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MINERALS & MINING PROGRAM

STATE OF SOUTH DAKOTA
DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
BOARD OF MINERALS AND ENVIRONMENT

IN THE MATTER OF THE LARGE SCALE MINE PERMIT APPLICATION OF POWERTECH (USA) INC.	**CLEAN WATER ALLIANCE - EXPERT WITNESS DISCLOSURE**

The Clean Water Alliance, by and through its attorney, hereby designates the following expert witnesses:

Lilias Jarding, Ph.D, Environmental Policy Specialist
Oglala Lakota College
P.O. Box 490
Kyle, SD 57752
Dr. Jarding will testify as to her concerns and opinions about the potential and unaddressed impacts of the proposed Dewey-Burdock, as generally expressed in a February 12, 2009 letter to the DENR, a copy of which, along with her CV are on the enclosed Discovery CD.

Hannon LeGarry, Ph.D, Math & Science Department,
Oglala Lakota College
P.O. Box 490
Kyle, SD 57752
Dr. LeGarry is a geologist. He will testify about the geology in the proposed Powertech Dewey-Burdock ISL mine/processing plant cites, as set forth in his report, a copy of which, along with his CV are contained on the Discovery CD accompanying this notice.

Andrew J. Long, PhD, Research Hydrologist
U.S. Geological Survey, 1608 Mountain View Rd.
Raid City, SD 57702
Dr. Long will testify as to his findings and opinions about the flow directions of the major Black Hills aquifers, including from the area of the proposed Powertech mine/processing plants upon the attached

master's thesis of his research assistant Jonathan McKaskey, entitled "Hydrogeologic Framework for Madison and Minnelusa Aquifers in the Black Hills Area," a copy of which, along with his CV are contained on the enclosed Discovery CD.

Wilmer Mesteth
Oglala Sioux Tribal Historic Preservation Officer
Oglala Lakota College
P.O. Box 490
Kyle, SD 57752
Mr. Mesteth will testify as to the cultural resources existing and how endangered by the proposed Powertech Dewey-Burdock ISL mine/processing plants, as set forth in his previously submitted Declaration, a copy of which, is contained on the enclosed Discovery CD.

Dated this 15 day of August, 2013.

BRUCE ELLISON
328 East NY Street
P.O. Box 2508
Rapid City, SD 57709
belli4law@aol.com
Attorney for Clean Water Alliance

844 Park Avenue South, #9
Brookings, South Dakota 57006
(605) 697-5139
liliasj@hotmail.com

February 16, 2009

South Dakota Board of Minerals and Environment
c/o Mr. Eric Holm and Ms. Roberta Fivecoate
Minerals and Mining Program
Department of Environment and Natural Resources
523 East Capitol Avenue
Pierre, South Dakota 57501-3182

RE: Special, Exceptional, Critical, or Unique Lands Determination
Pending Application by Powertech (USA), Inc.

Dear Board of Minerals and Environment:

This letter is presented in opposition to Powertech (USA), Inc.'s request for dismissal of Nominating Petitions presented by the Oglala Sioux Tribe, Charmaine White Face, Defenders of the Black Hills, and Debra White Plume in the above matter. Please accept this letter as testimony and evidence at your consolidated hearing to be held on February 19, 2009.

It is my professional opinion, as a specialist in Environmental Policy, that the Nominating Petitions listed above should be given the greatest deference for reasons that I outline below. Powertech's proposed in situ leach mining project would cause substantial and irreversible damage to the nominated lands. These lands include significant archeological, wildlife, cultural, historic, and other resources that clearly fit within South Dakota statute's definition of "special, exceptional, critical or unique" lands. South Dakota statute requires that only one of these characteristics, listed in SDCL 45-6B-33.3, be present in order for lands to be so designated.

The nominated lands could not be fully restored if mining took place. In situ mining has significant surface and subsurface impacts, and the full extent of this project is not clear. By their nature, uranium exploration, mining, and processing emit radioactive materials to the environment, including not only uranium, but also its air- and water-borne byproducts. The inspection report indicates that heavy metals would also be disturbed underground and brought to the surface. These materials can be spread by both wind and water and would emit radiation for the foreseeable future. Any disturbance of the numerous historic, archeological, and cultural resources at the proposed mining site cannot be mitigated.

Because these resources could not be restored after mining, all resources must be adequately identified and evaluated before any further activity takes place on the nominated lands. Sites have been identified that may be eligible for the National

Register of Historical Places. Augustana College's survey indicates that some sites may be unique. The Nominating Petitions provide additional information on cultural and historic resources that have not been fully identified. There may well be resources that simply should not be disturbed.

Given this situation, it is alarming that the DENR's inspection report indicates that mining could be allowed to begin before a complete evaluation is conducted.[1] The preliminary information that is currently available indicates that further study is needed before any formal decision could possibly be made.

In addition to the lack of complete information, it is significant that arid areas are very slow to recover from any disturbance, placing these lands within the statute's definition of "special, exceptional, critical, or unique" lands. The South Dakota State Historical Society mentions the area's high level of erosion. This would make restoration of even basic flora difficult, if it was possible.

The presence of erosion also indicates that contaminants are likely to spread beyond where they are initially brought to the surface. This would cause negative impacts to additional resources. And as DENR representatives noted in the inspection report, there would be additional concerns if land application was used to dispose of mining wastewater.

Underground water resources associated with the nominated lands are also a concern, as they impact a broad area. The in situ leach mining process works by intentionally releasing contaminants into aquifers. Incidents of horizontal contamination ("excursions") are typical of in situ leach mining operations. Excursions are the norm, not the exception.[2] If mining was allowed to proceed, there could be significant negative economic and health impacts, as the area's subsurface water is necessary to livestock operations and human occupation.

In addition, vertical leaks among water bodies have been documented in the immediate area.[3] These vertical leaks increase the likelihood that in situ mining, which places an aquifer under substantial pressure, could contaminate more than one aquifer in the southern Black Hills. Thus the resources impacted could be quite extensive. Additional evaluation is needed.

The impacts on special, exceptional, critical, or unique lands could be larger than the DENR estimates in its inspection report on this matter. The report says that the proposed in situ mining operation would have a ten to fifteen year life.[4] The experience of the Wyoming Department of Environmental Quality (DEQ) at the Smith Ranch-

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[1] South Dakota Department of Environment and Natural Resources. December 17, 2008. *Special, Exceptional, Critical, or Unique Inspection: Powertech (USA), Inc.*, page 8.

[2] Lists of excursions at operating in situ leach facilities can be found at http://www.wise-uranium.org/umopwy.html#CHRISVIOL

[3] J. M. Boggs and A. M. Jenkins. 1980. *Analysis of Aquifer Tests Conducted at the Proposed Burdock Uranium Mine Site.* Tennessee Valley Authority. For additional information on the commonality of vertical leaks, see W. P. Staub, et al. 1986. *An Analysis of Excursions at Selected In Situ Uranium Mines in Wyoming and Texas.*

[4] See above: South Dakota Department of Environment and Natural Resources. 2008, page 2.

Highland project, as of March 2008, is shown in Attachment A. The DEQ said that restoration of just one wellfield had been ongoing for ten years, despite estimates that it would take 3 to 5 years. In 20 years of operation at the Smith Ranch-Highland project, only two wellfields had been restored. This information relates to current mining technology. In light of this, a longer timeframe should be taken into consideration when estimating the likely impacts on special, exceptional, critical or unique lands and their associated resources.

Another reason that mining's impacts on the nominated lands may be underestimated is the presence of mining wastes, which are typically under-played by the applicant. I have attached photos labeled "In Situ Mining Above Ground" and "Kingsville Dome In Situ Site, TX." which show piles of wastes that are the result of in situ well drilling (Attachments B and C). These wastes are, of course, exposed to the elements and can be spread beyond the mine site by wind or water.

A third photo, labeled "Trevino In Situ Site Hebbronville, TX.," (Attachment D) also shows the scale of disturbance from in situ operations. This photo includes holding ponds and shows seepage apparently coming out of those ponds. It is not uncommon for ponds associated with in situ mine projects to leak.[5] There have also been catastrophic failures of mine waste retention dams, as you are probably aware from both recent news stories and South Dakota's history.

The surface impacts of the Smith Ranch-Highland project in Wyoming are shown in Attachments E, F, and G, which include:

- A satellite photo of the site, showing the extent of the disturbance created by mining activities;
- An photo of numerous wellheads, which are surrounded by disturbed and bare ground; and
- A photo illustrating the combined impacts of wellheads and traffic.

As these photos show, the disturbances from in situ mining are extensive enough that they cannot be mitigated, and they would be devastating to the nominated lands. These lands need to be protected.

There are additional examples of impacts on the nominated lands that could not be mitigated. These include recent surface water and groundwater contamination at the Smith Ranch-Highland mine, which are detailed in Attachment A. The Wyoming DEQ reports over 80 spills, "in addition to numerous pond leaks, well casing failures and excursions" at the mine.

Clearly, the damage to the nominated lands and their associated resources could not be mitigated in any meaningful way. The Wyoming DEQ's information on a modern, currently-operating in situ leach mine should serve as a cautionary note. It suggests that full information on the nominated lands must be gathered and that the full

[5] Some examples at operating in situ leach facilities, as well as information on other types of leaks and spills, can be found at http://www.wise-uranium.org/umopwy.html#CHRISVIOL

implications of these Nominations should be carefully considered before any further action is taken or any further activity is allowed on the proposed mine site.

There is an additional concern. The applicant's failure to involve Native Americans, who hold this area sacred, indicates a lack of thoroughness. Native nations have a well-known stake in the Black Hills and surrounding lands. The Oglala and other Lakota (Sioux), in particular, clearly have extensive information on cultural, archeological, and historic resources, as indicated in the Nominating Petitions.

A complete analysis of the area's special, exceptional, critical, or unique lands obviously includes full consultation and active participation by those who have the longest-term information on the area and its resources.

Various documents mention an MOA, which appears to be directly relevant to this proceeding. I have been unable to find a copy on DENR's webpage on this matter. I hereby a request a copy of the MOA, and I request that it be posted on the DENR's webpage with the other materials relevant to this proceeding. Until all interested parties have had the opportunity to provide input on the MOA and its adequacy, this proceeding should be halted. From the information given in the Nominating Petitions, this agreement appears to be non-binding. Based on long experience in environmental policy and with the uranium industry, it is my opinion that "gentlemen's agreements" have no place in the regulatory process.

My final concern is the applicant's response to Eric Holm, Natural Resources Project Engineer, in a letter dated October 7, 2008. At the end of this letter, the company was asked if it "is planning on adding any additional areas to the proposed mine permit boundary." The company replies "Powertech has no plans *at this time* to include additional lands within the proposed permit area." [italics added]

This statement is not clear and may indicate only that a formal plan has not been completed. However, the evidence suggests that discussions or preliminary actions may be underway that would expand the mine permit boundary. The company has acquired additional property in the area in the past two months, according to its "Management Discussion and Analysis" issued on January 22, 2009. This has occurred since the October letter was written, and additional information should be pursued.[6]

The applicant should be required to submit information on all lands that its operation might impact. Without full information on the company's long-term aspirations – not just its formal plans as of October -- the impacts on special, exceptional, critical or unique lands cannot be properly evaluated.

From the information that is available, it is my opinion that the proposed mine site includes special, exceptional, critical, or unique lands. However, full information should be gathered and evaluated to insure that all the evidence has been considered. The land is clearly ecologically fragile, and it would be impossible to mitigate several of the

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[6] Attachment H shows the first two pages of this document, with the relevant discussion on page two. Full text available upon request.

types of resources that are under consideration. The concerns raised in the Nominating Petitions and all testimony should be addressed at this stage of the proceedings and before any further activity is allowed to take place on the proposed mining or processing sites.

If you have any questions, please feel free to contact me.

Sincerely,

Lilias Jarding

Lilias Jones Jarding, Ph.D.

ATTACHMENT A

Department of Environmental Quality

To protect, conserve and enhance the quality of Wyoming's environment for the benefit of current and future generations.

Dave Freudenthal, Governor

John Corra, Director

March 10, 2008

CERTIFIED MAIL, RETURN RECEIPT REQUESTED #7005 1820 0005 1478 8828

Mr. John McCarthy
Power Resources, Inc.
P.O. Box 1210
Glenrock WY 82637

RE: Insitu Uranium Permits 603 and 633, Notice of Violation, Docket No. 4231-08

Dear Mr. McCarthy:

Enclosed you will find a Notice of Violation issued under the provisions of W.S.§ 35-11-415(a) and (b)(ii). The Notice of Violation is based on the investigation conducted Mr. Mark Moxley during the fall of 2007. The investigation found that PRI failed to conduct concurrent reclamation which is a violation of Chapter 3, Section 2(k)(i)(D), and that PRI failed to follow the approved permits.

The Wyoming Department of Environmental Quality/Land Quality Division (LQD) is attempting to resolve this issue without further enforcement action, and requires that you contact Mr. Donald R. McKenzie, LQD Administrator at 307-777-7046 **within fifteen (15) days of receipt of this letter** to schedule a meeting to resolve this enforcement action. Should resolution of this enforcement action be reached as a result of this meeting, a Settlement Agreement including a penalty assessment will be signed by both parties.

Respectfully,

John V. Corra
Director
Department of Environmental Quality

Donald R. McKenzie
Administrator
Land Quality Division

Enclosures: Notice of Violation
Investigation Report

cc: Lowell Spackman, District I w/attachments
Mark Moxley, District II w/attachments
Docket # 4231-08 w/attachments
Doug Mandeville, NRC w/attachments

DEPARTMENT OF ENVIRONMENTAL QUALITY
STATE OF WYOMING

NOTICE OF VIOLATION

IN THE MATTER OF THE NOTICE OF VIOLATION ISSUED TO POWER RESOURCES, INC.
P.O. BOX 1219
GLENROCK, WY 82637
Re: Insitu Uranium Operation, Permit #603
Re: Insitu Uranium Operation, Permit #633

DOCKET NO. 4231-08

NOTICE

NOTICE IS HEREBY GIVEN THAT:

1. Notice of Violation is being sent to you pursuant to W.S. §35-11-701(c) which requires that a written notice shall be issued in the case of failure to correct or remedy an alleged violation specifying the provision of the act, rule, regulation, standard, permit, license, or variance alleged to be violated.

2. As a result of Land Quality Division (LQD) concerns over the slow pace of groundwater restoration of wellfields at Power Resources, Inc. Permits 603 and 633 Insitu Uranium Mine, an investigation was conducted of the mine and reclamation plans in the approved permits, plus information provided in annual reports. This investigation was conducted by LQD staff during October and November of 2007. In addition to the violations cited below, LQD identified serious deficiencies with both permits. The plans contained in the permit documents are dated and incomplete in numerous ways: spill detection, reporting, and follow-up protocols are not defined in the permit; groundwater restoration procedures, necessary facilities, and time schedules for restoration must be thoroughly described; waste disposal facilities and processes must be described for all waste streams; all critical process installations need thorough construction details and specifications; and topsoil protection procedures are not adequately defined. As a consequence of the inadequacies of the permits, both operations are seriously under-bonded.

3. The investigation found that PRI failed to conduct concurrent reclamation which is a violation of Chapter 3, Section 2(k)(i)(D) requiring concurrent reclamation; and that PRI failed to follow the approved permits, which is a violation of W.S. §35-11-415(a). The following lists the specific violations:

   Permit 603

   a. Wellfield C was in production for approximately ten years. The approved Mine Plan states, *"Once a wellfield is installed it takes approximately one to three years to recover the leachable uranium from a production area."* Extending the production time period has become a routine practice and is not in compliance with the approved permit or the requirement for concurrent reclamation.

   b. In addition to the production phase, Wellfield C has now been in restoration for ten years. The 2007 Annual Report states that the ground water quality is similar to *"end of mining"* wellfield conditions. The permit states that restoration and stability are estimated to take approximately five years. This restoration delay is not in compliance with the approved permit or the requirement for concurrent reclamation.

   c. Wellfield E has removed 100% of the leachable reserves, and in recent years wellfield production has slowed to maintenance levels. This rate of production delays completion of mining and restoration of this wellfield unit. This is not in compliance with the approved permit, and is a violation of Chapter 2, Section 2(b)(ii) which requires coordination of the Mine and Reclamation Plans to facilitate orderly development and reclamation.

d. The timetable listing the schedule of mining-related activities in the permit (Figure A, page OP-3A) and the timetable provided in the 2007 annual report both indicate that PRI is not in compliance with their restoration schedules for Wellfields C, D, and E. The schedule shows that Wellfield C should be decommissioning instead of in restoration, and that Wellfields D and E should be in restoration instead of production.

Permit 633

a. The permit indicates that "An updated schedule will be supplied with the annual report if the mining or restoration schedule varies from Table 3-1." The timetable commitments in the permit are not consistent with wellfield status. Therefore, the table in the annual report is the schedule that PRI is committed to for wellfield status. Based on this table, PRI is not in compliance with their restoration schedules for Wellfields 2, 3, and 4/4A. The annual report text indicates that Wellfield 2 will continue to be in production, while the annual report schedule referred to in the permit shows that it will be in restoration in 2008. Wellfields 3 and 4/4a should be in restoration instead of production.

b. The permit states that it generally takes "three years for uranium production, and three years for aquifer restoration." Actual times for wellfield production and restoration are, thus far, 2-3 times longer than permit commitments.

4. Wyoming Statute §35-11-901(a) provides that any person who violates any provision of the Environmental Quality Act or any rule, standard, permit, license or variance adopted hereunder is liable to a penalty of ten thousand dollars ($10,000.00) for each day of violation, which penalty may be recovered in a civil action brought by the Attorney General in the name of the People of the State of Wyoming.

NOTHING IN THIS NOTICE shall be interpreted to in any way, limit or contravene any other remedy available under the Environmental Quality Act, nor shall this Order be interpreted as being a condition precedent to any other enforcement action.

SIGNED this 7th day of March, 2008

John V. Corra
Director
Department of Environmental Quality

Donald R. McKenzie
Administrator
Land Quality Division

Please direct all inquiries regarding this Notice of Violation to Mr. Donald R. McKenzie, Administrator, Land Quality Division, Wyoming Department of Environmental Quality, 122 West 25th Street, Cheyenne, WY 82002. Telephone No. (307) 777-7046.

ec: Lowell Spackman, District I
Mark Moxley, District II
Docket # 4231-08
Doug Mandeville, NRC

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MINERALS & MINING PROGRAM

Report of Investigation

Operator	:	**Power Resources, Inc.**
Facility	:	**Smith Ranch - Highland Uranium Project** **Mine Permit #603 (Highland) and #633 (Smith Ranch)**
Prepared By	:	**Mark Moxley, LQD District 2 Supervisor**
Date	:	**November 21, 2007**

Background:

This investigation was conducted at the request of Rick Chancellor, LQD Administrator, in response to concerns over recent spills and the slow pace of groundwater restoration at the Smith Ranch-Highland ISL operation. PRI's operation is located in Converse county in LQD District 1. An investigator was brought in from LQD District 2 with the intention of having a fresh pair of eyes look at the operation. The investigation was intended to identify and focus on "big picture" issues, not specific details. The investigation proceeded as follows:

- Review of permit documents and annual reports
- Interviews with LQD District 1 staff
- Site tour and interviews with PRI staff
- Interviews with LQD District 3 staff
- Follow-up reviews and discussions

PRI began producing in 1988 and is currently the only significant producer of uranium in Wyoming. They are currently producing at capacity levels (2 million pounds of yellow-cake in 2006 and they are expecting similar production in 2007). PRI has applied for a mine permit amendment to add the Reynolds Ranch property and they are also planning to consolidate the Smith Ranch and Highland permits. This will result in a combined mine permit area some 41,000 acres in size. PRI is planning to increase their throughput capacity next year and add approximately 30 people to their current staff of 100. They are also considering adding facilities to provide toll milling services to process feedstock from other operators.

Given that PRI's operation has for many years been the major uranium producer in Wyoming, there is an expectation that the operation might serve as a model for excellence in ISL mining. Unfortunately, this is not the case. There are a number of major long-standing environmental concerns at this operation that demand immediate attention. Recommendations are made as to how to address these concerns.

Currently the uranium industry is experiencing a major boom. Drilling and pre-permitting investigations are proceeding on many different properties around the state, including several owned by PRI. The LQD is expecting numerous new ISL mine permit applications within the coming 12-18 months. This increase in workload will be a major challenge for the LQD staff. Achieving regulatory effectiveness and efficiency will be a high priority for LQD and it will require the cooperation of the industry.

Major Regulatory Issues and Concerns with Permits 603 & 633:

1. Mine Permit:

The mine permit document is the primary regulatory mechanism governing the operation. The mine and reclamation plan should describe in detail how the operation will be conducted so as to comply with all of the major regulatory requirements. The mine and reclamation plans should be updated and maintained so as to be a definitive reference for the operator, the regulatory agencies, and also the public. Having a definitive mine and reclamation plan is particularly important for new staff. In the case of the Smith Ranch - Highlands operation (mine permits #603 and #633), the plans contained in the permit document are out of date and incomplete in several important areas. The following major deficiencies were noted:

A. The approved mining and reclamation schedules are not being followed and are not current. PRI is not conducting contemporaneous restoration as required by their permit and WDEQ-LQD regulations. See discussion under item 2, below.

B. Spill detection, reporting, delineation, remediation, follow-up and tracking protocols are not defined in the permit and should be. PRI experiences spills on a routine basis. See discussion under item 3 below.

C. Groundwater restoration processes, facilities and procedures (incorporating and defining BPT), flow rates and time schedules should be thoroughly described in the permit so that expectations are clear. This has implications for bonding also.

D. Waste disposal facilities and processes should be clearly defined for all waste streams. One example of inaccurate information in permit #603 (on pages OP-15 and 19) states that byproduct solid waste materials will be disposed at the ANC Gas Hills facility (which closed in 1994). This waste actually goes to the Pathfinder Shirley Basin facility.

E. Construction details and specifications should be thoroughly described for critical process installations, including wells, pipelines, header houses, ponds, etc. One example of inaccurate information in permit #603(on page OP-24)states that well casing joints are fastened with screws. This practice is not consistent with the regulations and was discontinued years ago.

F. Topsoil protection procedures are not adequately defined to assure that disturbance is minimized and that the soil resource is protected. PRI's typical wellfield installation procedures result in the near total disturbance of the native vegetation and soils. This is not consistent with the regulation that allows for "minor disturbance" without topsoil stripping. More definitive procedures should be implemented to restrict and consolidate disturbance from roadways and pipelines and to insure careful topsoil salvage from well sites, mud pits, pipelines, roadways, etc.

With the permit updates required by Chapter 11 and the proposed consolidation of the Highland and Smith Ranch permits, now is an opportune time to correct permit deficiencies and construct a permit that is informative and useful to all parties.

2. **Contemporaneous Reclamation:**

One of the fundamental requirements for any mining operation is that reclamation be conducted concurrently with mining. Not only is this the most efficient operational strategy but it also insures that the reclamation liability is kept at a reasonable and manageable level. This approach ensures that the public is protected in the event of a forfeiture.

The schedule in permit #603, Highland, dates from 2005. An identical schedule was provided in the July, 2007 annual report. That schedule shows that restoration of the C wellfield should have been completed in 2006 and decommissioning should now be in progress. In actuality the restoration of the C wellfield has been on-going for ten years and the RO treatment phase has only just recently begun. According to the schedule, restoration of the D wellfield should have commenced in 2006 and restoration of the E wellfield should have commenced in early 2007. The annual report states that both the D and E wellfields are still in production. According to the schedule there should now be five wellfields in production (D-ext, F, H, I & J), two in restoration (D & E) and three restored (A, B & C). In fact there are currently 7 wellfields in production, one in restoration (C), and only 2 restored (A & B) at Highland.

The schedule contained in permit #633, Smith Ranch, dates from 1998. A more current schedule was provided in the July, 2007 annual report, yet even this recent schedule is not being followed. According to that schedule, wellfields 1, 3 and 4/4A should now be in restoration. Production from these wellfields was started in 1997, 1998 and 1999 respectively. Restoration of wellfield 1 is to be complete by mid 2008 and restoration in wellfield 2 is to commence in early 2008. However, as reported in the annual report only wellfield 1 is in restoration (no completion date stated) and no mention is made of any other planned restoration. In addition, a new wellfield (K) went into production this year and it does not even appear on the schedule. According to the schedule there should now be three wellfields in production (2, 15 & 15A)and three in restoration (1,3 & 4/4A). In fact there are currently five wellfields in production and only one in restoration. No wellfields have been restored at Smith Ranch.

It is readily apparent that groundwater restoration is not a high priority for PRI. Reclamation is not contemporaneous with mining. A total of 12 wellfields are now in production and restoration is proceeding (slowly) in only 2 wellfields. Only 2 wellfields (A and B) have been restored in 20 years of operation. The permits project that production will typically last for 3-5 years per wellfield and restoration will take 3-5 years per wellfield. It appears in reality that both production and restoration timeframes have doubled or tripled and yet additional wellfields are being brought into production.

It is recommended that a notice of violation be issued to PRI for failure to conduct concurrent reclamation and failure to follow the approved schedules. A rigorous compliance schedule should be implemented to accelerate restoration. A thorough re-evaluation of the operation schedules is warranted. As pointed out below, new deep disposal wells (DDW's) and RO units will be required to support restoration operations. LQD approval of the Reynolds Ranch amendment as well as any new wellfields should be contingent on installation of appropriate DDW's and RO units and completion of restoration in existing wellfields.

3. **Spills, Leaks and Excursions:**

Over the years there have been an inordinate number of spills, leaks and other releases at this operation. Some 80 spills have been reported, in addition to numerous pond leaks, well casing failures and excursions. Unfortunately, it appears that such occurrences have become routine. The LQD currently has two large three- ring binders full of spill reports from the Smith Ranch - Highland operations.

Protocols for spill detection, reporting, control, delineation, remediation and tracking should be defined in the mine plan to cover all potential fluid types (injection fluids, production fluids, waste fluids, chemicals and petroleum products) and all potential sources (buried pipelines, surface pipelines, wellhead fittings, headerhouses, ponds, well casing failures, etc.). Protocols should include mapping and delineation of the extent of soil and/or groundwater contamination associated with each occurrence. A GIS system should be developed to facilitate long term tracking of all spills and releases. An updated cumulative spill map showing all historic spills and releases should be presented in each annual report along with documentation of follow-up actions. Excursion protocols are addressed in some detail in the permit, but excursions should be tracked on a cumulative basis in the annual report.

Cumulative tracking of spills and releases is important to insure appropriate follow-up on every incident. Some of the spills may have little impact individually, but cumulatively they might have a significant effect on soils and/or groundwater. A cumulative record will also assist in pinpointing potential problem areas and developing appropriate preventative measures. PRI should develop and implement an inspection and maintenance program designed to prevent future spills. Spills should not and need not be an accepted consequence of ISL mining.

4. **Reclamation Cost/Bonding:**

The reclamation cost estimates contained in PRI's annual reports assume completion of all groundwater and surface reclamation in 4 years with a staff of 26 people (1/4 of current staff), using the existing facilities with the addition of only 2 new 400gpm RO units. This scenario is totally infeasible and unsupported by any critical path timeline or water balance. Rough calculations based primarily on PRI's figures reveal an alarming scenario.

- Adding the pore volumes for all of the existing wellfields gives a total pore volume (PV) for the project (excluding restored wellfields A&B) of 5,133 Ac.Ft.

- PRI's bond calculation includes only one PV of groundwater sweep, vs three PV's specified in the permit. [Removal of this volume of water from the aquifer would be problematic and warrants further evaluation.] PRI's four existing deep disposal wells (DDW's) have a combined capacity of approximately 600gpm (@100% availability). Disposal of one PV would take more than 5 years! This is not an acceptable schedule. A more reasonable scenario would require at least doubling the disposal capacity (1,200gpm), which would require 4 or 5 new DDW's. These would also be needed for disposal of RO brine and should be included in the bond.

- PRI's bond calculation includes only 3 pore volumes of RO treatment. The approved reclamation plan specifies circulation of a total of 6 PV's (3 groundwater sweep and 3 RO). It is likely that at least 5 PV's of RO treatment would be required if only one PV of groundwater sweep was completed. Using the five existing RO units on the site, plus two new 400 gpm units included in the bond calculation, producing a combined total of 1,360gpm of permeate (@80/20 permeate to brine ratio @100% availability), it would take 854 days (2.3 years) to treat one PV! It would take at least 11.5 years to treat 5 pore volumes. This is a not an acceptable schedule. A more realistic reclamation scenario would require increasing the RO capacity by 2-3 times (3,000 - 4,000 gpm permeate production). The additional RO units, as well as the additional building space, ancillary treatment facilities and piping, should be included in the bond.

- Using the existing RO units (plus the two bonded RO units) and existing DDW's, reclamation would take 20+ years, assuming groundwater restoration was achieved without any problems. (5 years for one PV of GW sweep + 11.5 years for 5 PV's of RO treatment + 1 year stability monitoring + 1 year decommissioning + 1 year of surface reclamation). Clearly this is not an acceptable schedule, but it does point out the need for reevaluation of the reclamation plan, restoration schedule and the bond calculation.

- PRI's bond calculation includes minimal funds for new infrastructure, maintenance, replacement and repair. Only two new 400 gpm RO units are included in the bond estimate. The need for new wells, including DDW's, water storage and treatment ponds, additional RO units, membranes, pumps, piping and general wellfield renovation should be anticipated and included in the bond calculation.

- PRI's bond calculation assumes a staff of only 26 people, with 22 of them on a salary of only $34,000 per year! If their current operations require a staff of 100 people then it will take at least 1/2 to 2/3 of that staff to conduct restoration. The restoration operations will look very similar to production operations. Operation of RO units, in particular, is very high maintenance and labor intensive. Retaining competent staff will require that wages and benefits be at least $50,000 per year.

- Considering that reclamation will take several times longer, require at least twice the staff with higher wages and require much greater investments in infrastructure than PRI has estimated, a realistic reclamation cost estimate for this site would likely be on the order of $150 million, as compared to PRI's current calculation of $38,772,800. PRI is presently bonded for a total of only $38,416,500. No bond adjustments have been made since 2002. Clearly the public is not protected. It is recommended that PRI's bond be immediately raised to a level of $80 million until a thorough evaluation, including critical path analysis, can be completed and an appropriate bonding level established. No permit amendments should be approved or new wellfields authorized until the bonding situation is corrected.

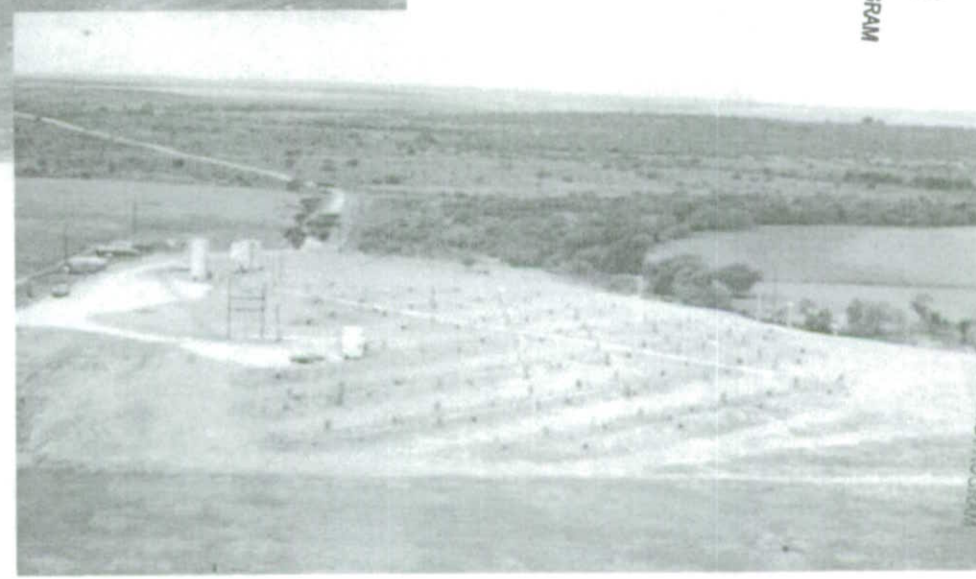
5. **Regulatory compliance:**

Achieving environmental compliance at an operation of the size and complexity of PRI's Smith Ranch - Highland Mine requires a high level of commitment from both the company and the regulatory agency. PRI's environmental efforts have suffered from inadequate staffing, high turnover, lack of institutional memory and a low level of corporate commitment. There has been a lack of continuity and follow-through on many issues. At this point in time, overall environmental compliance at this operation is poor. PRI should retain a full-time environmental staff of 4-5 qualified people, including a groundwater hydrologist to manage the groundwater restoration. It is recommended that LQD immediately assign a staff person full-time to manage this project as their #1 priority, and that monthly inspections be conducted to get a handle on the issues identified in this investigation.

