whether they are male or female.

Please give AGE in years if under 20, and to nearest decade if 20+ (e.g. 30s, 40s, etc.)

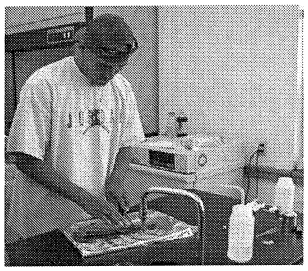
Line No.	Sex	AGE		Line No.	Sex	AGE		Line No.	Sex	AGE
1				7				13		
2				8				14		
3				9				15		
4				10				16		
5				11				17		
6				12				18		

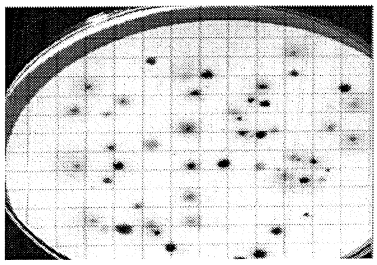
Total # of household members		Total number of adults	

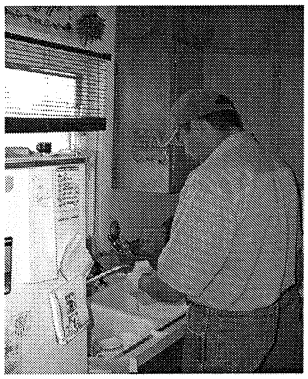
Just to make sure that I have a complete listing:

1) Are there any other persons such as small children or infants that we have not listed? YES ☐ --> ENTER EACH IN TABLE NO ☐

2) Are there any other people who may not be members of your family, such as lodgers or friends who usually live here? YES ☐ --> ENTER EACH IN TABLE NO ☐







Student research technician prepares fish sample to test it for mercury contamination (left), test for bacterial contamination of river water is positive (center) and student collects home well water samples for analysis (right).

SECTION 2: WATER SOURCES

This next section has questions about your main sources of water for drinking, cooking, bathing and washing. We are asking these questions to determine what community needs are for available, clean and safe water. This information will help us raise funds to improve access to safe drinking water for Reservation residents.

2.1 **Do you use the same water source for all of your home water needs?** Y / N
If you answered "Yes," what is your water source for your home?

If you answered "No," then you are using two or more sources of water at home. (For instance, maybe you buy water in town for drinking and cooking, but use your well water for everything else.) Please check one or more answers for each of the columns below, about how you use each type of water source.

2.2	**How do you use each of the following water sources?** (For water sources you don't use, please check the first column.)	We don't use this water source	Drinking/ making coffee, juice, etc.	Brushing Teeth	Cooking	Dishwashing	Bathing/ Showering	Laundry	Cleaning home
01	We use our well water for:								
02	We haul well water from someone else's house for:								
03	We have a cistern which we fill from _____; we use this water for:								
04	We haul town water from _____ (e.g. Crow, Wyola, Hardin, LG, Ft Smith, Pryor) for:								
05	We buy bottled water for:								
We also regularly get water from this source(s), for home use, and use it for...									
06	Developed spring								
07	Undeveloped spring								
08	River/stream								
9	Natural pond or lake								
10	Dammed pond or lake								
11	Rainwater								
12	Other source (please describe):								

2.3 Do you treat your well water before using it? Y/N

If yes, how? (circle best answer)

01 Boiling
02 Chlorination
03 Filtering equipment, specify type: _____
04 Other (please describe):

2.4 Do you store your drinking water? Y / N

If yes, how? (circle best answer)

01 Cistern
02 Metal tank
03 Plastic tank
04 Plastic jugs
05 Other (please describe):

2.5 About how much of your well water do you yourself drink per day (as water, or made into coffee or juice, etc.)?

01	1 cup	04	4 cups	07	7 cups
02	2 cups	05	5 cups	08	More, about _____ cups/day
03	3 cups	06	6 cups		

2.6 About how much of your well water does your family, including you, drink per day (as water, or made into coffee, etc.)? (Note that 1 quart = 4 cups)

01	none at all	04	2 quarts	07	5 quarts
02	less than 1 quart	05	3 quarts	08	6-7 quarts
03	1 quart	06	4 quarts (1 gallon)	09	8 quarts (2 gallons) or more

2.7 Do you often drink water from another source, for instance, at work or at another family member's or friend's home? Y / N

If yes, what is the source of that water? _____

If yes, about how many cups do you drink per day from that source?

01	1 cup	04	4 cups	07	7 cups
02	2 cups	05	5 cups	08	More, about _____ cups/day
03	3 cups	06	6 cups		

Comments:

2.8 Does your main source of water for your family's home vary by season? Y / N If yes, please describe which season and what water source. (For instance, "In the summer we get spring water from the mountains for drinking, maybe once/month.")

_____

_____

SOURCES OF WATER FOR OTHER ACTIVITIES

2.9 Do you camp out for Crow Fair, Lodge Grass 4th of July powwow, and/or other powwows?

No, we don't camp out for powwows ____. Yes, we camp about _____ times a year for powwows.

If yes, we would like to ask you about the drinking water sources you use while camping at powwows.

Drinking water source: _____

Drinking water storage: _____

2.10 Do you participate in camp meetings, or camp out with other Church activities?

No, we don't camp out for church activities ____. Yes, we do, about _____ times a year.

If yes, we would like to ask you about the drinking water sources you use while camping.

Drinking water source: _____

Drinking water storage: _____

2.11	Do you participate in any ceremonial activities (Sundance, Native American church, Tobacco Society, etc) where water from other sources is used for drinking? ☐ It's not appropriate for me to answer this question. No, we don't ____. Yes, we do _____. If yes, we would like to ask you about the drinking water sources used. Drinking water source: _____ Drinking water storage: _____
2.12	Do you go to the mountains for hunting, family camping, moving cattle or other activities? No, we don't ____. Yes, we do _____. If yes, we would like to ask you about the drinking water sources you use in the mountains. Drinking water source: _____ Drinking water treatment: _____ Drinking water storage: _____
2.13	Do you go out in the prairies/grasslands for moving cattle, horseback riding, gathering or other activities? No, we don't ____. Yes, we do _____. If yes, we would like to ask you about the drinking water sources you use on these days. Drinking water source: _____ Drinking water treatment: _____ Drinking water storage: _____
2.14	Do you participate in the sweat lodge? ☐ It's not appropriate for me to answer this question (skip to #2.17). No, we don't _____ (skip to #2.17). Yes, we do _____. If yes, we would like to ask you about water sources for the sweats you attend.