End of Report

In Situ Mining Above Ground

ATTACHMENT B



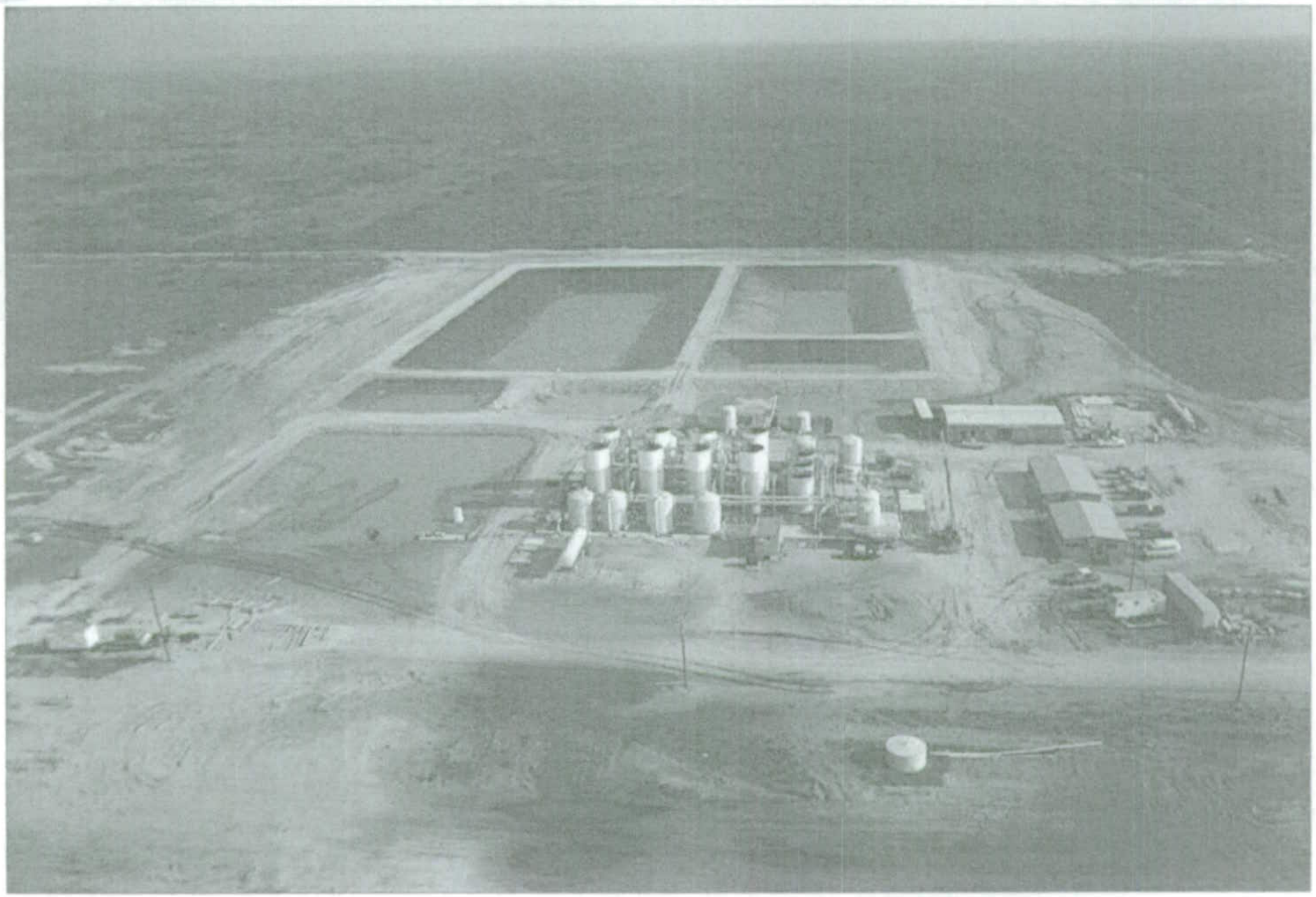
Kingsville Dome In Situ Site, TX.

ATTACHMENT C

RECEIVED
AUG 16 2013
MINERALS & MINING PROGRAM

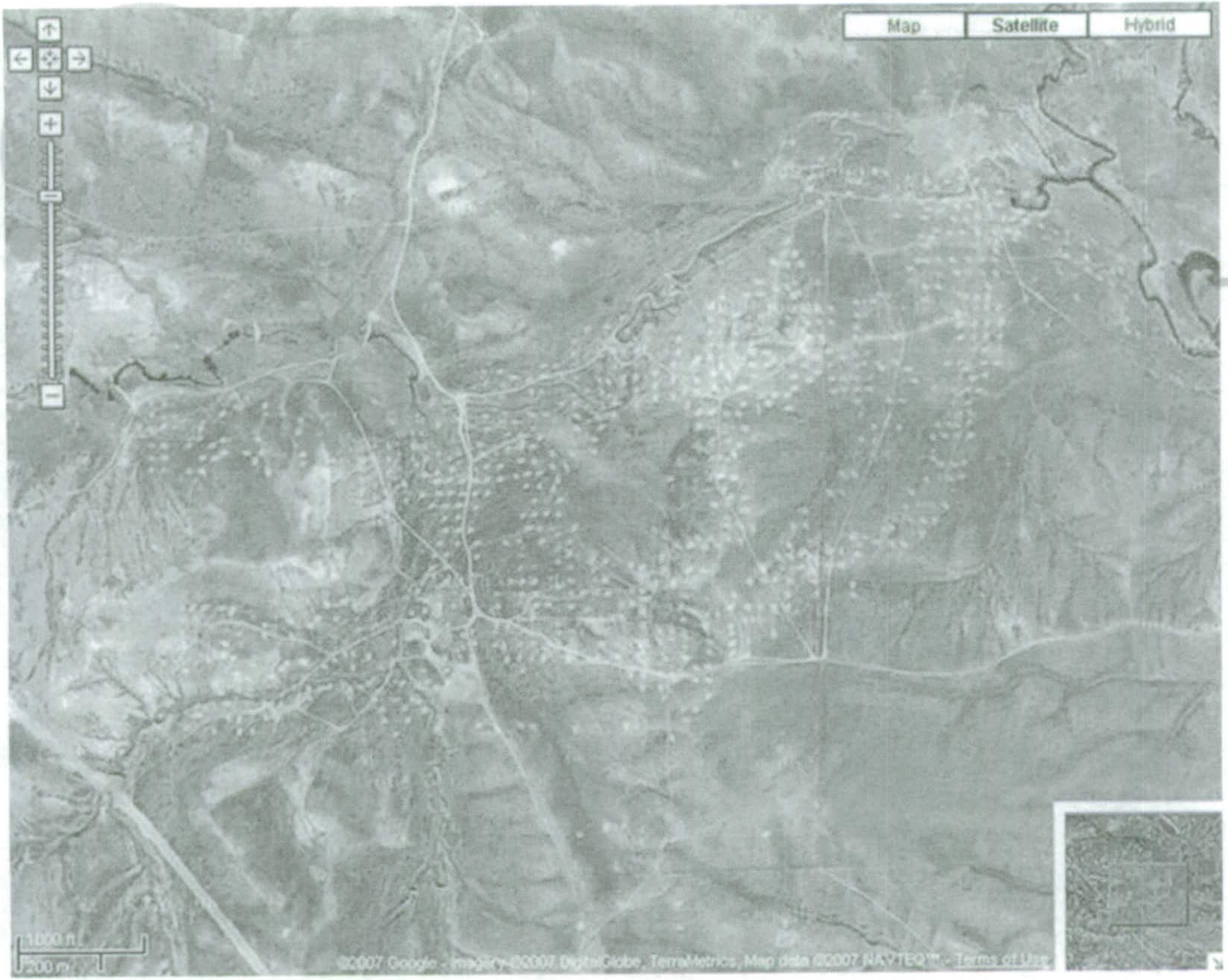
RECEIVED
FEB 19 2009
MINERALS & MINING PROGRAM

Trevino In Situ Site
Hebbronville, TX.

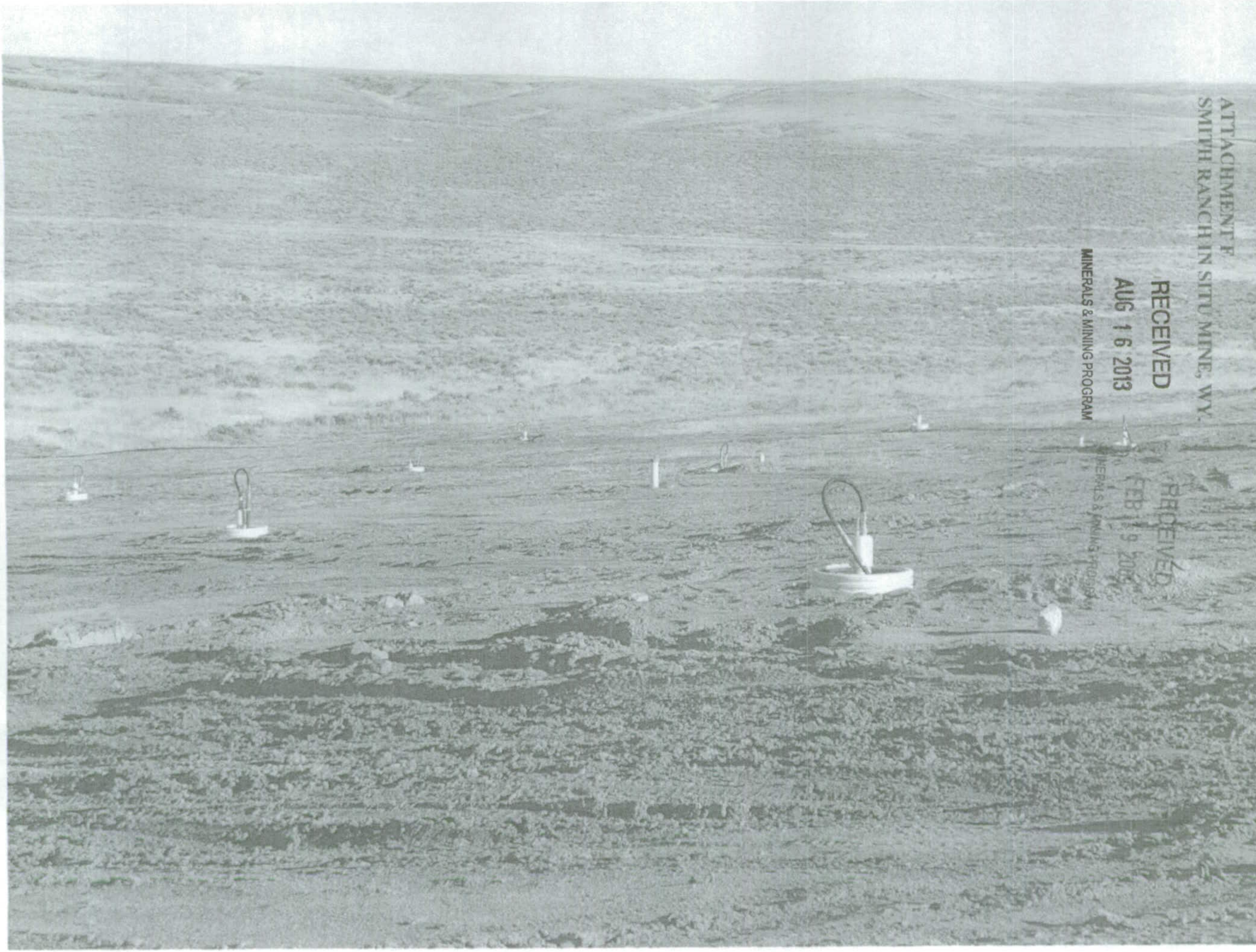


ATTACHMENT D

ATTACHMENT E



Smith Ranch In Situ Leach Mine from a satellite, Wyoming



ATTACHMENT F
SMITH RANCH IN SITU MINE, WY.

RECEIVED
AUG 16 2013
MINERALS & MINING PROGRAM

RECEIVED
FEB 19 20

Smith Ranch
In Situ Mine, WY.

ATTACHMENT H

POWERTECH URANIUM CORP.

POWERTECH URANIUM CORP.

(An Exploration Stage Company)
MANAGEMENT DISCUSSION AND ANALYSIS
(January 22, 2009)

GENERAL

The following discussion of performance, financial condition and future prospects should be read in conjunction with the consolidated financial statements of Powertech Uranium Corp. (the "Company") and notes thereto for the quarter ended December 31, 2008 and the year ended March 31, 2008. Additional information is available on SEDAR at www.sedar.com. References to "CAD$" refer to Canadian currency and "$" to United States currency.

DISCLAIMER FOR FORWARD LOOKING INFORMATION

Certain statements in this quarterly report are forward-looking statements, which reflect management's expectations regarding the Company's future growth, results of operations, performance and business prospects and opportunities. Forward-looking statements consist of statements that are not purely historical, including any statements regarding beliefs, plans, expectations or intentions regarding the future. Such statements are subject to risks and uncertainties that may cause actual results, performance or developments to differ materially from those contained in the statements. No assurance can be given that any of the events anticipated by the forward-looking statements will occur or, if they do occur, what benefits we will obtain from them. These forward-looking statements reflect management's current views, are based on certain assumptions, and speak only as of December 31, 2008. These assumptions, which include, management's current expectations, estimates and assumptions about certain projects and the markets the Company operates in, the global economic environment, interest rates, exchange rates and its ability to manage its assets and operating costs, may prove to be incorrect. A number of risks and uncertainties could cause its actual results to differ materially from those expressed or implied by the forward looking statements, including, but not limited to: (1) the risk that nuclear energy will not be accepted by the public as a safe and viable means of generating electricity; (2) a downturn in general economic conditions in the United States, Europe and internationally; (3) a decrease in the demand for uranium and uranium related products; (4) the number of competitors; (5) the uncertainty of government regulation in the United States, Europe and internationally; (6) political and economic conditions in uranium producing and consuming countries; (7) delays in the receipt of any permits or approvals required for the Company's operations; (8) failure to obtain additional capital at all or on commercially reasonable terms; and (9) other factors beyond the Company's control.

There is a significant risk that the Company's forecasts and other forward-looking statements will not prove to be accurate. Investors are cautioned not to place undue reliance on these forward-looking statements. No forward-looking statement is a guarantee of future results. The Company disclaims any intention or obligation to update or revise any forward-looking statements, whether as a result of new information, future events or otherwise.

Additional information about these and other assumptions, risks and uncertainties are set out in the section entitled "Risk Factors and Uncertainties" in the Company's annual Management Discussion and Analysis for the year ended March 31, 2008.

NATURE OF BUSINESS

The Company is a Toronto Stock Exchange ("TSX") (symbol "PWE") and a Frankfurt Stock Exchange (symbol "P8A") listed mineral exploration/development company which, through its wholly-owned subsidiary Powertech (USA) Inc., is focused on the exploration and development of uranium properties in the United States.

POWERTECH URANIUM CORP.
(An Exploration Stage Company)
MANAGEMENT DISCUSSION AND ANALYSIS
(January 21, 2009)

Directors and Officers

The Company's Board of Directors that were re-elected at the Annual and Special General Meeting of the Shareholders held on July 15, 2008 are Wallace M. Mays, Richard F. Clement, Jr., Thomas A. Doyle, Greg Burnett, Douglas E. Eacrett, Malcolm Clay, Robert Leclère, and Gérard Pauluis.

The Company's current officers include the following persons:

Wallace M. Mays	Chairman of the Board, Chief Operating Officer
Richard F. Clement, Jr	President, Chief Executive Officer
Thomas A. Doyle	Chief Financial Officer, Vice President – Finance and Treasurer
Greg Burnett	Vice President – Administration and Secretary
James Bonner	Vice President – Exploration
Richard Blubaugh	Vice President – Health, Safety and Environmental Resources
John Mays	Vice President – Engineering

MINERAL PROPERTY INTERESTS

South Dakota, USA

Dewey-Burdock Project – Custer and Fall River Counties

Through December 1, 2008, the Company's Dewey-Burdock Project is comprised of 18 mining leases covering approximately 14,000 net surface acres and 7,300 net mineral acres. The Company has purchased approximately 560 net mineral acres. In addition, the Company staked and acquired 238 mining claims in Dewey-Burdock covering approximately 4,700 acres. In December 2008, the Company purchased 59 mining claims in the Dewey--Burdock area from Bayswater Uranium Corporation ("Bayswater"). This purchase included other mining claims and State mining leases located in two of the Company's Wyoming exploration prospects, see discussion below.

During January 2009, the Company acquired 124 claims and 30 leases covering approximately 6,000 acres, from Neutron Energy, Inc. ("Neutron"), in exchange for some of the Company's noncore properties in New Mexico, Wyoming and South Dakota. In South Dakota, the Company transferred to Neutron approximately 360 acres of claims and leases, along with associated historical drilling data. The acreage is located several miles away from the Dewey-Burdock project. See discussion below regarding the New Mexico and Wyoming exchanges.

The Dewey-Burdock deposit contains National Instrument 43-101 compliant inferred uranium resources of 7.6 million pounds with an average grade of 0.21% U_3O_8, and is located in the well-known Edgemont Uranium District. Thirty-four mining claims, included above, were staked within the project area to correct defects associated with County filing requirements on some fractional claims located in 2007 and acquire additional buffer lands for the Aquifer Exemption boundary.

A new uranium exploration permit application for 30 additional drill holes was submitted to the South Dakota Department of Environment and Natural Resources ("SD DENR"). The purpose of this new drill program is to confirm that the area for the proposed plant site will not be built over potential ore. The drilling program was approved by the Board of Minerals and Environment at the November 19, 2007 hearing. Drilling is scheduled to begin upon issuance of the permit and acceptance of surety bond.

The following major milestones have been completed through January 22, 2009:

- The draft Technical Evaluation Report ("TER") and Environmental Report ("ER") that will be submitted to the U.S. Nuclear Regulatory Commission ("NRC") are undergoing technical and administrative reviews both internally and externally, prior to completion and submittal.

LILIAS JONES JARDING, Ph.D.

ACADEMIC EXPERIENCE

Associate Professor, Oglala Lakota College, Rapid City, S.D.: 2010-present
Teach undergraduate courses, serve on graduate student committees, and take an active role in the College and regional communities. Courses taught include:

- American Government
- Introduction to Social Science
- Technical Writing
- Social Policy
- General Psychology
- American Indian History
- American History to 1865
- Environmental Policy and Politics
- International Politics

Assistant Professor, South Dakota State University, Brookings, S.D.: 2008-2009 (9-month position). Taught undergraduate courses, performed administrative duties, and provided service to the campus and regional communities. Courses taught:

- Public Administration
- Natural Resources Politics
- American Government
- American Government – Honors
- American Political Issues
- Civil Rights and Liberties

Adjunct Instructor, Political Science and Ethnic Studies, Colorado State University, Fort Collins, CO.: 2001-2007. Taught undergraduate courses:

- Gender, Class and Race in the United States
- Empirical Political Analysis
- American Government
- Public Administration
- Environmental Politics and Policy

Instructor, Political Science, South Dakota State University, Brookings, S.D.: 1996-1998. Administrative duties, served on committees, and taught undergraduate courses:

- Public Administration
- Natural Resources Policy
- American Government
- Public Policy
- State and Local Government
- Women and Politics
- The Presidency

Instructor, Oglala Lakota College, Pine Ridge, S.D.: Summer 1997. Taught Environmental Politics and Policy.

Instructor, Moorhead State University, Moorhead, MN.: 1995-1996 (9-month position). Taught undergraduate courses:

- American Government

- Legislative Process
- Political Parties
- Environmental Politics and Policy
- Public Policy

Graduate Assistant:

Political Science, Colorado State University, Ft. Collins, CO.: 1992-1995.
Assisted professors in classroom and administrative duties for courses on: Environmental Politics and Policy; Civil Rights and Liberties; American Government; State and Local Government

Public and Human Services Administration, Moorhead State University, Moorhead, MN.: 1990-1992.
Performed administrative duties for Department Chair.

SELECTED OTHER PROFESSIONAL EXPERIENCE

Operations Manager, Lakota People's Law Project, Rapid City, S.D. 2009-2010.

- Oversaw general functioning of Rapid City office for human rights law firm.
- Research and writing on Indian Child Welfare Act and on uranium activities.
- Grant proposal writing.

Owner, NPPhD: NonProfit Doctor, Fort Collins, CO. 2005-2008.
Provided consulting services to nonprofit agencies and government entities:

- Project management involving paid staff, volunteers, and diverse clients.
- Research and Writing: policy analysis, needs assessment, evaluation.
- Staff, board, and public training.
- Fundraising: Wrote proposals that brought nearly $12 million in federal funds into northern Colorado; capital campaigns; foundation grants.

Community Development Specialist, Colorado State University Cooperative Extension, Fort Collins, CO.: 2001-2003.

- Provided technical assistance to local governments in 15 counties.
- Increased communities' governmental, social, and technical capacity in a variety of subject areas.
- Supervised up to 30 student workers.

Executive Director, Bison Land Resource Center, South Dakota and Wyoming: 1998-2001.
Oversaw organization that focused on natural resources issues in the northern Great Plains, including fundraising, coordination of three-state volunteers, and research and writing on energy issues.

Executive Director, EcoSolutions, Inc., Minneapolis, MN.: 1988-1992.
Oversaw waste reduction organization, including research, manual writing, fundraising, and public relations.

Research and Documentation Coordinator, Black Hills Alliance, Rapid City, S.D. 1979-1981.
Coordinated research and fact-checking for organization focused on uranium mining. Oversaw library and several staff.

EDUCATION

Colorado State University, Ft. Collins, CO.
Ph.D., Political Science: 2001
Areas of Emphasis: Environmental Politics and Policy
American Government
Public Administration and Policy

Moorhead State University, Moorhead, MN.
M.S., Public and Human Services Administration: 1992

University of Wisconsin, Madison, WI.
Law Student (Completed First Year): 1978-1979

Lawrence University, Appleton, WI. B.A., History: 1977

PUBLICATIONS

Refereed Journals

The New Nuclear Era in the Western United States: Regulators' Response to the Uranium Boom. Under Revision, *Social Science Journal.*

History of Uranium Activities' Impacts on Lakota Territory. *Indigenous Policy Journal*, Fall 2011.

The Magna Carta and the Constitution of the Iroquois Confederacy. September 2009. *Indigenous Policy Journal*, XX: 2.

Comparison of Native American and Non-Indian Media Coverage of Land and Resource Issues in the Self-Determination Era. 2004. *Social Science Journal*, XLI: 4.

Tribal-State Relations Involving Land and Resources in the Self-Determination Era. June 2004. *Political Research Quarterly*, 295-303.

The Department of the Interior's Appeals Process and Native American Natural Resource Policy: 1970-1994. 1999. *Policy Studies Journal,* XXVII: 2: 217-241.

Assessing Transboundary Environmental Impacts on the U.S.-Mexico and U.S.-Canada Borders. Spring/Summer 1997. *Journal of Borderland Studies*, XII: 1/2. Co-authors: Pamela Duncan and Stephen Mumme.

Civil Rights on the White Earth Reservation. Winter-Spring 1994. *New Political Science*, 28/29: 217-250.

Encyclopedia Entries

Encyclopedia of United States – American Indian Policy, Relations, and Law. Contributor (18 entries). CQ Press. 2008.

Encyclopedia of Minorities in American Politics. Contributor (28 entries). Oryx Press. December 1999.

Research, Papers, and Publications (selected)

Uranium Impacts in Lakota Territory. March 2010. Lakota People's Law Project.

Report on the 100th Meridian Boater Survey. Wyoming: 2008; *Colorado*: 2006 and 2007. United States Fish and Wildlife Service.

Comments on Proposed Rules on In Situ Leach Uranium Mining. North Dakota Geological Survey. June 2008.

Proposed Virginia Uranium Project: Summary Information. Citizens' Environmental Legal Defense Fund. February 2008.

Northeastern Colorado Labor Force Study: Final Report. Northeastern Colorado Association of Local Governments and CSU/DOLA Technical Assistance Program. August 2003.

Sedgwick County Wind Farm Feasibility Study. Sedgwick County Economic Development and CSU/DOLA Technical Assistance Program. November 2002.

Economic Impacts of Methamphetamine Use in the 13th Judicial District of Colorado. CSU/DOLA Technical Assistance Program. October 2002. Co-Author: Trisha Bentz.

AWARDS AND HONORS

Graduate, Colorado Institute for Leadership Training.

Leadership Fellowship, Bush Foundation, St. Paul, MN.

Sam C. May Graduate Student Research Paper Award, Western Governmental Research Association.

Research Fellowships, United States Environmental Protection Agency, National Network for Environmental Management Studies:
Federal environmental spending on Native American reservations.
Agency experience with Transboundary Environmental Impact Statements.

Ted Robinson Memorial Award, Southwestern Political Science Association.

Award for Energy Innovation, United States Department of Energy (Project Administrator).

PRESENTATIONS

Uranium Issues in the Black Hills, June 2008 - present. Nine presentations in western South Dakota.

South Dakota Legislature, Senate Agriculture and Natural Resources Committee, February 2013. Background of Proposed Uranium Legislation.

National Park Service, April 2012. Climate Change Policy and Impacts in South Dakota.

Western Social Science Association, April 2009.
Moderator: Energy Issues
Paper Presentations:

- The Magna Carta and the Constitution of the Iroquois Confederacy: Foundations of the U.S. Constitution

- The New Nuclear Era in the Western United States: Regulators' Responses to the Uranium Boom

Uranium Mining in Northern Colorado?, April 2007 - August 2008. Approximately 150 presentations on this topic in northern Colorado.

Colorado House of Representatives Committee on Agriculture, Livestock and Natural Resources, March 2008. Comments on Uranium Mining and Land Use.

South Dakota Water Management Board, April 2, 2008, Comments on Proposed Administrative Rules on Underground Injection Control Wells.

Colorado Child and Adolescent Mental Health Coalition, April 10, 2005. Program Evaluation: Improving Outcomes Measurements for Non-Profits and Local Government.

Western Social Science Association, April 22, 2004. Northeastern Colorado Labor Force Study.

Western Political Science Association, March 2003. Tribal-State Relations Involving Land and Resources in the Self-Determination Era.

Minnesota State University - Mankato, September 9, 2000. Understanding the National Environmental Policy Act (NEPA) and the Environmental Impact Statement Process.

St. Thomas University, Minneapolis, MN., Conference on Energy Policy in the Upper Midwest, April 15, 2000. Coal Policy and Railroad Expansion in South Dakota and Wyoming.

South Dakota Political Science and Public Affairs Association, March 27, 1999. A Comparison of Indian and Non-Indian Media Coverage of Land and Resource Issues in the Self-Determination Era.

American Political Science Association, August 31, 1997. Neither Fish Nor Fowl: Federalism, Native Americans, and United States Institutions.

Western Social Science Association, April 24, 1997. The Department of the Interior Appeals Process and Native American Natural Resources: 1970-1994.

American Political Science Association, September 3, 1995. ' Shadow Federalism:' Natural Resources, Native Americans, and National Interactions.

Western Social Science Association, April 28, 1995. 'Shadow Federalism:' Natural Resources, Native Americans, and Federal Power.

American Political Science Association, September 2, 1994. Reservation Environmental Issues: Federal Funding and the Shortcomings of a Subsystems Approach.

Western Social Science Association, April 23, 1994.
Moderator: Tribes, Public Policy, and the Environment.
Paper Presentation: Reservation Environmental Issues: Problems in Federal and Tribal Government Responses.

Western Political Science Association, March 11, 1994. Civil Rights and Sovereignty: Conflict on the White Earth Reservation.

CAMPUS AND COMMUNITY SERVICE (2003-Present)

Institutional Development Committee, Oglala Lakota College, 2010–Present. Member and Policy Subcommittee Chair.

Thunder Valley Community Development Corporation, 2009-2011. Volunteer and Consultant.

Strategic Planning Committee, Oglala Lakota College, 2011. Member and Academic Subcommittee.

Izaak Walton League, Rapid City Chapter, 2011–Present. Vice President.

Clean Water Alliance, 2010-present. Research on uranium mining; meeting facilitator and listserv moderator.

Women's History Month, South Dakota State University, March 2009. Panelist.

Indigenous Policy Journal, 2009-present. Editorial Advisory Board

Year of Science, South Dakota State University, 2008-2009. Committee member.

Honors College, South Dakota State University, 2008-2009. Participant.

Constitution Day, South Dakota State University, September 2008. Panelist.

Coloradoans Against Resource Destruction, 2007-2009. Research on uranium mining; meeting facilitator.

Big Thompson Watershed Forum, 2003-2006. Serve on Water Quality Goals and Communications Committee.

Member, Larimer County Environmental Advisory Board, Larimer County, CO., 2003-2005. Provided recommendations on environmental issues to County Commissioners.

EXPERT OPINION REGARDING THE PROPOSED DEWEY-BURDOCK PROJECT ISL MINE NEAR EDGEMONT, SOUTH DAKOTA

Hannan E. LaGarry, Ph. D.
210 North Main Street, Chadron NE 69337
hlagarry@olc.edu

INTRODUCTION

In early March 2010 I was contacted by Lilias Jarding (WMAN) to review an application to the US Nuclear Regulatory Commission for construction of an ISL facility (the Dewey-Burdock Project) for mining uranium near Edgemont, South Dakota. I had previously provided an expert opinion to the Western Nebraska Resources Council (among others) regarding ISL uranium mining near Crawford, Nebraska. I am offering this expert opinion regarding ISL uranium mining near Edgemont because I am concerned that the issues that I raised in the earlier opinion also apply to the proposed Dewey-Burdock Project. As I have stated previously, I am not against uranium mining in fact or principle. This issue isn't about uranium. It's about protecting the region's water supply, and the future inhabitability of southwestern South Dakota and adjacent Nebraska. In this document, I will briefly explain the basis for my concerns.

PROFESSIONAL BACKGROUND

I have 20 years experience studying the rocks and fossils of northwestern Nebraska and adjacent South Dakota. From 1988-1991 I collected fossils from northern Sioux County, Nebraska for my dissertation work. From 1991-1996 I led field parties from the University of Nebraska State Museum while mapping the fossils and geology of the Oglala National Grassland in Sioux and Dawes counties, Nebraska. From 1996-2006 I led teams of geologists from the Nebraska Geological Survey that mapped in detail the surficial geology of most of northwestern Nebraska (a total of 80 1:24,000 quadrangles). The completion of this work frequently required detailed study of equivalent strata in adjacent South Dakota. These maps, including digital versions (ArcInfo) and supporting field notes, are available from the University of Nebraska-Lincoln School of Natural Resources (contact James B. Swinehart). As a direct consequence of this mapping, I have published peer-reviewed articles on the Chadron Formation (Terry & LaGarry 1998), the Brule Formation (LaGarry 1998), the mapping of surficial deposits (Wysocki & others 2000, 2005), and local faults (Fielding & others 2007). From 2006-2008 I continued this work as an Adjunct Professor of Geology at Chadron State College (CSC) in Chadron, Nebraska. During this time I worked with and advised students studying the region's groundwater, surface water, and geologic structures (principally faults). In May 2008, my CSC colleagues and I, along with Chadron residents, scientists from the Nebraska Geological Survey, the United States Geological Survey, the University of Nebraska School of Natural Resources, and the Upper Niobrara-White Natural Resource District, convened "Our Water, Our Future: a Town Hall Meeting." Our consensus opinion was that water shortages and declining water quality are real and worsening problems in northwestern Nebraska and the northern Great Plains region. Since 2008 I have been serving the Oglala Sioux Tribe as an Instructor in the Department of Math, Science, & Technology at Oglala Lakota College (OLC), and since 2009, as co-chair of that department. Since joining the faculty at OLC, I have been working with students and faculty to continue to study the geology, groundwater, surface water, and heavy metal contamination of southwestern South Dakota and the Pine Ridge Reservation. In pursuing these studies, we have formed working partnerships with Chadron State College, the South Dakota Geological Survey, the South Dakota School of Mines and Technology, South Dakota State University, the University of Illinois Urbana-Champaign, the University of Illinois Center for Advanced Materials Purification of Water Systems, the Department of Health Physics at the University of Michigan School of Nuclear Engineering, the University of Washington Burke Museum, and the University of Washington Native American Research Center for Health. Our research has been funded for the next 5 years by the National Science Foundation Tribal Colleges and Universities Program.

THE CONCERNS

My concerns regarding the Dewey-Burdock Project are centered around the problems of secondary porosity in the form of faults and joints, the lack of confinement, artesian flow, and the horizontal flow of water within the uranium-bearing strata. I found the Powertech's environmental report to be poorly referenced overall, but especially parts concerning the geology of the region. The conclusions concerning the geology within the proposed area are based on in-house studies and unpublished theses and reports. It is beyond the scope of this opinion to review the entire scientific literature for the region, but I provide the most readily available recent research. Where appropriate, I also refer to specific sections of Powertech's environmental report to the US Nuclear Regulatory Commission (NRC) for the construction of the Dewey-Burdock Project.

The problem of secondary porosity

Secondary porosity, in the form of intersecting faults and joints, is common in all of the rocks north, east, and south of the Black Hills Dome, especially north of and along the Pine Ridge Escarpment (see Swinehart & others 1985). These faults and joints are generally oriented NW-SE and SW-NE, and are most likely a result of the ongoing uplift of the Black Hills of southwestern South Dakota. Although a few people consider the Black Hills uplift to have ended by the late Cretaceous (~65 Ma), the Black Hills were tectonically active in the late Eocene (Evans & Terry 1994), and continued to fault, fracture, and fold the rocks of northwestern Nebraska and southwestern South Dakota into the middle Miocene (Fielding & others 2007). Based on numerous small earthquakes along the Sandoz Ranch-Whiteclay Fault, the area is still tectonically active (McMillan & others 2006). These earthquakes are relatively mild, and don't significantly damage surface infrastructure. However, even small earthquakes represent shifting and flexing of the earth's crust, and are continuously creating, closing, and redistributing the secondary porosity of the region's rocks. This means that joints incapable of transmitting water one day may be able to transmit water at a later date. These faults and fractures transect all major bedrock units of the region. These faults likely connect the uranium-bearing strata to adjacent aquifers as well as modern river alluvium.

In 2007, Chadron Creek, the stream that supplies water to the city of Chadron, Nebraska, went dry for the first time in the citys' history. Subsequent study of the creek's water flow rates by Chadron State College students suggested that normal amounts of water are flowing from the springs, but the water is disappearing into deeper alluvium or into fractures in the rock (Balmat & others 2008, Butterfield & others 2008). Following these observations, a Chadron State College graduate student began studying the widespread faults and lineaments of northwestern Nebraska and southwestern South Dakota using data collected by high-flying aircraft, satellites, and the space shuttle (Balmat & Leite 2008). Many of the faults in northwestern Nebraska and southwestern South Dakota persist for tens of miles (Diffendal 1994, Fielding & others 2007). Also, many of the ancient river deposits of the Tertiary strata, along with the alluvium deposited by modern rivers such as the Cheyenne River, the White River, and Hat Creek, follow fault zones because fractured rock erodes more easily. A review of the scientific literature shows that faults and joints are well-known in rocks surrounding the Black Hills, and are known to interconnect major aquifers and the land surface (Swinehart & others 1985, Peters & others 1988, Fielding & others 2007). Powertech's application asserts that although fault zones are known both north and south of the project area (section 3.3.2.1), there are no known faults within the project area and therefore little or no secondary porosity. This is a false perception, because joints (cracks in the rock lacking measurable displacement) are exceedingly common in this region and form the vast majority of secondary porosity and contaminant pathways.

The problem of lack of confinement

In order for ISL mining to be considered safe, the uranium-bearing, mined strata must be isolated from rocks above and below by confining layers. There are three principal pathways through which contaminated water could migrate away from the uranium-bearing strata through adjacent confining layers. The first, and most common, are along joints and faults (see above). Where present, joints and faults penetrate confining layers above and below. The second is through thinning or pinching out of confining layers. In their application to the NRC, Powertech concedes that the upper confining layers thin and there are breaches in the upper confining layers (sections 3.3.2.2, 3.4.3.1.7, 3.4.3.1.10, and 3.4.3.2). The third pathway for mine fluids to breach containment is through perforations made by wells. In Powertech's application, they repeatedly mention "thousands of exploratory wells," along with wells that supply drinking water (the uranium-bearing strata are a local drinking water supply) and water for livestock. In addition, many of these wells are abandoned and most likely improperly plugged (section 3.4.1.2). Once mining begins, and minerals are being extracted, flow pathways within the uranium-bearing rocks will change, potentially creating circumstances in which any one of these wells could allow lixiviant to breach confinement. Once into adjacent water-bearing strata or the land surface, contaminants can enter rivers and flow downstream with each successive rain event, or flow downgradient into other water supplies.

The problem of artesian flow

Artesian flow occurs when there is a hydrologic connection, through faults or highly permeable strata, between groundwater sources and the land surface. The weight of water in overlying strata exerts pressure downward into water within the uranium-bearing strata, which can then be released as artesian water flow where the topographically lower uranium-bearing strata is exposed at the surface, or where it is punctured by drilling. Artesian flow was observed or predicted by Powertech in their Dewey-Burdock Project proposal (sections 3.4.1.2, 3.4.3.1, and 3.4.3.1.7). Artesian flow is most likely where the upper confining layer is perforated by secondary porosity (section 3.3.2.1), poorly constructed or improperly sealed exploration wells (sections 3.3.2 and 3.4.1.2), or thinning or absence of upper confining layers (section 3.4.3.1.7). Artesian flow could transmit lixiviant, the most toxic mineral-laden of waters, onto the land surface (and into Cheyenne River, White River, or Hat Creek alluvium) and discharge large amounts of contaminants into aquifers or faults in a very short time.

The problem of horizontal flow

Confining layers adjacent to uranium-bearing strata limit the unwanted spread of contaminants from an ISL site. However, horizontal flows within the uranium-bearing strata are also of concern. Such flow can rapidly redirect lixiviant or mine waste away from the mine site and into unexpected breaches in the confining layers. In their application to the NRC, Powertech reports horizontal flows within the uranium-bearing strata (the Inyan Kara Group) of up to 35.5 meters/day (Chilson Member, section 3.3.2.2) based on local conditions, and of up to 6,000 ft^2/day (section 3.4.3.1.2) elsewhere in the Black Hills region. Even if secondary porosity, artesian flow, or lack of confinement did not contaminate nearby water supplies, down gradient flow along the Cascade and Chilson anticlines (Rothrock 1931a, 1931b, 1948) would transmit contaminants to the major, mapped faults north of the Pine Ridge in Nebraska in less than 5 years (using the smaller value).

CONCLUDING REMARKS

Based on the arguments presented above, it is my expert opinion that ISL mining in the Edgemont, South Dakota should not be allowed. Artesian flow, the potential lack of confinement due to secondary porosity and drilling, along with potentially high horizontal flow in the uranium-bearing strata indicate that during the course of its operation the Dewey-Burdock ISL Project will most likely contaminate the region with unconfined lixiviant. This contamination could plausibly pollute groundwaters and surface waters southwards into Nebraska and surface waters within the Cheyenne River drainage eastwards into greater South Dakota. Also, based on my reading of Powertech's application, no review of the geologic literature was conducted. In my view, the use of outdated scientific literature, or in this case, a general lack of review of recent study, should not be seen as an opportunity to operate in a knowledge vacuum. Much of the Great Plains region was studied prior to the 1980's and the general acceptance of Plate Tectonics Theory, and therefore generally misrepresents the geologic setting of the region. This was true of the geologic literature used to justify ISL mining near Crawford, Nebraska, and is also true of the data used to justify proposed mining near Edgemont, South Dakota. It is incumbent upon potential ISL operators, as it is with any natural resource consumers, to seek out the most recent research and expert opinions on the geological settings in which they propose to operate.

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Butterfield, A. C., J. L. Balmat, J. W. Balmat, K. Young, M. Culver, C. A. Kaiser, J. Zweibel, M. B. Leite, & H. E. LaGarry. 2008. Discharge of Chadron Creek, Dawes County, Nebraska. Proceedings of the 118th Annual Meeting of the Nebraska Academy of Sciences, pp. 64-65.

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McMillan, M. E., P. L. Heller, & S. L. Wing. 2006. History and causes of post-Laramide relief in the Rocky Mountain Orogenic Plateau. Geological Society of America Bulletin 118(3/4):393-405.

Peter, K. D., K. E. Kolm, & T. C. Nichols, Jr. 1988. Lineaments: significance, criteria for determination, and varied effects on ground-water systems – a case history in the use of remote sensing, pp. 46-68 *in* (A. I. Johnson & C. B. Petersson, eds.) Geotechnical Applications of Remote Sensing and Remote Data Transmission. American Society for Testing and Materials, Philadelphia, Pennsylvania.

Rothrock, E. P. 1931. The Cascade Anticline. South Dakota Geological Survey Reports of Investigations 8, 25 p.

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Rothrock, E. P. 1948. Structures in Fall River County. South Dakota Geological Survey Reports of Investigations 62, 64 p.

Swinehart, J. B., V. L. Souders, H. M. DeGraw, & R. F. Diffendal Jr. 1985. Cenozoic paleogeography of western Nebraska, pp. 209– 229 in (R. M. Flores & S. S. Kaplan, eds.), Cenozoic Paleogeography of West-Central United States. Proceedings of Rocky Mountain Paleogeography Symposium 3, Society of Economic Paleontologists and Mineralogists. Denver, Colorado.

Terry, D. O., Jr. & H. E. LaGarry. 1998. The Big Cottonwood Creek Member: a new member of the Chadron Formation in northwestern Nebraska, pp. 117-142 in (D. O. Terry, Jr., H. E. LaGarry, & R. M. Hunt, Jr., eds.) Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (late Eocene to early Miocene, North America). Geological Society of America Special Paper 325, 216 p.

Terry, D. O., Jr. 1998. Lithostratigraphic revision and correlation of the lower part of the White River Group: South Dakota to Nebraska, pp. 15-38 in (D. O. Terry, Jr., H. E. LaGarry, & R. M. Hunt, Jr., eds.) Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (late Eocene to early Miocene, North America). Geological Society of America Special Paper 325, 216 p.

Wysocki, D. A., P. J. Schoeneberger, & H. E. LaGarry. 2005. Soil Surveys: a window to the subsurface. Geoderma 126:167-180.

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Hannan E. LaGarry

CURRICULUM VITAE

updated 12 August 2013

CONTACT INFORMATION

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EDUCATION

Regents' Diploma, 1980. Norwood-Norfolk Central School, Norwood NY.

B. A. (Geology), 1985. State University of New York @ Potsdam NY (Advisor: W. Kirchgasser).

M. S. (Geology), 1988. Fort Hays State University, Hays KS (Advisor: R. J. Zakrzewski).

Ph. D. (Geology), 1997. University of Nebraska-Lincoln, Lincoln NE (Advisor: R. M. Hunt, Jr.).

CURRENT EMPLOYMENT

2013-present **STAFF INSTRUCTOR/RESEARCHER,** Math, Science, & Technology, Oglala Lakota College. Dr. Dawn Frank, VP for Instruction (605-455-6035)

WORK EXPERIENCE (see BIBLIOGRAPHY for list of publications)

1985	**PALEONTOLOGICAL FIELD ASSISTANT,** Sternberg Memorial Museum
1985-1987	**GRADUATE TEACHING ASSISTANT,** Fort Hays State University
1986	**PROJECT PALEONTOLOGIST I,** Illinois State Museum
1988	**INSTRUCTOR OF GEOLOGY,** Fort Hays State University
1988	**PROJECT PALEONTOLOGIST III,** Illinois State Museum
1988-1989	**GRADUATE TEACHING ASSISTANT,** University of Nebraska-Lincoln
1989-1990	**GRADUATE TECHNICAL ASSISTANT,** University of Nebraska-Lincoln
1991-1995	**RESEARCH TECHNICIAN III,** University of Nebraska State Museum
1991-1995	**PHYSICAL SCIENCE TECHNICIAN,** USDA NRCS National Soil Survey Center
1996-1997	**RESEARCH ASSISTANT II,** University of Nebraska-Lincoln
1997-1998	**RESEARCH GEOSCIENTIST,** University of Nebraska-Lincoln
1999-2006	**ASSISTANT GEOSCIENTIST,** University of Nebraska-Lincoln
2007-2008	**INTERPRETER,** Hudson-Meng Bison Kill Site (USFS), Crawford, Nebraska
2008-2009	**STAFF INSTRUCTOR/RESEARCHER,** Oglala Lakota College
2009-2012	**CO-CHAIR, MATH, SCIENCE, & TECHNOLOGY,** Oglala Lakota College
2012-2013	**CHAIR, MATH, SCIENCE, & TECHNOLOGY,** Oglala Lakota College

ADJUNCT & COURTESY APPOINTMENTS

2011-present **CURATOR,** Oglala Lakota College center for Science and Technology/Oglala Sioux tribe Collections and Specimen Repository, Piya Wiconi, Kyle SD 57752

1999-2006 **COURTESY APPOINTMENT, Department of Geosciences,** University of Nebraska-Lincoln.

2006-2008 **ADJUNCT PROFESSOR OF GEOSCIENCES, Department of Physical & Life Sciences,** Chadron State College, Nebraska

COLLEGE & UNIVERSITY COURSES TAUGHT

FORT HAYS STATE UNIVERSITY, HAYS, KANSAS

1985-1986 **Historical Geology laboratory** (1 credit hour, 2 semesters)
1985-1986 **Invertebrate Paleontology laboratory** (1 credit hour, 2 semesters)
1987 **Field Methods** (3 credit hours, 1 semester)
1987 **Field Camp** (6 credit hours, 1 summer session)
1987 **Structural Geology** (3 credit hours, 1 semester)

BARTON COUNTY COMMUNITY COLLEGE, GREAT BEND, KANSAS

1988 **Life of the Past** (3 continuing education credit hours, 1 semester)

UNIVERSITY OF NEBRASKA-LINCOLN, LINCOLN, NEBRASKA

1988-1989 **Historical Geology laboratory** (1 credit hour, 2 semesters)
1990-1991 **Invertebrate Paleontology laboratory** (1 credit hour, 2 semesters)
1991-2002 **Independent Study in Geology** (3 credit hours, 3 semesters)
1992-1995 **Physical Geology laboratory** (1 credit hour, 4 semesters)
1995-1996 **Independent Study in Museum Studies** (3 credit hours, 2 semesters)
1998-2005 **Regional Field Geology** (1 required credit hour, 8 semesters)

CHADRON STATE COLLEGE, CHADRON, NEBRASKA

2006 **Sedimentology & Stratigraphy** (3 credit hours, 1 semester)
2007-2008 **Earth Systems Science** (3 general studies credit hours, 3 semesters)

OGLALA LAKOTA COLLEGE, KYLE, SOUTH DAKOTA

2008 **Groundwater** (3 credit hours, 1 semester)
2008-2009 **Introduction to Statistics** (3 credit hours, 3 semesters)
2009 **Renewable Energy** (3 credit hours, 1 semester)
2009 **Junior/Senior Research** (3 credit hours, 1 semester)
2009 **Anatomy & Physiology II** (4 credit hours, 1 semester)

RESEARCH INTERESTS

1984-1985 **Lake acidification, northern Adirondack Mountains, New York**
1984-1985 **Ordovician marine paleoecology, Trenton Group of northern New York**
1985-present **Taphonomy & paleoecology of Neogene mammals, Nebraska**
1985-present **Taxonomy & systematic description of Neogene mammals, Nebraska**
1988-present **Biostratinomy of the Deer Creek Formation (Pennsylvanian), Nebraska**
1988-present **Reptiles, amphibians, & lungfish, Eskridge Formation (Permian), Nebraska**
1988-present **Taphonomy & paleoecology of Paleogene faunas, Nebraska**
1991-present **Cenozoic paleosols of western Nebraska & southwestern South Dakota**
1993-present **Cenozoic trace fossils of northwestern Nebraska**
1996-present **Cenozoic lithostratigraphy of western Nebraska**
1998-present **Cenozoic lithostratigraphy of north-central Nebraska**
2008-present **Cenozoic lithostratigraphy of southwestern South Dakota**
2008-present **Groundwater and mineral resources of the Pine Ridge Reservation**

FIELD EXPERIENCE

1981-1988	**Precambrian & early Paleozoic rocks, northern New York State**
1984-1985	**Limnology of acidified lakes, northern New York State**
1984-1985	**Early Paleozoic strata, northern New York State**
1985-1988	**Cretaceous & Neogene rocks & fossils of western Kansas**
1985-1988	**Late Paleozoic rocks & fossils of eastern Kansas**
1986-1987	**Paleozoic & Mesozoic strata, Utah & Colorado**
1988-1989	**Wisconsinan peat bogs, archeology, & vertebrates, northern Illinois**
1988-1995	**Late Paleozoic rocks & fossils of eastern Nebraska**
1989-1990	**Paleogene carnivores, Agate Fossil Beds National Monument**
1991-2002	**Vertebrate fossil resources of the Oglala National Grassland, Nebraska**
1996-present	**Cenozoic lithostratigraphy & fossils of NW Nebraska & SW South Dakota**
1998-present	**Cenozoic lithostratigraphy & fossils of north-central Nebraska**
1998-present	**Cenocoic paleosols a& modern soils, northern Great Plains, USA**
2000-2005	**Pleistocene strata & paleosols of eastern Nebraska**
2006-present	**Archeology of NW Nebraska & SW South Dakota**
2008-present	**Groundwater and surface water of NW Nebraska & SW South Dakota**

STUDENT RESEARCH SUPERVISED

UNIVERSITY OF NEBRASKA-LINCOLN

1989-1992 **Michael R. Myers, Department of Geology [independent study].** *"Mortality profiles of* Mammuthus imperator *(Leidy), Sheridan County, Nebraska."*

1989-1992 **W. Brantly Wells, Department of Geology [independent study].** *"Vertebrate trace fossils of the Toadstool Park Trackway Site, Oglala National Grassland, Nebraska."*

1991-1992 **Dennis W. Moser, Department of Geology [class project].** *"Biostratinomy of the Haynies limestone bed (Pennsylvanian), a compound distal tempestite from southeastern Nebraska"* **(1992 STUDENT PAPER AWARD, North-Central Section, Geological Society of America)**.

1991-1992 **Steven L. Holmes, Department of Geology [class project].** *"Biostratinomy of the Haynies limestone bed (Pennsylvanian), a compound distal tempestite from southeastern Nebraska"* **(1992 STUDENT PAPER AWARD, North-Central Section, Geological Society of America)**.

1996-1997 **April Whitten, Department of Anthropology [MS thesis: LuAnn Wandsnider, Advisor].** *"Late Holocene environments at the Arner Hearth Site, northwestern Nebraska."*

1996-1997 **Justin A. Kinsley, Department of Museum Studies [Independent Study].** *"A vertebrate coprocoenocis from the Orella Member of the Brule Formation (Oligocene), northwestern Nebraska."*

2000-2001 **Erin L. Richardson, Department of Anthropology [MS thesis: LuAnn Wandsnider, Advisor].** *"Holocene landscape reconstruction at the Sand Creek Hearth Site, Dawes County, Nebraska, USA."*

UNIVERSITY OF CALIFORNIA-BERKELEY

1999-2003 **Caroline A. E. Stromberg, Department of Evolutionary and Integrative Biology [Ph. D. dissertation: David A. Lindberg, Advisor].** *"Origin and spread* *of Tertiary grasslands in North America"* **(2003 ALFRED SHERWOOD ROMER PRIZE, Society of Vertebrate Paleontology)**.

TULANE UNIVERSITY

2001-2002 **Stephanie G. Thomas, Department of Geology [American Association of State Geologists Undergraduate Field Mentorship Program].** *"Lithostratigraphic revision and redescription, White River and Arikaree groups"*

CHADRON STATE COLLEGE

2006-2007 **Jennifer L. Balmat, Department of Physical & Life Sciences [Undergraduate Capstone Thesis: Michael B. Leite, advisor]** *"Physical sedimentology of the Hudson-Meng Bison Kill Site, northwestern Nebraska"*

2006-2007 **Joshua W. Balmat, Department of Physical & Life Sciences [Undergraduate Capstone Thesis: Michael B. Leite, advisor]** *"Buried soils and ancient landscapes at the Hudson-Meng Bison Kill Site, northwestern Nebraska"*

OGLALA LAKOTA COLLEGE

2008-2009 **Helene Quiver-Gaddy, Math & Science Department [Undergraduate Senior Research: Hannan E. LaGarry, advisor]** *"New lithostratigraphic correlations of the White River Group from northwestern Nebraska to southwestern South Dakota"*

2009 **Dylan Brave, Math & Science Department [Undergraduate Junior Research: Hannan E. LaGarry, advisor]** *"New vertebrate trackway sites from the White River Group (Late Eocene) of southwestern South Dakota"*

STUDENTS EMPLOYED

1989-1992 **Michael R. Myers (undergraduate in Geology), University of Nebraska-Lincoln.** Vertebrate fossil resource inventories of the Oglala National Grassland.

1989-1995 **W. Brantly Wells (undergraduate in Geology), University of Nebraska-Lincoln.** Vertebrate fossil resource inventories of the Oglala National Grassland.

1989-1995 **Chris E. Rudnick (graduate in Geology), University of Nebraska-Lincoln.** Vertebrate fossil resource inventories of the Oglala National Grassland.

1991-1992 **Daryl K. Pavey (undergraduate in Biology), University of Nebraska-Lincoln.** Vertebrate fossil resource inventories of the Oglala National Grassland.

1993-1994 **Michelle K. David (graduate in Geology), Fort Hays State University.** Vertebrate fossil resource inventories of the Oglala National Grassland.

1994-1995 **Carrie L. Herbel (graduate in Geology), University of Nebraska-Lincoln.** Vertebrate fossil resource inventories of the Oglala National Grassland.

1996-1997 **David L. Dyer (graduate in Museum Studies), University of Nebraska-Lincoln.** Curated White River Group vertebrate fossils from northwestern Nebraska.

1996-1997 **Justin A. Kinsley (undergraduate in Museum Studies), University of Nebraska-Lincoln.** Curated White River Group vertebrate fossils from northwestern Nebraska.

2002-2003 **Stephanie G. Thomas (undergraduate in Geology), Tulane University.** Geologic mapping (STATEMAP) in northwestern Nebraska.

2007 **Jennifer L. Balmat (undergraduate in Geology), Chadron State College.** Renovation of the Eleanor Barbour Cook Museum of Geology.

2007 **Joshua W. Balmat (undergraduate in Geology), Chadron State College.** Renovation of the Eleanor Barbour Cook Museum of Geology.

2008-2009 **Helene Quiver-Gaddy (undergraduate in Environmental Science), Oglala Lakota College.** Lithostratigraphy of the White River Group in SW South Dakota.

2009 **Dylan Brave (undergraduate in Conservation Biology), Oglala Lakota College.** Fossil mammal trackways of the White River Group, South Dakota.

2009 **Curtis Belile (undergraduate in Natural Resources), Oglala Lakota College.** Uranium contamination in southwestern South Dakota.

SCHOLARSHIPS, HONORS, & AWARDS

1980 **National Honor Society**
Alumni Fund Scholarship (Norwood-Norfolk Central School Alumni: $150)

1985 **Earth Stewardship Award** (Earth Stewardship Council, Washington, DC: $150)
Graduate Teaching Assistantship (FHSU Department of Earth Sciences: $2,450)

1986 **Graduate Teaching Assistantship** (FHSU Department of Earth Sciences: $3,250)

1987 **Sigma Xi** (Hays, Kansas Chapter)

1988 **Distinguished Masters Thesis Award** (Midwestern Council of Graduate Schools)
Graduate Teaching Assistantship (UNL Department of Geology: $6,000)

1989 **Graduate Teaching Assistantship** (UNL Department of Geology: $7,000)
M. C. Green Fieldwork Scholarship (University of Nebraska State Museum: $1,000)

1990 **Curatorial Assistantship** (University of Nebraska State Museum: $7,000)
Student Seminar Award – 1st place (UNL Department of Geology: $100)
Eunice & T. Mylan Stout Student Paper Award (Nebraska Geological Society: $50)
M. C. Green Fieldwork Scholarship (University of Nebraska State Museum: $1,000)

1991 **Global Climate Change Internship** (USDA NRCS National Soil Survey laboratory)
Eunice & T. Mylan Stout Student Paper Award (Nebraska Geological Society: $50)
Lincoln Gem & Mineral Club Scholarship (Lincoln Gem & Mineral Club:$150)
Curatorial Assistantship (University of Nebraska State Museum: $7,000)

1992 **Student Seminar Award – 1st place** (UNL Department of Geology: $100)
Student Paper Award (North-Central Section, Geological Society of America: $50)

1993 **Curatorial Assistantship** (University of Nebraska State Museum: $7,000)

1994 **Student Presentation Travel Award** (UNL Department of Geology: $250)

1996 **Volunteer Service Recognition** (Nebraska National Forest)
Student Presentation Travel Award (UNL Department of Geology: $250)

1997 **Extra Effort Cash Award** (USDA NRCS National Soil Survey Center: $500)

2004 **Letter of Commendation** (USDA NRCS: CSD STATEMAP Research Program)

2009 **Special Invitation Travel Award** (NSF BIO Directorate, 2009 JAM: $1200)

PROFESSIONAL MEMBERSHIPS & AFFILIATIONS

1985-1988 **PALEONTOLOGICAL SOCIETY**

1985-2000 **SOCIETY OF VERTEBRATE PALEONTOLOGY**

1986-2000 **KANSAS ACADEMY OF SCIENCE**

1987-2000 **SIGMA XI**

1988-present **NEBRASKA ACADEMY OF SCIENCES**

2006-2007 **ASSOCIATION FOR WOMEN GEOSCIENTISTS**

2006-present **GEOLOGICAL SOCIETY OF AMERICA**

SERVICE TO PROFESSIONAL ORGANIZATIONS

1992 **TECHNICAL SESSION CONVENER:** 7th Annual Meeting of the Society for the Preservation of Natural History Collections, Lincoln, Nebraska.

EARTH SCIENCE SECTION CHAIR: 102nd Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

1995 **SYMPOSIUM CO-CONVENER (with D. O. Terry, Jr. & R. M. Hunt, Jr.):** *Depositional Environments, Lithostratigraphy, and Biostratigraphy of the White River and Arikaree Groups.* 29th Annual Meeting of the North & South-Central Sections, Geological Society of America, Lincoln, Nebraska.

FIELD TRIP CO-LEADER (with D. O. Terry, Jr.): *The White River Group Revisited: Vertebrate Trackways, Ecosystems, and Stratigraphic Revision, Redefinition, and Redescription.* 29th Annual Meeting of the North & South Central Sections of the Geological Society of America, Lincoln, Nebraska.

1996 **FIELD TRIP CO-LEADER (with D. O. Terry, Jr., R. Benton, & E. Evanoff):** *Hayden's Lakes Revisited: The Origin and New Stratigraphic interpretations of the White River Sequence, South Dakota, Nebraska, and Wyoming.* 1996 Annual Meeting of the Geological Society of America, Denver, Colorado.

1998 **FIELD TRIP CO-LEADER (with B. A. Beasley):** *Fossil Resource Management of the Oglala National Grassland and the Toadstool Park Trackway Site.* 5th Conference on Fossil Resources, Rapid City, South Dakota.

1999 **EARTH SCIENCE SECTION CO-CHAIR (with S. Tucker):** 109th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

DEHNER AWARD JUDGE (posters): 131st Annual Meeting of the Kansas Academy of Science, Manhattan, Kansas.

2000 **SYMPOSIUM CO-CONVENER (with E. L. Richardson):** *Nebraska Stratigraphy*, 110th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

EARTH SCIENCE SECTION CO-CHAIR (with A. Carter): 110th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

2002 **EUNICE & T. MYLAN STOUT STUDENT PAPER AWARD JUDGE (platform):** 112th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

DEHNER AWARD JUDGE (platform): 134th Annual Meeting of the Kansas Academy of Science, Hays, Kansas.

2003 **EUNICE & T. MYLAN STOUT STUDENT PAPER AWARD JUDGE (platform):** 113th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

2004 **NEBRASKA GEOLOGICAL SOCIETY STUDENT PAPER AWARD JUDGE (platform):** 114th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

2005 **NEBRASKA GEOLOGICAL SOCIETY STUDENT PAPER AWARD JUDGE (platform):** 115th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

2006 **NEBRASKA GEOLOGICAL SOCIETY STUDENT PAPER AWARD JUDGE (platform):** 116th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

2007 **EARTH SCIENCE SECTION CHAIR:** 117th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

FIELD TRIP CO-LEADER (with L. A. LaGarry, M. P. Muniz, & L. D. Agenbroad): *Geoarcheology of the Hudson-Meng Bison Kill Site, Oglala National Grassland, Nebraska.* 65th Annual Meeting of the Plains Anthropological Society, Rapid City, South Dakota.

2008 NEBRASKA GEOLOGICAL SOCIETY STUDENT PAPER AWARD JUDGE (platform): 118th Annual Meeting of the Nebraska Academy of Sciences, Lincoln, Nebraska.

SERVICE TO FEDERAL & STATE AGENCIES

1992 **Paleontological resources of the Oglala National Grassland,** US Forest Service (Region 2), US Forest Service Regional Team Leadership Meeting, Nebraska National Forest, Chadron, Nebraska.

1993-2004 **North American Geologic-map Data Model Science-Language Technical Team, Sedimentary & Surficial Deposits subgroups,** US Geological Survey National Geologic Mapping Working Group Steering Committee.

2004 **Petrocalcic soils tour of the north-central Great Plains (with J. Wilson & P. Young). NRCS National Soil Survey Laboratory,** USDA Natural Resources Conservation Service, Lincoln, Nebraska.

2009 **Tribal Colleges & Universities Information and Planning Meeting,** National Science Foundation BIO Directorate, Washington, DC.

Research Experiences for Undergraduates Program workshop facilitator (with L. Patino), Tribal Colleges & Universities Program Leadership Conference, National Science Foundation, Albuquerque, New Mexico

SERVICE TO COLLEGES & UNIVERSITIES

2007-2008 **FACULTY MENTOR (with 6 others),** *"People, Planet, & Prosperity"* Environmental Protection Agency (student) Sustainability Design Competition, Chadron State College, Chadron, Nebraska.

2008 **MANUSCRIPT REVIEWER (with 3 others),** *"Outside the Lines"* student essay competition and published volume, Chadron State College, Chadron, Nebraska.

2008-2009 **Instructional Affairs Committee (Distance Learning Subcommittee),** Oglala Lakota College, Kyle, South Dakota

2008-2009 **Higher Learning Commission Focus Visit Task Force (faculty representative),** Oglala Lakota College, Kyle, South Dakota

2008-2009 **Institutional (Research) Review Board (Math & Science Department representative),** Oglala Lakota College, Kyle, South Dakota

2009 **Graduate Study Advisory Group,** Oglala Lakota College, Kyle, South Dakota

JUDGE OF 7th & 8th GRADE PROJECTS, Oglala Lakota College Reservation-wide Science Fair, MIE Conference Room, Piya Wiconi Administrative Campus

"Oglala Lakota College Department of Math, Science, & Technology: the year in review," Oglala Lakota College Annual Faculty Retreat, Rapid City, South Dakota.

"Oglala Lakota College Department of Math, Science, & Technology: the year in review," Oglala Lakota College Board of Trustees Annual Retreat, Rapid City, South Dakota.

"Water and uranium on the Pine Ridge Reservation," All-Faculty Meeting Special Presentation, Piya Wiconi Administrative Campus, Oglala Lakota College, Kyle, South Dakota

SERVICE TO ACADEMIC DEPARTMENTS & STUDENT ORGANIZATIONS

1983 **SECRETARY, Students for Environmental Awareness** SUNY @ Potsdam

1984-1985 **VICE PRESIDENT, Students for Environmental Awareness** SUNY @ Potsdam

1984-1985 **Student Member, Geology Club** Geology Department, SUNY @ Potsdam

1985-1988 **Student Member, Sternberg Geology Club** FHSU Dept. of Earth Sciences

1988-1993 **Student Member, Geology Club** UN-L Department of Geosciences

1993-1995 **STUDENT REPRESENTATIVE at faculty meetings** UN-L Department of Geosciences

2006-2007 **Faculty Member, Geology Club** Chadron State College

2009 **"Student participation in research at OLC's Department of Math, Science, & Technology,"** Native Science Field Center Program National Leadership Conference, Rapid City, South Dakota.

"Student research opportunities in the OLC Department of Math, Science, & Technology," Department of Math, Science, & Technology Student Intern Meeting (October), Piya Wiconi Administrative Campus, Oglala Lakota College, Kyle, South Dakota

SERVICE TO COMMUNITY & NONPROFIT ORGANIZATIONS

1993 **FIELD TRIP CO-LEADER (with L. A. LaGarry & D. A. Nixon)** *"Nebraska Rocks!"* Homestead Council, Girl Scouts of America.

2008 **Expert opinion,** *"Geological and hydrological implications of proposed Crow Butte Resources' North Trend Expansion of in-situ leach mining north of Crawford, Nebraska,"* provided to Western Nebraska Resources Council, Owe Aku, and concerned residents http://savecrowbutte.org/files/Crow%20Butte%20LBP-08-06%20042908.pdf

PROGRAM CHAIR & MODERATOR, *"Our Water, Our Future: A Hard Look at the Dry Facts"* Town Hall Meeting, Chadron State College Student Center Ballroom, Chadron, Nebraska.

Expert Opinion, *"Geology, groundwater resources, and implications of Crow Butte Resources' continued in-situ leach mining north of Crawford, Nebraska,"* provided to Western Nebraska Resources Council, Owe Aku, concerned residents, and the Oglala Sioux Tribe http://plentyinternational.wordpress.com/2008/07/31/expert-opinion-regarding-isl-mining-in-dawes-county-nebraska/

2009 **PROGRAM CO-CHAIR (with Darwin Apple) & MODERATOR,** *"Informational Meeting Between Oglala Lakota College and Renewable Energy Development Experts*," Oglala Lakota College MIE (Math & Science Department) Conference Room, Kyle, South Dakota

2010 **Expert Opinion., "***Expert opinion regarding the proposed dewey-burdock project ISL mine near Edgemont, South Dakota,"* provided to Western Nebraska Resources Council, Owe Aku, concerned residents, and the Oglala Sioux Tribe http://pbadupws.nrc.gov/docs/ML1006/ML100680016.pdf

2012 **Expert Opinion,** *"Expert opinion on the environmental safety of in-situ leach mining of uranium near Marsland, Nebraska*," provided to Western Nebraska Resources Council, Owe Aku, concerned residents, and the Oglala Sioux Tribe http://pbadupws.nrc.gov/docs/ML1302/ML13029A806.pdf

PROFESSIONAL CONFERENCES ATTENDED (dates)

American Association for the Advancement of Science (1988)

Cenozoic Vertebrate Tracks and Traces Conference (2007)

Conference on Fossil Resources (1992, 1994, 1998)

Digital Mapping Techniques Conference (2000)

Geological Society of America (1994, 1996, 1999, 2006, 2007)

Geological Society of America (Northeast Region) (1984)

Geological Society of America (North-central Region) (1992, 1995)

Geological Society of America (Rocky Mountain Region) (1997, 2011)

Island in the Plains Historical & Archeological Symposium (2006, 2007)

Kansas Academy of Science (1987-88, 1991-92, 1994, 1999, 2001, 2002)

National Science Foundation Joint Annual Meeting (2009)

Nebraska Academy of Sciences (1989-93, 1995-2000, 2002-08, 2012)

North American Paleontological Convention (2001)

Northern Plains Governors' Conference (1992)

Plains Anthropological Society (2006, 2007)

Society of Vertebrate Paleontology (1985, 1987, 1991-93)

Society for the Preservation of Natural History Collections (1992, 2013)

Western South Dakota Hydrology Conference (2009)

PROFESSIONAL DEVELOPMENT ACTIVITIES

1991 **Laboratory Exercises in Paleopedology (Instructor: G. Retallack),** University of Nebraska-Lincoln Department of Geology, Lincoln, NE

1999 **Digital Mapping Methods: Accurate Digital Data Capture and Analysis for the Field Geoscientist,** Geological Society of America short course, Denver, CO

2008 **Quality Education for Minorities Network Grant-writing Workshop,** National Science Foundation (Research in Disabilities Education Program), Washington, D.C.

National Science Foundation Tribal College Workshop, NSF Office of Budget, Finance, & Award Management (Division of Institution & Award Support), Arlington, VA

2009 **UNCFSP Tribal College Technical Assistance Training,** United Negro College Fund Special Projects unit, Albuquerque, NM

Funding Opportunities (NSF BIO Directorate), National Science Foundation 2009 Joint Annual Meeting, Washington, DC

Special Networking Session (NSF BIO Directorate), National Science Foundation 2009 Joint Annual Meeting, Washington, DC

Tribal Colleges & Universities Program Leadership Conference, National Science Foundation (Division of Education & Human Resources), Albuquerque, New Mexico

Incorporating Native Culture into the STEM Curriculum, National Science Foundation (Tribal Colleges & Universities Program/Quality Education for Minorities Network), Albuquerque, New Mexico

INVITED PUBLIC LECTURES

1994 ***"Mapping vertebrate fossil resources in northwestern Nebraska"*** Stout Lecture Series, Department of Geology, University of Nebraska-Lincoln, Lincoln, Nebraska..

1996 ***"The geology of Nebraska north of the Pine Ridge"*** CHAUTAUQUA '96, Chadron/ Dawes County Chamber of Commerce, Chadron, Nebraska.

1999 ***"New stratigraphic classification of the 'basal Chadron Formation' of northwestern Nebraska"*** Crawford Rock Club Annual Rock & Fossil Swap, Crawford, Nebraska.

2002 ***"Late Cretaceous and early Tertiary stratigraphy of the French Creek agate locality near Fairburn, South Dakota"*** **(with L. A. LaGarry)** 54^{th} Annual Lincoln Gem & Mineral Show, Lincoln, Nebraska.

2003 ***"Diet and behavior in fossil carnivores"*** Friends of the Prehistoric Prairies Discovery Center Annual Meeting, Crawford, Nebraska.

2004 ***"Recent advances in the Tertiary stratigraphy of Nebraska"*** Water Center Seminar Series, School of Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska.

***"Tracks and trails from the Tertiary of Nebraska"* (with W. B. Wells)** Nebraska Geological Society, Omaha, Nebraska.

2005 ***"Recent research at Agate Fossil Beds National Monument"*** 40th Anniversary Celebration Program, Agate Fossil Beds National Monument, Nebraska.