Location of sweat lodge (district)	Water sources used for sweat
At our house	We get drinking water for the sweat from: _____ (e.g. our well, town water, bottled water, the river, a spring, etc.)
	We get dipper water for the sweat from: _____. We do / do not heat our dipper water by the fire.
	We get bathing water for the sweat from: _____. We do / do not heat our bathing water by the fire. We bathe by jumping in the river: never or almost never / in warm weather / year round
At someone else's house in this district of the Reservation:	We get drinking water for the sweat from: _____ (e.g. our well, our cistern, town water, bottled water, the river, a spring, etc.)
	We get dipper water for the sweat from: _____. We do / do not heat our dipper water by the fire.
	We get bathing water for the sweat from: _____. We do / do not heat our bathing water by the fire. We bathe by jumping in the river: never or almost never / in warm weather / year round

2.17 Do you or other adults in your family rinse off after the sweat or swim or bathe in any local river, irrigation ditch, pond, lake or reservoir? Y / N
(NOTE: We are asking because we will test the water quality of any rivers, ditches, etc. that a number of people are using for swimming or bathing.)

2.17b If yes, how often?

01 Daily
02 >1/week
03 <1/week
04 < 1/month

2.17c If yes, where?

01 Stream/River: _____
02 Irrigation Ditch: _____
03 Lake/Pond: _____
04 Reservoir: _____

2.18 Do any of the children in your family rinse off after the sweat or swim or bathe in any local river, irrigation ditch, pond, lake or reservoir? Y / N
(NOTE: We are asking because we will test the water quality of any rivers, ditches, etc. that a number of children are using for swimming or bathing.)

2.18b If yes, how often?

01 Daily
02 >1/week
03 <1/week
04 < 1/month

2.18c If yes, where?

01 Stream/River: _____
02 Irrigation Ditch: _____
03 Lake/Pond: _____
04 Reservoir: _____

HOME WELLS

We'd like to ask a few questions about your home well. These questions relate to the quality of your water, and any possible sources that could contaminate your well water. Do you have a home well? Y/N.

2.19 What is your well water quality like? (Circle all that apply, and fill in blanks if appropriate.)

01 clear
02 colored: _____
03 no odor
04 smells like: _____
05 tastes fine
06 tastes like: _____

Do you get scale (white powdery build up) or colored staining on your hot water heater, coffee maker, toilet, shower, etc.? (If so, please describe.)

2.20 Has the quality and/or quantity of your well water changed over the years? Y / N / I don't know
If yes, please describe:

2.21 How would you classify the area your property is in?

01 rural, forested
02 rural, prairie/grassland
03 rural, dry land farming
04 rural, irrigated crops
05 Suburban (Crow Agency, Hardin, Pryor, Lodge Grass, etc.)
06 swamp/marshy
07 Other (describe):

2.22 How large is the property your well is on?

01 less than 1 acre
02 1-9 acres
03 10-49 acres
04 50-249 acres
05 250-1,000 acres
06 > 1,000 acres

2.23 What is the primary land use on your property?

01 residential
02 livestock operation
03 farming
04 other:

If there are livestock on your property, about how many animals graze within 200 yards of your house?

2.24 Are you aware of any inactive wells on your property? Y / N

If yes, are they properly capped to protect your groundwater?

01 yes 02 no 03 don't know

2.25 What is/are the primary use(s) for the well we will be testing? (check all important uses)

01 household 03 irrigation 05 other:

02 garden 04 livestock watering

2.26 Has the Indian Health Service or anyone else ever tested the water quality in this well before? Y / N / ??

If yes, do you have a copy of those results? Y / N

2.27 Has your well been tested by the Montana Well Educated program before? Y / N (If yes, year _____)

2.28 What is the approximate age of your well?

01 less than 2 years 03 5 - 14 years 05 more than 30 years

02 2 - 4 years 04 15 - 30 years 06 no idea

2.29 What is the depth of your well?

01 less than 50 feet 03 150 - 299 feet 05 don't know

02 50 - 149 feet 04 more than 300 feet

2.30 Are you familiar with the function of your well, and do you feel confident that you understand all the necessary maintenance and safety procedures to protect your groundwater?

01 Yes, I understand well function, maintenance and safety procedures

02 No, I feel like I could know more about maintaining my well and protecting my groundwater.

If the following were available to learn more about wells, I might participate:

A printed information mailed to my home

B project staff or intern visiting my home to discuss the issues with me

C public informational session in my community

D articles in the local papers or IHS newsletter

E other:

2.31a Is your household on a septic system? Y / N / don't know

2.31b If yes, have you had your septic tank pumped or cleaned in the last two years? Y / N / don't know

2.31c If yes, how far is your septic system from your well head? (100 feet is about 33 long steps.)

01 less than 100 feet 02 more than 100' 03 don't know where the system is

2.32 Our well head (see photos below):

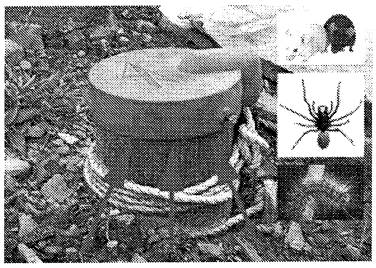
01 has a water-tight cap ("sanitary cap") on it

02 has an old style (not water-tight) cap on it, and the cap is in good condition

03 has a cap on it, but the cap is cracked or damaged in some way

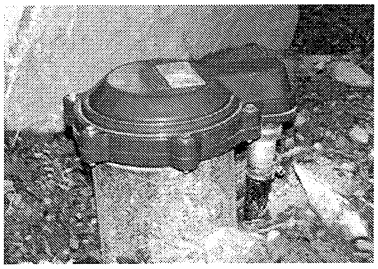
04 is not capped

05 I don't know



(Bugs and even rodents can crawl in to the well through this crack.)

Old style standard well head cap



(The water-tight seal on this cap keeps bugs and mice out of your well.)

Sanitary well head cap

2.33 Are any of the following within 100 feet of your well head?

01 Stored chemicals or gasoline
02 Pasture or kennel for animals
03 An old outhouse
04 Another active well head
05 Another well head, but not in use
06 Fertilized or sprayed yard, field or croplands
07 Other possible source of contamination: _____

2.34 The top of our well head:

01 Is a foot or more above ground level
02 Is less than a foot above ground level

2.35 Our well head:

01 has never been submerged by a flood
02 has been flooded, in the years:

2.36 Our well head:

01 is in a small depression (water would collect around it)
02 is in the middle of a small mound (the ground slopes down going away from the well head)
03 is on flat, level ground

2.37 Has there ever been a chemical spill within 100 feet of your well head? (e.g. car oil, pesticides, paint, etc.)

01 No, not that I'm aware of
02 Yes, car oil
03 Yes, gasoline
04 Yes, paint
05 Yes, pesticide
What type?
06 Yes, other
What chemical?