2006 ***"Geological survey (1996-2006) in northwestern Nebraska"*** 2nd Annual Earth Day Celebration, Chadron State College, Chadron, Nebraska.

2008 ***"Introduction and agenda- Our Water, Our Future: A Hard Look at the Dry Facts"*** Town Hall Meeting, Chadron State College Student Center Ballroom, Chadron, Nebraska.

***"Geology and groundwater resources of northwestern Nebraska and southwestern South Dakota"* (with L. A. LaGarry)** Oglala Sioux Tribe Natural Resources Regulatory Agency meeting, Pine Ridge, South Dakota

"Oglala Lakota College's potential role in managing the vertebrate fossil resources of the Pine Ridge Reservation" Oglala Sioux Parks & Recreation Authority public information meetings in Red Shirt and Kyle, South Dakota

2009 ***"The local uranium mining scene"*** Western Mining Action Network Annual Meeting (Defenders of the Black Hills), Rapid City, South Dakota

2012 ***"Uranium and groundwater on the Pine Ridge Reservation"*** American Indian Science and Engineering Society, Black Hills State University, Spearfish, South Dakota

2013 ***"Uranium mining in western South Dakota"*** Dakota Rural Action Network, Spearfish, South Dakota

GRANTS & CONTRACTS (~ $8,344,790 to date, including matching funds)

1991 **CO-INVESTIGATOR (with R. M. Hunt, Jr.): Nebraska National Forest** Paleontological resource inventories of the Oglala National Grassland **($40,000).**

PRINCIPLE INVESTIGATOR: Nebraska Geological Society's Yatkola-Edwards Research Grant Vertebrate taphonomy and paleoecology in NW Nebraska **($250).**

1992 **CO-INVESTIGATOR (with R. M. Hunt, Jr.): Nebraska National Forest** Paleontological resource inventories of the Oglala National Grassland **($48,000).**

1993 **CO-INVESTIGATOR (with R. M. Hunt, Jr.): Nebraska National Forest** Paleontological resource inventories of the Oglala National Grassland **($42,000).**

1994 **CO-INVESTIGATOR (with R. M. Hunt, Jr.): Nebraska National Forest** Paleontological resource inventories of the Oglala National Grassland **($42,000).**

1995 **CO-INVESTIGATOR (with R. M. Hunt, Jr.): Nebraska National Forest** Paleontological resource inventories of the Oglala National Grassland **($60,000).**

1999 **CO-INVESTIGATOR (with J. B. Swinehart): US Geological Survey STATEMAP Program** Geologic Mapping in NW Nebraska **($178,000).**

2000 **CO-INVESTIGATOR (with J. B. Swinehart & R. M. Hunt, Jr.): US Geological Survey STATEMAP Program** Geologic mapping in NW Nebraska **($192,000).**

2001 **CO-INVESTIGATOR (with J. B. Swinehart & B. E. Bailey): US Geological Survey STATEMAP Program** Geologic mapping in NW Nebraska **($196,000).**

2002 **CO-INVESTIGATOR (with J. B. Swinehart & B. E. Bailey): US Geological Survey STATEMAP Program** Geologic mapping in NW Nebraska **($200,000).**

2003 **CO-INVESTIGATOR (with J. B. Swinehart, B. E. Bailey, & R. M. Hunt, Jr.): US Geological Survey STATEMAP Program** Geologic mapping in northwestern Nebraska **($220,000).**

2004 **CO-INVESTIGATOR (with J. B. Swinehart, R. M. Joeckel, B. E. Bailey, R. M. Hunt, Jr., G. A. Liggett, & R. Lisichenko): US Geological Survey STATEMAP Program** Geologic mapping in northwestern and eastern Nebraska **($340,000).**

2005 **CO-INVESTIGATOR (with J. B. Swinehart, R. M. Joeckel, M. B. Leite, and R. Lisichenko): U. S. Geological Survey STATEMAP Program** Geologic mapping in northwestern and southeastern Nebraska **($196,000).**

2006 **CO-INVESTIGATOR (with L. A. LaGarry & M. B. Leite): US Forest Service Region 2 (Hudson-Meng Bison Kill Site)** Holocene geochronology in the vicinity of the Hudson-Meng Bison Kill Site **($11,200).**

2007 **CO-INVESTIGATOR (with R. Weedon, M. B. Leite, C. McAllister, S. Rolfsmeier, & L. Stewart-Phelps): Chadron State College VISION 2011 Strategic Planning Committee** Laying the groundwork for the second century of the CSC natural history museum **($37,790).**

CO-INVESTIGATOR (with M. B. Leite): Nebraska National Forest Photogrammetry and casting of the Toadstool Park Trackway Site, Oglala National Grassland, Nebraska **($15,400).**

2009 **CO-INVESTIGATOR (with G. Giraud): NSF Model Institutions for Excellence Phase III** Modular science, technology, engineering, and mathematics (STEM) course content for sharing among tribal colleges **($900,000).**

CO-INVESTIGATOR (with C. J. Tinant): NSF Tribal Colleges & Universities Program Phase I Faculty and curriculum development, scientific collections and library development, and student research support and dissemination **($2,500,000).**

CO-INVESTIGATOR (with G. Giraud): NSF Experimental Program for Stimulating Competitive Research RII T1 Undergraduate research, workforce development, and K-12 outreach **($875,000).**

2010 **PRINCIPAL INVESTIGATOR: USDA NIFA Tribal College Equity Program** Development of instruction and online curriculum in Agriculture & Natural Resources **($395,650)**

CO-INVESTIGATOR (with C. J. Tinant): NSF Academic Research Infrastructure/ARRA "Yuowanca Okiya" laboratory renovations **($500,000).**

CO-INVESTIGATOR (with C.J. Tinant): National Science Foundation (TCUP), Pre Engineering Educational Collaborative Pre-engineering curriculum, service learning, and outreach **($1,250,000).**

2012 **CO-INVESTIGATOR (with C. J. Tinant): NSF Tribal Colleges & Universities Program Phase III** Unsolicited supplement ($**500,000)**

2013 **PRINCIPAL INVESTIGATOR: Van Vlack Family Endowment** Digital petrographic microscope **($7,500).**

(SUBMITTED) PRINCIPAL INVESTIGATOR: NSF Experimental Program For Stimulating Competitive Research RII T1 Cyber informatics, workforce development, and K-12 outreach **($850,000).**

<u>PERMITS & AUTHORIZATIONS</u>

1990 **SPECIAL-USE PERMIT (3 years, User Number 2033)** Nebraska National Forest, Chadron, Nebraska. Permission to excavate federally owned and protected vertebrate fossils from the Oglala National Grassland during dissertation fieldwork and paleontological resource inventories.

1991-1995 **ARCHEOLOGICAL SITE EVALUATION CLEARANCE** Nebraska National Forest, Chadron, Nebraska. Clearance to assess potential archeological sites during dissertation fieldwork and paleontological resource inventories of the Oglala National Grassland.

1993 **SPECIAL-USE PERMIT RENEWAL (User Number 2033-4)** Nebraska National Forest, Chadron, Nebraska. Permission to excavate federally owned and protected vertebrate fossils from the Oglala National Grassland during dissertation fieldwork and paleontological resource inventories.

1994-1995 **SPECIAL-USE PERMIT (3 years, User Number 2033-4)** Nebraska National Forest, Chadron, Nebraska. Permission to excavate federally owned and protected vertebrate fossils from the Oglala National Grassland during dissertation fieldwork and paleontological resource inventories.

1998-2000 **ARCHEOLOGICAL SITE EVALUATION CLEARANCE** Nebraska National Forest, Chadron, Nebraska. Clearance to assess potential archeological sites during STATEMAP fieldwork in the Pine Ridge Ranger District, Dawes County, Nebraska.

1998-2000 **SPECIAL-USE PERMIT (3 years, User Number 2033-4)** Nebraska National Forest, Chadron, Nebraska. Permission to excavate federally owned and protected vertebrate fossils from the Pine Ridge Ranger District, Dawes County, Nebraska, during STATEMAP fieldwork.

1998-2000 **SPECIAL-USE PERMIT (3 years, User Number 2033-4)** Nebraska National Forest, Chadron, Nebraska. Permission to trench covered or weathered exposures and collect rock and volcanic ash samples from the Pine Ridge Ranger District, Dawes County, Nebraska, during STATEMAP fieldwork.

MISCELLANEOUS

TELEVISION APPEARANCES

1996 **RESTLESS PRAIRIE (science documentary: 60 min.)** Joe Turco, Producer. Science, Outreach, & Specials Unit, University of Nebraska-Lincoln Television. Broadcast on Nebraska Educational Television (NETV) Network. *12 min segment: Toadstool Park Trackway site and Fossil Conservation on the Oglala National Grassland* **(with W. B. Wells & D. A. Nixon).**

RADIO APPEARANCES

2008 **Sound Off (KCSR Radio, Chadron, Nebraska: 30 min.)** *"Our Water, Our Future: A Hard Look at the Dry Facts"* Town Hall Meeting, Chadron State College Student Center Ballroom **(with Mr. Glen Price, landowner)**.

2008 **Community Focus (KCSR Radio, Chadron, Nebraska: 15 min.)** *"Our Water, Our Future: A Hard Look at the Dry Facts"* Town Hall Meeting, Chadron State College Student Center Ballroom.

FIELD HANDBOOK DATA SHEETS

1998 Schoeneberger, P. J., D. A. Wysocki, E. C. Benham, & **H. E. LaGarry.** ***Miscellaneous,*** pp. 7-1 to 7-14 *in* (P. J. Schoeneberger, D. A. Wysocki, E. C. Benham, & W. D. Broderson, compilers) *Field Book for Describing and Sampling Soils (Ver. 1.1).* USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln NE.

2002 Schoeneberger, P. J., D. A. Wysocki, E. C. Benham, & **H. E. LaGarry.** ***Miscellaneous,*** pp. 7-1 to 7-14 *in* (P. J. Schoeneberger, D. A. Wysocki, E. C. Benham, & W. D. Broderson, compilers) *Field Book for Describing and Sampling Soils (Ver. 2.1).* USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln NE.

ILLUSTRATION CREDITS

1985 ***"Artist's conception of a middle Ordovician life scene during Trenton (limestone) time. The orthocone cephalopod is similar to those found at the Clairmont Quarry."*** p. 297 *in* Van Diver, B. B. 1985. *Roadside Geology of New York.* Missoula, Montana, Mountain Press Publishing Company.

1996 ***"USGS quadrangles (solid lines) examined in the CSD open-file report by LaGarry and LaGarry, adjacent quadrangles also mapped, and federal lands of the Oglala National Grassland."*** p. 35 *in* Flowerday, C. A. 1996. *Fossil inventories yield geologic mapping, revision of the White River Group.* Resource Notes, 10:33-35.

PHOTOGRAPH CREDITS

1988 ***"Below: Each biological specimen found during the excavation was isolated from the majority of the surrounding sediment and was subsequently wrapped for removal to the laboratory. A portion of the pelvis of the stag-moose is seen in the center of the photo, and spruce logs in the foreground,"*** p. 41 *in* Warren, R. E. & R. W. Graham. 1988. Cervalces*: an Ice Age discovery.* The Living Museum, 50(3):38-41.

1996 ***"A field party made up of CSD, UNL Geology, and UN State Museum geologists examine the Chamberlain Pass Formation near Toadstool Park in northern Sioux County. Observers are (from left) Leigh Anne LaGarry, CSD; Dennis Terry, UNL Geology; Dave Loope, UNL Geology; Dave Nixon, UN State Museum; Brant Wells, UNL Geology; and Jim Swinehart, CSD."*** p. 33 *in* Flowerday, C. A. 1996. *Fossil inventories yield geologic mapping, revision of the White River Group.* Resource Notes, 10:33-35.

2004 ***"The petrocalcic field tour led by SNR geoscientist Hannan LaGarry stops to look at the Box Butte Formation on the highway south of Marsland in the upper Niobrara River valley. Co-leader and former SNR soil scientist Phil Young (far right, crouching) talks to the group, which includes scientists from various Great Plains offices of the U. S. Natural Resources Conservation Service and from the NRCS National Soil Survey Center in Lincoln. SNR soil scientist Francis Belohlavy sits in the cab of the white pickup."*** p. 6 *in* Flowerday, C. A. 2004. SNR tour helps federal scientists solve soil classification riddle, saves money. Natural Resource Links, 4(4):1-12.

"An example of a calcic, not a petrocalcic, horizon near Marsland. White concretions show carbonate buildup. Marks on tape measure are every 10 centimeters." p. 6 *in* Flowerday, C. A. 2004. SNR tour helps federal scientists soil classification riddle, saves money. Natural Resource Links, 4(4):1-12.

BOOK COVERS

1998 ***"Fine-grained volcaniclastic rocks of the White River Group initially studied by N. H. Darton (1899) at the Pine Ridge escarpment in northwestern Nebraska."*** Terry, D. O., Jr., H. E. LaGarry, & R. M. Hunt, Jr. (eds.). 1998. Depositional Environments, Lithostratigraphy, and Biostratigraphy of the White River and Arikaree Groups (Late Eocene to Early Miocene, North America). Geological Society of America Special Paper 325, 216 pp.

NEWSPAPER ARTICLES

2006 ***"Earth Day celebration to focus on water in the High Plains"*** **(with L. A. LaGarry)** p. 4A *in* The Chadron Record, Wednesday, April 12, 2006 (www.thechadronnews.com).

BIBLIOGRAPHY

PEER-REVIEWED PAPERS

1990 Thomasson, J. R., R. J. Zakrzewski, **H. E. LaGarry,** & D. E. Mergen. ***A late Miocene (Late Early Hemphillian) biota from northwestern Kansas.*** National Geographic Research, 6(2):231-244.

1993 **LaGarry, H. E.** & M. R. Myers. ***Mortality profiles of* Mammuthus imperator *(Leidy), Sheridan County, Nebraska.*** Transactions of the Kansas Academy of Science, 96(3-4):196-203.

1994 **LaGarry, H. E.** ***Results & recommendations of the 1991 paleontological resource survey of the Oglala National Grassland,*** pp. 69-72 *in* (R. Benton & A. Elder, eds.) Proceedings of the 3rd Conference on Fossil Resources. Natural Resources Report NPS/NRFOBU/NRR-94-14, 98 p.

1995 Terry, D. O., Jr., **H. E. LaGarry,** & W. B. Wells. ***The White River Group revisited: vertebrate trackways, ecosystems, and lithostratigraphic revision, redefinition, and redescription,*** pp. 43-57 *in* (C. Flowerday, ed.) Geologic field trips in Nebraska and adjacent parts of Kansas and South Dakota. University of Nebraska-Lincoln Conservation and Survey Division Guidebook 10, 136 p.

1997 **LaGarry, H. E.** ***Paleontological resource inventories of the Oglala National Grassland: a model for generating paleontological and geological research on public lands,*** pp. 108-113 *in* (M. Johnson & J. McChristal, eds.) Proceedings of the 4th Conference on Fossil Resources. Natural Resources Report NPS/NRFLFO/NRR-97/01, 239 p.

LaGarry, H. E. & D. O. Terry, Jr. ***Regional distribution of lithotopes within the Chadron Formation of northwestern Nebraska,*** pp. 9-22 *in* (R. Hunter, ed.) Geology and paleontology of the White River Formation. Tate Geological Museum Guidebook 2, 139 p.

1998 Terry, D. O. Jr., **H. E. LaGarry,** & R. M. Hunt, Jr. (eds.). ***Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (Late Eocene to Early Miocene, North America).*** Geological Society of America Special Paper 325, 216 p.

Terry, D. O., Jr. & **H. E. LaGarry.** ***The Big Cottonwood Creek Member: a new member of the Chadron Formation of northwestern Nebraska,*** pp. 117-142 *in* (D. O. Terry, Jr., H. E. LaGarry, & R. M. Hunt, Jr., eds.) Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (Late Eocene to Early Miocene, North America). Geological Society of America Special Paper 325, 216 p.

LaGarry, H. E. ***Lithostratigraphic revision and redescription of the Brule Formation (White River Group), northwestern Nebraska,*** pp. 63-92 *in* (D. O. Terry, Jr., H. E. LaGarry, & R. M. Hunt, Jr., eds.) Depositional environments, lithostratigraphy, and biostratigraphy of the White River and Arikaree Groups (Late Eocene to Early Miocene, North America). Geological Society of America Special Paper 325, 216 p.

LaGarry, H. E., W. B. Wells, D. O. Terry, Jr., & D. A. Nixon. ***The Toadstool Park Trackway Site, Oglala National Grassland, Nebraska,*** pp. 92-107 *in* (J. Martin & R. Benton, eds.) Proceedings of the 5th Conference on Fossil Resources. Dakoterra 5, 143 p.

2000 Wysocki, D. A., P. J. Schoeneberger, & **H. E. LaGarry.** ***Geomorphology of soil landscapes,*** pp. E5-E39 *in* (M. E. Sumner, editor-in-chief) CRC Handbook of Soil Science, Chemical Rubber Company Press.

2004 **LaGarry, H. E.** ***Taphonomic evidence of bone processing from the Oligocene of northwestern Nebraska.*** University of Nebraska-Lincoln School of Natural Resources Professional Paper 2, 35 p.

2005 Wysocki, D. A., P. J. Schoeneberger, & **H. E. LaGarry.** ***Soil surveys: a window to the subsurface.*** Geoderma 126:167-180.

2007 Fielding, C. R., **H. E. LaGarry,** L. A. LaGarry, B. E. Bailey, & J. B. Swinehart. ***Sedimentology of the Whiteclay gravel beds in northwestern Nebraska, USA: structurally controlled drainage promoted by early Miocene uplift of the Black Hills Dome.*** Sedimentary Geology 202:58-71.

2008 **LaGarry, H. E.** ***Taphonomic evidence of predation and scavenging from the Minium Quarry Local Biota (late Miocene) of north-central Kansas, USA,*** pp. 61-76 *in* (G. H. Farley & J. R. Choate, eds.) Unlocking the Unknown: Papers Honoring Dr. Richard J. Zakrzewski. Fort Hays Studies Special Issue 2, 153 p.

Diffendal, R. F., M. R. Voorhies, E. J. Voorhies, **H. E. LaGarry,** C. L. Timperley, & M. E. Perkins. ***Geologic Map of the O'Neill 1° x 2° Quadrangle, Nebraska, with Configuration Maps of Surfaces of Formations (1:250,000).*** University of Nebraska-Lincoln School of Natural Resources (Conservation & Survey Division) map GMC-34 (25" x 36" map w/ 29 p. explanation booklet).

ABSTRACTS

1987 **LaGarry, H. E.** ***Camelidae (Mammalia: Artiodactyla) from the Minium Quarry local biota (Early Hemphillian), Graham County, Kansas.*** Kansas Academy of Science Abstracts, 6:29.

1988 **LaGarry, H. E.** ***Notes on the taphonomy of the Early Hemphillian-aged Minium Quarry local biota, Graham County, Kansas.*** Kansas Academy of Science Abstracts, 7:22.

1989 **LaGarry, H. E.,** C. E. Rudnick, & J. I. Kirkland. ***Biostratinomy, paleoecology, and storm wave disturbance in the Pennsylvanian-aged "Haynies limestone" bed (Deer Creek Fm.) of Cass County, Nebraska.*** Proceedings of the 99th Annual Meeting of the Nebraska Academy of Sciences, pp. 58-59.

Bailey, B. E., C. L. Herbel, **H. E. LaGarry,** C. E. Rudnick, & M. R. Voorhies. ***Population dynamics of Pleistocene* Equus *from the "*Equus *beds:" age profiles of fossil horse dentitions from Gordon Quarry, Late Irvingtonian, Sheridan County, Nebraska.*** Proceedings of the 99th Annual Meeting of the Nebraska Academy of Sciences, p. 49.

1990 **LaGarry, H. E.** & C. Wellstead. ***New Permian vertebrate localities in the Eskridge Fm., Richardson County, Nebraska.*** Proceedings of the 100th Annual Meeting of the Nebraska Academy of Sciences, pp. 61-62

1991 **LaGarry, H. E.** ***Carnivore-induced bone modification patterns in large ungulates of the Minium Quarry local biota (Late Miocene) of north-central Kansas.*** Kansas Academy of Science Abstracts, 10:16.

LaGarry, H. E. ***Taphonomic evidence of predation and scavenging in the Minium Quarry local biota (Early Hemphillian) of northwestern Kansas.*** Journal of Vertebrate Paleontology-Abstracts, 11(3):41A.

LaGarry, H. E. ***Stratigraphy and sedimentology of the upper Trenton Group (Middle Ordovician), Kellogg Hill, New York.*** Proceedings of the 101st Annual Meeting of the Nebraska Academy of Sciences, pp. 58-59.

LaGarry, H. E. ***Community paleoecology and biofacies analysis of the upper Trenton Group (Middle Ordovician), Kellogg Hill, New York.*** Proceedings of the 101st Annual Meeting of the Nebraska Academy of Sciences, p. 59.

1992 **LaGarry, H. E.** ***1991 paleontological resource survey of the Oglala National Grassland (Roundtop 7.5' Quadrangle), Sioux County, Nebraska.*** Kansas Academy of Science Abstracts, 11:22.

LaGarry, H. E., C. E. Rudnick, D. W. Moser, & S. L. Holmes. ***Taphonomy of the Haynies limestone bed (Pennsylvanian), a compound distal tempestite from southeastern Nebraska.*** Geological Society of America Abstracts with Programs, 24(4):7.

LaGarry, H. E. ***Cladistic reanalysis of the Camelidae (Mammalia: Tylopoda).*** Proceedings of the 102nd Annual Meeting of the Nebraska Academy of Sciences, pp. 68-69.

LaGarry, H. E. ***The impact of unauthorized collecting of vertebrate fossils on the Oglala National Grassland (Roundtop 7.5' Quadrangle), Sioux County, Nebraska.*** Proceedings of the 102nd Annual Meeting of the Nebraska Academy of Sciences, p. 69.

LaGarry, H. E. ***Unauthorized collecting of fossil vertebrates on federal lands in northwest Nebraska: a case study.*** Seventh Annual Meeting of the Society for the Preservation of Natural History Collections Program and Abstracts, p. 17.

1993 Myers, M. R. & **H. E. LaGarry.** ***Mortality profile of Mammuthus imperator (Leidy) from the Rushville and Gordon Quarries (Irvingtonian) of Sheridan County, Nebraska.*** Proceedings of the 103rd Annual Meeting of the Nebraska Academy of Sciences, pp. 61-62.

Nixon, D. A. & **H. E. LaGarry.** ***Oligocene trackways in the White River Group type section at Toadstool Park, Sioux County, Nebraska.*** Proceedings of the 103rd Annual Meeting of the Nebraska Academy of Sciences, pp. 64-65.

LaGarry, H. E., D. A. Nixon, & W. B. Wells. ***1992 USDA Forest service survey and assessment of Toadstool Park as a sensitive site.*** Proceedings of the 103rd Annual Meeting of the Nebraska Academy of Sciences, pp. 61-62.

Nixon, D. A. & **H. E. LaGarry.** ***New trackway site in the White River Group type section at Toadstool Park, Nebraska; paleoecology of an Oligocene braided stream, riparian woodland, and adjacent grassland.*** Journal of Vertebrate Paleontology – Abstracts, 13(3):51A.

LaGarry, H. E. ***Survey of paleontological resources on U. S. Forest Service lands (Oglala National Grassland) in NW Nebraska.*** Journal of Vertebrate Paleontology-Abstracts, 13(3):45A.

1994 Terry, D. O., Jr. & **H. E. LaGarry.** ***Lithostratigraphic correlation and provisional redefinition of the Eocene-Oligocene White River Group, Nebraska and South Dakota.*** Geological Society of America Abstracts with Programs, 26(7):249.

LaGarry, H. E., D. A. Nixon, W. B. Wells, & B. A. Beasley. ***1993 paleontological resource survey of the Oglala National Grassland, Nebraska.*** Kansas Academy of Science Abstracts, 13:24.

LaGarry, H. E. ***Results and recommendations of the 1991 paleontological resource survey of the Oglala National Grassland,*** p. 25 *in* (R. Benton & A. Elder, eds.) Proceedings of the Third Conference on Fossil Resources in the National Park Service (Natural Resources Report NPS/NRFOBU/NRR-94/14).

1995 **LaGarry, H. E.** ***Provisional revision of lithostratigraphic boundaries of the Brule Formation in northwestern Nebraska.*** Geological Society of America Abstracts with Programs, 27(3):66-67.

Terry, D. O., Jr. & **H. E. LaGarry.** ***Provisional redescription and redefinition of the upper part of the Chadron Formation in northwestern Nebraska.*** Geological Society of America Abstracts with Programs, 27(3):89.

Wells W. B., D. O. Terry, Jr., & **H. E. LaGarry**. ***Stratigraphic implications of a fluvial origin for the "nodular zones," Brule Formation (Orella Member), northwestern Nebraska.*** Geological Society of America Abstracts with Programs, 27(3):95.

LaGarry, H. E. ***Bone processing behaviors of extinct mammals from the Eocene-Oligocene White River Group of northwestern Nebraska*,** Geological Society of America Abstracts with Programs, 27(3):67.

LaGarry, H. E., W. B. Wells, D. A. Nixon, & B. A. Beasley. ***1994 paleontological resource survey of the Oglala National Grassland, Nebraska.*** Proceedings of the 105th Annual Meeting of the Nebraska Academy of Sciences, pp. 55-56.

LaGarry, H. E. ***Geology of the "Old Floyd Hall Place" (UNSM localities Sx-6 and Sx-7), Sioux County, Nebraska.*** Proceedings of the 105th Annual meeting of the Nebraska Academy of Sciences, p. 55.

1996 **LaGarry, H. E.**, L. A. LaGarry, & D. O. Terry, Jr. ***A new vertebrate fauna from the Chamberlain Pass Fm. (Eocene), Sioux County, Nebraska.*** Proceedings of the 106th Annual Meeting of the Nebraska Academy of Sciences, pp. 45-46.

LaGarry, H. E. & L. A. LaGarry ***New geologic maps of the Montrose, Orella, Wolf Butte, Roundtop, and Horn 7.5' USGS Quadrangles, Sioux and Dawes Counties, Nebraska.*** Proceedings of the 106th Annual Meeting of the Nebraska Academy of Sciences, p. 45.

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NEBRASKA GEOLOGICAL SURVEY OPEN-FILE MAPS

Table 1. Open-file (OFM) and open-file digital (OFDM) maps from the Alliance 1:250,000 Quadrangle available from the Nebraska Geological Survey (University of Nebraska-Lincoln Conservation & Survey Division, School of Natural Resources). Digital maps were produced by the Department of Geosciences at Fort Hays State University, supervised by R. Lisichenko, J. Heinrichs, G. Liggett, and K. R Neuhauser. All maps are Nebraska quadrangles except as noted.

Map Name[1]	Date[2]	Map No.[3]	Authors
Sherrill Hills (WY-NE)	1997	53	LaGarry & LaGarry
Story	1997	54	LaGarry & LaGarry
(digital version 1.1)	2001	54D	LaGarry, LaGarry, & Swinehart
Story NE	1997	55	LaGarry & LaGarry
(digital ver. 1.1)	2001	55D	LaGarry, LaGarry, & Swinehart
Lone Tree Ranch	1997	56	LaGarry & LaGarry
(digital ver. 1.1)	2001	56D	LaGarry, LaGarry, & Swinehart
Wayside	1997	57	LaGarry & LaGarry
(digital ver. 1.1)	2001	57D	LaGarry, LaGarry, & Swinehart
Bohemian Creek	1997	58	LaGarry & LaGarry
(digital ver. 1.1)	2001	58D	LaGarry, LaGarry, & Swinehart
Kirtley (WY-NE)	1997	59	LaGarry & LaGarry
Warbonnet Ranch	1997	60	LaGarry & LaGarry
(digital ver. 1.1)	2001	60D	LaGarry, LaGarry, & Swinehart
Bodarc	1997	61	LaGarry & LaGarry
(digital ver. 1.1)	2001	61D	LaGarry, LaGarry, & Swinehart
Five Points	1997	62	LaGarry & LaGarry
(digital ver. 1.1)	2001	62D	LaGarry, LaGarry, & Swinehart
Whitney	1997	63	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2001	63D	LaGarry, LaGarry, & Swinehart
Trunk Butte	1997	64	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2001	64D	LaGarry, LaGarry, & Swinehart
Chadron West	1997	65	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2001	65D	LaGarry, LaGarry, & Swinehart
Crawford	1998	66	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	66D	LaGarry, LaGarry, & Swinehart
Crow Butte	1998	67	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	67D	LaGarry, LaGarry, & Swinehart
Chimney Butte	1998	68	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	68D	LaGarry, LaGarry, & Swinehart
Coffee Mill Butte	1998	69	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	69D	LaGarry, LaGarry, & Swinehart
Dead Mans Creek	1998	70	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	70D	LaGarry, LaGarry, & Swinehart
Belmont	1998	71	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	71D	LaGarry, LaGarry, & Swinehart
Coffee Mill Butte SW	1998	72	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	72D	LaGarry, LaGarry, & Swinehart
Coffee Mill Butte SE	1998	73	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2002	73D	LaGarry, LaGarry, & Swinehart
Van Tassell (WY-NE)	1999	74	LaGarry, LaGarry, & Swinehart

Continued on next page

Table 1 (continued).

Map Name[1]	Date[2]	Map No.[3]	Authors
Harrison West	1999	75	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	75D	LaGarry, LaGarry, & Swinehart
Harrison East	1999	76	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	76D	LaGarry, LaGarry, & Swinehart
Andrews	1999	77	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	77D	LaGarry, LaGarry, & Swinehart
Smiley Canyon	1999	78	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	78D	LaGarry, LaGarry, & Swinehart
Van Tassell SE (WY-NE)	1999	79	LaGarry, LaGarry, & Swinehart
Harrison SW	1999	80	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	80D	LaGarry, LaGarry, & Swinehart
Harrison SW	1999	81	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	81D	LaGarry, LaGarry, & Swinehart
Kyle Creek	1999	82	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	82D	LaGarry, LaGarry, & Swinehart
Glen	1999	83	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2002	83D	LaGarry, LaGarry, & Swinehart
Isinglass Buttes	2000	84	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2003	84D	LaGarry, LaGarry, & Swinehart
Chadron NE	2000	85	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2003	85D	LaGarry, LaGarry, & Swinehart
Chadron East	2000	86	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2003	86D	LaGarry, LaGarry, & Swinehart
Bordeaux	2000	87	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2003	87D	LaGarry, LaGarry, & Swinehart
Kings Canyon/Chadron 3 NW	2000	88	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2003	88D	LaGarry, LaGarry, & Swinehart
Hay Springs Creek/Chadron 3 NE	2000	89	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2003	89D	LaGarry, LaGarry, & Swinehart
Sand Canyon West/Chadron 3 SW	2000	90	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2003	90D	LaGarry, LaGarry, & Swinehart
Sand Canyon East/Chadron 3 SE	2000	91	LaGarry, Swinehart, & LaGarry
Beaver Wall	2001	92	LaGarry, Swinehart, & LaGarry
Whiteclay	2001	93	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2005	93D	LaGarry, LaGarry, & Swinehart
Whiteclay SW	2001	94	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2004	94D	LaGarry, LaGarry, & Swinehart
Whiteclay SE	2001	95	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2005	95D	LaGarry, LaGarry, & Swinehart
Hay Springs	2001	96	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2004	96D	LaGarry, LaGarry, & Swinehart
Hay Springs NE	2001	97	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2005	97D	LaGarry, LaGarry, & Swinehart

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Table 1 (continued).

Map Name[1]	Date[2]	Map No.[3]	Authors
Hay Springs SW	2001	98	LaGarry, Swinehart, & LaGarry
(digital version 1.1)	2004	108D	LaGarry, LaGarry, & Swinehart Hay
Springs SE	2001	99	LaGarry, Swinehart, & LaGarry
Montrose	2001	108	LaGarry & LaGarry
(digital version 1.1)	2001	108D	LaGarry, LaGarry, & Swinehart
Orella	2001	109	LaGarry & LaGarry
(digital version 1.1)	2001	109D	LaGarry, LaGarry, & Swinehart
Wolf Butte	2001	110	LaGarry & LaGarry
(digital version 1.1)	2001	110D	LaGarry, LaGarry, & Swinehart
Roundtop	2001	111	LaGarry, LaGarry, & Swinehart
(digital version 1.1)	2001	111D	LaGarry, LaGarry, & Swinehart
Horn	2001	112	LaGarry & LaGarry
(digital version 1.1)	2001	112D	LaGarry, LaGarry, & Swinehart
Clinton NW	2002	113	LaGarry, Swinehart, & LaGarry
Clinton NE	2002	114	LaGarry, Swinehart, & LaGarry
Clinton SW	2002	115	LaGarry, Swinehart, & LaGarry
Clinton	2002	116	LaGarry, Swinehart, & LaGarry
Rushville SE	2002	117	LaGarry, Swinehart, & LaGarry
Rushville SW	2002	118	LaGarry, Swinehart, & LaGarry
Rushville NE	2002	119	LaGarry, Swinehart, & LaGarry
Rushville	2002	120	LaGarry, Swinehart, & LaGarry
Gordon NW	2003	121	LaGarry, Swinehart, & LaGarry
Hog Island	2003	122	LaGarry, Swinehart, & LaGarry
Gordon	2003	123	LaGarry, Swinehart, & LaGarry
Gordon SE	2003	124	LaGarry, Swinehart, & LaGarry
South of Gordon	2003	125	LaGarry, Swinehart, & LaGarry
Coburn Canyon	2003	126	LaGarry, Swinehart, & LaGarry
Bovee Valley West/Rushville 3 SW	2003	127	LaGarry, Swinehart, & LaGarry
Bovee Valley East/Rushville 3 SE	2003	128	LaGarry, Swinehart, & LaGarry
Whistle Creek NW	2004	129	LaGarry, Swinehart, & LaGarry
Whistle Creek NE	2004	130	LaGarry, Swinehart, & LaGarry
Marsland NW	2004	131	LaGarry, Swinehart, & LaGarry
Marsland	2004	132	LaGarry, Swinehart, & LaGarry
Box Butte Reservoir West	2004	133	LaGarry, Swinehart, & LaGarry
Box Butte Reservoir East	2004	134	LaGarry, Swinehart, & LaGarry
Box Butte NW	2005	137	LaGarry, Swinehart, & LaGarry
Box Butte NE	2005	138	LaGarry, Swinehart, & LaGarry
Skunk Lake NW	2005	139	LaGarry, Swinehart, & LaGarry
Skunk Lake NE	2005	140	LaGarry, Swinehart, & LaGarry
Smith Lake	2005	141	LaGarry, Swinehart, & LaGarry

Continued on next page

Table 1 (continued).

Map Name[1]	Date[2]	Map No.[3]	Authors
Twin Lakes NE	2005	142	LaGarry, Swinehart, & LaGarry
Dolly Warden Lake	2005	143	LaGarry, Swinehart, & LaGarry
Billys Lake	2005	144	LaGarry, Swinehart, & LaGarry

Notes for Table 1:

1. **Where two names are given, the former name is listed first, and the current name second**
2. **Date indicates when map went on open file.**
3. **Numbers were assigned by the Conservation & Survey Division, and "D" denotes a digital version**

Table 2. Open-file (OFM) maps from the O'Neill 1:250,000 Quadrangle available from the Nebraska Geological Survey (University of Nebraska-Lincoln Conservation & Survey Division, School of Natural Resources). All maps are Nebraska quadrangles except as noted.

Map Name	Date	Map No.	Authors
Meadville NW	in review	pending	LaGarry, LaGarry, & Diffendal
Meadville NE	in review	pending	LaGarry, Diffendal, & LaGarry
Springview NW	in review	pending	LaGarry, Diffendal, & LaGarry
Burton	in review	pending	LaGarry, Diffendal, & LaGarry
Mills	in review	pending	LaGarry, Diffendal, & LaGarry
Jamison	in review	pending	LaGarry, Diffendal, & LaGarry
Meadville	in review	pending	LaGarry, Diffendal, & LaGarry
Huddle Table	in review	pending	LaGarry, Diffendal, & LaGarry
Springview	in review	pending	LaGarry, Diffendal, & LaGarry
Springview SE	in review	pending	LaGarry, Diffendal, & LaGarry
Jamison SW	in review	pending	LaGarry, Diffendal, & LaGarry
Mariaville	in review	pending	LaGarry, Diffendal, & LaGarry
Ainsworth NW	in review	pending	LaGarry, Diffendal, & LaGarry
Dutch Creek	in review	pending	LaGarry, Diffendal, & LaGarry
Bassett NW	in review	pending	LaGarry, Diffendal, & LaGarry
Riverview	in review	pending	LaGarry, Diffendal, & LaGarry
Carns	in review	pending	LaGarry, Diffendal, & LaGarry
Newport NE	in review	pending	LaGarry, Diffendal, & LaGarry

ARCHIVED FIELD NOTES

Table 3. Field notes archived at the Conservation & Survey Division of the University of Nebraska-Lincoln. All compilations are color .jpg files on CDROM. Copies of these notes also reside with the author(s).

Author(s)	Date[1]	Vol.[2]	Pages	Compiler (date)
LaGarry, H. E.	1985-1986	1	117[3]	R. W. Vasek (2003)
LaGarry, H. E.	1986-1987	2	117[3]	R. W. Vasek (2003)
LaGarry, H. E.	1987-1988	3	117[3]	R. W. Vasek (2003)
LaGarry, H. E.	1987-1988	3B	45[3]	R. W. Vasek (2003)
LaGarry, H. E.	1987-1988	4	117[3]	R. W. Vasek (2003)
LaGarry, H. E.	1988-1989	5	117[3]	R. W. Vasek (2003)
LaGarry, H. E.	1988-1989	6	117[3]	R. W. Vasek (2003)
LaGarry, H. E.	1989-1992	7	117[3]	R. W. Vasek (2003)
LaGarry, H. E.	1992-1993	8	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E.	1993-1994	9	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E.	1994-1995	10	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E.	1994-1995	11	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E.	1994-1995	12	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. Armantrout	1994-1995	12B	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1994-1995	13	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1995-1996	14	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1996-1997	15	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1996-1997	16	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1998-1999	17	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1998-1999	18	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1998-1999	18B	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1998-1999	19	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1998-1999	20	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1998-1999	21	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1999-2000	22	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1999-2000	23	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1999-2000	24	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1999-2000	25	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1999-2000	26	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	1999-2000	27	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2000-2001	28	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2000-2001	29	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2000-2001	30	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2000-2001	31	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2000-2001	32	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2000-2001	34	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2001-2002	38	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2001-2002	40	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2001-2002	42	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2001-2002	44	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2002-2003	45	167[3,4]	R. W. Vasek (2003)
LaGarry, H. E. & L. A. LaGarry	2002-2003	46	167[3,4]	R. W. Vasek (2003)

Notes for Table 3:

1. **Includes notes archived for the Nebraska National Forest (1991-1995) and the U. S. Geological Survey STATEMAP Program (1996-2006).**
2. **Volume numbers were assigned by the authors.**
3. **Includes inserts (typically other peoples' published work used as reference material).**
4. **Includes maps (original field maps and compilations of original maps at various scales).**

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Read Full Professional Summary

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Hydrogeologic Framework for the Madison and Minnelusa Aquifers in the Black Hills Area

by

Jonathan D.R.G. McKaskey

A thesis submitted to the Graduate Division
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN GEOLOGICAL ENGINEERING

SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY

RAPID CITY, SOUTH DAKOTA

2013

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Head of Department of Geology and Geological Engineering

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Dr. Douglas Wells, Dean of Graduate Education

Abstract

More than 50 percent of the public drinking water systems and more than 90 percent of the population in South Dakota rely solely on groundwater. This dependence on groundwater raises important questions regarding the Madison and Minnelusa aquifers in and near the Black Hills of South Dakota, including groundwater availability, the effects of water use or drought, mixing of regional flow and local recharge, and the effects of capture zones of springs and wells on the groundwater-flow system. These questions are best addressed with a three-dimensional numerical groundwater-flow model that includes the entire Black Hills area. In preparation for such a model, a three-dimensional hydrogeologic framework was constructed for the Black Hills and surrounding area. The study area includes approximately 60,000 square miles, extending approximately 150 miles from the center of the Black Hills in all directions. Structural-contour maps, potentiometric maps, and summaries of aquifer properties presented in this report will enhance groundwater modeling of the Madison and Minnelusa aquifers on a regional scale and allow for more realistic modeling of boundary conditions on a local, site-specific scale.

Structural-contour maps and well logs quantifying the top and bottom altitudes of the Madison and Minnelusa aquifers were aggregated from numerous previous investigations to construct continuous surfaces defining the hydrogeologic framework. The primary challenge in this aggregation was that structural-contour maps from different sources frequently were inconsistent for overlapping areas, usually as a result of varying resolution in spatial data. For these inconsistencies, a systematic workflow was developed to determine which source was most accurate or reliable and would be used in the final aggregation.

Potentiometric maps delineating the hydraulic head of the Madison and Minnelusa aquifers are a result of aggregating numerous previous investigations using a method similar to the construction of the structural-contour maps, with modifications based on additional groundwater-level measurements. The data were combined to construct continuous surfaces defining the regional potentiometric surface for the Madison and Minnelusa aquifers. The Minnelusa aquifer potentiometric map is largely similar to recent publications. The Madison aquifer potentiometric map enhances understanding of a trough, or valley-shaped feature, in the potentiometric surface extending from Rapid City through Philip and eastward. This trough was previously identified by Downey in U.S. Geological Survey Professional Paper 1402-E but not shown in many other recent publications.

Aquifer properties, including hydraulic conductivity, transmissivity, and storage coefficient, also were summarized from 40 wells for which estimates were available from various types of aquifer tests. Hydraulic ranged from $2x10^{-3}$ ft/day to 113.62 ft/day for the Madison aquifer and from 0.36 ft/day to 24.43 ft/day for the Minnelusa aquifer. Storage coefficient values derived from pumping tests ranged from $1x10^{-7}$ to $2x10^{-3}$ for the Madison aquifer and from $7x10^{-5}$ to $2x10^{-3}$ for the Minnelusa aquifer.

Acknowledgements

I would like to acknowledge the cooperation of several funding organizations without the support of which this project would not have come to fruition: the U.S. Geological Survey (USGS) South Dakota Water Science Center, the Black Hills National Forest, the National Park Service, and the City of Rapid City.

Dr. Andrew Long of the USGS South Dakota Water Science Center has been an integral part of this project and I am grateful for the opportunity to work as a student hydrologist for the USGS under his guidance from June 2010 to May 2013.

I am thankful for the time and effort of my major advisor, Dr. Arden Davis, for his thoughts on the project and countless edits to this work. Dr. Davis has also provided personal support over the several years of graduate school and through my undergraduate degree.

Thanks to my other committee members, Dr. Kurt Katzenstein, for the great personal and professional support he has given through my undergraduate and graduate degree, and Dr. Jennifer Benning for being willing to take part in the review of this project.

I would like to thank my wife, Christie McKaskey, for supporting me through several years of additional schooling and being understanding when I would seemingly spend more time on school work than with her and our young son, Miles. Last, I would like to thank my young son, Miles, for not coloring on any of my thesis drafts. Well, not too much, anyway.

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Appendices

List of Figures

Introduction

Purpose and Scope

The purpose of this study is to create a hydrogeologic framework for future use in a regional groundwater model of the Madison and Minnelusa aquifers in the Black Hills area. Developing a regional groundwater flow model that includes the areas of numerous previous studies will have multiple benefits over a continuation of many site-specific modeling efforts. First, developing a single regional groundwater-flow model is more cost effective than developing several smaller models. Second, a regional groundwater model will provide better simulation of boundary conditions for site-specific models. Third, artesian springs, critical water sources common in the Black Hills, which capture groundwater from regional areas, will be better represented with a regional groundwater model. A regional groundwater model will provide a regional perspective on the following questions: (1) What is the influence of the regional aquifers on local groundwater flow? (2) What is the aquifer sensitivity in different areas to pumping and drought? (3) How might future data collection efforts be planned most effectively?

During this work, a hydrogeologic framework was constructed by aggregating data from previous studies of the Madison and Minnelusa aquifers. The scope of this work was on a regional scale including and surrounding the Black Hills of South Dakota and Wyoming. Focus was placed on previous studies in the immediate Black Hills area, but publications regarding the surrounding region were included. The hydrogeologic framework included delineation of elevations of aquifer tops and bottoms, creation of potentiometric surfaces, and summaries of available estimates for aquifer properties. It was outside the scope of the study to perform a detailed review of previous publications and their source data (e.g., evaluating specific well logs used in a previous publication to delineate the top of an aquifer). However, previous publications were evaluated relative to the apparent abundance and quality of source data (e.g., resolution of control points) in their respective study areas.

The products of this work are digital rasters defining aquifer tops, potentiometric surfaces, and a digital database summarizing existing estimates for aquifer properties. The results of this work should be considered preliminary and will be subject to U.S. Geological survey review before they are prospectively published in a Scientific Investigations Report.

Previous Investigations

Developing a numerical groundwater-flow model requires collecting and analyzing data, constructing surfaces for aquifer tops, bottoms, and potentiometric surfaces, and developing estimates for aquifer properties. As a result of various previous investigations in the Black Hills area, many of the basic data components necessary for developing a hydrogeologic framework for a numerical groundwater model already exist.

The Black Hills Hydrology Study, summarized by Carter and others (2002; 2003) and Driscoll and others (2002), included numerous investigations that described general hydrologic conditions in the Black Hills area. Other previous investigations with detailed information for focused areas of study in the northern, southern, and eastern Black Hills include Greene and others (1998), a groundwater flow model for Madison and Minnelusa aquifers in the Spearfish, South Dakota area, Long and Putnam (2002), a conceptual model for the Madison and Minnelusa aquifers in the Rapid City, South Dakota area, Putnam and Long (2007a; 2007b; 2009), dye test results for the Rapid City and Spearfish, South Dakota areas and a numerical groundwater model for the Rapid City, South Dakota area, and Long and others (2008; 2012), conceptual models using environmental tracers and mixing to describe hydrogeologic processes in the eastern and southern Black Hills. Regional data beyond the Black Hills are also available from Konikow (1976), a regional groundwater model of the Madison aquifer, and Downey (1986), part of a Regional Aquifer-System Analysis by the U.S. Geological survey.

The Regional Aquifer-System Analysis, initiated in 1978 and completed in 1995, defined regional hydrogeology and established a regional framework of background information for many of the principal aquifers of the United States. However, this regional information is of very coarse resolution and there have been many recent localized studies contributing more detailed information on the hydrogeology specific to the Madison and Minnelusa aquifers in and around the Black Hills area.

Geologic maps and cross sections for the Black Hills area are available from Strobel and others (1999), Redden and DeWitt (2008), and Love and Christiansen (1985). Many previous studies were used in delineating the structure tops of the Madison and Minnelusa aquifers in various areas in and around the Black Hills area, creating potentiometric surfaces for the Madison and Minnelusa aquifer, and in summarizing existing estimates for aquifer properties. These sources are summarized in sections of this report dedicated to the individual components of the hydrogeological framework.

Several groundwater-flow models exist for the Madison and/or Minnelusa aquifers that include the study area for this report (Figure 1). Regional models include Downey (1986) and Konikow (1976). These regional models were of coarse resolution, with Downey (1986) representing the entire Black Hills region in just a few grid cells.

Konikow (1976) improved on Downey's (1986) regional model but still represented the outcrop of the Madison aquifer in the Black Hills area with only 23 cells. As hydrologic information has become more readily accessible and computing power allowed for finer-gridded models, groundwater-flow models have been able to represent the Madison and Minnelusa aquifers at a finer resolution. The Madison and Minnelusa aquifers have been modeled by Greene and others (1998) in the northern Black Hills in the vicinity of Spearfish, South Dakota, and by Putnam and Long (2009) in the Rapid City, South Dakota, area.

Description of Study Area

Study Area

The study area is centered around the Black Hills of western South Dakota and eastern Wyoming, and extends west-east from approximately 50 miles west of Gillette, Wyoming, to 20 miles east of Philip, South Dakota. The study area extends north-south from the North Dakota border to about 10 miles south of Lusk, Wyoming. The Hartville and Laramie uplifts and a series of steep faults (Love and Christiansen, 1985) form an irregular boundary in the southeastern part of the study area. In parts of this irregular boundary, the Paleozoic rocks dip as steeply as 10,000 feet vertically over just a few miles in distance. In all, the study area includes approximately 60,000 square miles.

Regional Geology

The Black Hills uplift (Figure 2) is a domal structure situated east of the Powder River Basin and south southwest of the Williston Basin, originating approximately 60 to 65 million years ago during the Laramide orogeny (Darton and Paige, 1925). At the center of the Black Hills, Precambrian rocks of varying metamorphic and igneous origin

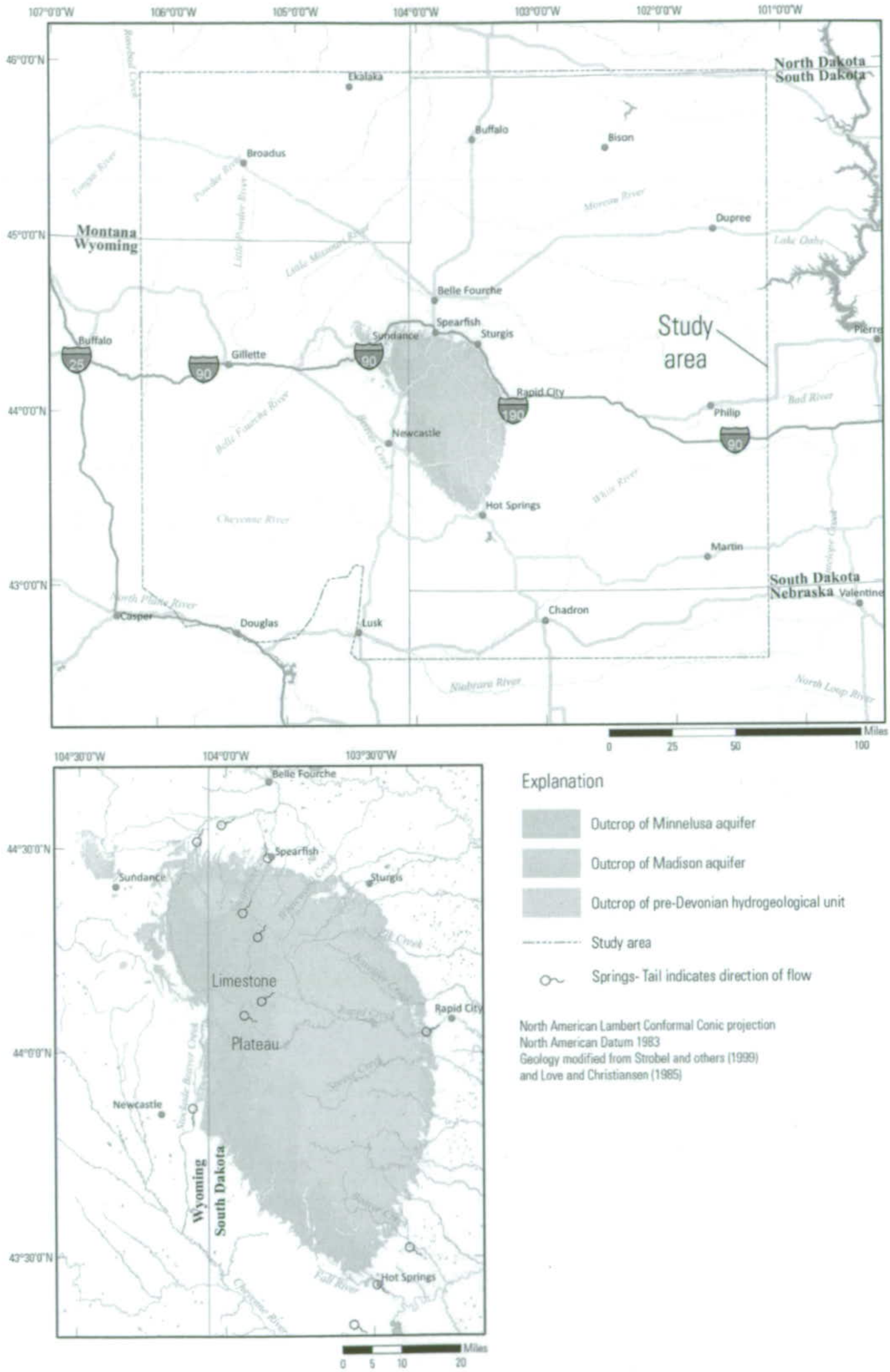

Figure 1. Delineation of study area and generalized geology.

are exposed. Geologic units overlying Precambrian rocks are exposed in a radial fashion around the Black Hills uplift and dip outward from the Precambrian core of the Black Hills. The western flank of the Black Hills dips steeply into the Powder River Basin just west of the lower Cretaceous principal aquifer (Figure 2). The Powder River Basin has a Precambrian basement elevation of approximately 11,000 feet below sea level. At Harney Peak, the highest point in the Black Hills, the Precambrian rocks reach 7,242 feet above sea level.

Several North American principal aquifers, as delineated by Miller (2000), are exposed in the study area (Figure 2). The Black Hills regional groundwater-flow model will simulate flow in the Madison and Minnelusa aquifers of Paleozoic age (Figure 2; Figure 3). These aquifers are of primary importance in the immediate vicinity of the Black Hills, where drilling depth and water quality are not limiting factors when considering a new well. Farther from the Black Hills, other primary aquifers (Figure 2) are shallower and more readily targeted for water wells. The Madison aquifer has been considered for large groundwater withdrawals in areas near the Black Hills for various industrial uses such as the ETSI coal slurry pipeline just north of Lusk, Wyoming, near where the Wyoming, Nebraska, and south Dakota state boundaries meet (Rahn, 1979).

Hydrogeology

The hydrogeologic units studied in this report are Precambrian through Paleozoic in age. The aquifers of focus are Paleozoic sedimentary rocks and are composed of mostly shallow-water marine carbonate, clastic, and evaporite deposits of Upper Devonion through early Permian age (Peterson, 1984). The three hydrogeologic units that will compose this study are the Minnelusa, the Madison, and the pre-Devonian hydrogeologic units, following the example of Putnam and Long (2009) and Long and Putnam (2002) (Figure 3).

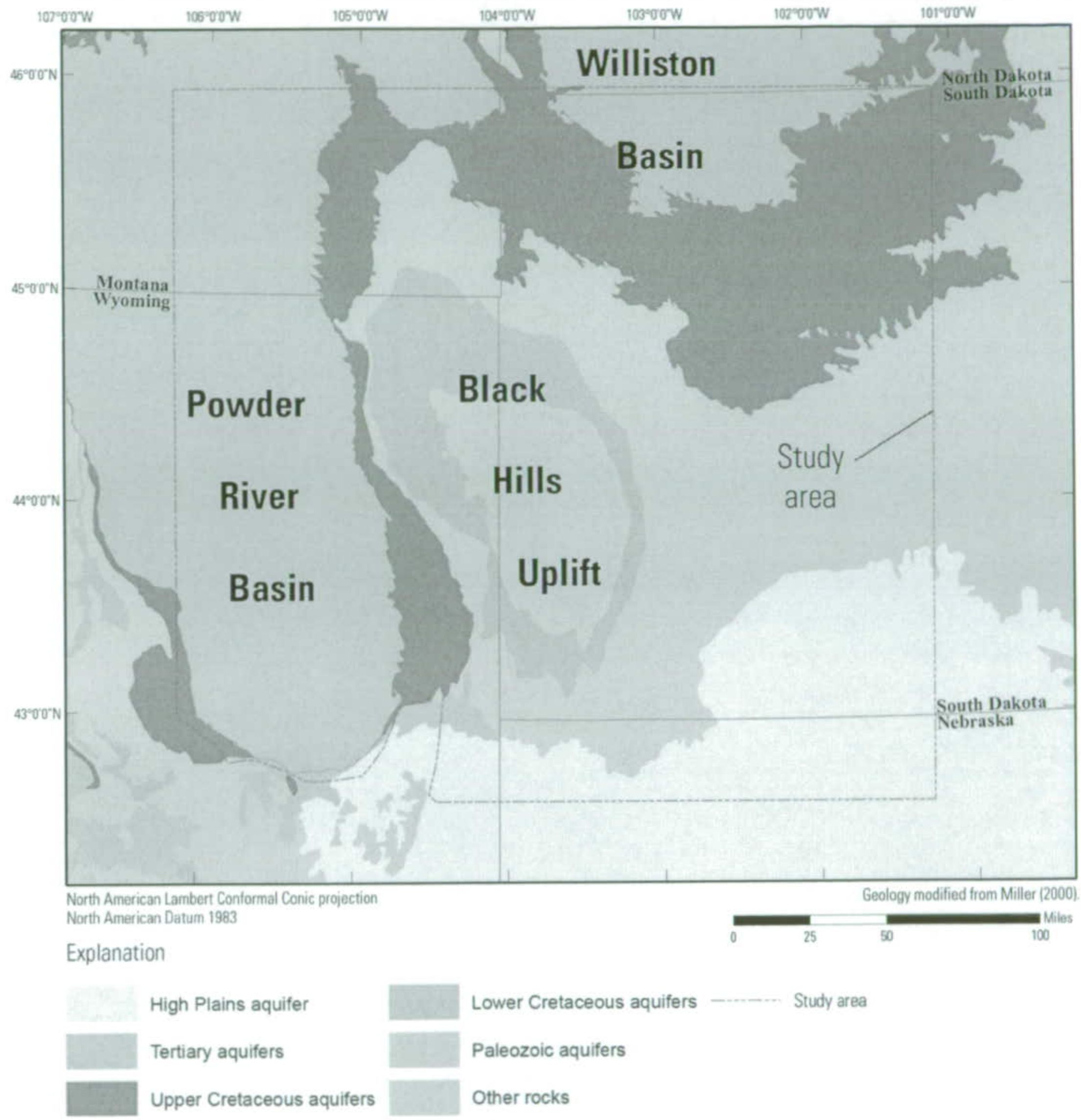

Figure 2. Distribution of North American principal aquifers in relation to the study area.

Erathem	System	Symbol	Stratigraphic unit	Description	Hydrogeologic Unit
Paleozoic	Permian	PIPm	Minnelusa Formation	Yellow to red cross-bedded sandstone, limestone, and anhydrite locally at top. Interbedded sandstone, limetone, dolomite, shale, and anhydrite in middle sections. Red shale with interbedded limestone and standstone at base.	Minnelusa
	Pennsylvanian				
	Mississippian	MDme	Madison (Pahasapa) Limestone	Massive light-colored limestone. Dolomite in part. Cavernous in upper part.	Madison
	Devonian		Englewood Formation	Pink to tan limestone. Shale locally at base.	
	Ordivician	Ou	Whitewood (Red River) Formation	Tan dolomite and limestone	pre-Devonian
			Winnepeg Formation	Green shale with siltstone	
	Cambrian	O€d	Deadwood formation	Massive to thin-bedded sandstone, glauconitic shale, dolomite, and limesone conglomerate.	
Precambrian		p€u	Undifferentiated metamorphic and igneous rocks	Schist, slate, quartzite, and arkosic grit. Intruded by diorite, metamorphosed to amphibolite, and by granite and pegmatite.	

Modified from Driscoll and others, 2002

Figure 3. Generalized hydrostratigraphic correlation chart of study area.

Minnelusa Aquifer

In the study area, the Pennsylvanian and Permian Minnelusa aquifer consists of sandstone, shale, carbonate, and some interbedded anhydrite (Downey, 1984). Putnam and Long (2009) considered the Minnelusa as two parts for modeling purposes. The upper 200 to 300 feet of the Minnelusa aquifer, composed of thick sandstone and thin limestone, dolomite, and mudstone, is more permeable because of the coarse sands, solution openings, and breccia pipes. This upper section has been assigned an age of lower Permian, based on correlations with the Hartville Formation south and west of the Black Hills (Robinson and others, 1964). The lower section of the Minnelusa aquifer, as designated by Long and Putnam (2002), is composed of shale, limestone, and dolomite, is less permeable and, on a regional scale, restricts flow between the Minnelusa aquifer and the underlying Madison aquifer (Kyllonen and Peter, 1987; Greene, 1993). Where the

Minnelusa aquifer is exposed at the surface, the formation tends to locally have greater permeability because of weathering (Long and Putnam, 2002). At the base of the Minnelusa is a discontinuous layer of red clay varying from 0 to 50 feet in thickness (Long and Putnam, 2002). This red clay layer is a paleosol that developed on the surface of the ancient karst topography of the Madison Limestone (Gries, 1996).

It is not certain whether the “upper and lower” division made in the Black Hills area by Long and Putnam (2002) can be extrapolated to other parts of the study area (e.g., the Wyoming area in the Powder River Basin), but similarities in change in hydraulic head over time indicate that it could be an appropriate assumption (Bartos and others, 2002).

The Minnelusa Formation is composed mostly of sandstone facies immediately surrounding most of the Black Hills, but in the southeastern Black Hills area it was described by Downey (1984) as primarily red shale with silt, some carbonate rock, gray shale, and evaporite (Downey, 1984). The source of the larger sandstone units in the Minnelusa aquifer was interpreted by Downey (1984) to be reworked sands deposited earlier and derived from paleostructures to the west.

The Minnelusa aquifer generally decreases in thickness to the north (Downey, 1984). In the Black Hills area, the Minnelusa decreases in thickness by 400 feet from the southern to northern Black Hills. The difference in thickness between these two areas is likely to be caused by the dissolution of as much as 80 percent gypsum and anhydrite from Minnelusa surface exposures (Redden and DeWitt, 2008). Dissolution is shown by pockets of breccias on the surface exposures of the Minnelusa aquifer. The dissolution of gypsum in the aquifer is also apparent on a more regional scale, causing the Minnelusa to be thinner nearer to surface outcrops than in areas of the deeper subsurface (Redden and DeWitt, 2008). This pattern of changes in thickness extends around the Black Hills and is referred to as a "dissolution front" (Bowles and Braddock, 1963). The dissolution of this gypsum started in the Tertiary period and is still continuing today, as demonstrated by periodic discharges of water mixed with gypsum and other constituents of the Minnelusa aquifer at springs such as Cascade Springs near Hot Springs, South Dakota (Hayes, 1999). The dissolution of gypsum is also shown by numerous sinkholes in units directly overlying the Minnelusa Formation. In the northeastern Black Hills, these gypsum beds are almost absent (Redden and DeWitt, 2008). The absence of gypsum beds in the northern Black Hills and the evidence of active dissolution of gypsum in the southern Black Hills likely indicates that the "dissolution front" is closer to surface exposures of the Minnelusa in the southern Black Hills than in the northern Black Hills.

In areas surrounding the Black Hills, the Minnelusa aquifer is defined as units equivalent to the Minnelusa Formation, including the Hartville Group, the Amsden Formation, and the Tensleep Sandstone where present in the study area (Schoon, 1979; Downey, 1984).

The Minnelusa aquifer is overlain by the Opeche Shale (Long and Putnam, 2002) in the vicinity of the Black Hills and by other Permian age shales in the rest of the study area of sufficient thickness to act as a confining bed (Long and Putnam, 2002).

The Minnelusa Formation is used as an aquifer by many residents in the Black Hills area. In terms of how productive the Minnelusa Formation is as an aquifer, in the Rapid City area of the eastern Black Hills, Long and Putnam (2002) determined that wells completed in the Minnelusa aquifer in their study area are typically able to produce

5 to 700 gallons per minute (gal/min). Of these, 66 percent produce 5 to 50 gal/min, 28 percent produce 50 to 200 gal/min, and only 6 percent produce 200 to 700 gal/min (Long and Putnam, 2002). The depths of wells range from 80 to 3000 feet in depth; 90 percent of those wells are shallower than 1000 feet depth, and 60 percent are less than 500 feet in depth (Long and Putnam, 2002). These percentages were determined from the model area of Putnam and Long (2009) in the Rapid City area.

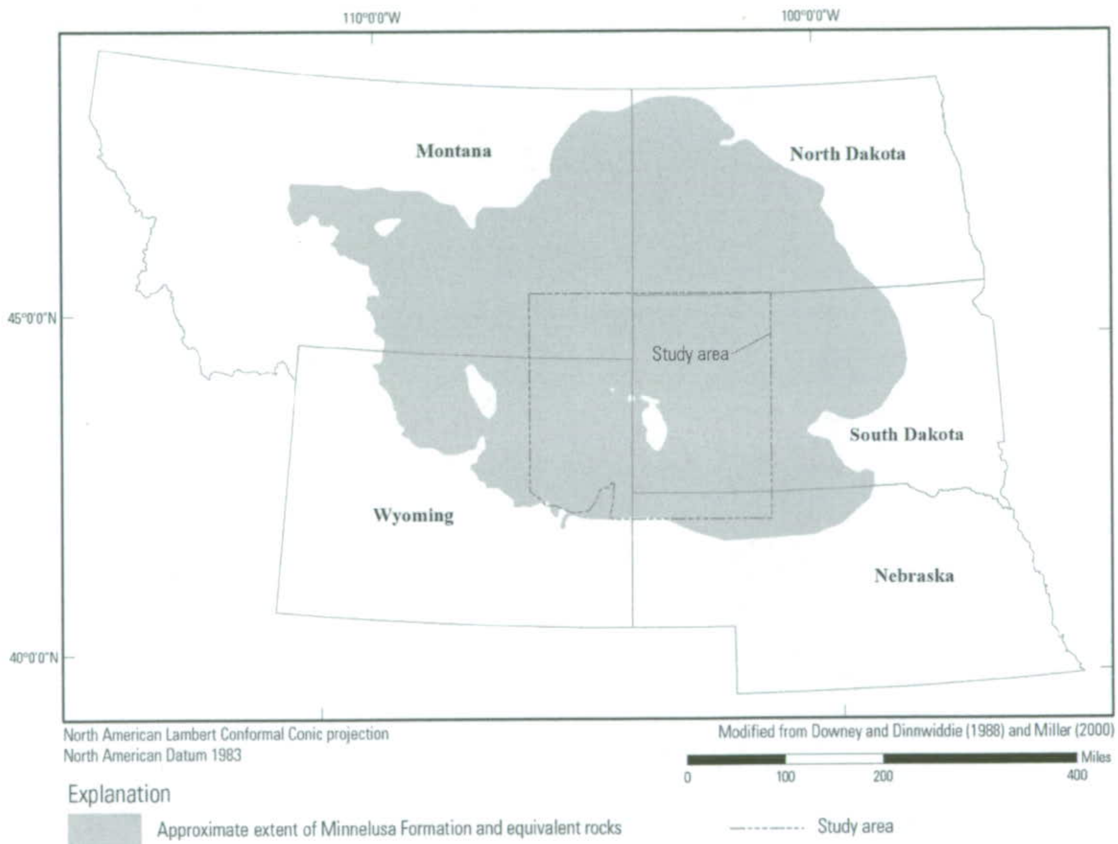

Figure 4. Approximate areal extent of Minnelusa formation and equivalent rocks.

Madison Aquifer

In the study area, the Madison aquifer consists of the Mississippian Madison Limestone and the Lower Mississippian-Devonian Englewood Formation. Although formal geologic nomenclature for the Madison Limestone in the immediate Black Hills area is the "Pahasapa Limestone" (Redden and DeWitt, 2008), the formation is equivalent to the regional Madison Limestone. The Madison Limestone is a massive grey limestone, generally dolomitic, ranging in thickness from about 250 feet to more than 1200 feet in thickness (Peale and Merrill, 1893; Darton, 1901). The outcrop of the Madison Limestone on the western flank of the Black Hills is one of the highest erosional features in the Black Hills. Although the Precambrian rocks at Harney Peak show the officially highest elevation in the Black Hills, the Limestone Plateau of the western flank of the Black Hills (Figure 1) composes most of the high-elevation land of continuous area in the Black Hills. Although the Madison Limestone composing the Limestone Plateau as a geologic formation is flat-lying or dips slightly westward, the potentiometric surface generally locally slopes eastward, allowing for emergent springs that are the headwaters for Rapid Creek, which flow easterly across the Black Hills (Figure 1). Spearfish Creek has the largest watershed within the Limestone Plateau (Figure 1) and is mostly fed by groundwater (Driscoll and Carter, 2001), which likely emerges as springflow from the base of the Madison aquifer at either side of the stream.

The Englewood Formation, included in the Madison hydrogeologic unit, underlies the Madison Limestone and is of lower Mississippian and upper Devonian age (Downey, 1984). The Englewood Formation is composed of argillaceous, dolomitic limestone. It was considered by Strobel and others (1999) as a single hydrogeologic unit with the Madison Limestone and could even be considered a "member" of the Madison Limestone because of its lithology (Long and Putnam, 2002), but not because of its hydrogeologic characteristics. The Englewood Formation acts as a confining layer for the Madison aquifer; several springs in the Black Hills emerge at the contact between the Madison aquifer and the underlying Englewood Formation.