2.38 Are there any surface dumps, buried dumps, or abandoned cars nearby? Y / N / I don't know
If yes, please describe location and type of waste, to the best of your knowledge:

2.39 Do you have any suggestions for what could be done to improve availability of clean water for our communities?

_____

_____

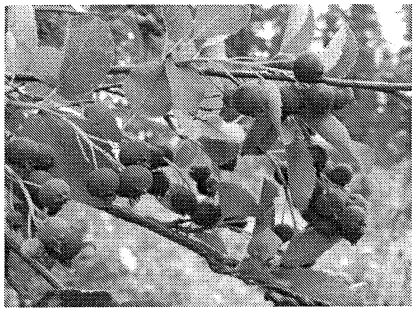
_____

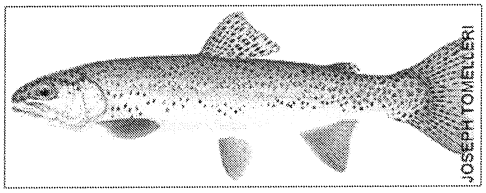
_____

_____

Optional local food/health survey

You do NOT need to complete this part to get your well water tested for free. However, if you do choose to complete it, you will receive an additional $25 in gift card value ($50 instead of $25).





Why are we asking these questions? You do not need to fill out this section of the survey in order to have your well water tested for free. However, if you choose to fill it out, it will help us find out if people are potentially being exposed to chemicals in other ways, especially through local foods or local jobs. It will also help us find out if there are clusters of cancers or other chronic illnesses that could be related to polluted well water or other chemical exposures. We will report all results back to the community, so people can choose ways to reduce their exposures to hazardous chemicals. The stipend for completing both the water section and this food/health section of the survey is $50.00. Remember that you are free to skip any questions you'd prefer to not answer. Thank you.

LOCAL FOOD SOURCES

This section is about your household's local sources of food. Levels of chemicals in store-bought foods are limited by governmental regulations, so there is some protection for consumers. Foods obtained by hunting, fishing or gathering, or obtained directly from neighbors could be contaminated without anyone knowing. ***If we find that people eat a lot of local foods, we plan to test these foods for contaminants. We are most concerned about lead shot contaminating game meat, mercury in fish, and pesticides contaminating local plants.***

3.1 How often does your family eat meat from hunting any of the following?

	01 daily	02 >once/ week	03 <once/ week	04 <once/ month	05 never	Which organ meats does your family eat (if any)?	What is your primary hunting area (general answer, e.g. Big Horn Mountains)?
a) Mule deer							
b) Whitetail deer							
c) Elk							
d) Buffalo							
e) Antelope							
f) Other animal(s):							

3.2 Does your family gather and eat berries when they are in season? Y / N

If yes, what kind(s) of berries, and where are they gathered (general answer)?

Kind of berry	Place gathered (e.g. Little Big Horn River valley, Big Horn Mountains)
choke cherries	
june berries	
buffalo berries	
wild plums	
gooseberries	
currants	
elderberries	
blueberries	
other:	

3.2 During the growing season, how often does your household eat roots/leaves/flowers from gathering (e.g. turnips, or mint tea)?

	How often?	Which food?
01	Daily	
02	>1/week	
03	<1/week	
04	<1/month	
05	never	

3.2b If you listed one or more plants in question 3.2 (on previous page), what is the general area where you go to collect it? (Common name of plant in English or Crow; general answer for gathering area, e.g. "Wolf Mountains" or "along roadside in Lodge Grass area")

3.3 Are any of these foods or berries growing near agriculture fields (where they might get sprayed along with the crops)? Y / N. If yes, which foods and/or berries?

Do you eat any fish or other seafood? Y / N (If "no," skip to question 3.8.) (We have been testing local fish for mercury contamination. Some types of store bought fish can also be contaminated with mercury. We will send you information about local and/or store bought fish if they are part of your diet.)

3.5 On average, how many servings of the following locally caught fish do you eat per MONTH? (A standard serving is 6 oz.)

Walleye	0	1	2	3	4	5	6	>= 7
Trout (brown, rainbow or cutthroat)	0	1	2	3	4	5	6	>= 7
Catfish	0	1	2	3	4	5	6	>= 7
Bass	0	1	2	3	4	5	6	>= 7
Other:	0	1	2	3	4	5	6	>= 7

3.6 If you eat locally caught fish, please describe where each species is caught (name of river, approximate location). (We don't want to know your favorite fishing hole, we just want to know generally where we should be testing fish for mercury.)

3.7 On average, how many servings of the following fish and shellfish from stores and restaurants do you eat per MONTH? (A standard serving is 6 oz., about 1/3 of a pound)

Total fish consumed (not incl shellfish)	0	1	2	3	4	5	6	>= 7
Total shellfish consumed (e.g. shrimp)	0	1	2	3	4	5	6	>= 7
Canned albacore (white) tuna	0	1	2	3	4	5	6	>= 7
Canned chunk light tuna	0	1	2	3	4	5	6	>= 7
Swordfish, shark, tilefish, mackerel	0	1	2	3	4	5	6	>= 7
Sardines, scallops, shrimp, crab, or other shellfish	0	1	2	3	4	5	6	>= 7
Trout or catfish	0	1	2	3	4	5	6	>= 7
Salmon (Atlantic? Alaskan?)	0	1	2	3	4	5	6	>= 7
Any other store or restaurant fish, not included above	0	1	2	3	4	5	6	>= 7

SECTION 4: Lung Health

Lung cancer is the most common type of cancer on the Reservation. We are trying to find out what people are being exposed to that could contribute to the risk of lung cancer. Radon is an odorless, colorless gas that can seep from the ground into your home. It occurs naturally in most of Montana, including our area. Radon gas can accumulate in people's homes. Breathing air with radon in it is the second leading cause of lung cancer, next to smoking. Through this project, you can get your home screened for radon gas for free. If your home has high levels of radon, it can be fixed.

4.1 To the best of your knowledge, has your home ever been tested for radon?

- 01 Yes, the level of radon was low enough that a mitigation system wasn't needed.
- 02 Yes. The radon level was unsafe, and a mitigation system was installed.
- 03 Yes. The radon level was unsafe, but a mitigation system has not been installed.
- 04 Yes, it was tested by _____ but I don't know the results of the test.
- 05 No, our home has never been tested for radon.
- 06 I don't know.

4.2 For people answering 4.1 (03), (04), (05) or (06): We can test your home for radon (for free). Would you be interested in this service?

- 01 Yes, please put me on your list to schedule a radon test (at same time as water sampling).
- 02 No, not at this time.

4.3 For people answering 4.1 (03), (04), (05) or (06): Buildings with radon problems usually accumulate the highest radon levels in the basement or lowest level of the home. Does anyone sleep in a basement or lowest level room?

- 01 Yes (please describe):
- 02 No.
- 03 Not usually.

4.4 For people answering 4.1 (03), (04), (05) or (06): How your house is constructed can make a difference in how much radon can leak into your lower level rooms. Which best describes your home?

- 01 Our home rests directly on a foundation (concrete or other).
- 02 There is a crawl space between the bottom floor and the ground.
- 03 There is a basement.
- 04 Other (describe):

4.5 Exposure to asbestos in home building materials can cause respiratory problems. To the best of your knowledge, is there any asbestos or asbestos-containing materials in your house? For instance, "popcorn ceilings" sometimes contain asbestos.

- 01 Yes. Describe: _____
- 02 Maybe, I'm concerned about: _____
- 03 No, there aren't any asbestos containing materials.
- 04 I don't know.