The Madison Limestone is a sequence of carbonates and evaporates deposited in environments ranging from warm, shallow-water to deep-water facies (Downey, 1984). These facies vary both laterally and vertically (Downey, 1984). Coinciding with important paleostructure trends, the Madison Limestone is thickest in the central part of the Williston Basin and the deepest parts of the Powder River Basin (Peterson, 1984).

Sando and Dutro (1974) described ancient features in the Madison Limestone (e.g., enlarged joints, sinkholes, caves, and solution breccias) in north-central Wyoming and noted that many of these open surfaces are filled by sand and residual products of a transgressive sea of late Mississippian age (Downey, 1984). The carbonate rocks in the Madison Limestone are soluble in water, so dissolution of these rocks is common (Downey, 1984). Numerous, extensive cave networks in and near outcrop areas of the Madison Limestone near the Black Hills (e.g., Wind Cave and Jewel Cave) are evidence of this dissolution process leading to the development of secondary porosity zones in the Madison Limestone (Downey, 1984). The solution cavities at the surface also could exist elsewhere in the subsurface, explaining many anecdotal accounts of encountering zones of lost circulation while drilling for oil in deeper parts of the Williston Basin (Schoon, 1979). In April, 2013, a company attempting to drill to Precambrian rocks in Wasta, South Dakota asked to temporarily abandon a well due to an extended period of lost circulation in the Madison Limestone (Derric Iles, personal communication, 2013). Because of these extensive solution enlargements, resulting in primary flow resembling conduit flow, the Madison Limestone can be considered karstic (Long and Putnam, 2002).

The Madison Limestone has been subdivided into four geomorphic sub-units, based on cliff-forming characteristics (Miller, 2005). In the Black Hills area, these geomorphic sub-units described by Miller (2005) were designated as 1, 2, 3, and 4 (from lowest to highest) and range in thickness from 130 to 165 feet, 81 to 120 feet, 140 to 150 feet, and 0 to 85 feet respectively. The upper units, 3 and 4, are the most permeable because of the numerous breccias, caverns, and other karst features (Putnam and Long, 2009). Although the upper units have many solution openings, these features are less common in the contact zones between the geomorphic units (Miller, 2005) and generally decrease in frequency of occurrence in the stratigraphically lower parts of the formation (Greene, 1993). However, the lower parts of the Madison Limestone, geomorphic zub-units 1 and 2, are known to have zones of high secondary porosity in and near outcrop areas. Generally, the zone of relatively greater secondary permeability in the upper Madison Limestone ranges in thickness from 100 to 200 feet in the Black Hills area (Long and Putnam, 2002).

Surface exposures of the Madison aquifer have many depressions filled with reddish-brown sandstone and silt, marking the karst topography between the Madison Limestone and the Minnelusa Formation (Redden and DeWitt, 2008). This contact is considered to be an unconformity and can form as much as 180 feet of topography between the two units, as seen in Pringle, South Dakota (Redden and DeWitt, 2008).

The Madison Limestone is a source of petroleum in the northern Great Plains (Downey, 1984). During the 1960s, it was estimated that more than 90 percent of petroleum production in North Dakota was from the Madison Limestone (Downey, 1984).

In the Black Hills area, the Madison Limestone is considered as one geologic unit, but in Wyoming, Montana, and North Dakota, it is considered as the Madison Group (Schoon, 1979). The Madison Group consists of the Lodgepole Limestone, Mission Canyon Limestone, and Charles Formation (Downey, 1984). Rocks Miller's (2005) geomorphic sub-units of the Madison Limestone may be loosely correlated with the units of the Madison Group.

The Madison Limestone is overlain directly by the Big Snowy Group in far northwestern South Dakota, ranging in thickness from 0 to 50 feet. Elsewhere in the study area, the Madison Limestone is overlain directly by the Minnelusa formation.

The Madison Limestone is confined from below by the Englewood Limestone, Whitewood Formation, Deadwood Formation, and Precambrian rocks. Fracture interconnection between zones of greater permeability appears to be the major route of water flow in the Cambrian-Ordovician and Madison aquifers (from Downey, 1984).

In the Black Hills area, the Madison Limestone is used as an aquifer by many residents. Wells completed in the Madison Limestone typically have higher yields than other aquifers in the area and the potentiometric head is typically artesian or flowing-artesian in many areas, making the Madison Limestone a desirable target for water wells. In terms of the productivity of the Madison Limestone as an aquifer, in the Black Hills area, Long and Putnam (2002) determined that wells completed in the Madison aquifer in their study area are typically able to produce 5 to 2,500 gal/min. Of these, 64 percent produce 5 to 50 gal/min, 11 percent produce 50 to 200 gal/min, and 25 percent produce

200 to 500 gal/min (Long and Putnam, 2002). The wells range from 20 to 4,600 feet in depth; 78 percent of these are shallower than 1,000 feet in depth, and 41 percent are less than 50 feet in depth (Long and Putnam, 2002).

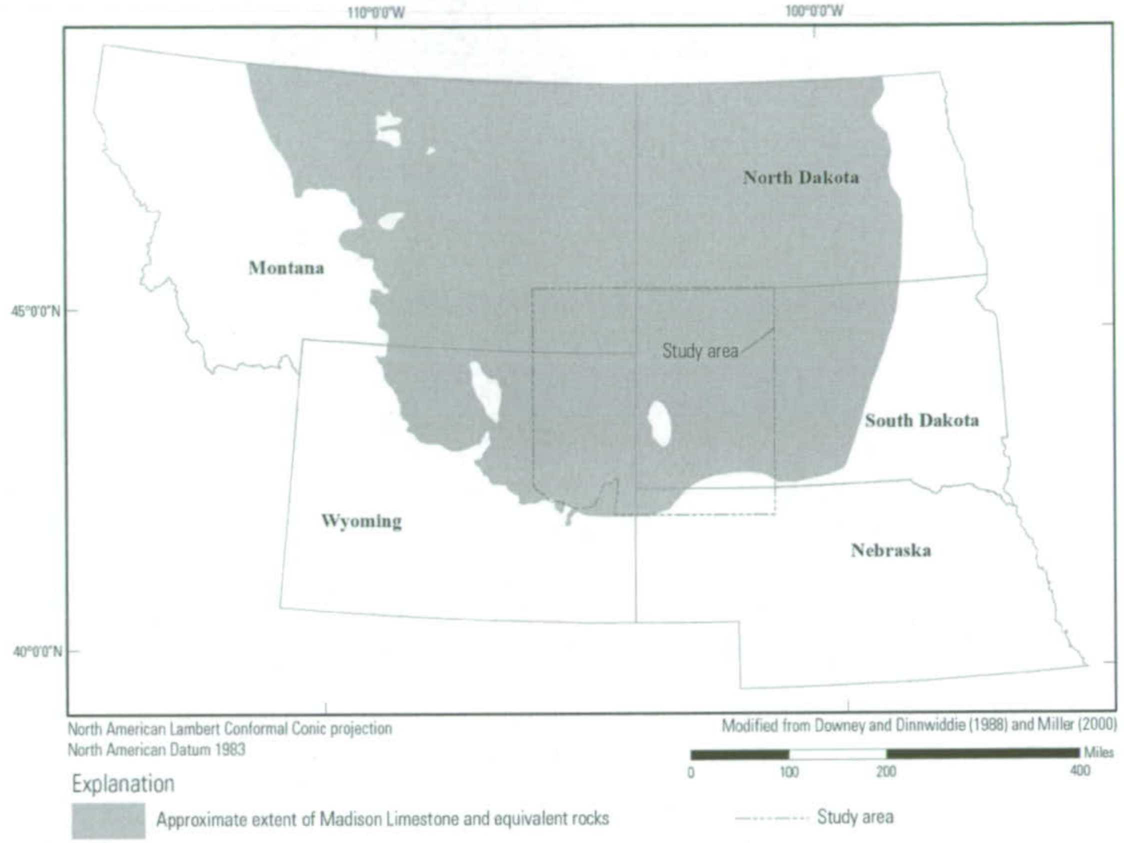

Figure 5. Approximate areal extent of Madison Limestone and equivalent rocks

Pre-Devonian Hydrogeologic Unit

The pre-Devonian hydrogeologic unit consists of various formations but mainly includes shaly carbonates, shale, and evaporates of Ordovician and Cambrian age representing shoreward facies of a transgressive sea. Precambrian rocks and Tertiary intrusions also are included in the pre-Devonian hydrogeologic unit. Geologic formations in the Black Hills area included in the pre-Devonian hydrogeologic unit from youngest to oldest are the Whitewood (Red River) Formation, the Winnipeg Formation, and the

Deadwood Formation. Hydrogeologically equivalent geologic formations in other parts of the study area include the Stony Mountain Formation, Bighorn Dolomite, Flathead Sandstone, and Emerson Formation. These formations are considered aquifers locally, where drilling depth or water quality does not prevent their use (Downey, 1984; Driscoll and others, 2002).

The Winnipeg Formation, stratigraphically equivalent to the Saint Peter Sandstone in the midwestern United States (Downey, 1984), is composed mostly of green shale and siltstone and ranges from 0 to 60 feet thick in the Black Hills area. The Whitewood Formation, often referred to as the Whitewood Dolomite or the Red River Formation, is a carbonate sequence composed of a pink to tan limestone and ranges from 0 to 60 feet in thickness in the Black Hills area (Downey, 1984). Both the Winnipeg and the Whitewood formations increase in thickness to the north. These formations have been eroded to a "feather edge" in the central Black Hills area trending east-northeast through Pactola Reservoir (Redden and DeWitt, 2008). Several meters of thickness of the Winnipeg Formation probably exist farther south but are largely concealed (Redden and DeWitt, 2008). The Whitewood Formation continues south of the line trending through Pactola Reservoir to just south of Little Elk Creek, but only discontinuously (Redden and DeWitt, 2008). In some areas of discontinuity, in place of the Whitewood Formation there exists a few meters of "very well rounded unfossiliferous sandstone" usually included in the Deadwood Formation. This sandstone indicates a possible break in erosion during the Silurian time period (Redden and DeWitt, 2008).

The Ordovician-age Winnipeg and Whitewood formations are major petroleum reservoirs in the Williston Basin, where they increase to a maximum thickness of approximately 1400 feet in the deepest parts of the basin (Redden and DeWitt, 2008).

In most of South Dakota, North Dakota, and eastern Wyoming, the Deadwood Formation is predominantly sandstone (Peterson, 1984). In the Black Hills, the Deadwood formation is primarily sandstone with layers of glauconitic shale, dolomite, with a sandstone conglomerate locally at the base (Driscoll and others, 2002). The Deadwood Formation ranges in thickness from 0 to 500 feet (Carter and others, 2002) and thins southward in the Black Hills area.

Precambrian rocks form the basement of the northern Great Plains and are included in the pre-Devonian hydrogeologic unit. The ages of Precambrian rocks in northwestern Wyoming and western South Dakota range from approximately 1,750 million years (m.y.) old to about 2,700 m.y. old. In most of the study area the Precambrian rocks are directly overlain by upper Cambrian rocks, except in the central Black Hills, where the Precambrian rocks form an "erosional high". In some areas, it is not certain whether the thinner areas of the upper Cambrian (e.g., Deadwood formation) are due to "depositional draping" over Cambrian structural highs or are buried hills on the Precambrian surface (Peterson, 1984; Redden and DeWitt, 2008). Intrusive bodies (e.g., Tertiary intrusions) are also included in the pre-Devonian hydrogeologic unit because of their low permeability.

Hydrogeologic Framework

Three hydrogeologic units were established to simplify the groundwater-flow model (Figure 3): the Minnelusa aquifer, the Madison aquifer, and the pre-Devonian hydrogeologic unit. After these hydrogeologic units were established, data pertaining to structural contours, potentiometric surfaces, and aquifer properties were assimilated from various sources, including existing structural contour maps, potentiometric maps, existing borehole logs, digital elevation data, and existing aquifer-test data. For assimilation of data, an iterative workflow (Figure 6) was established with these main steps: (1) gather and use the most reliable and consistent data, using ArcMap's "Topo to Raster" tool to aggregate and interpolate data, (2) check surfaces for consistency, re-evaluate the input data used, and correct the surface to match surface elevations at geologic contacts, and (3) prepare the data in a format convenient for data input for MODFLOW (Harbaugh, 2005).

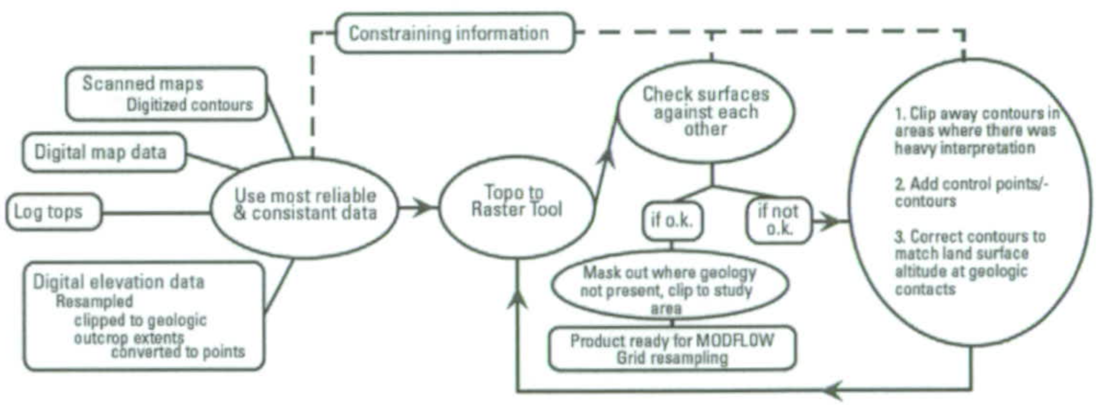

Figure 6. Iterative workflow for collection, interpretation, and interpolation of data for the creation of structural contour maps.

Altitudes of the Tops and Bottoms of Hydrogeologic Units

Structural-contour maps and well logs quantifying the top and bottom altitudes of the Madison and Minnelusa aquifers were aggregated from numerous previous investigations to construct continuous surfaces defining the hydrogeologic framework. The primary challenge in this aggregation was that structural-contour maps from different sources frequently were inconsistent for overlapping areas, usually because of varying resolution in spatial data. To determine which maps (or parts of maps) to use, several factors were considered. Generally, the most recent contour maps were considered first. If the most recent source map had good control, meaning that there were many data points to define a surface, then that map was used. If an older map had much better control for certain areas, data from those areas with better control were used instead. Contour data from different sources were edge matched by using the "Topo to Raster" tool in ArcGIS (ESRI, 2013). Occasionally, problems arose where contours from different sources did not edge-match perfectly. In these situations, the contour data were clipped back to leave a gap between contours from different sources, and the contour data with better control were given preference. The "Topo to Raster" tool was better able to interpolate between contour data after this process.

Resulting contours for the tops of the aquifers are shown with 500 ft contour intervals. Because some authors of the source data did not dash contours where approximated, and the source data were all completed at different resolutions, the resulting contours shown in this report are not dashed. The publication of the source data should be referenced if there is question about accuracy in a certain area.

Minnelusa Aquifer

The altitude of the Minnelusa aquifer was interpreted by using five steps to combine source data (Figure 7) in order to develop a continuous structural surface (Figure 8). First, existing maps (Gries, 1981b; Peter and others, 1987; Peter and others, 1988; Crysdale, 1990; Carter and Redden, 2000b; and Bartos and others, 2002) in areas "b, c, d, e, f, and g" of Figure 7 were trimmed to edge match where they had good control for the top of the Minnelusa aquifer. Second, borehole data in area "h" of Figure 7 for the top of Minnelusa aquifer or Big Snowy unit (North Dakota Oil and Gas Division, 2011) were analyzed with geostatistics in ArcGIS (ESRI, 2013) to remove potentially spurious data points and then included as data. Third, missing data were filled. Areas labeled "a" in Figure 7 were filled by taking an existing map for the top of the Madison aquifer (Swenson, 1976) and adding the thickness of the Minnelusa aquifer (Downey, 1984). In some areas where the surface appeared to be relatively smooth, blank areas were left open for interpolation between contours. In some areas hand control points had to be added to assist in interpolation. Fourth, a 30-meter resolution digital elevation model (DEM) from the National Elevation Dataset (Gesch and others, 2002) was resampled to

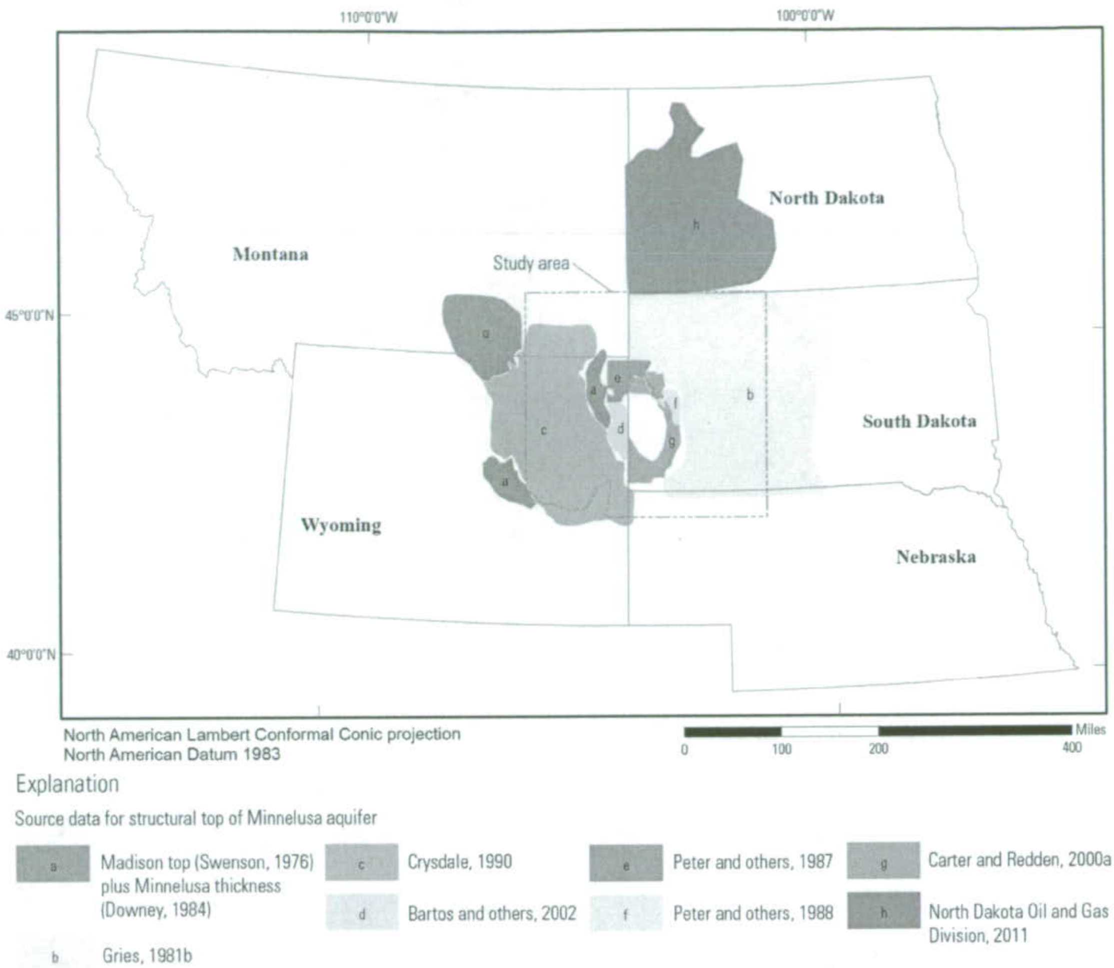

Figure 7. Source data for delineation of the altitude of the top of the Minnelusa aquifer.

100-meter resolution, clipped to outcrop areas of the Minnelusa aquifer, and converted to points for use in aquifer top delineation (not shown in Figure 7). Fifth, the resulting raster for the Minnelusa aquifer was evaluated and corrected at geologic contacts on the down-dip side of Minnelusa outcrops to ensure that the Minnelusa was not erroneously modeled as above the actual land surface in these areas.

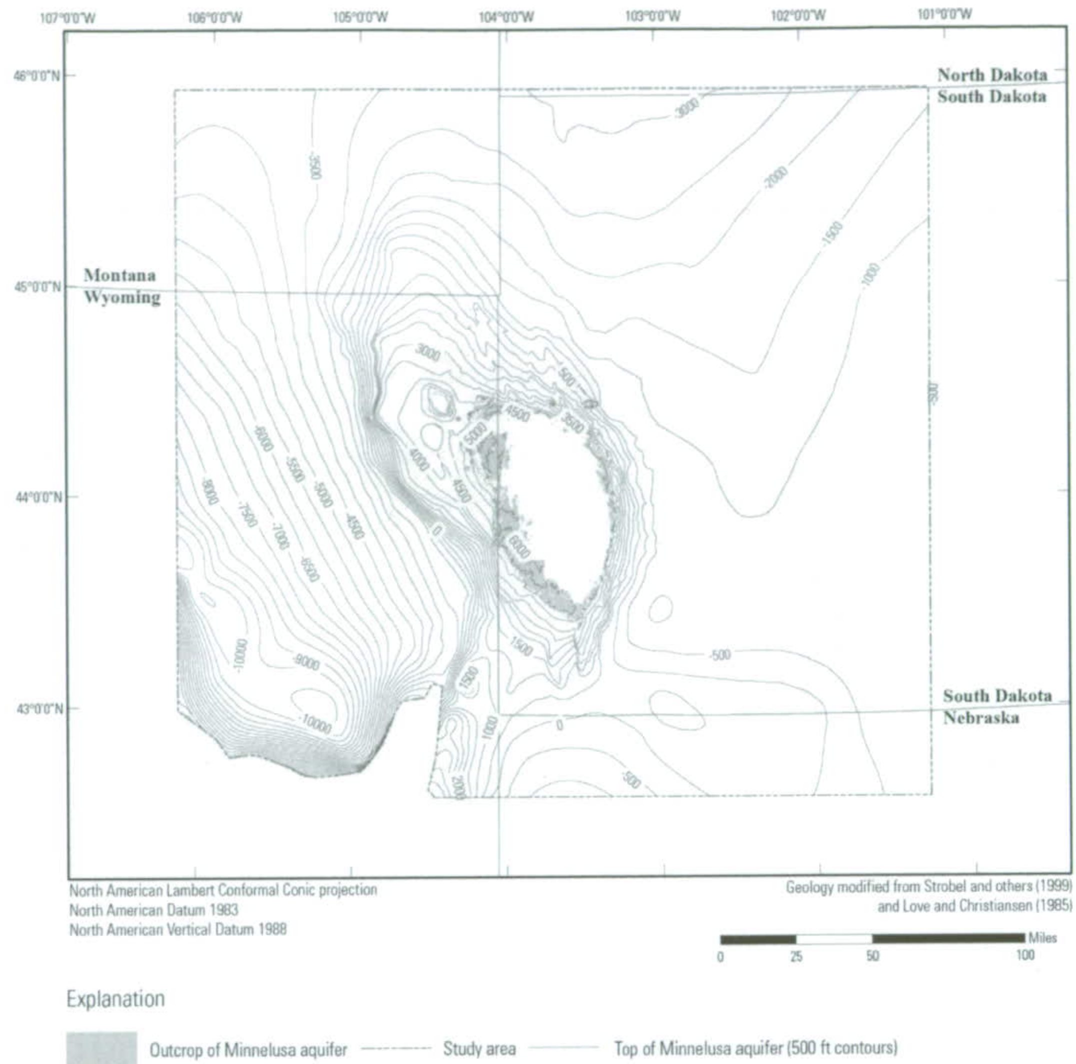

Figure 8. Altitude of the top of the Minnelusa aquifer.

Altitudes of the top of the Minnelusa aquifer range from 10,000 feet below sea level in the southern Powder River Basin to approximately 6,000 feet above sea level in the western Black Hills. The altitude of the top of the Minnelusa aquifer drops to approximately 3,000 feet below sea levelat the North Dakota-South Dakota border, dipping farther northward into the Williston Basin. In the focus area of the study, the dip of the Minnelusa aquifer is steepest in the eastern Black Hills dropping approximately

4,000 feet in altitude in less than 20 miles before it levels off just east of Rapid City, South Dakota.

Madison Aquifer

The altitude of the Madison aquifer was interpreted by using six steps to combine source data in various areas (Figure 9), in order to develop a continuous structural surface (Figure 10). First, existing maps (Swenson, 1976; Gries, 1981a; Bergantino and Feltis, 1985; Carter and Redden, 1999b; Bartos and others, 2002) in areas “a, c, e, f, and g” in Figure 9 were trimmed to edge match where there was good control for the Madison

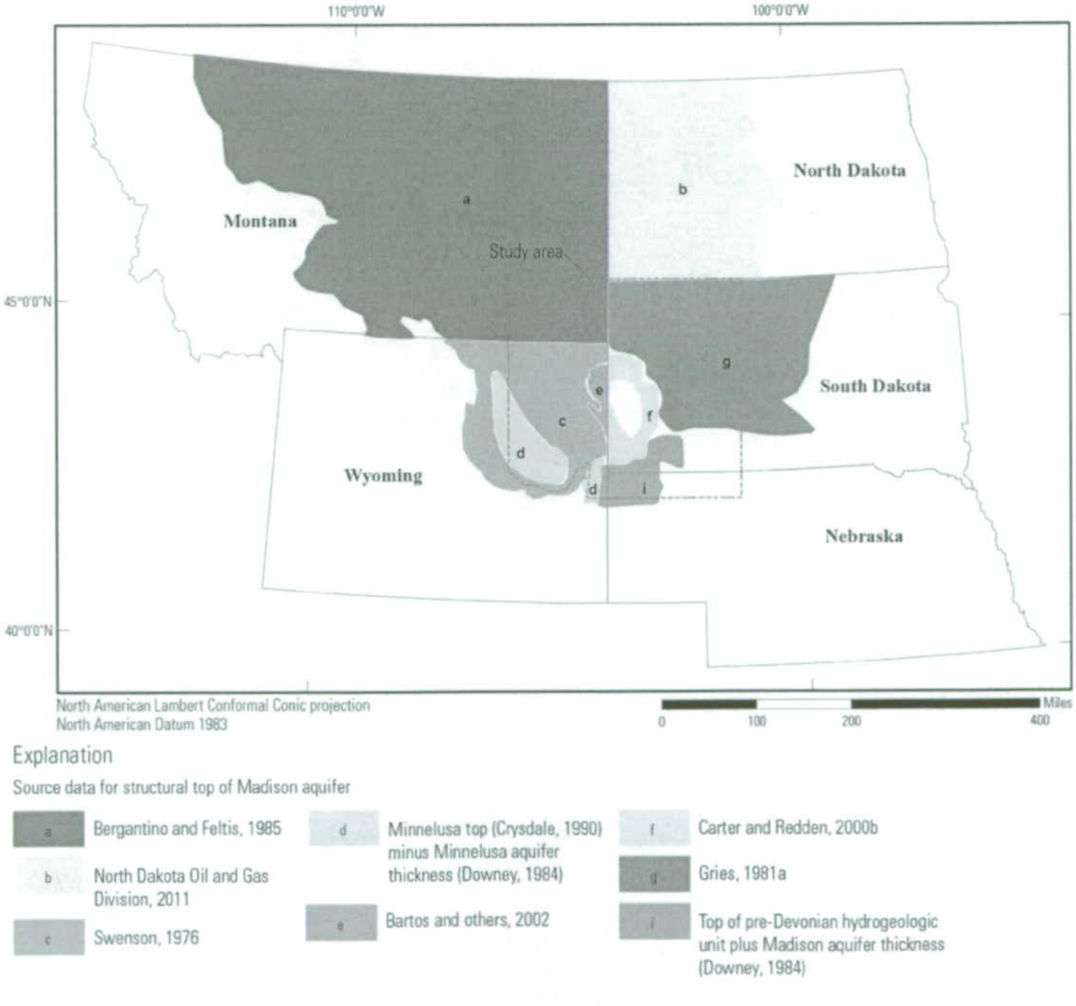

Figure 9. Source data for delineation of the altitude of the top of the Madison aquifer.

aquifer surface. Second, borehole data in area "b" of Figure 9 for the top of the Madison aquifer (North Dakota Oil and Gas Division, 2011) were analyzed with geostatistics in ArcGIS (ESRI, 2013) to remove potentially spurious data points and then included as data. Third, missing data in areas labeled "d" in Figure 9 were filled by taking an existing map for the top of the Minnelusa aquifer (Crysdale, 1990) and subtracting the thickness of the Minnelusa aquifer (Downey, 1984). Fourth, in area "i" of Figure 9 the thickness of the Madison aquifer (Downey, 1984) was added to the pre-Devonian hydrogeologic structure top surface developed in this report. Fifth, a 30-meter resolution DEM from the National Elevation Dataset (Gesch and others, 2002) was resampled to 100-meter resolution, clipped to outcrop areas of the Madison aquifer, and converted to points for use in aquifer top delineation (not shown in Figure 9). Using any finer than 100-meter resolution was too memory-intensive for the interpolation program, but 100-meter resolution will be sufficient for the 250-meter grid cell size in the focus area of the model. Sixth, the resulting raster for the Madison aquifer was evaluated and corrected at geologic contacts on the down-dip side of Madison outcrops to ensure that the Madison was not erroneously modeled as above the actual land surface.

Altitudes of the top of the Madison aquifer range from -11,000 feet in the southern Powder River Basin to approximately 7,000 feet in the western Black Hills along the Limestone Plateau (Figure 1). The altitude of the top of the Madison aquifer drops to approximately -4,000 feet at the North Dakota-South Dakota border, dipping farther northward into the Williston Basin. In the focus area of the study, the dip of the Madison aquifer is steepest in the eastern Black Hills dropping approximately 5,000 feet in altitude in less than 20 miles before it levels off to the east toward Philip, South Dakota.

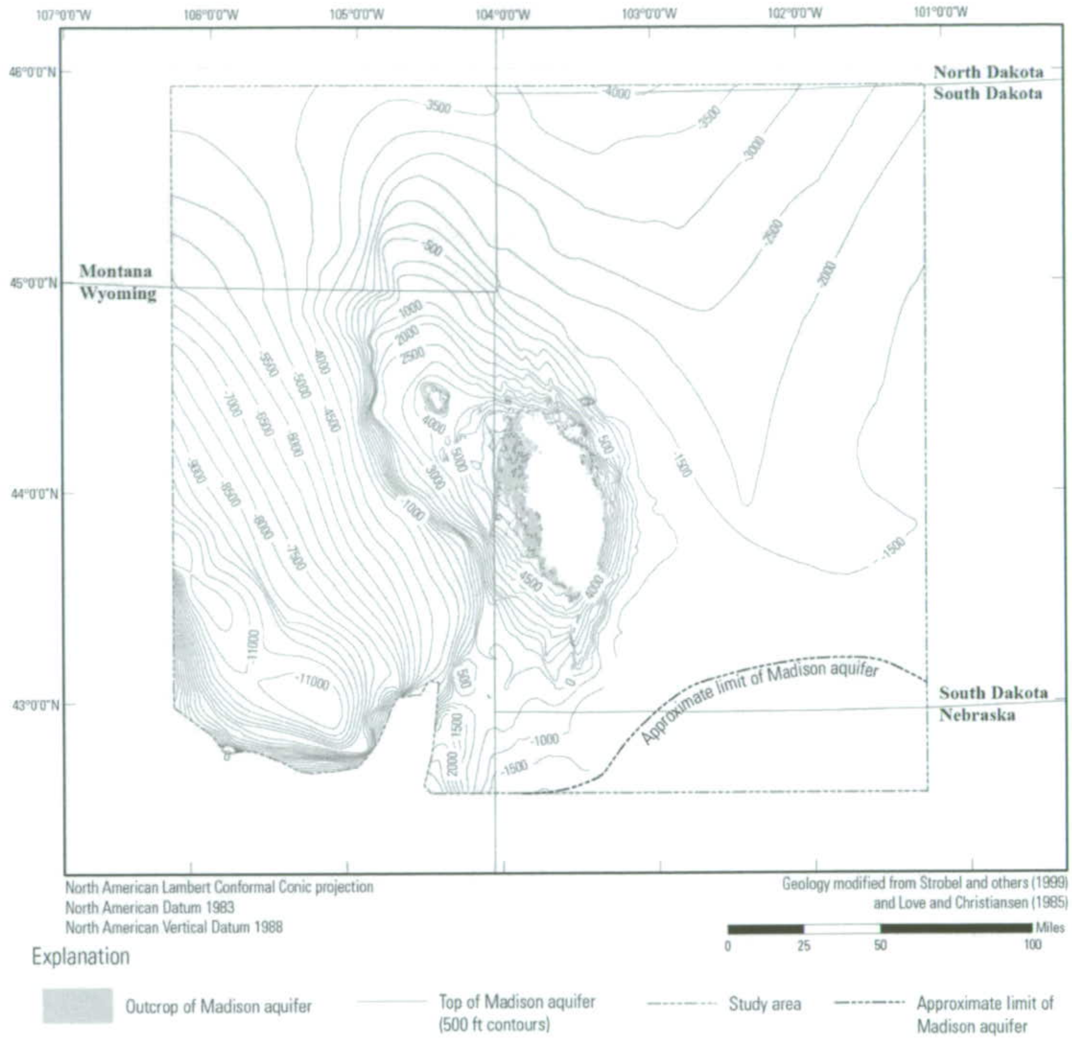

Figure 10. Altitude of the top of the Madison aquifer.

Pre-Devonian Hydrogeologic Unit

The altitude of the pre-Devonian hydrogeologic unit was interpreted by using six steps to combine source data (Figure 11), in order to develop a continuous structure surface (Figure 12). First, existing maps (Bergantino and Clark, 1985; Blackstone, 1993; McCormick, 2010; Nebraska Conservation and Survey Division, 2011) in areas "a, c, g, and h" in Figure 11 were trimmed to edge-match where there was good control for the pre-Devonian hydrogeologic unit surface. Second, borehole data in area "b" of Figure 11 for the top of the pre-Devonian hydrogeologic unit (North Dakota Oil and Gas Division, 2011) were analyzed with geostatistics in ArcGIS (ESRI, 2013) to remove potentially spurious data points and then included as data. Third, in area "e", an interpolated thickness of the Whitewood Formation and the Winnipeg Formation was added to existing map data for the top of the Deadwood Formation (Carter and Redden, 1999c).