4.6 Mold is a fungus that decays wood, carpeting, drywall and other materials. Do you have any problems with mold in your home? (Mold can cause respiratory problems.)

- 01 Yes. (Specify:)
- 02 We used to have mold problems, but it was fixed by:
- 03 No, we have never had mold problems in this home.
- 04 I don't know.

4.7 Carbon monoxide is an odorless, colorless gas that comes from poorly working gas appliances which aren't completely burning their fuel. If you have any gas appliances in your home, do you also have a carbon monoxide detector?

01 No, we don't have any gas appliances (furnace, range, water heater, etc.).

02 Yes, we have one or more gas appliances, and:

A. We don't have a CO detector.

B. We do have a CO detector.

C. I don't know whether we have a CO detector.

03 I don't know whether we have any gas appliances.

4.8 Do any members of your household smoke cigarettes or pipes? Y / N

If yes, # of people _____

a) If yes, how often?

01 several smokes per day
02 once or twice per day
03 not every day
04 at least once a week
05 infrequently (<1/week)
06 no one ever does
07 prefer not to answer

b) If yes, how often is someone smoking inside the house?

01 every day
02 6 days/wk
03 5 days/wk
04 4 days/wk
05 3 days/wk
06 2 days/wk
07 1 day/wk
08 no one ever smokes inside the house.
09 prefer not to answer

4.9 Is there anything else about the condition of your home, or the materials it is made out of, that you are concerned could be a health risk to your family? (e.g. exposed insulation, leaky gas line, railroad ties used in construction, water leakage which could lead to mold, etc.) Y / N

If yes, please describe:

SECTION 5: Your Jobs, Hobbies and Home Projects

Another place people are commonly exposed to hazardous chemicals or microbes is in the workplace. This could include contact with liquid or solid chemicals, or breathing smoke or fumes or ash. Spraying pesticides, working in pesticide-treated fields, working in a hospital lab, applying wood preservative, breathing smoke while fighting fire, handling coal ash, using cleaning chemicals or past employment in the carpet factory - are examples of exposure.

5.1 Are you currently working at home, for your family or for an employer?

01 No, I'm not. (Skip to 5.2.)

02 Yes, I am. (Please answer the rest of this question and following ones.)

a Job Title _____

b What do you do? _____

c What does this company do or make? _____

d How long have you worked there? _____ years _____ months

e Do you handle or are you exposed to any hazardous chemicals or microbes on this job? Y / N
If yes, please describe:

_____

_____

If you are exposed to chemicals or microbes at your job, please also answer the following:

f After work, do you usually drive home in your work clothes and boots? _____ Yes _____ No

g Do you usually change your clothes & shoes before entering your home after work? _____ Yes _____ No

h Are your work clothes usually washed separately from the rest of the family's laundry? _____ Yes _____ No

Comments:

5.2 What other kinds of jobs, hobbies or activities have you had that might have exposed you to hazardous chemicals or microbes? This could include contact with liquids or solids, or breathing smoke or fumes or ash. Spraying pesticides, working in pesticide-treated fields, working in a hospital lab, applying wood preservative, silversmithing, working in a place with chemical fumes,smoke or ash, fighting fire - are examples of exposure. Please check all that apply, and fill in length of time you were exposed and type of exposure. (e.g. 10 years construction; paint, wood preservatives, removing asbestos.)

	Firefighting. Length of Time: _____. Exposure _____
	Coal mining. Length of Time: _____. Exposure _____
	Building Construction. Length of Time: _____. Exposure _____
	Road Construction. Length of Time: _____. Exposure _____
	Spraying pesticides. Length of Time: _____. Exposure _____
	Coal burning power plant worker. Length of Time: _____. Exposure _____
	Car repair/garage. Length of Time: _____. Exposure _____
	Carpet Factory (e.g. Crow Agency). Length of Time: _____. Exposure _____

	Smoking cigarettes or cigars. Length of Time: _____. (Non-ceremonial tobacco use.)
	Hospital work. Length of Time: _____. Exposure _____
	Custodial/cleaning. Length of Time: _____. Exposure _____
	Other factory work. Describe: _____ Length of Time: _____. Exposure _____
	Other work (please describe): _____. Length of Time: _____. Exposure _____
	Other work (please describe): _____. Length of Time: _____. Exposure _____
	Other work (please describe): _____. Length of Time: _____. Exposure _____
	Hobby/craft (please describe): _____. Length of Time: _____. Exposure _____

5.3 Are there any other routine activities that you feel we should know about, i.e., that could increase exposure to chemicals or microbes? This could include things such as your house being sprayed by crop dusters, neighboring feedlot or leaking septic system, or exposures from neighbors' uses of chemicals, etc. Y / N

If yes, please describe:

_____

_____

_____

_____

_____

SECTION 6: HEALTH STATUS AND PERCEPTIONS OF RISK

This section asks about any chronic health conditions affecting you or your family members. We'd also like to know if there is anything in your environment (water supply, home, work, etc.) that you suspect could be causing health problems, or making them worse. *We are asking because many people have told us that there seems to be clusters of chronic illnesses in some parts of the Reservation, and we are trying to find out if some of these illnesses could be related to contaminated water or radon in homes.* Remember that you are always free to skip questions that you do not wish to answer. Your answers are kept strictly confidential.

6.1	Do you have any chronic diseases? (See list below.) Y / N If yes, please complete this question.	Diagnosis (e.g. type 1 or 2 diabetes; type of cancer, etc.)	At what age was your condition diagnosed?	Is there a family history of this condition?	Do you suspect an environmental exposure might be a factor? (If so, any idea what?)

6.2	Do any of your other household members have any chronic diseases? (See list below.) Y / N If yes, please complete this question.	Age of person now (e.g. 60s)	Diagnosis (e.g. type 1 or 2 diabetes; type of cancer, etc.)	At what age was their condition diagnosed?	Is there a family history of this condition?	Do you suspect an environmental exposure might be a factor? (If so, any idea what?)
	01 diabetes					
	02 cancer Type of cancer (e.g. lung, stomach, breast, cervical, etc.):					
	03 heart disease					
	04 respiratory disease					
	05 asthma					
	06 allergies To food, medicines, and/or environmental factors such as dust, pollen or pet hair. Please note what happens if the person is exposed.					
	06(b) excema (allergic skin problem)					
	07 chronic fatique (tired all the time)					
	08a frequent gastro-intestinal problems					

cont'd.	Do you or any of your household members have any chronic diseases? *(Cont'd.)*		Age of person now	Diagnosis (e.g. type 1 or 2 diabetes; type of cancer, etc.)	When did your/their symptoms start?	Is there a family history of this condition?	Do you suspect an environmental exposure might be a factor?
	08b	*Helicobacter pylori* infection					
	09	arthritis					
	10	anemia					
	11	lead poisoning					
	12	sleep problems or severe insomnia					
	13	ear infections					
	14	urinary infections					
	15	autism					
	16	Asberger's syndrome					
	17	ADHD (Attention Deficit Hyperactivity Disorder)					
	18	Multiple sclerosis (MS)					
	19	Any other chronic health concerns?					