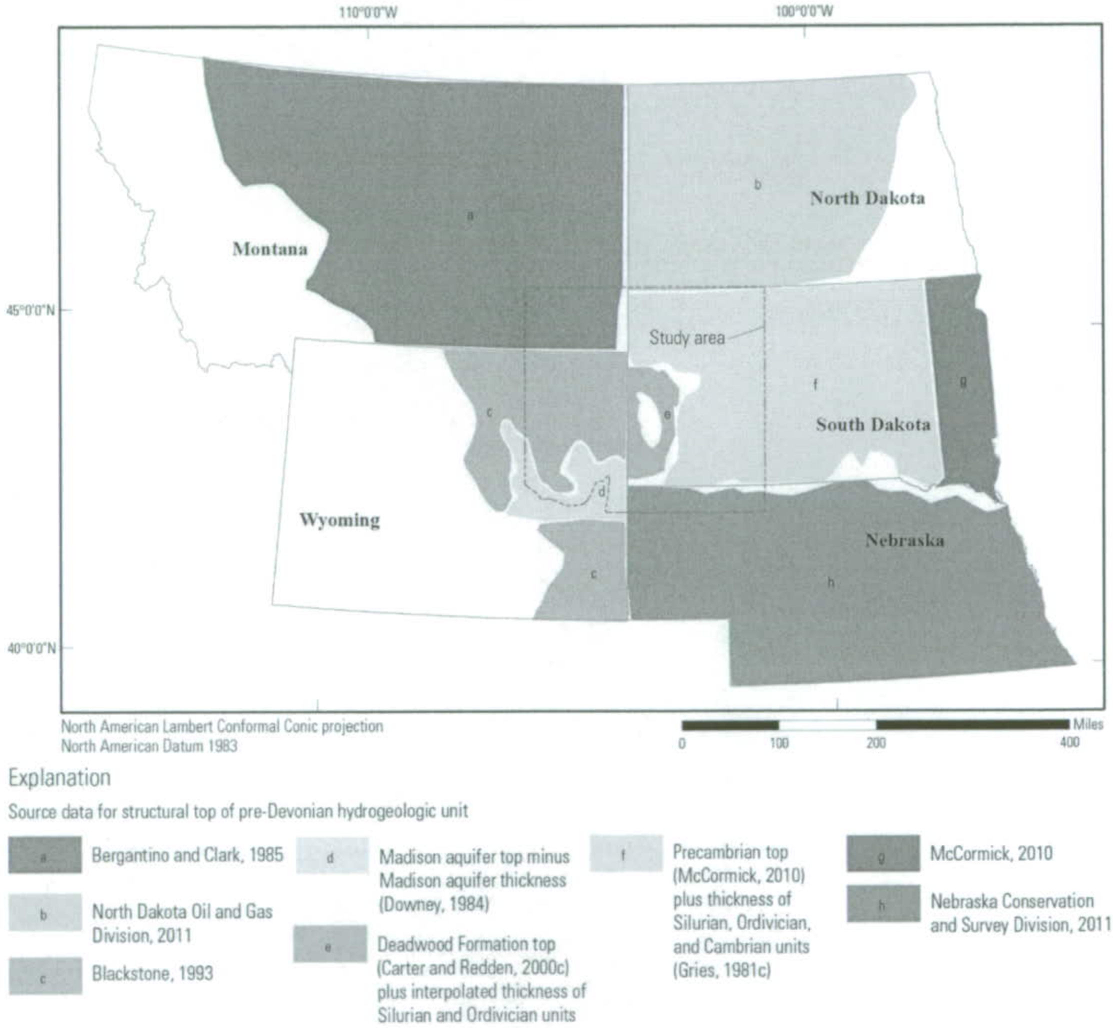

Figure 11. Source data for delineation of the altitude of the pre-Devonian hydrogeologic unit.

Fourth, in area "f" existing map data for the thickness of Silurian, Ordovician, and Cambrian formations (Gries, 1981c) were added to the top of the Precambrian surface (McCormick, 2010). Fifth, similar to the construction of a 30-meter resolution DEM from the National Elevation Dataset (Gesch and others, 2002) was resampled to 100-meter resolution, clipped to outcrop areas of the pre-Devonian hydrogeologic unit, and converted to points for use in aquifer top delineation (not shown in Figure 11).Sixth, missing data in area "d" were filled by subtracting the thickness of the Madison aquifer (Downey, 1984) from the Madison aquifer structure top surface developed in this report. Seventh, the resulting raster surface for the pre-Devonian hydrogeologic unit was evaluated and corrected at contacts on the down-dip side of outcrops to ensure that the surface was not erroneously modeled as above the land surface

Altitudes of the top of the pre-Devonian hydrogeologic unit range from -12,500 feet in the southern Powder River Basin to approximately 7,200 feet in the central core of the Black Hills at Harney Peak. The surface elevation at the point where Harney Peak would be located is not shown as 7,242 feet because of resampling the DEM from 30-meter to 100-meter resolution. The altitude of the top of pre-Devonian hydrogeologic unit drops to approximately -7,000 feet at the North Dakota-South Dakota border, dipping farther northward into the Williston Basin. In the focus area of the study, the dip of the pre-Devonian hydrogeologic unit is steepest in the eastern Black Hills dropping approximately 5,000 feet in altitude in less than 20 miles before it levels off to the east toward Philip, South Dakota.

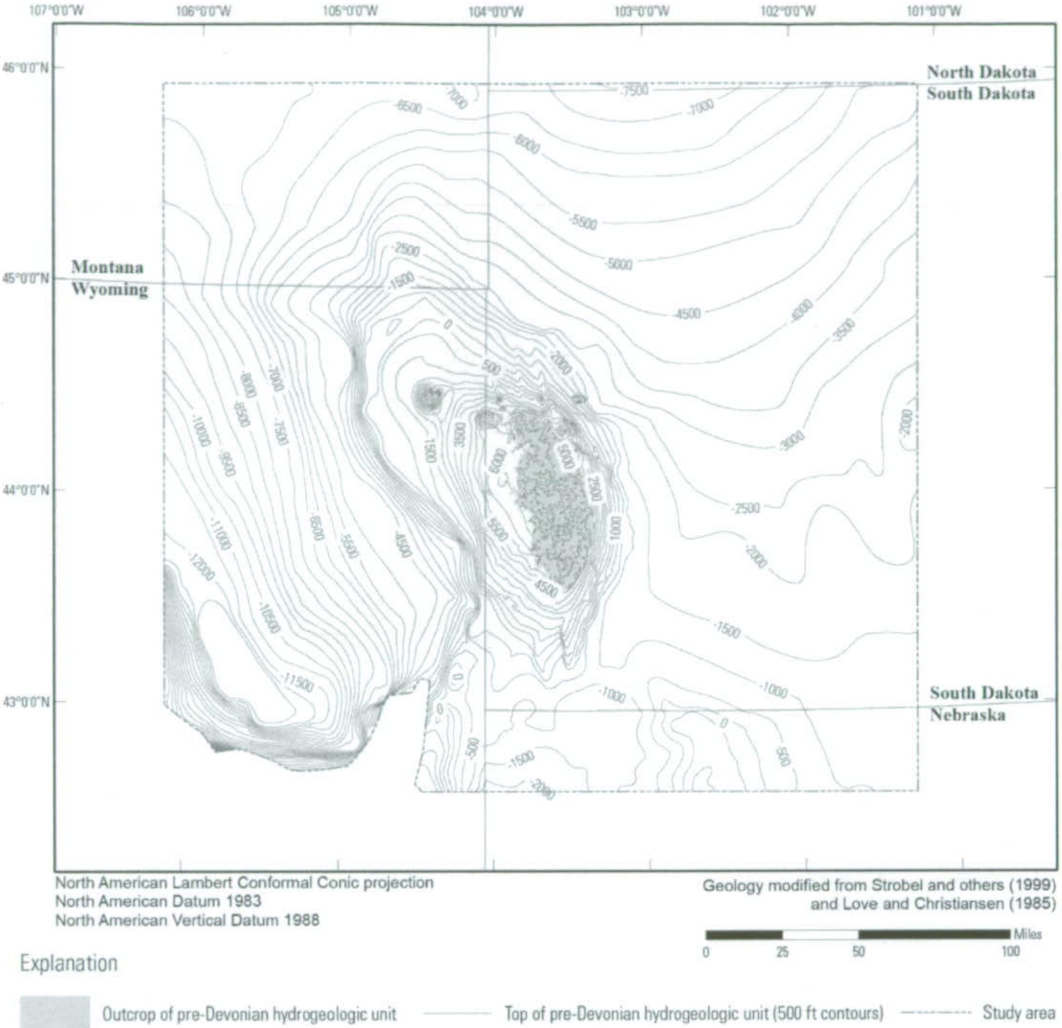

Figure 12. Altitude of the top of the pre-Devonian hydrogeologic unit.

Aquifer Properties

Aquifer properties summarized in this report include horizontal hydraulic conductivity, vertical hydraulic conductivity, transmissivity, and storage coefficient. The estimates are based on previous investigations, and the methods of estimation vary (Appendix A). Locations of estimates for hydraulic conductivity, transmissivity, and storage coefficient are shown on Figure 13 and are summarized in (Appendix A). The aquifer tests are composed of both single and multiple-well tests and also include a

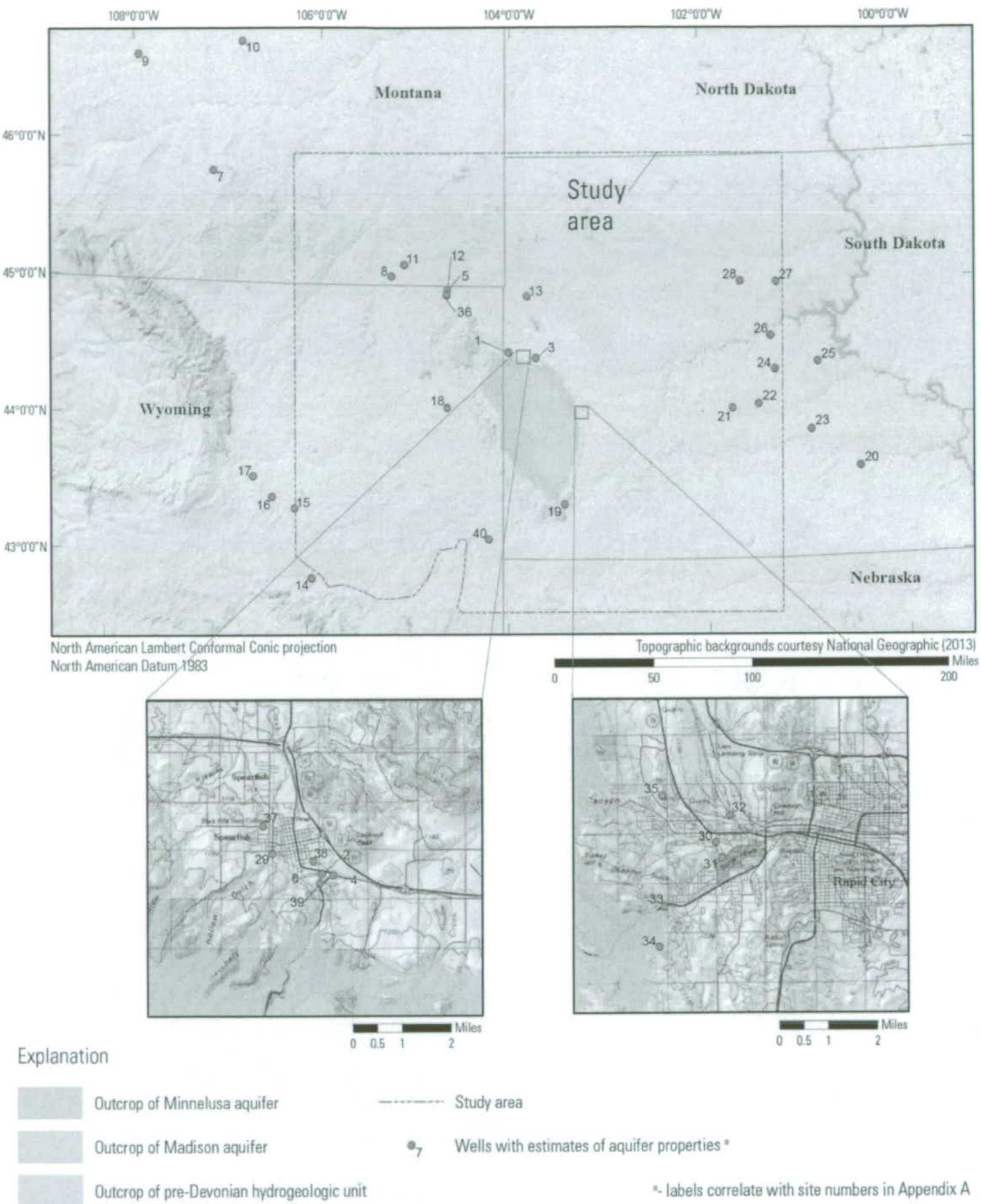

Figure 13. Locations of aquifer tests for hydraulic conductivity, transmissivity, and storativity for the Madison and Minnelusa aquifers.

number of estimates based on carbon-14 (C-14) ages of groundwater. The area for which these estimates should be considered accurate varies with test method. Although an estimate based on an air-pressurized slug-test might be valid for only a few feet surrounding the borehole of a well, an estimate based on a multiple-well pumping test could be valid for distances of 2,000 feet or more from the observation well. For multiple-well pumping tests with many observation wells covering a large area, estimates of aquifer properties could represent values on a regional scale. Estimates of aquifer properties vary greatly due to anisotropy and secondary porosity. Other aquifer tests might be useful for general properties of the Madison and Minnelusa aquifers but are located along the edges of the Bighorn Mountains in steeply dipping, highly fractured rock (Cooley, 1986; Blankennagel and others, 1981).

Hydraulic Conductivity (K_h) Estimates

Hydraulic conductivity is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Heath, 1983). Estimates for horizontal hydraulic conductivity in and near the study area were described in Appendix A. In and near the study area, horizontal hydraulic conductivity ranges from 0.002 to 113.64 feet per day, with an average of 11.4 feet per day (Appendix A). Zonal model-calibrated estimates of horizontal hydraulic conductivity for the Madison aquifer in the area of Rapid City, South Dakota range from 0.1 to 388.8 ft/day (Putnam and Long, 2009). Model calibrated estimates of horizontal hydraulic conductivity for the same area range from 1.0 to 5.2 ft/day.

Factors affecting hydraulic conductivity include effective porosity (including secondary porosity) and pore diameters (Freeze and Cherry, 1979). Hydraulic conductivity also varies with the temperature and density of groundwater (Freeze and

Cherry, 1979). In areas where there is a relatively high geothermal gradient, water density and viscosity at the hotter temperature will affect the fluid properties of the groundwater and thus the hydraulic conductivity.

Vertical hydraulic conductivity describes the ease of groundwater flow in the vertical direction from one aquifer to another. In and near the study area, estimates of vertical hydraulic conductivity range from approximately 0.1 to 0.5 times the horizontal hydraulic conductivity. Bulk estimates of vertical hydraulic conductivity vary, based on the aquifer material and other factors such as the presence of fracturing, faulting, or breccia pipes (Hayes, 1999). In the groundwater-flow model, individual breccia pipes or instances of faulting will not be modeled individually, so vertical hydraulic conductivity estimates should be adjusted in large grid cells where they are present. Also, model inputs for vertical hydraulic conductivity should be increased in areas where direct hydraulic connection between the Madison and Minnelusa aquifers is inferred based on field data or conceptual models.

Transmissivity (T) Estimates

Transmissivity is defined as the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Heath, 1983) and is equal to hydraulic conductivity multiplied by the saturated thickness (Freeze and Cherry, 1979). Estimates for transmissivity in and near the study area range from 0.9 to 41,700 ft^2/day, with an average of approximately 11,850 ft^2/day (Appendix A). For modeling purposes, estimates of transmissivity from previous reports have been converted to estimates of hydraulic conductivity based on the thickness of the aquifer (as derived from surfaces created as part of this project) where the well is located (Appendix A).

Storage Coefficient (S) Estimates

Storage coefficient is the volume of water released from an aquifer per unit decline in hydraulic head per unit area of the aquifer (Heath, 1983). The value of storage coefficient can vary from zero up to the effective porosity of the aquifer. In confined aquifers, storage coefficient is usually much less than 0.01, typically from 10^{-3} to 10^{-5} (Freeze and Cherry, 1979). Storage coefficient could vary greatly from unsaturated zones of an aquifer to saturated and confined areas. Storage coefficient values gathered from previous publications for the study area ranged from 6×10^{-9} to 2×10^{-3}, with an average of 2.9×10^{-4} (Appendix A). Putnam and Long (2009) zonal estimates storage coefficient of the Madison and Minnelusa aquifers to range from 0.03 to 0.09 where the aquifers are unconfined and approximately 0.0003 where the aquifers are confined.

Potentiometric Surfaces

Potentiometric surfaces were constructed in a method similar to the creation of structural tops, as described above. Potentiometric maps from previous investigations were aggregated into a single dataset, although the full extents of the individual data were not always used. The determination of what parts of each dataset to use in final aggregation was made with the following considerations: (1) the most recent potentiometric contour maps were given priority (if they had good control points), (2) if another map had better control in an area and the added control changed the interpretation of the surface, the map with better control in the area was used. These data were edge matched, with weight given to map sections with better control, using the "Topo to

Raster" tool in ArcGIS (ESRI, 2013). Given problems in interpolation, edge-matching then was adjusted using the same method of "clipping" as in the creation of structural top data. In some areas, hand contouring was needed to assist the computer interpolator in developing a realistic potentiometric surface. The resulting raster surfaces representing the potentiometric surfaces were contoured at an interval of 200 feet. Apparent groundwater-flow were based on the 200 feet potentiometric contours. The actual groundwater flow direction could differ from drawn flow directions because of anisotropy in the Madison and Minnelusa aquifers (Greene and Rahn, 1995).

Because the hydraulic heads in the various publications were measured at various times, and these different sources were combined into one map, potentiometric levels were not interpreted for a particular date. Therefore, the potentiometric maps represent an average potentiometric surface for the area. It was outside the scope of the study to perform a detailed analysis correcting individual water-level measurements based on an available long-term records showing fluctuation of potentiometric water levels in their respective aquifers. This would be a task spanning several years at great expense, with little benefit gained. For a groundwater-flow model at a regional scale, an average potentiometric surface should suffice, especially given a coarse-resolution model grid farther away from the focus area in the study in the immediate vicinity of the Black Hills.

Resulting contours for the potentiometric surface of the aquifers are shown with 200 ft contour intervals. Although structural contour maps in this report were not dashed where approximated, the potentiometric contours are dashed where approximated. The publications of the source data gave sufficient data for inference of where the potentiometric contours should be dashed in this report.

Madison Aquifer

The potentiometric surface for the Madison aquifer was constructed from seven existing datasets, as outlined in Figure 14. In some areas where existing data were not reliable or did not exist, contours were added by hand. One area where contours were added by hand is area "g", east of the Black Hills. There are several U.S. Geological

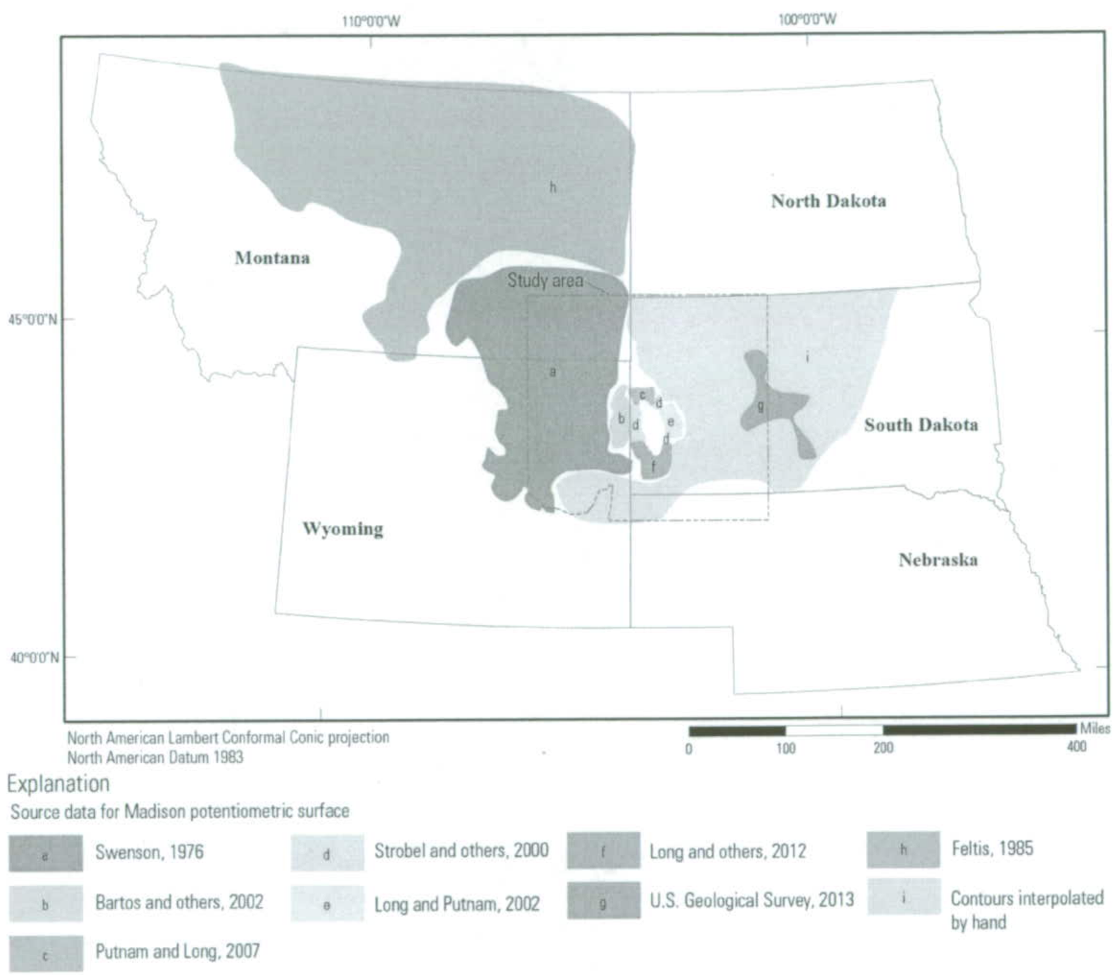

Figure 14. Data sources used in development of the Madison potentiometric surface.

Survey wells (area "h" in Figure 14; U.S. Geological Survey, 2013) that are not known to have been used in previous descriptions of the potentiometric surface of the Madison aquifer. These wells support Downey's (1986) interpretation of a slight trough in the potentiometric surface of the Madison aquifer extending eastward from Rapid City. Hand-drawn contours were added to further reflect this interpretation; the resulting contours are shown in Figure 15. This interpretation shows a zone of greater transmissivity and a subsequent lowering of hydraulic heads of the Madison aquifer in the area. This zone of greater transmissivity could be caused by complicated faulting in the basement rock in the area (P.H. Rahn and K.A. McCormick, personal communication, 2012). In a pumping test of the Arikaree Formation near Pine Ridge, SD, Greene and others (1991) hypothesize that temperature departures from normal geothermal gradients seen during pumping was due to leakage from lower units- presumably the Madison aquifer. Lowering of the head in the Madison aquifer would likely also lower the head in the Minnelusa aquifer, especially if there is increased vertical hydraulic conductivity in the Minnelusa confining unit (Long and Putnam, 2002).

Generally, groundwater flows from the west to the east in the study area, around the Black Hills. Two main regional groundwater divides exist in the study area. The first extends westward from the northwestern corner of the Black Hills. North of this regional groundwater divide, water flows to the north and then continues into the Williston Basin, or flows east-southeasterly through South Dakota, although data in North Dakota and northern South Dakota area insufficient to say this definitively. South of this regional groundwater divide, water flows southeasterly through the Powder River Basin, eastward through an area south of the Black Hills, and continues eastward. The second regional groundwater divide of note extends eastward from the northeastern corner of the Black Hills. North of this regional groundwater divide water flows east and likely leaks into other hydrogeologic units, including the Dakota Sandstone, as shown by Stotler and

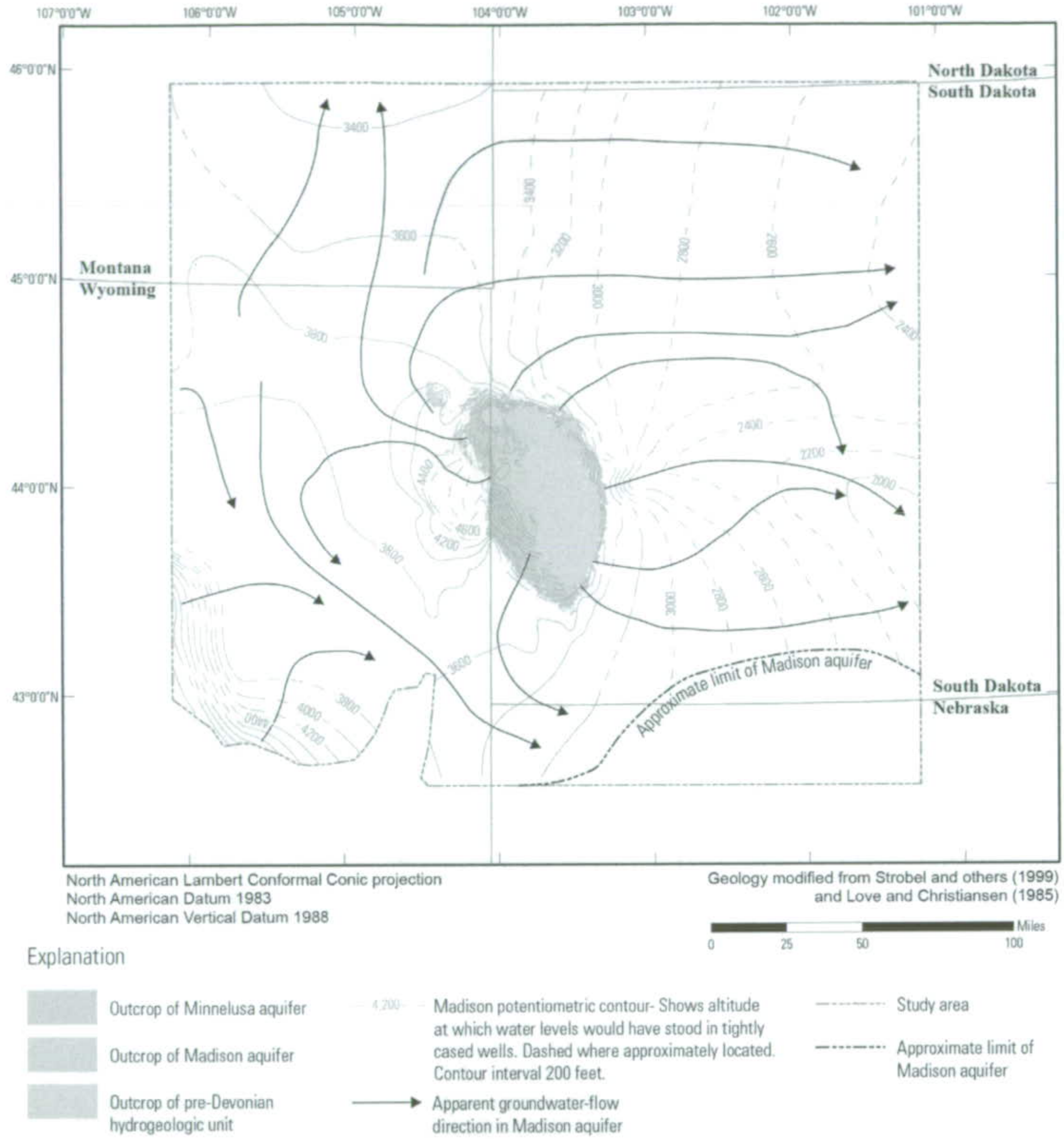

Figure 15. Potentiometric surface of the Madison aquifer.

others (2010). South of this regional groundwater divide, water flows into the trough in the potentiometric surface and continues to flow toward the southeast.

Along the edge of the southwestern Black Hills, the potentiometric surface of the Madison aquifer follows the edge of the zone where the Powder River Basin meets the

Black Hills uplift (Figure 17; Figure 2). This could be a zone of structural weakness where greater fracturing of the Madison aquifer occurred.

Minnelusa Aquifer

The potentiometric map of the Minnelusa aquifer was constructed from seven existing datasets, as outlined on Figure 16. Areas in which existing data were not reliable or did not exist were contoured in a manner similar to the potentiometric map of the Madison aquifer. U.S. Geological Survey wells (U.S. Geological Survey, 2013; area "h" on figure Figure 16) were used to interpolate a hydraulic gradient between existing contours east of

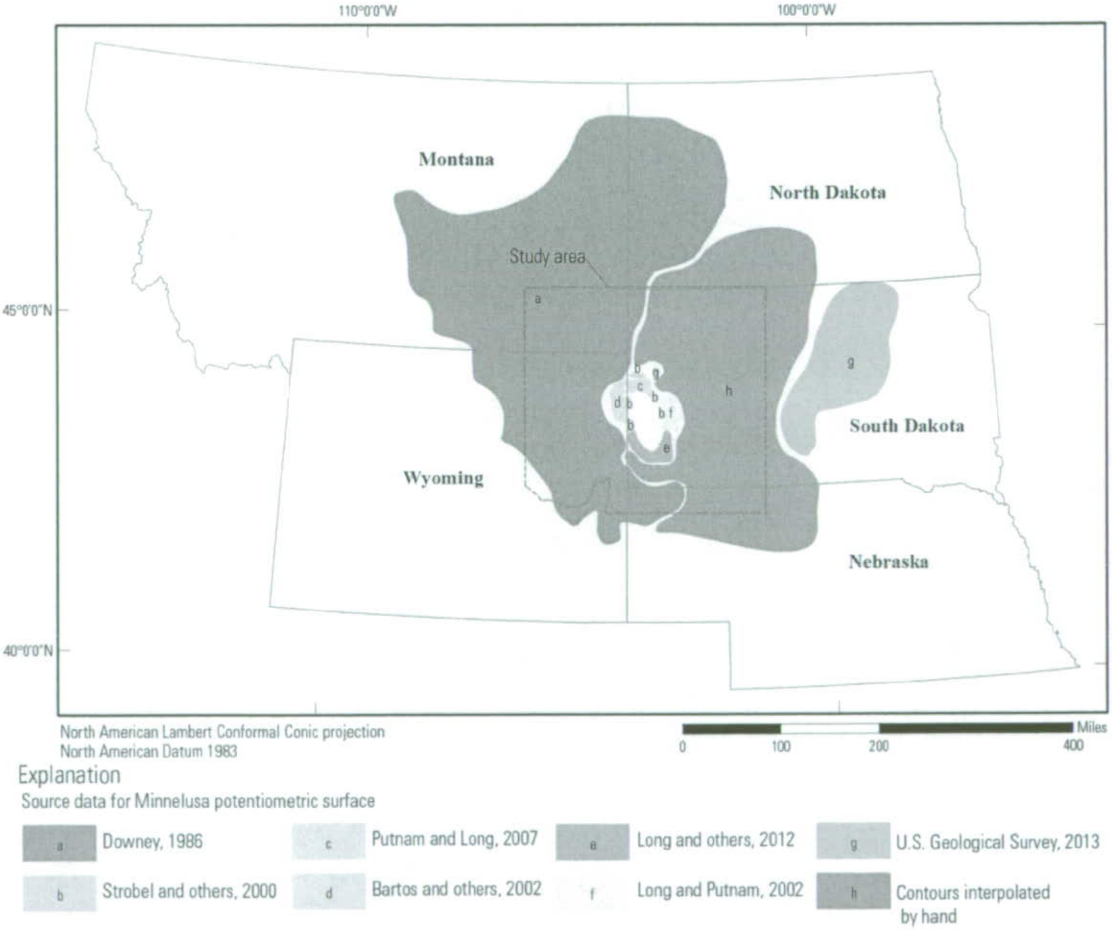

Figure 16. Data sources used in the development of the Minnelusa potentiometric surface.

Rapid City to the eastern boundary of the study area. In the construction of the potentiometric surface, care was taken to represent a slight lowering of head in the Minnelusa aquifer in the area of the trough in the potentiometric surface of the Madison aquifer extending east of Rapid City, because there is evidence to show these aquifers are in hydraulic connection (Long and Putnam, 2002).

Regional groundwater flow in the Minnelusa aquifer (Figure 17) mirrors that of the Madison aquifer, with the same general groundwater divide areas. There was not enough supporting evidence in the data for the Minnelusa aquifer to interpret a trough as pronounced as in the Madison aquifer trending eastward from the Black Hills, although a shallow trough was interpreted. Increased resolution of data could better align the placement of these troughs. Regional groundwater flow directions are similar in both the Madison and Minnelusa aquifers, but hydraulic gradients in the Minnelusa aquifer do not appear to be as steep as in the Madison aquifer. Along the edge of the southwestern Black Hills, similar to the Madison aquifer, the potentiometric surface of the Minnelusa Formation follows the edge of the zone where the Powder River Basin meets the Black Hills uplift (Figure 17; Figure 2). This may be a zone of structural weakness and an indication of greater fracturing in the Minnelusa aquifer.

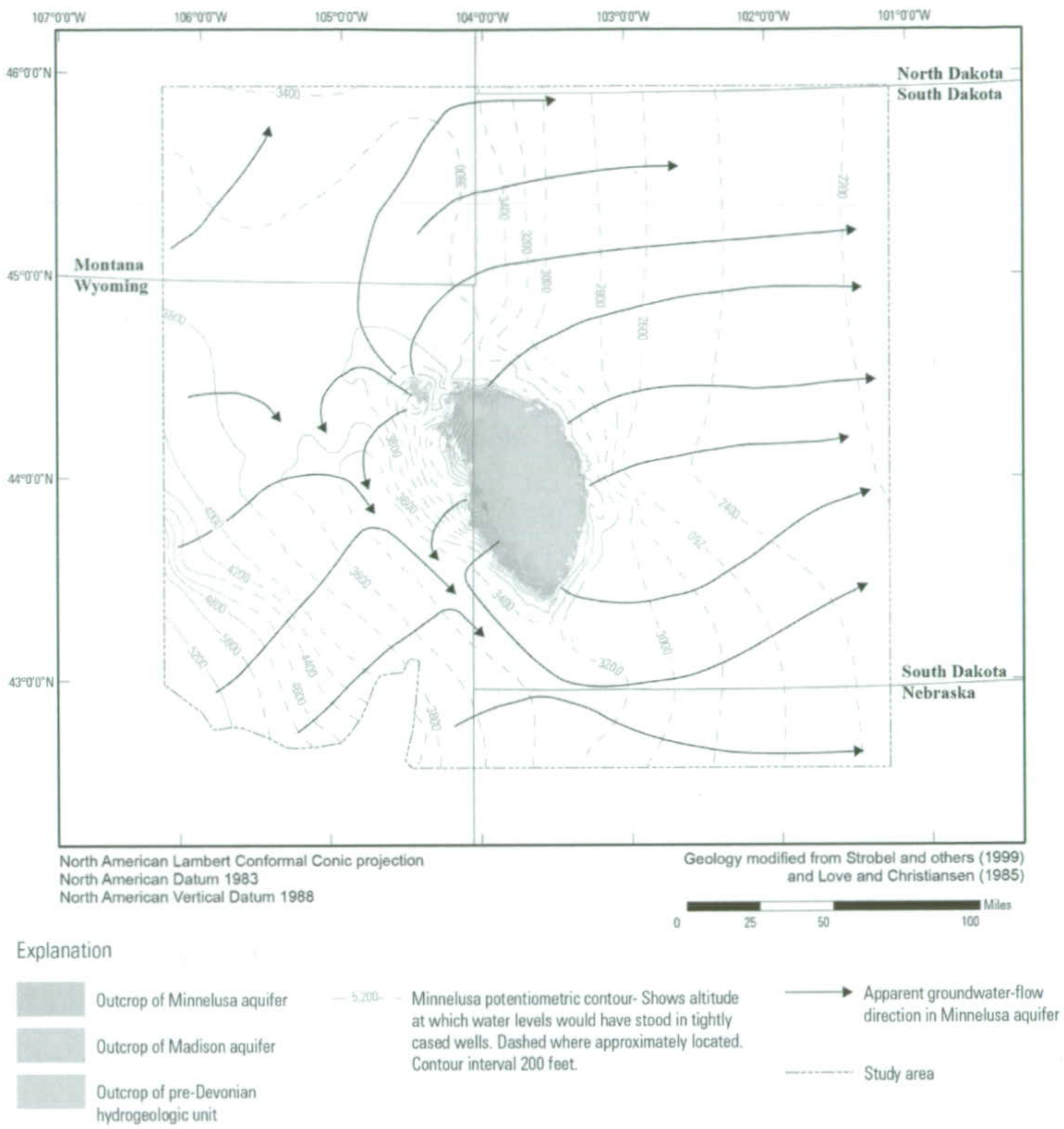

Figure 17. Potentiometric surface of the Minnelusa aquifer.

Discussion on Potentiometric Surfaces

North central south Dakota and all of North Dakota lack potentiometric data. These areas should be considered for placement of observation wells in the Madison and Minnelusa aquifers. Additional wells in this area would be beneficial in further delineation of potentiometric surfaces of the Madison and Minnelusa aquifers.

As part of the work with the potentiometric maps, unsaturated zones of the Madison and Minnelusa aquifer were determined. The term unsaturated will be used to mean the aquifer is unsaturated or partially saturated, but not confined. To determine the unsaturated zones in each aquifer, the altitudes of the structural tops were subtracted from the potentiometric surface maps. For example, to form one side of the boundary of the Madison aquifer's unsaturated zone, the altitude of the top of the pre-Devonian hydrogeological unit was subtracted from the altitude of the Madison potentiometric surface. The other side of the boundary was determined by subtracting the altitude of the structural top of the Madison aquifer from the altitude of the Madison potentiometric surface. The area between the zones where these two calculations yielded values of approximately zero were considered unsaturated (Figure 18). The Minnelusa unconfined zone (Figure 18) was constructed similarly.

The unsaturated zones of the Minnelusa and Madison aquifers are thinner along the eastern flank of the Black Hills. This is likely because of the influence sinking streams have on the recharge rate in the eastern Black Hills. Streams in the Black Hills are noted to have lost as much as 100 ft^3/second (Brown, 1944) across the Madison and Minnelusa outcrops, often leaving the stream dry across much of the outcrop. The stream losses have enough concern that citizens have attempted to plug these loss zones with rip-rap and concrete (Brown, 1944). After an attempt to plug loss zones on Spring Creek, the loss threshold across the outcrop of the Madison aquifer was reduced from >100 ft^3/second to approximately 6 ft^3/second (Brown, 1944). In the western Black Hills, the unsaturated zones are much wider, indicating that either groundwater flow is much faster in these areas or is rather emerging as spring flow at the headwaters of streams that flow east across the Black Hills (Figure 1).

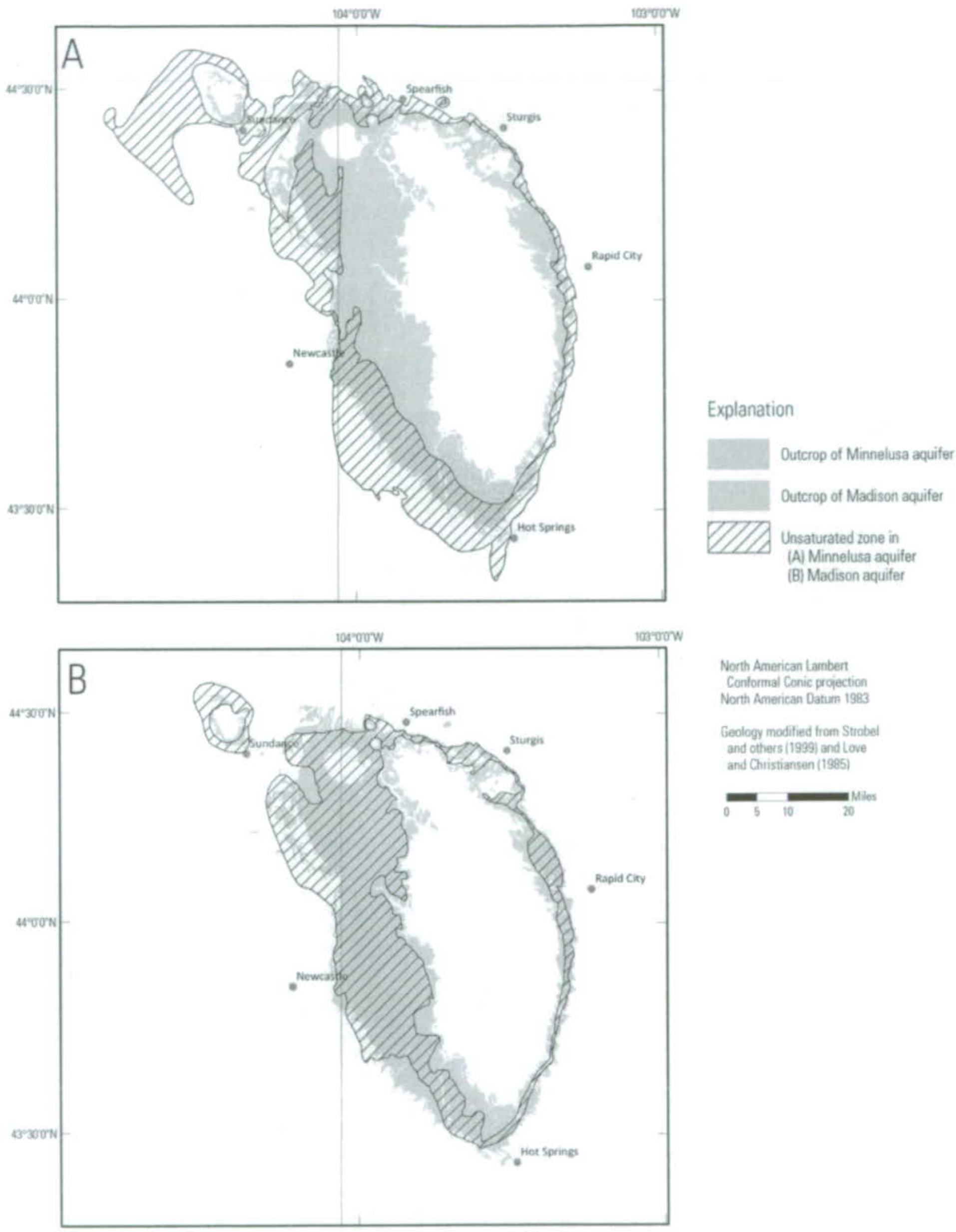

Figure 18. Unsaturated zones for (A) Minnelusa aquifer and (B) Madison aquifer

Conceptually, the Madison aquifer will have higher head closer to the outcrops of the two aquifers, allowing some vertical flow from the Madison aquifer, at a higher head, to the Minnelusa aquifer, at a lower head (Figure 19). Farther from the outcrops of the aquifers, the Minnelusa aquifer often has higher head, allowing for vertical flow from the Minnelusa aquifer, at a higher head, to the Madison aquifer, at a lower head (Figure 19). Analysis of the potentiometric surfaces of the Madison and Minnelusa aquifers, as produced for this report, supports this conceptual idea (Figure 19, Figure 20).

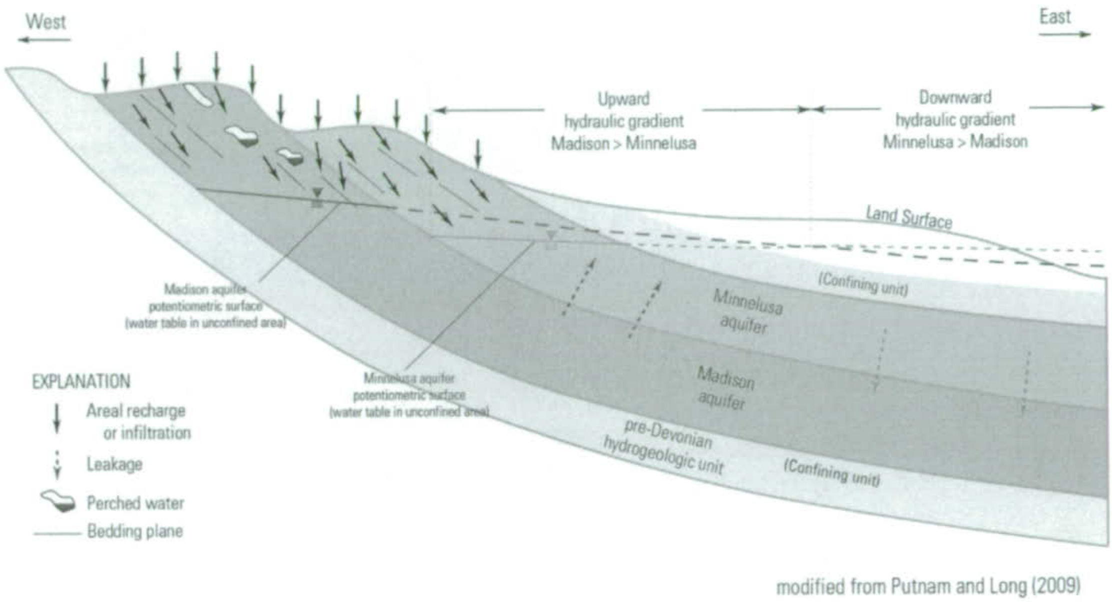

Figure 19. Conceptual model of vertical gradients in the Madison and Minnelusa aquifers.

The potentiometric surface of the Minnelusa aquifer was subtracted from that of the Madison aquifer to determine the magnitude and direction of vertical hydraulic gradient between the two aquifers (Figure 20). Areas A and B in Figure 20 could be a result of insufficient potentiometric data in one of the aquifers (e.g., in area A, where, given current data, troughs in the potentiometric surfaces do not line up exactly). Given more reliable information, shifting the potentiometric contours slightly could change the apparent vertical hydraulic gradient. Generally, the Minnelusa aquifer has a higher potentiometric surface than the Madison aquifer in and near outcrops of the Minnelusa

Formation. Farther away from outcrops, the Madison aquifer generally has a higher potentiometric surface. In much of the study area the elevation of the potentiometric surfaces of the Madison and Minnelusa aquifers are within +/- 250 feet of one another. Significant pumping (i.e., for coal slurry, hydraulic fracturing, or other heavy industrial use) in the areas where the difference between the respective potentiometric surfaces is relatively small could greatly influence the potentiometric surfaces in areas surrounding the wells.

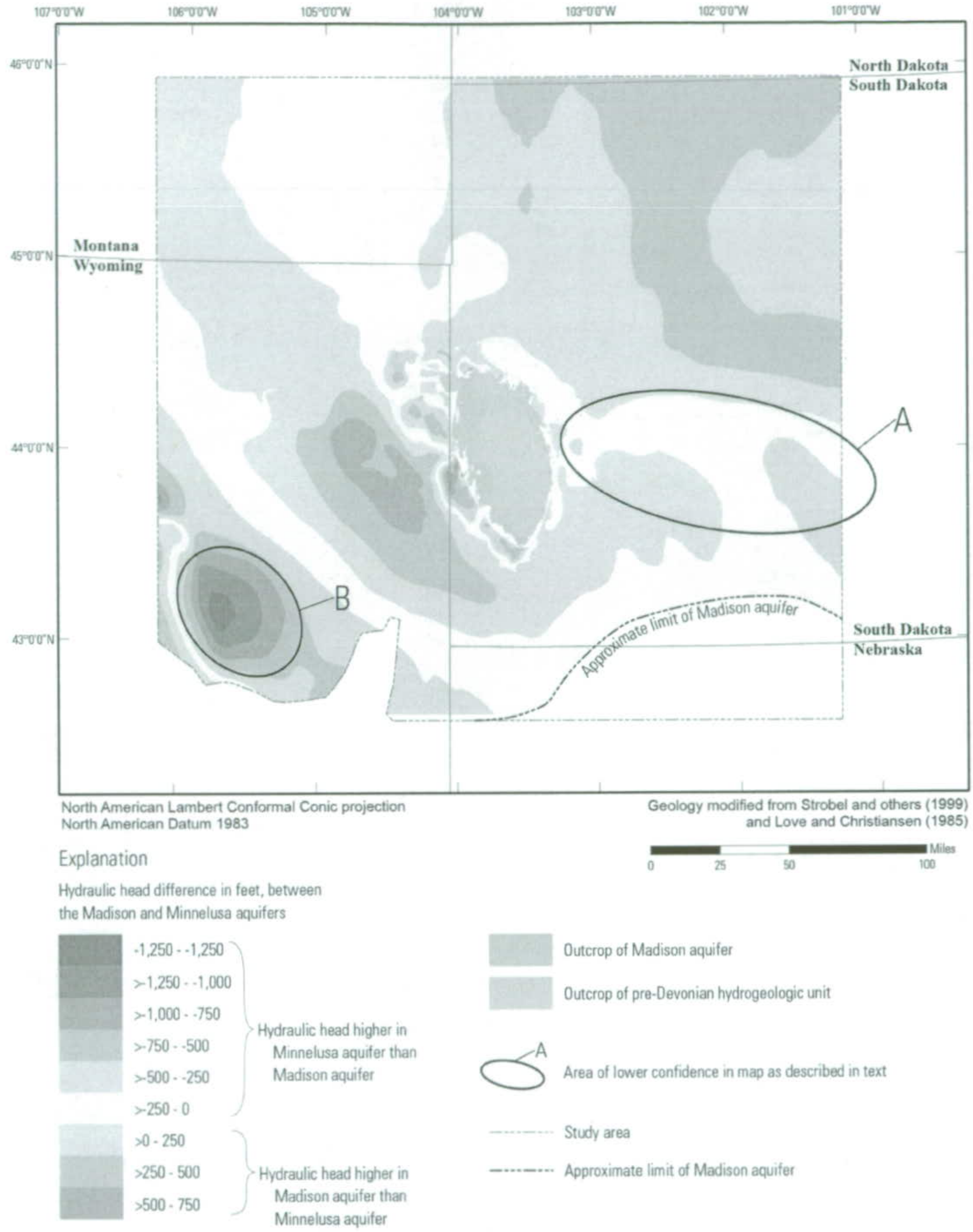

Figure 20. Difference in hydraulic head between the Madison and Minnelusa aquifers.

Summary and Conclusions

The dependence of residents in the Black Hills area on groundwater raises important questions regarding groundwater availability, effects of water use or drought, mixing of regional groundwater flow and local recharge, and the effects of capture zones of springs and wells on the groundwater-flow system. These questions are best addressed with a groundwater-flow model including the entire Black Hills and surrounding area.

The hydrogeologic framework created in this report for the Madison and Minnelusa aquifers, including data delineating aquifer tops and bottoms, potentiometric surfaces, and summaries of existing estimates of aquifer properties, will assist in creation of a regional groundwater flow model.

The structural contours shown in this report were aggregated from the most current available data and will aid in estimation of drilling depths. The potentiometric surface of the Madison aquifer presented in this report has supported previous interpretations of a trough extending east-southeastward from Rapid city. The vertical gradient between potentiometric surfaces of the Madison and Minnelusa aquifer will assist in determining likely flow direction of leakage between the two aquifers. In most of the study area the potentiometric surfaces of the Madison and Minnelusa aquifers are within +/- 250 feet of one another. Significant pumping of one of the aquifers could change the vertical gradient over a large area.

This hydrogeologic framework will be an integral part of a regional groundwater flow model as well as for water inventories and water-resources management in the future.

Future Work

Additional water-level measurements for the Madison and Minnelusa aquifers could be helpful for future interpretations of potentiometric surfaces. An effort should be made to establish additional paired observation wells for these two aquifers where potentiometric data for the Madison aquifer are scarce or do not exist. This effort could include drilling new wells or less-expensive options such as locating abandoned wells, drilling through the concrete plugs, and perforating the well through the aquifer of interest. This option would likely be a fraction of the cost of drilling a new well. Although locating wells could be difficult, the lithologies of many abandoned oil wells are well documented and geophysical logs are often available. The information gained through this process could be invaluable to the long-term water management goals of various government agencies, local municipalities, and private interests. The areas that could benefit the most from this are northern and central South Dakota and all of North Dakota where the aquifers are present. There are no known water levels for the Madison or Minnelusa aquifer in all of North Dakota, and in most of the northern and central areas of South Dakota (Figure 14; Figure 15). These areas will be important in water management of the Madison and Minnelusa aquifers because of the potential for increased use for hydraulic fracturing and other heavy industrial needs.

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Appendix A. Table Summarizing Aquifer Property Estimates

[ft, feet; K_h, horizontal hydraulic conductivity; K_v, vertical hydraulic conductivity; T, transmissivity S, storage coefficient; --, no data or not applicable; ^{14}C, Carbon-14]

Site number	Well name	Approximate Location		Aquifer	K_h (ft/day)	K_v (ft/day)	T (ft^2/day)	S	Test Method	Distance from well estimate is accurate[b]	Source
		Latitude[a]	Longitude[a]								
1	LA-87B	44.517889	-104.006958	Minnelusa	0.36[c]	--	125	--	Air-pressurized slug test	Few feet around borehole	Greene and others, 1998
2	LA-88B	44.481838	-103.848368	Minnelusa	0.48[c]	--	185	0.000000006	Air-pressurized slug test	Few feet around borehole	Greene and others, 1998
3	LA-88A	44.476373	-103.729515	Minnelusa	1.12[c]	--	396	0.000000004	Air-pressurized slug test	Few feet around borehole	Greene and others, 1998
4	Golf Course	44.481419	-103.843724	Minnelusa	24.43[c]	--	9,600	0.00007	Interference test	1000-2000 ft	Greene and others, 1998
5	Madison no. 1	44.933185	-104.643616	Minnelusa	1.40	--	--	--	Single well Test	--	Blankennagel and others, 1977
6	LA-88C	44.481796	-103.848725	Madison	0.002[c]	--	0.9	0.001	Air-pressurized slug test	Few feet around borehole	Greene and others, 1998
7[d]	Sarpy Mine	45.80358307	-107.0985389	Madison	1.78	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
8	Ranch Creek	45.06220363	-105.2139426	Madison	0.79	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
9[d]	Keg Coulee	46.63103248	-107.9374832	Madison	0.59	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
10[d]	Mysse flowing well	46.75858261	-106.8404374	Madison	0.28	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
11	Belle Creek	45.14664317	-105.0845517	Madison	0.80	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
12	Mysse flowing well	44.97209255	-104.6391994	Madison	0.34	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
13	Delzer No.2	44.92326845	-103.8188996	Madison	0.18	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
14[d]	Conoco No.175	42.84371127	-105.9708737	Madison	0.30	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
15[d]	MKM	43.35052334	-106.1606679	Madison	0.36	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
16[d]	Shidler	43.428019	-106.3912799	Madison	0.43	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
17[d]	Conoco No.44	43.5749758	-106.5879574	Madison	0.08	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
18	Upton	44.10970694	-104.6262154	Madison	0.13	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
19	Evans Plunge	43.40140258	-103.4416782	Madison	0.53	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
20[d]	Kosken	43.64019764	-100.4393345	Madison	2.23	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
21	Philip	44.09390844	-101.7223655	Madison	0.59	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
22	Midland	44.12009818	-101.4555674	Madison	0.80	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
23[d]	Murdo	43.92223086	-100.9256065	Madison	0.92	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
24	Hilltop Ranch	44.37016948	-101.2801487	Madison	0.89	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
25[d]	Prince	44.41702922	-100.8375167	Madison	1.53	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
26	Hamilton	44.61410872	-101.3137104	Madison	0.69	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
27	Eagle Butte	45.00590203	-101.2394984	Madison	1.57	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
28	Dupree	45.01827248	-101.6112176	Madison	1.17	--	--	--	^{14}C age dating	Groundwater-flow path[e]	Busby and others, 1991
29[f]	Dickey	44.487857	-103.868805	Madison	113.62[c]	--	41,700	0.0003	Interference test	1000-2000 ft	Greene and others, 1998
29[f]	Dickey	44.487857	-103.868805	Madison	61.85[c]	--	22,700	0.0001	Specific-capacity test	Tens of feet around borehole	Greene and others, 1998
30	LC	44.079545	-103.272278	Madison	2.74[c]	0.0068	1,600	0.0001	Multiple well pumping	1000-2000 ft	Greene, 1993
31	SP-2	44.074982	-103.269781	Madison	3.87[c]	0.016	2,600	0.0001	Multiple well pumping	1000-2000 ft	Greene, 1993
32	BHPL	44.087475	-103.266354	Madison	9.52[c]	0.011	5,200	0.0001	Multiple well pumping	1000-2000 ft	Greene, 1993
33	CL-2	44.060691	-103.293405	Madison	74.91[c]	0.0091	40,000	0.00033	Multiple well pumping	1000-2000 ft	Greene, 1993
34	CHLN-2	44.048947	-103.295524	Madison	74.07[c]	0.0053	40,000	0.00033	Multiple well pumping	1000-2000 ft	Greene, 1993
35	CQ-2	44.093532	-103.294187	Madison	34.21[c]	--	17,000	0.002	Multiple well pumping	1000-2000 ft	Greene, 1993
36	Madison no. 1	44.933185	-104.643616	Madison	1.90	--	--	--	Single well Test	--	Blankennagel and others, 1977
38	College	44.495872	-103.872694	Madison	16.24[c]	--	5,100	0.00001	Specific-capacity test	Tens of feet around borehole	Greene and others, 1998
39	Ellingson	44.485494	-103.852112	Madison	6.76[c]	--	2,900	0.000001	Specific-capacity test	Tens of feet around borehole	Greene and others, 1998
40	Nevin	44.479208	-103.849439	Madison	--	--	--	0.0000001	Specific-capacity test	Tens of feet around borehole	Greene and others, 1998
41	ETSI	43.143968	-104.202162	Madison	0.32[c]	--	455	0.00012	Multiple well pumping	--	Rahn, 1979

[a]- In decimal degrees, North American Datum, 1983 (NAD83)

[b]- As described in source publication

[c]- K_h calculated from transmissivity estimates from previous investigations, divided by thickness derived from structure tops made as part of this project.

[d]- Well is located outside of study area

[e]- K_h calculated from ^{14}C age correlation along approximate groundwater-flow path from recharge area

[f]- Duplicate entry because estimates exist from two types of aquifer tests

Vita

Jonathan Dennis Roger George McKaskey was born on 28 October 1984 to Dennis and Catherine McKaskey. He grew up in Charlotte, North Carolina and graduated high school from Northwest School of the Arts in 2003, where his education had an emphasis on jazz performance on trombone.

Jonathan attended South Dakota School of Mines and Technology during the fall 2003 and spring 2004 semesters. From April 2005 to April 2007, Jonathan volunteered as a full-time church missionary for the Church of Jesus Christ of Latter-day Saints in western Ukraine. Jonathan returned to South Dakota School of Mines and Technology for the fall 2007 semester and graduated with a Bachelor of Sciences degree in Geological Engineering in May, 2011.

Jonathan graduated with a Master of Science degree in Geological Engineering from the South Dakota School of Mines and Technology in the summer semester of 2013 under the direction of major advisor, Dr. Arden Davis. Jonathan's thesis work was a direct result of his work for the U.S. Geological Survey South Dakota Water Science Center from June 2010 to May 2013 under the supervision of research hydrologist Dr. Andrew J. Long. While working for the U.S. Geological survey, Jonathan co-authored Scientific Investigations Report 2011-5235, "Groundwater Flow, Quality (2007-10), and Mixing in the Wind Cave National Park Area, South Dakota".

Jonathan is married to Christie L. B. McKaskey and, at the time of this report, has one child, Miles Girard McKaskey.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
POWERTECH (USA) INC.,	)	Docket No. 40-9075-MLA
	)	
(Dewey-Burdock In Situ Uranium Recovery Facility)	)	

Declaration of Wilmer Mesteth

1. My name is Wilmer Mesteth. I am the Tribal Historic Preservation Officer ("THPO") for the Oglala Sioux Tribe of the Pine Ridge Reservation. In my activities as the THPO, I regularly review cultural resource reports and surveys, including the survey and reporting methods.

2. The Oglala Sioux Tribe is a body politic comprised of approximately 41,000 citizens with territory of over 4,700 square miles in the southwestern portion of South Dakota. The Oglala Sioux Tribe is the freely and democratically-elected government of the Oglala Sioux people, with a governing body duly recognized by the Secretary of Interior. The Oglala Sioux Tribe is the successor in interest to the Oglala Band of the Teton Division of the Sioux Nation, and is a protectorate nation of the Unites States of America. The Oglala Band reorganized in 1936 as the "Oglala Sioux Tribe of the Pine Ridge Indian Reservation" ("Oglala Sioux Tribe" or "Tribe") under section 16 of the Indian Reorganization Act of June 18, 1934, ch. 576, 48 Stat. 987, 25 U.S.C. § 476, and enjoys all of the rights and privileges guaranteed under its existing treaties with the United States in accordance with 25 U.S.C. § 478b. Its address is P.O. Box 2070, Pine Ridge, South Dakota 57770-2070.

3. In 1992 the U.S. Congress adopted amendments to the National Historic Preservation Act (P.L. 102-575) that allow federally recognized Indian tribes to take on more formal responsibility for the preservation of significant historic properties on tribal lands. Specifically, Section 101(d)(2) allows tribes to assume any or all of the functions of a State Historic Preservation Officer ("SHPO") with respect to tribal land.

4. I am familiar with the license application recently submitted to the Nuclear Regulatory Commission (NRC) by the Canadian company Powertech Uranium Corp., doing business as Powertech (USA) Inc. ("Powertech" or "Applicant") for the proposed Dewey-Burdock in-situ leach uranium mine in southwest South Dakota.

5. The lands encompassed by the Powertech proposal are within the Territory of the Great Sioux Nation, which includes the band of the Oglala Lakota (Oglala Sioux Tribe)

aboriginal lands. As a result, the cultural resources, artifacts, sites, etc., belong to the Tribe. By enacting NEPA (42 U.S.C. § 4330 *et seq.)*, NAGPRA, (25 U.S.C. 3001 *et seq*), NHPA (16 U.S.C.S. § 470 *et seq.*) and other statutes, the United States Government has assured that the cultural resources of a tribe will be protected, even when they are not within reservation boundaries. Since there are cultural resources identified in the license application, and there may well be more that only the Tribe can identify and ensure that they are properly protected, the Tribe has a protected interest here. Any harm done to these artifacts, perhaps because the Applicant did not properly judge the significance of certain artifacts or other resources, will be an injury to the Tribe, caused by the actions of the Applicant, and condoned by the NRC, the Tribe's trustee. While only the federal government can actually *consult* with the Tribe, the Tribe maintains that the application's determination of cultural resources in the area may not be fully comprehensive.

6. In any case, the discovery of an Indian camp and prehistoric artifacts in the Tribe's treaty and aboriginal territory at issue in this application implicates important tribal interests such that the Tribe's rights are threatened by the Applicant's mining activity in its aboriginal territory.

7. The Oglala Sioux Tribe is taking the necessary course of action to participate fully as a party in this proceeding in part in order to safeguard its interests in the protection of cultural and historic resources at and in the vicinity of the mine site.

8. Included within the territory the Powertech application contemplates are current or extinct water resources. Such resources are known to be cultural resources itself and been known as favored camping sites of indigenous peoples, both historically and prehistorically, and the likelihood that cultural artifacts and evidence of burial grounds exist in these areas is strong.

9. While the Powertech application includes some evidence of a cultural resource study, the Tribe cannot verify that a comprehensive study identifying all such resources has been adequately conducted. No such study has been conducted by the Tribe.

10. Powertech's Environmental Report accompanying the license application indicates that personnel from the Archaeology Laboratory at Augustana College ("Augustana"), Sioux Falls, South Dakota, conducted on-the-ground field investigations between April 17 and August 3, 2007. To my knowledge, the Tribe was not involved in this study, and has not made a similar study of the proposed mining area.

11. As stated in the Powertech Environmental Report, at 3-179, the Augustana study found that "the sheer volume of sites documented in the area [was] noteworthy," and the area proposed for mining was found to have a "high density" of cultural resources. As also recognized in the environmental report, this indicates that use of the area by indigenous populations was, and has been, extensive.

12. The Powertech Environmental Report also states, at 3-178, Augustana documented 161 previously unrecorded archaeological sites and revisited 29 previously recorded sites during the current investigation. Among these were some 200 hearths within 24 separate sites. Significantly, however, twenty-eight previously recorded sites were not relocated during the current investigation.

13. Powertech asserts in its Environmental Report, at page 2-9, Table 2.11-1, that impacts to cultural resources will be "none." However, the Memorandum of Agreement (with amendments) entered into between Powertech and the Archaeological Research Center (ARC), a program of the South Dakota State Historical Society, reproduced in the Environmental Report at Appendix 4.10-B, specifically recognizes that "Powertech has determined that the Project may have an affect on archaeological or historic sites that contain or are likely to contain information significant to the state or local history or prehistory…."

14. Significantly, Powertech has not entered into any such Memorandum of Agreement with the Tribe, or sought the Tribe's participation in the development of any stipulations purported to result in the diminishment of impacts to the Tribe's cultural and historic resources at the site. Nor has Powertech sought to include the Tribe in any of the "Dispute Resolution" procedures through which it purports to remedy disagreements regarding the significance of cultural resources on the site, or the impact of any mining operations on these cultural resources. As a result, Powertech has failed to adequately include the Tribe in this process, and leaves the Tribe's cultural resources at risk.

15. I have also reviewed the official Transcript of Proceedings In the Matter of Consideration of Petitions to Place Proposed Powertech (USA), Inc., In Situ Leach Mining Area On The Preliminary List of Special, Exceptional, Critical, and Unique Lands, held Thursday, February 19, 2009 before the State of South Dakota Department of Environment and Natural Resources, Board of Minerals and Environment where substantial issues related to the cultural significance of the historic resources in the area of the proposed mining operations were discussed through testimony given by witnesses first being duly sworn. (Attached). Also discussed in detail at the hearing were the April 17 and August 3, 2007 Augustana studies, relied upon by Powertech in its Environmental Report as the exclusive evidence of the impact of the proposed project on cultural resources.

16. At the February 19, 2009 hearing, Oglala Sioux Tribe member Garvard Good Plume testified after being duly sworn that he and his familial relations, including his great grandfather, his mother and father had used, dwelled, and camped on the lands subject to the Powertech mining proposal. Transcript at p. 86 and following. Significantly, he also testified that his grandparents and their relatives were buried in those areas.

17. Also at the February 19, 2009 hearing, trained archaeologist Mr. Ben Rhodd identified significant defects in the process employed by Augustana in its cultural survey, including the failure to conduct an inquiry into or an evaluation of the ethnographic information available for the site. This information includes consultation with members of the

indigenous community, the elders who have been in the area, medicine people, oral historians, and others who are familiar with the area. Transcript at p. 108-109.

18. Appearing at the hearing, and testifying after being duly sworn, was the Assistant State Archaeologist, Mr. Michael Fosha, employed by the State of South Dakota, State Historical Society, Archaeological Research Center (ARC). Mr. Fosha asserts in his testimony that he contracted Augustana to conduct its study in 2007, and asserts that additional studies were conducted in 2008. Transcript at 173. There are no references in Powertech's Environmental Report to any studies or any information collected in 2008. Mr. Fosha admits in his testimony that no Native American Tribes, including the Oglala Sioux Tribe, were contacted or consulted with regarding the Augustana survey.

19. As part of the Augustana study, Mr. Fosha indicates that there were some 217 sites identified, and that some 81 had not been fully evaluated during the 2007 or 2008 Augustana evaluation. Powertech's Environmental Report does not refer to 217 sites, but rather some 190 sites (see Environmental Report at 3-178). This discrepancy and the failure of a full evaluation of some 81 sites within the proposed mining area evidence a potentially serious failure to conduct a proper cultural resources study.

20. Overall, the numbers and density of cultural resources at the site proposed for mining demonstrate that the mining activity is likely to adversely impact the cultural resources of the Oglala Sioux Tribe. The failure to involve the Tribe in the analysis of these sites, or to conduct any ethnographic studies in concert with a field study further exacerbate the impacts on the Tribe's interests as a procedural matter in negatively affecting the Tribe's ability to protect its cultural resources. If the project were to not go forward as planned, the interests of the Oglala Sioux Tribe would be protected as the potential for impact to the Tribe's cultural resources would be diminished or outright eliminated.

This Affidavit is submitted in accordance with 10 C.F.R. Section 2.304(d) and 28 U.S.C. Section 1746. I declare under penalty of perjury that the foregoing is true and correct.

Executed on April 1, 2010 at Pine Ridge Indian Reservation.

Wilmer Mesteth

Wilmer Mesteth