6.3	Is there anything in your environment that you believe could be linked to poor health of any of your household members? In other words, has anyone had an illness that you thought was caused by something in the air or water where he or she has ever lived or worked? Y / N	
	01 water pollution 02 air pollution 03 air pollution from trash burning or dumpsters on fire 04 land fills 05 mold 06 food quality 07 leaking septics 08 agriculture (e.g., pesticides) 09 animal feedlots 10 mining 11 power plants 12 oil contamination 13 illegal dumping 14 unusual animal or fish diseases: wildlife or domestic (e.g., wasting, fin rot, sores, etc) 15 exposure at work (specify): 16 Other (specify):	If yes, please describe:
6.4	Have you ever needed to call poison control or go to the emergency room for poisoning, for anyone in your home? Y / N. If yes, please describe:	
6.5	Does it seem to you that there is an unusually high rate of any particular disease(s) in your own neighborhood or other neighborhoods? Y / N If yes, please describe:	
6.6	Do you have any suggestions for what could be done to reduce people's exposures to chemicals (in water, food, homes, workplaces) in our communities?	

This completes the Household Questionnaire. Thank you very much for your responses. I would like to assure you that all survey information will be kept strictly confidential.

APPENDIX D

SUPPORTING INFORMATION FOR CHAPTER 4

Number of Wells Sampled by Contaminant and by River Valley							
	River Valley	Cases					
		Valid		Missing		Total	
		N	Percent	N	Percent	N	Percent
Nitrate and Nitrite as N in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Bicarbonate	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
pH	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Total Dissolved Solids at 180C in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Alkalinity in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Sulfate in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Hardness in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Mg in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Mn in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Sodium in mg/L	Pryor	19	100.0%	0	0.0%	19	100.0%
	Big Horn River Valley	23	100.0%	0	0.0%	23	100.0%
	Little Big Horn River Valley	110	100.0%	0	0.0%	110	100.0%
Iron in mg/L	Pryor	18	94.7%	1	5.3%	19	100.0%
	Big Horn River Valley	20	87.0%	3	13.0%	23	100.0%
	Little Big Horn River Valley	99	90.0%	11	10.0%	110	100.0%
Total Uranium in mg/L	Pryor	9	47.4%	10	52.6%	19	100.0%
	Big Horn River Valley	12	52.2%	11	47.8%	23	100.0%
	Little Big Horn River Valley	73	66.4%	37	33.6%	110	100.0%

Appendix D: Well Water Contaminant Concentrations by River Valley

Contaminant	River Valley			Statistic	SE
Nitrate in mg/L	Pryor	Mean		1.97342	0.760847
		95% Confidence Interval for Mean	Lower Bound	0.37494	
			Upper Bound	3.5719	
		Median		0.93	
		Variance		10.999	
		Std. Deviation		3.316457	
		Minimum		0.025	
		Maximum		13.9	
		Range		13.875	
		Skewness		2.984	0.524
		Kurtosis		9.797	1.014
	Big Horn River Valley	Mean		7.2187	2.415774
		95% Confidence Interval for Mean	Lower Bound	2.20869	
			Upper Bound	12.2287	
		Median		1.6	
		Variance		134.227	
		Std. Deviation		11.58564	
		Minimum		0.025	
		Maximum		39.8	
		Range		39.775	
		Skewness		1.783	0.481
		Kurtosis		2.24	0.935
	Little Big Horn River Valley	Mean		0.3825	0.095327
		95% Confidence Interval for Mean	Lower Bound	0.19356	
			Upper Bound	0.57144	
		Median		0.025	
		Variance		1	
		Std. Deviation		0.999801	
		Minimum		0.025	
		Maximum		6.5	
		Range		6.475	
		Skewness		4.077	0.23
		Kurtosis		18.366	0.457

Contaminant	River Valley			Statistic	SE
Bicarbonate	Pryor	Mean		350.2632	17.35253
		95% Confidence Interval for Mean	Lower Bound	313.8069	
			Upper Bound	386.7195	
		Median		329	
		Variance		5721.094	
		Std. Deviation		75.63791	
		Minimum		267	
		Maximum		531	
		Range		264	
		Skewness		0.981	0.524
		Kurtosis		0.546	1.014
	Big Horn River Valley	Mean		413.7826	21.64636
		95% Confidence Interval for Mean	Lower Bound	368.8908	
			Upper Bound	458.6744	
		Median		388	
		Variance		10777	
		Std. Deviation		103.8123	
		Minimum		229	
		Maximum		607	
		Range		378	
		Skewness		0.142	0.481
		Kurtosis		-1.015	0.935
	Little Big Horn River Valley	Mean		495.2909	11.25995
		95% Confidence Interval for Mean	Lower Bound	472.9741	
			Upper Bound	517.6078	
		Median		485.5	
		Variance		13946.5	
		Std. Deviation		118.0953	
		Minimum		228	
		Maximum		886	
		Range		658	
		Skewness		0.48	0.23
		Kurtosis		0.61	0.457

Contaminant	River Valley			Statistic	SE
pH	Pryor	Mean		7.911	0.1864
		95% Confidence Interval for Mean	Lower Bound	7.519	
			Upper Bound	8.302	
		Median		7.5	
		Variance		0.66	
		Std. Deviation		0.8123	
		Minimum		7.3	
		Maximum		9.4	
		Range		2.1	
		Skewness		1.151	0.524
		Kurtosis		-0.644	1.014
	Big Horn River Valley	Mean		7.461	0.0478
		95% Confidence Interval for Mean	Lower Bound	7.362	
			Upper Bound	7.56	
		Median		7.4	
		Variance		0.052	
		Std. Deviation		0.2291	
		Minimum		7.1	
		Maximum		7.9	
		Range		0.8	
		Skewness		0.505	0.481
		Kurtosis		-0.649	0.935
	Little Big Horn River Valley	Mean		7.629	0.0487
		95% Confidence Interval for Mean	Lower Bound	7.532	
			Upper Bound	7.726	
		Median		7.45	
		Variance		0.261	
		Std. Deviation		0.5112	
		Minimum		6.8	
		Maximum		9	
		Range		2.2	
		Skewness		1.092	0.23
		Kurtosis		0.159	0.457

Contaminant	River Valley			Statistic	SE
Total Dissolved Solids at 180C in mg/L	Pryor	Mean		533.05	65.949
		95% Confidence Interval for Mean	Lower Bound	394.5	
			Upper Bound	671.61	
		Median		463	
		Variance		82635.61	
		Std. Deviation		287.464	
		Minimum		238	
		Maximum		1360	
		Range		1122	
		Skewness		1.423	0.524
		Kurtosis		2.448	1.014
	Big Horn River Valley	Mean		2243.61	435.731
		95% Confidence Interval for Mean	Lower Bound	1339.96	
			Upper Bound	3147.26	
		Median		1720	
		Variance		4366808	
		Std. Deviation		2089.691	
		Minimum		367	
		Maximum		9180	
		Range		8813	
		Skewness		1.918	0.481
		Kurtosis		4.497	0.935
	Little Big Horn River Valley	Mean		1404.68	92.552
		95% Confidence Interval for Mean	Lower Bound	1221.25	
			Upper Bound	1588.12	
		Median		1135	
		Variance		942243.9	
		Std. Deviation		970.692	
		Minimum		265	
		Maximum		5980	
		Range		5715	
		Skewness		1.986	0.23
		Kurtosis		5.312	0.457

Contaminant	River Valley			Statistic	SE
Alkalinity in mg/L	Pryor	Mean		307.58	14.742
		95% Confidence Interval for Mean	Lower Bound	276.61	
			Upper Bound	338.55	
		Median		316	
		Variance		4129.035	
		Std. Deviation		64.258	
		Minimum		221	
		Maximum		436	
		Range		215	
		Interquartile Range		82	
		Skewness		0.329	0.524
		Kurtosis		-0.598	1.014
	Big Horn River Valley	Mean		339.57	17.904
		95% Confidence Interval for Mean	Lower Bound	302.44	
			Upper Bound	376.7	
		Median		318	
		Variance		7372.439	
		Std. Deviation		85.863	
		Minimum		188	
		Maximum		506	
		Range		318	
		Skewness		0.179	0.481
		Kurtosis		-0.947	0.935
	Little Big Horn River Valley	Mean		415.74	10.107
		95% Confidence Interval for Mean	Lower Bound	395.71	
			Upper Bound	435.77	
		Median		407.5	
		Variance		11235.7	
		Std. Deviation		105.999	
		Minimum		187	
		Maximum		776	
		Range		589	
		Skewness		0.593	0.23
		Kurtosis		0.709	0.457

Contaminant	River Valley			Statistic	SE
Sulfate in mg/L	Pryor	Mean		128.68	36.907
		95% Confidence Interval for Mean	Lower Bound	51.15	
			Upper Bound	206.22	
		Median		64	
		Variance		25880.01	
		Std. Deviation		160.873	
		Minimum		12	
		Maximum		648	
		Range		636	
		Skewness		2.166	0.524
		Kurtosis		5.311	1.014
	Big Horn River Valley	Mean		1242.96	256.663
		95% Confidence Interval for Mean	Lower Bound	710.67	
			Upper Bound	1775.24	
		Median		949	
		Variance		1515149	
		Std. Deviation		1230.914	
		Minimum		20	
		Maximum		4750	
		Range		4730	
		Skewness		1.399	0.481
		Kurtosis		1.698	0.935
	Little Big Horn River Valley	Mean		656.21	60.654
		95% Confidence Interval for Mean	Lower Bound	535.99	
			Upper Bound	776.42	
		Median		464	
		Variance		404685.8	
		Std. Deviation		636.149	
		Minimum		1	
		Maximum		3710	
		Range		3709	
		Skewness		2.154	0.23
		Kurtosis		5.769	0.457

Contaminant	River Valley			Statistic	SE
Hardness in mg/L	Pryor	Mean		233.26	42.033
		95% Confidence Interval for Mean	Lower Bound	144.96	
			Upper Bound	321.57	
		Median		253	
		Variance		33567.98	
		Std. Deviation		183.216	
		Minimum		1	
		Maximum		510	
		Range		509	
		Skewness		-0.094	0.524
		Kurtosis		-1.253	1.014
	Big Horn River Valley	Mean		845.87	144.938
		95% Confidence Interval for Mean	Lower Bound	545.29	
			Upper Bound	1146.45	
		Median		517	
		Variance		483164.5	
		Std. Deviation		695.1	
		Minimum		16	
		Maximum		2340	
		Range		2324	
		Skewness		0.904	0.481
		Kurtosis		-0.246	0.935
	Little Big Horn River Valley	Mean		467.52	43.839
		95% Confidence Interval for Mean	Lower Bound	380.63	
			Upper Bound	554.41	
		Median		409	
		Variance		211402.1	
		Std. Deviation		459.785	
		Minimum		2	
		Maximum		2580	
		Range		2578	
		Skewness		1.762	0.23
		Kurtosis		4.397	0.457

Contaminant	River Valley			Statistic	SE
Mg in mg/L	Pryor	Mean		24.58	4.181
		95% Confidence Interval for Mean	Lower Bound	15.79	
			Upper Bound	33.36	
		Median		28	
		Variance		332.146	
		Std. Deviation		18.225	
		Minimum		1	
		Maximum		50	
		Range		49	
		Skewness		-0.226	0.524
		Kurtosis		-1.364	1.014
	Big Horn River Valley	Mean		96.43	18.792
		95% Confidence Interval for Mean	Lower Bound	57.46	
			Upper Bound	135.41	
		Median		54	
		Variance		8122.439	
		Std. Deviation		90.125	
		Minimum		1	
		Maximum		316	
		Range		315	
		Skewness		1.297	0.481
		Kurtosis		1.037	0.935
	Little Big Horn River Valley	Mean		55.65	5.77
		95% Confidence Interval for Mean	Lower Bound	44.22	
			Upper Bound	67.09	
		Median		42	
		Variance		3662.687	
		Std. Deviation		60.52	
		Minimum		1	
		Maximum		301	
		Range		300	
		Skewness		1.884	0.23
		Kurtosis		4.197	0.457

Contaminant	River Valley			Statistic	SE
Mn in mg/L	Pryor	Mean		0.03932	0.034483
		95% Confidence Interval for Mean	Lower Bound	-0.03313	
			Upper Bound	0.11176	
		Median		0.005	
		Variance		0.023	
		Std. Deviation		0.150307	
		Minimum		0.002	
		Maximum		0.66	
		Range		0.658	
		Skewness		4.359	0.524
		Kurtosis		18.999	1.014
	Big Horn River Valley	Mean		0.1913	0.065435
		95% Confidence Interval for Mean	Lower Bound	0.0556	
			Upper Bound	0.32701	
		Median		0.005	
		Variance		0.098	
		Std. Deviation		0.313815	
		Minimum		0.005	
		Maximum		0.98	
		Range		0.975	
		Skewness		1.532	0.481
		Kurtosis		0.982	0.935
	Little Big Horn River Valley	Mean		0.07905	0.012016
		95% Confidence Interval for Mean	Lower Bound	0.05523	
			Upper Bound	0.10286	
		Median		0.02	
		Variance		0.016	
		Std. Deviation		0.126023	
		Minimum		0.005	
		Maximum		0.73	
		Range		0.725	
		Skewness		2.547	0.23
		Kurtosis		7.623	0.457

Contaminant	River Valley			Statistic	SE
Sodium in mg/L	Pryor	Mean		110.58	24.03
		95% Confidence Interval for Mean	Lower Bound	60.09	
			Upper Bound	161.07	
		Median		114	
		Variance		10971.81	
		Std. Deviation		104.746	
		Minimum		1	
		Maximum		296	
		Range		295	
		Skewness		0.392	0.524
		Kurtosis		-1.261	1.014
	Big Horn River Valley	Mean		375.48	76.433
		95% Confidence Interval for Mean	Lower Bound	216.97	
			Upper Bound	533.99	
		Median		221	
		Variance		134367.6	
		Std. Deviation		366.562	
		Minimum		11	
		Maximum		1410	
		Range		1399	
		Skewness		1.283	0.481
		Kurtosis		1.181	0.935
	Little Big Horn River Valley	Mean		311.55	27.704
		95% Confidence Interval for Mean	Lower Bound	256.64	
			Upper Bound	366.45	
		Median		251.5	
		Variance		84428.31	
		Std. Deviation		290.565	
		Minimum		4	
		Maximum		1880	
		Range		1876	
		Skewness		1.889	0.23
		Kurtosis		6.65	0.457

Contaminant	River Valley			Statistic	SE
Total Uranium in mg/L	Pryor	Mean		0.001889	0.000686
		95% Confidence Interval for Mean	Lower Bound	0.000307	
			Upper Bound	0.003471	
		Median		0.001	
		Variance		0	
		Std. Deviation		0.002058	
		Minimum		0.0005	
		Maximum		0.0065	
		Range		0.006	
		Skewness		1.794	0.717
		Kurtosis		2.668	1.4
	Big Horn River Valley	Mean		0.024958	0.008339
		95% Confidence Interval for Mean	Lower Bound	0.006605	
			Upper Bound	0.043311	
		Median		0.0135	
		Variance		0.001	
		Std. Deviation		0.028886	
		Minimum		0.0005	
		Maximum		0.101	
		Range		0.1005	
		Skewness		1.941	0.637
		Kurtosis		3.898	1.232
	Little Big Horn River Valley	Mean		0.006199	0.001062
		95% Confidence Interval for Mean	Lower Bound	0.004081	
			Upper Bound	0.008316	
		Median		0.002	
		Variance		0	
		Std. Deviation		0.009074	
		Minimum		0.0005	
		Maximum		0.042	
		Range		0.0415	
		Skewness		2.287	0.281
		Kurtosis		5.319	0.555

Contaminant	River Valley			Statistic	SE
Iron in mg/L	Pryor	Mean		0.04694	0.018096
		95% Confidence Interval for Mean	Lower Bound	0.00876	
			Upper Bound	0.08512	
		Median		0.025	
		Variance		0.006	
		Std. Deviation		0.076776	
		Minimum		0.025	
		Maximum		0.35	
		Range		0.325	
		Skewness		4.052	0.536
		Kurtosis		16.748	1.038
	Big Horn River Valley	Mean		0.4765	0.226322
		95% Confidence Interval for Mean	Lower Bound	0.0028	
			Upper Bound	0.9502	
		Median		0.025	
		Variance		1.024	
		Std. Deviation		1.012141	
		Minimum		0.025	
		Maximum		3.97	
		Range		3.945	
		Skewness		2.778	0.512
		Kurtosis		7.773	0.992
	Little Big Horn River Valley	Mean		0.96364	0.264056
		95% Confidence Interval for Mean	Lower Bound	0.43963	
			Upper Bound	1.48765	
		Median		0.1	
		Variance		6.903	
		Std. Deviation		2.627326	
		Minimum		0.025	
		Maximum		21.7	
		Range		21.675	
		Skewness		5.73	0.243
		Kurtosis		40.686	0.481

Contaminant	River Valley			Statistic	SE
Log 10 of TDS	Pryor	Mean		2.674276	0.049346
		95% Confidence Interval for Mean	Lower Bound	2.570604	
			Upper Bound	2.777948	
		Median		2.66558	
		Variance		0.046	
		Std. Deviation		0.215093	
		Minimum		2.37658	
		Maximum		3.13354	
		Range		0.75696	
		Skewness		0.392	0.524
		Kurtosis		-0.69	1.014
	Big Horn River Valley	Mean		3.192013	0.07977
		95% Confidence Interval for Mean	Lower Bound	3.026579	
			Upper Bound	3.357446	
		Median		3.23553	
		Variance		0.146	
		Std. Deviation		0.382565	
		Minimum		2.56467	
		Maximum		3.96284	
		Range		1.39817	
		Skewness		0.157	0.481
		Kurtosis		-0.86	0.935
	Little Big Horn River Valley	Mean		3.0626	0.025912
		95% Confidence Interval for Mean	Lower Bound	3.011243	
			Upper Bound	3.113958	
		Median		3.05489	
		Variance		0.074	
		Std. Deviation		0.271771	
		Minimum		2.42325	
		Maximum		3.7767	
		Range		1.35345	
		Skewness		0.054	0.23
		Kurtosis		0.028	0.457

Contaminant	River Valley			Statistic	SE
Log 10 of Alkalinity	Pryor	Mean		2.478957	0.020892
		95% Confidence Interval for Mean	Lower Bound	2.435063	
			Upper Bound	2.52285	
		Median		2.499687	
		Variance		0.008	
		Std. Deviation		0.091068	
		Minimum		2.344392	
		Maximum		2.639486	
		Range		0.295094	
		Skewness		-0.027	0.524
		Kurtosis		-0.911	1.014
	Big Horn River Valley	Mean		2.517155	0.023603
		95% Confidence Interval for Mean	Lower Bound	2.468205	
			Upper Bound	2.566105	
		Median		2.502427	
		Variance		0.013	
		Std. Deviation		0.113197	
		Minimum		2.274158	
		Maximum		2.704151	
		Range		0.429993	
		Skewness		-0.256	0.481
		Kurtosis		-0.656	0.935
	Little Big Horn River Valley	Mean		2.604773	0.010691
		95% Confidence Interval for Mean	Lower Bound	2.583584	
			Upper Bound	2.625962	
		Median		2.610119	
		Variance		0.013	
		Std. Deviation		0.112129	
		Minimum		2.271842	
		Maximum		2.889862	
		Range		0.61802	
		Skewness		-0.273	0.23
		Kurtosis		0.508	0.457

Contaminant	River Valley			Statistic	SE
Log 10 of Sulfate	Pryor	Mean		1.825891	0.118343
		95% Confidence Interval for Mean	Lower Bound	1.577262	
			Upper Bound	2.07452	
		Median		1.80618	
		Variance		0.266	
		Std. Deviation		0.515845	
		Minimum		1.079181	
		Maximum		2.811575	
		Range		1.732394	
		Skewness		0.276	0.524
		Kurtosis		-0.989	1.014
	Big Horn River Valley	Mean		2.840146	0.116342
		95% Confidence Interval for Mean	Lower Bound	2.598868	
			Upper Bound	3.081424	
		Median		2.977266	
		Variance		0.311	
		Std. Deviation		0.557956	
		Minimum		1.30103	
		Maximum		3.676694	
		Range		2.375664	
		Skewness		-0.845	0.481
		Kurtosis		1.062	0.935
	Little Big Horn River Valley	Mean		2.622935	0.045699
		95% Confidence Interval for Mean	Lower Bound	2.532362	
			Upper Bound	2.713509	
		Median		2.665057	
		Variance		0.23	
		Std. Deviation		0.479295	
		Minimum		0	
		Maximum		3.569374	
		Range		3.569374	
		Skewness		-1.604	0.23
		Kurtosis		7.216	0.457

Contaminant	River Valley			Statistic	SE
Log 10 of Hardness	Pryor	Mean		1.735807	0.271409
		95% Confidence Interval for Mean	Lower Bound	1.165598	
			Upper Bound	2.306016	
		Median		2.403121	
		Variance		1.4	
		Std. Deviation		1.183044	
		Minimum		0	
		Maximum		2.70757	
		Range		2.70757	
		Skewness		-0.844	0.524
		Kurtosis		-1.388	1.014
	Big Horn River Valley	Mean		2.721432	0.111991
		95% Confidence Interval for Mean	Lower Bound	2.489177	
			Upper Bound	2.953688	
		Median		2.713491	
		Variance		0.288	
		Std. Deviation		0.537091	
		Minimum		1.20412	
		Maximum		3.369216	
		Range		2.165096	
		Skewness		-1.462	0.481
		Kurtosis		2.687	0.935
	Little Big Horn River Valley	Mean		2.289911	0.074749
		95% Confidence Interval for Mean	Lower Bound	2.141761	
			Upper Bound	2.438062	
		Median		2.61164	
		Variance		0.615	
		Std. Deviation		0.783976	
		Minimum		0.30103	
		Maximum		3.41162	
		Range		3.11059	
		Skewness		-1.068	0.23
		Kurtosis		-0.078	0.457

Contaminant	River Valley			Statistic	SE
Log 10 of Mn	Pryor	Mean		-2.21037	0.114695
		95% Confidence Interval for Mean	Lower Bound	-2.45133	
			Upper Bound	-1.9694	
		Median		-2.30103	
		Variance		0.25	
		Std. Deviation		0.499945	
		Minimum		-2.69897	
		Maximum		-0.18046	
		Range		2.518514	
		Skewness		4.092	0.524
		Kurtosis		17.593	1.014
	Big Horn River Valley	Mean		-1.61714	0.20356
		95% Confidence Interval for Mean	Lower Bound	-2.0393	
			Upper Bound	-1.19498	
		Median		-2.30103	
		Variance		0.953	
		Std. Deviation		0.97624	
		Minimum		-3	
		Maximum		-0.00877	
		Range		2.991226	
		Skewness		0.646	0.481
		Kurtosis		-1.289	0.935
	Little Big Horn River Valley	Mean		-1.61299	0.065831
		95% Confidence Interval for Mean	Lower Bound	-1.74347	
			Upper Bound	-1.48252	
		Median		-1.69897	
		Variance		0.477	
		Std. Deviation		0.690438	
		Minimum		-2.30103	
		Maximum		-0.13668	
		Range		2.164353	
		Skewness		0.406	0.23
		Kurtosis		-1.298	0.457

Contaminant	River Valley			Statistic	SE
Log 10 of Sodium	Pryor	Mean		1.582311	0.191813
		95% Confidence Interval for Mean	Lower Bound	1.179327	
			Upper Bound	1.985295	
		Median		2.056905	
		Variance		0.699	
		Std. Deviation		0.836093	
		Minimum		0	
		Maximum		2.471292	
		Range		2.471292	
		Skewness		-0.519	0.524
		Kurtosis		-1.431	1.014
	Big Horn River Valley	Mean		2.344965	0.105148
		95% Confidence Interval for Mean	Lower Bound	2.126902	
			Upper Bound	2.563028	
		Median		2.344392	
		Variance		0.254	
		Std. Deviation		0.504271	
		Minimum		1.041393	
		Maximum		3.149219	
		Range		2.107826	
		Skewness		-0.524	0.481
		Kurtosis		0.4	0.935
	Little Big Horn River Valley	Mean		2.259297	0.050931
		95% Confidence Interval for Mean	Lower Bound	2.158354	
			Upper Bound	2.36024	
		Median		2.400496	
		Variance		0.285	
		Std. Deviation		0.534166	
		Minimum		0.60206	
		Maximum		3.274158	
		Range		2.672098	
		Skewness		-0.905	0.23
		Kurtosis		0.669	0.457

Contaminant	River Valley			Statistic	SE
Log 10 of Iron	Pryor	Mean		-1.49898	0.068102
		95% Confidence Interval for Mean	Lower Bound	-1.64267	
			Upper Bound	-1.3553	
		Median		-1.60206	
		Variance		0.083	
		Std. Deviation		0.288934	
		Minimum		-1.60206	
		Maximum		-0.45593	
		Range		1.14613	
		Skewness		3.249	0.536
		Kurtosis		10.96	1.038
	Big Horn River Valley	Mean		-1.06722	0.171627
		95% Confidence Interval for Mean	Lower Bound	-1.42644	
			Upper Bound	-0.708	
		Median		-1.60206	
		Variance		0.589	
		Std. Deviation		0.767539	
		Minimum		-1.60206	
		Maximum		0.59879	
		Range		2.20085	
		Skewness		1.124	0.512
		Kurtosis		-0.199	0.992
	Little Big Horn River Valley	Mean		-0.82204	0.08192
		95% Confidence Interval for Mean	Lower Bound	-0.9846	
			Upper Bound	-0.65947	
		Median		-1	
		Variance		0.664	
		Std. Deviation		0.815098	
		Minimum		-1.60206	
		Maximum		1.33646	
		Range		2.93852	
		Skewness		0.688	0.243
		Kurtosis		-0.7	0.481

Contaminant	River Valley			Statistic	SE
Log 10 of Uranium	Pryor	Mean		-2.90968	0.135008
		95% Confidence Interval for Mean	Lower Bound	-3.22101	
			Upper Bound	-2.59835	
		Median		-3	
		Variance		0.164	
		Std. Deviation		0.405024	
		Minimum		-3.30103	
		Maximum		-2.18709	
		Range		1.113943	
		Skewness		0.819	0.717
		Kurtosis		-0.453	1.4
	Big Horn River Valley	Mean		-1.88833	0.173757
		95% Confidence Interval for Mean	Lower Bound	-2.27076	
			Upper Bound	-1.50589	
		Median		-1.87236	
		Variance		0.362	
		Std. Deviation		0.601912	
		Minimum		-3.30103	
		Maximum		-0.99568	
		Range		2.305351	
		Skewness		-0.931	0.637
		Kurtosis		1.893	1.232
	Little Big Horn River Valley	Mean		-2.63039	0.073572
		95% Confidence Interval for Mean	Lower Bound	-2.77705	
			Upper Bound	-2.48372	
		Median		-2.69897	
		Variance		0.395	
		Std. Deviation		0.628598	
		Minimum		-3.30103	
		Maximum		-1.37675	
		Range		1.924279	
		Skewness		0.319	0.281
		Kurtosis		-1.269	0.555